Numerical simulations for the propagation of laser beams

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Numerical simulations for the propagation of laser beams

- Motivation -

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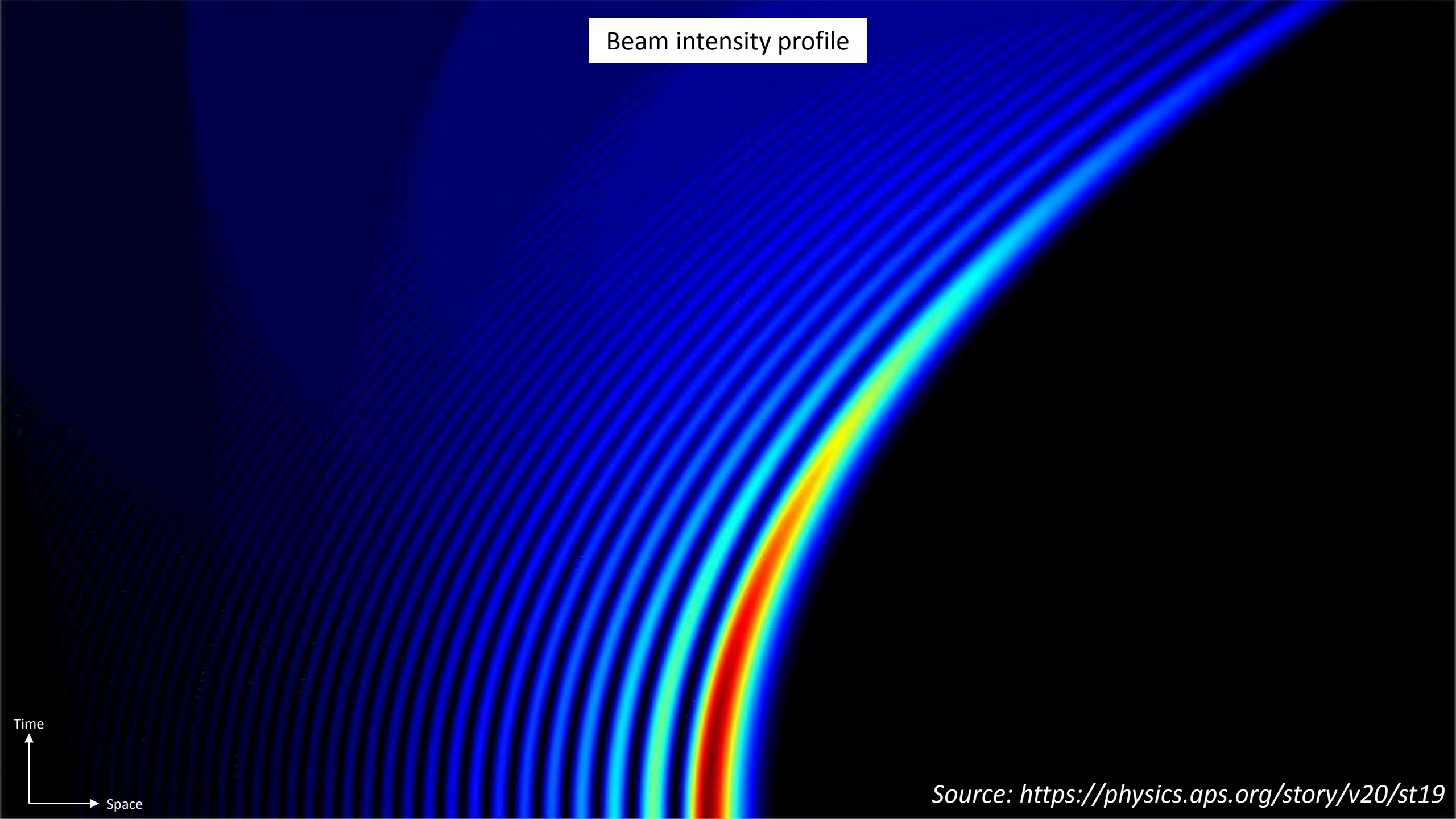

Source: https://physics.aps.org/story/v20/st19

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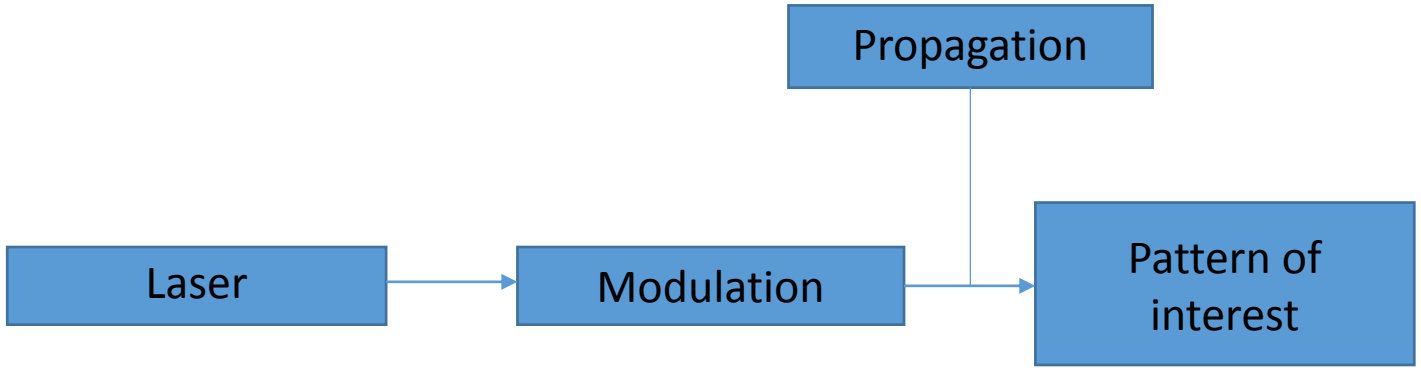

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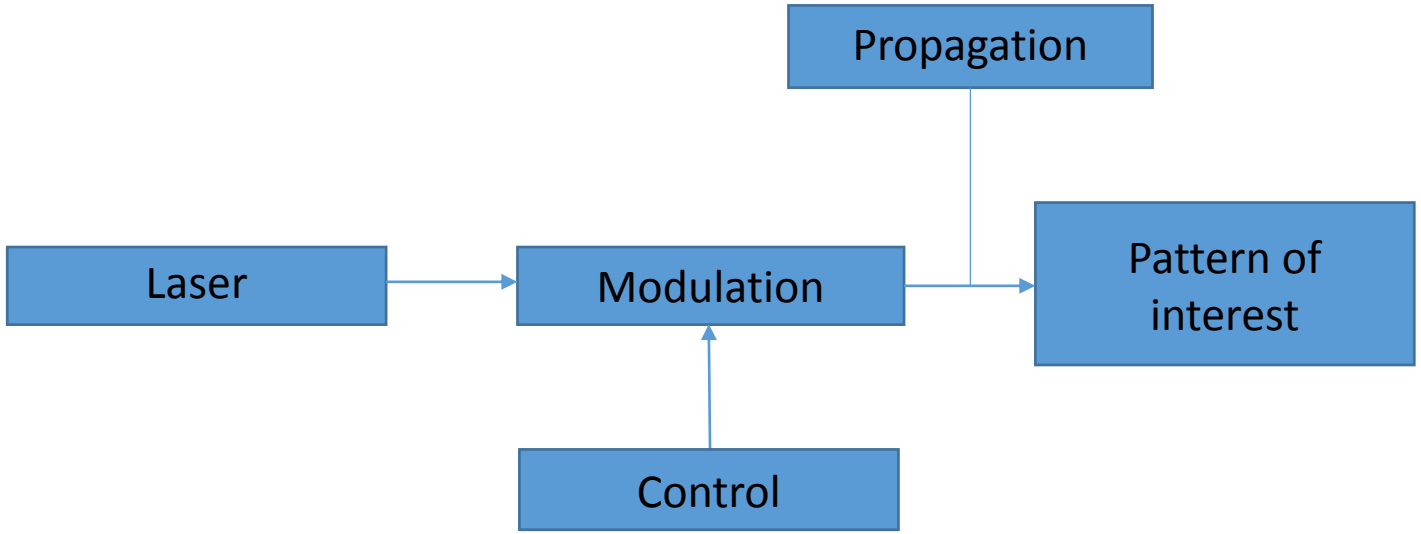

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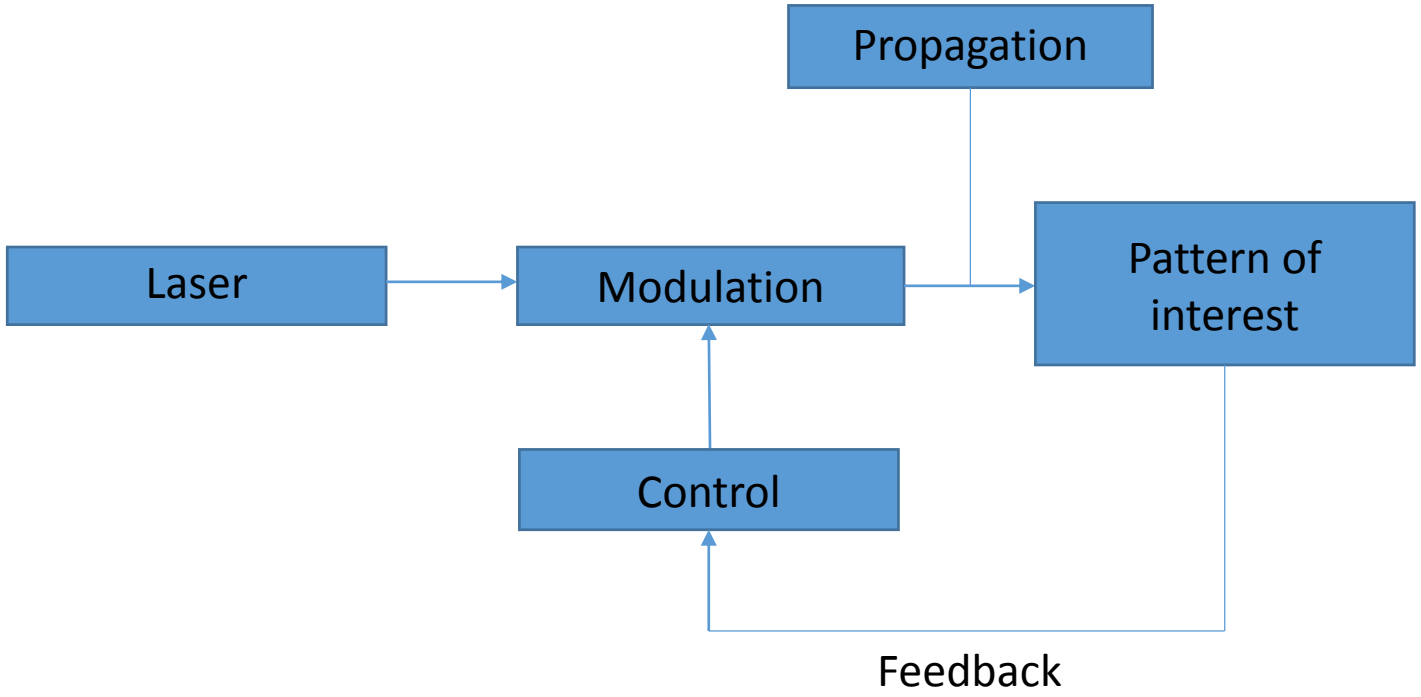

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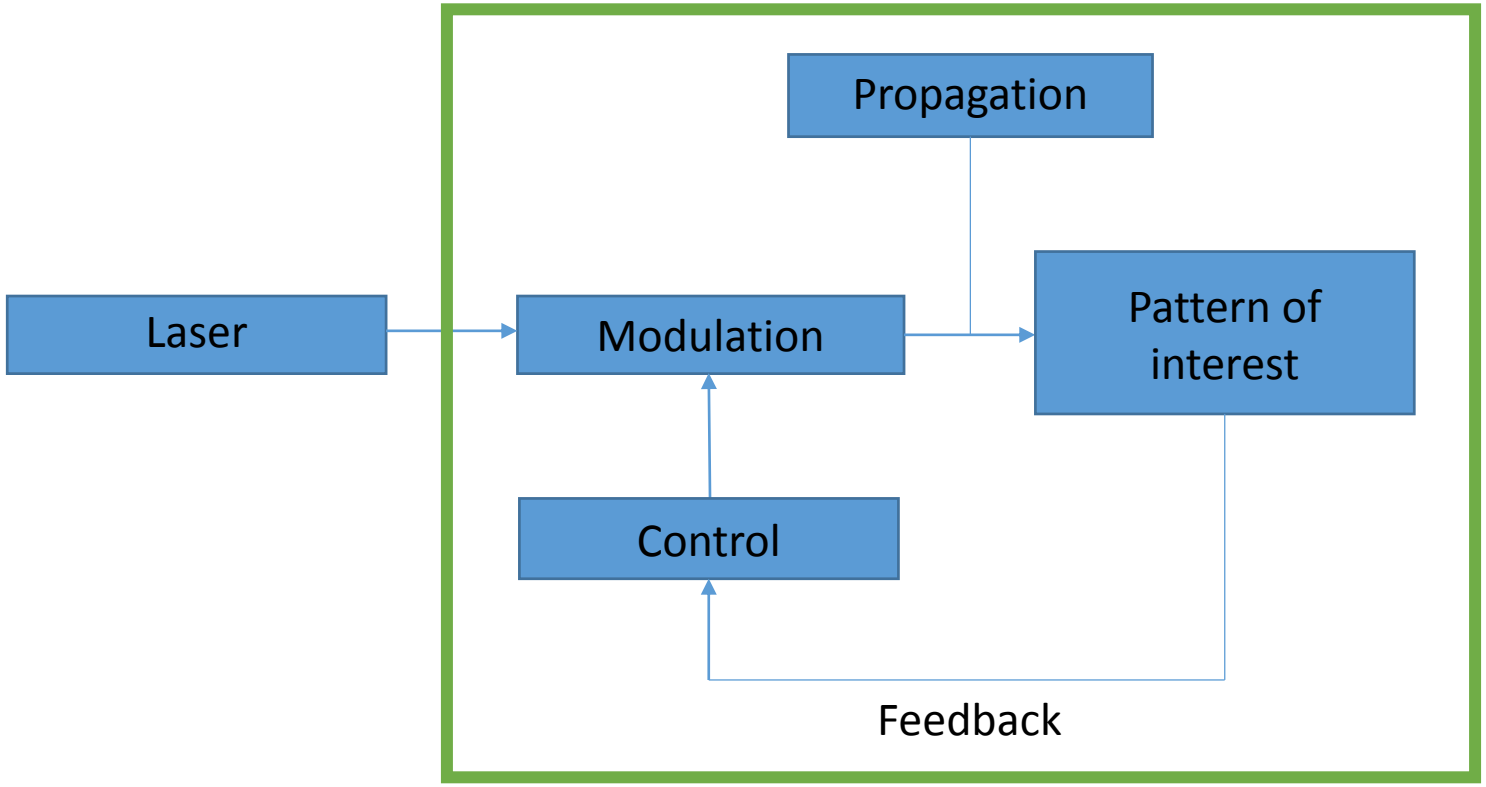

The simulation AKA my part

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Numerical simulations for the propagation of laser beams

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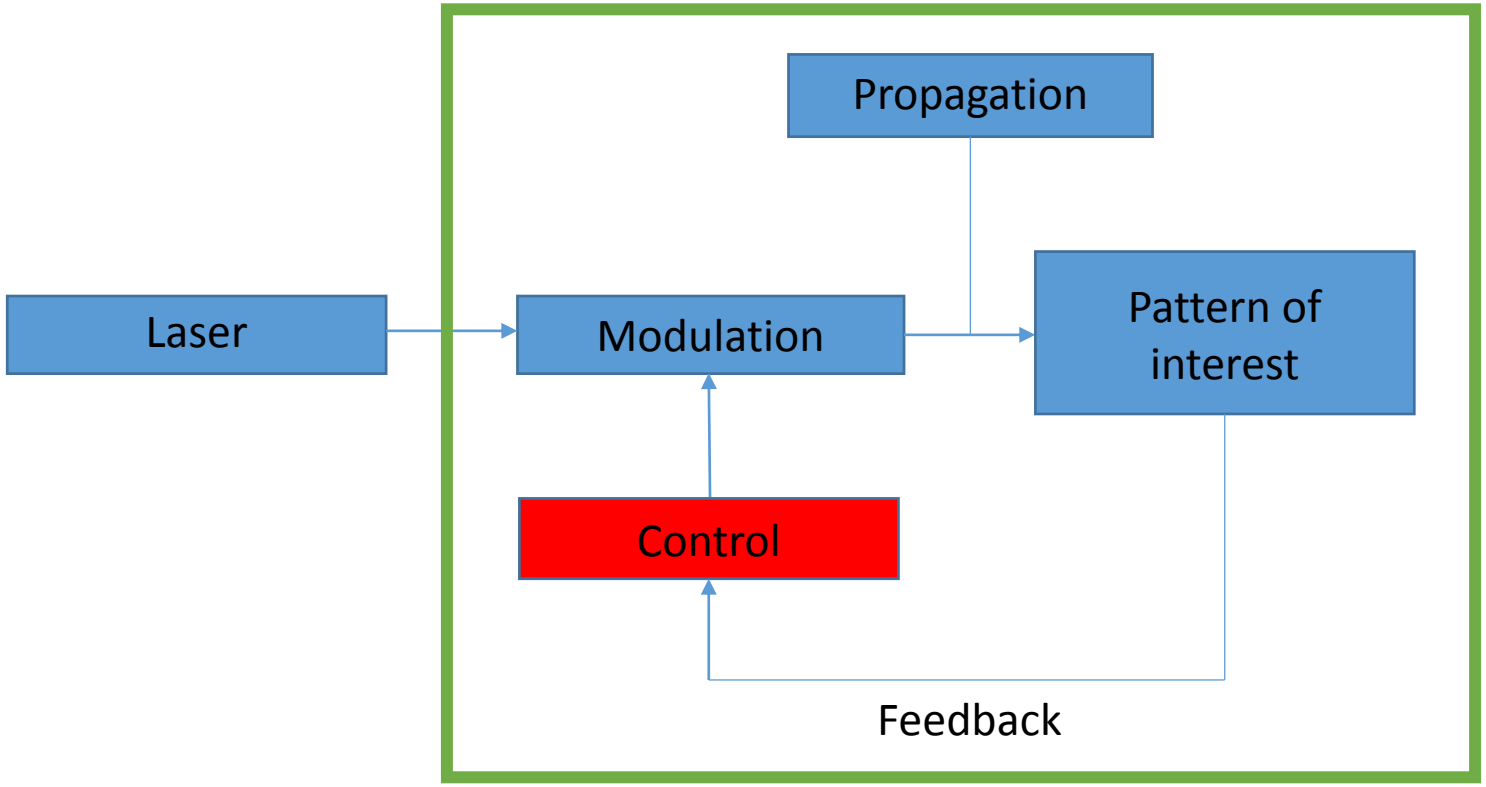

The simulation AKA my part

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Numerical simulations for the propagation of laser beams

- Algorithm overview -

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Numerical simulations for the propagation of laser beams

- Algorithm overview -

$$\frac{\partial \psi}{\partial t} = i\Delta\psi$$

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Numerical simulations for the propagation of laser beams

- Algorithm overview -

Numeric ← $\frac{\partial \psi}{\partial t} = i\Delta\psi$ → Analytical

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Numerical simulations for the propagation of laser beams

- Algorithm overview -

$$\frac{\partial \psi}{\partial t} = i\Delta\psi$$

Numeric

$$\psi(\boldsymbol{x}, t_{n+1}) = \boldsymbol{M}_E \psi(\boldsymbol{x}, t_n)$$

$$\psi(\boldsymbol{x}, 0) = \psi_0$$

Analytical

$$\psi(\boldsymbol{x}, t) = \int_{\mathbb{R}^n} \frac{1}{(4\pi i t)^{\frac{n}{2}}} e^{\frac{i|\boldsymbol{x}-\boldsymbol{y}|^2}{4t}} \psi_0(\boldsymbol{y})\, d\boldsymbol{y}$$

Numerical simulations for the propagation of laser beams

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Approximation, but computations are fast sometimes

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Exact, but solutions are scarce and difficult to compute

Numerical simulations for the propagation of laser beams

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problem maker

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Exact, but solutions are scarce and difficult to compute

ψ_0

problem makers

$V(\boldsymbol{x}, t) = 0$

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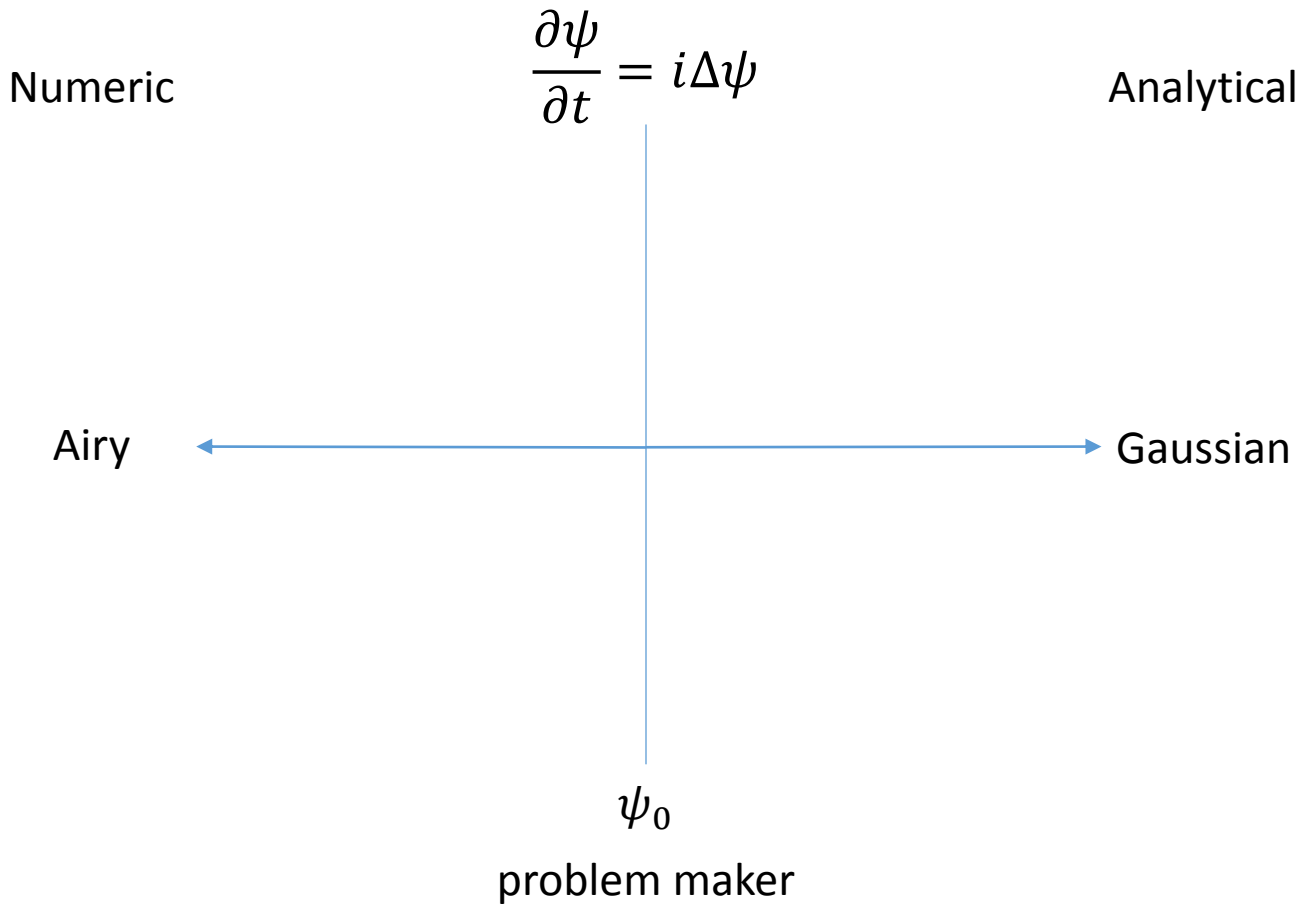
Numerical simulations for the propagation of laser beams

- Algorithm overview -



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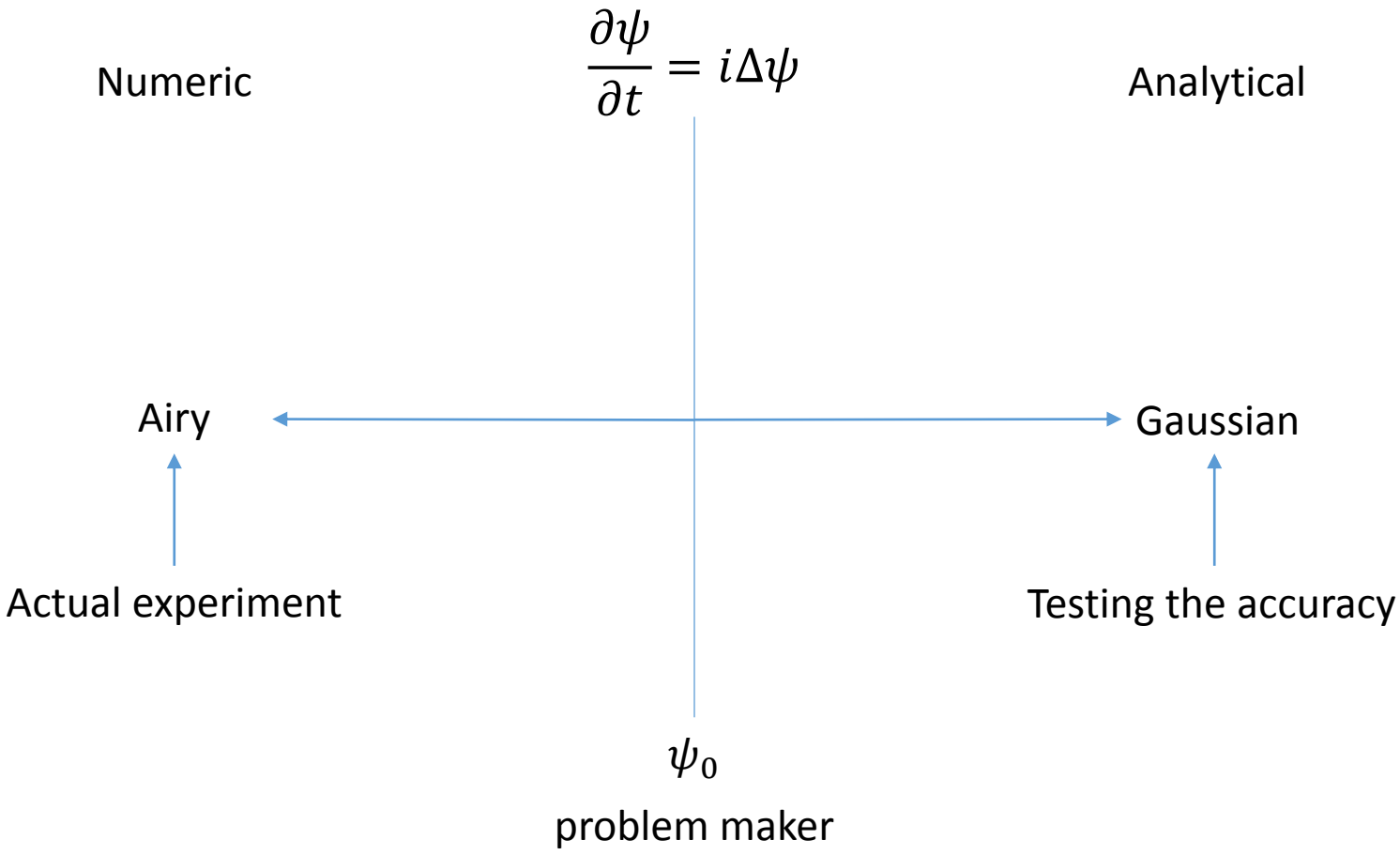
Numerical simulations for the propagation of laser beams

- Algorithm overview -



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Numerical simulations for the propagation of laser beams

- Algorithm -

$$\partial_t \psi = i\Delta\psi$$
$$\psi(\boldsymbol{x}, 0) = \psi_0$$
$$\psi: \mathbb{R}^D \times \mathbb{R} \to \mathbb{C}$$
$$\psi = \psi(\boldsymbol{x}, t) = \psi(x_0, x_1, \dots, x_{D-1}, t)$$

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Numerical simulations for the propagation of laser beams

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$$\partial_t \psi = i\Delta\psi$$
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$$\psi = \psi(\boldsymbol{x}, t) = \psi(x_0, x_1, \dots, x_{D-1}, t)$$

$$\psi(\boldsymbol{x}, t_n) = (\psi(x_{0,0}, t_n), \dots, \psi(x_{0,k-1}, t_n),$$
$$\psi(x_{1,0}, t_n), \dots, \psi(x_{1,k-1}, t_n),$$
$$\dots$$
$$\psi(x_{D-1,0}, t_n), \dots, \psi(x_{D-1,k-1}, t_n))$$

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$$\psi(x_{1,0}, t_n), \dots, \psi(x_{1,k-1}, t_n),$$
$$\dots$$
$$\psi(x_{D-1,0}, t_n), \dots, \psi(x_{D-1,k-1}, t_n))$$

$$\psi(\boldsymbol{x}, t_{n+1}) = \boldsymbol{M}_E(dx, dt)\psi(\boldsymbol{x}, t_n)$$

Matrix of transformation
specified by method

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$$\dots$$
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$$\psi(\boldsymbol{x}, t_{n+1}) = \boldsymbol{M}_E(dx, dt)\psi(\boldsymbol{x}, t_n)$$

$V(\boldsymbol{x}, t) = 0 \Rightarrow$ Big spatial domains $\Rightarrow$ Huge $M_E \in \mathbb{C}^{k^D \times k^D}$

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Numerical simulations for the propagation of laser beams

- Algorithm -

$$\boldsymbol{M}_E$$

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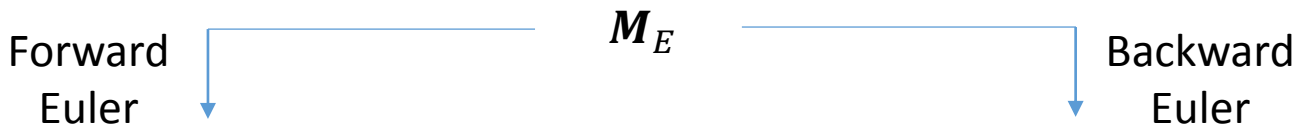
Numerical simulations for the propagation of laser beams

- Algorithm -



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Numerical simulations for the propagation of laser beams

- Algorithm -

$\boldsymbol{M}_E$

Forward Euler

$$\psi(\boldsymbol{x}, t_{n+1}) = \boldsymbol{M}_{FE}\psi(\boldsymbol{x}, t_n)$$

Backward Euler

$$\psi(\boldsymbol{x}, t_n) = \boldsymbol{M}_{BE}\psi(\boldsymbol{x}, t_{n+1})$$

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Numerical simulations for the propagation of laser beams

- Algorithm -

$\boldsymbol{M}_E$

Forward Euler

$$\psi(\boldsymbol{x}, t_{n+1}) = \boldsymbol{M}_{FE}\psi(\boldsymbol{x}, t_n)$$

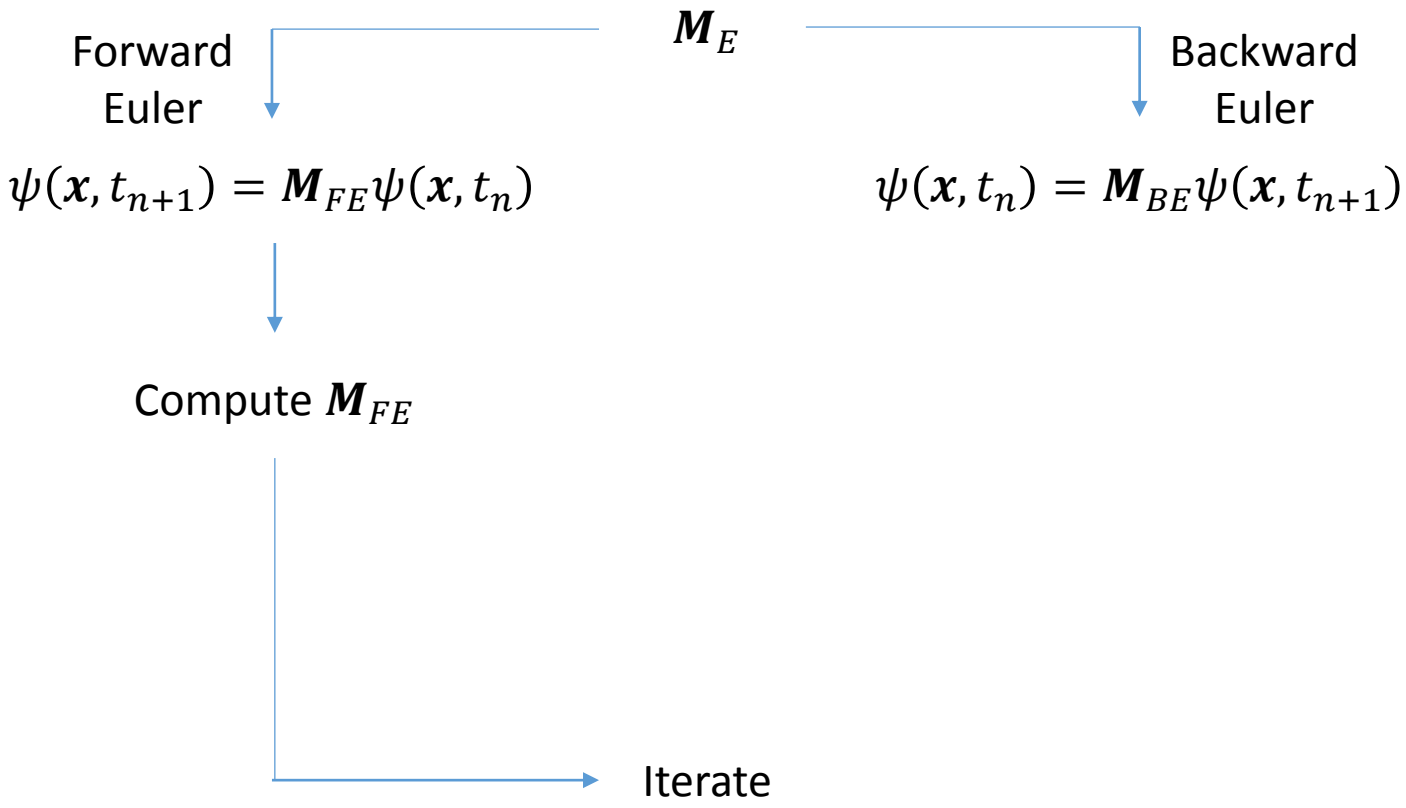
Compute $\boldsymbol{M}_{FE}$

Backward Euler

$$\psi(\boldsymbol{x}, t_n) = \boldsymbol{M}_{BE}\psi(\boldsymbol{x}, t_{n+1})$$

Numerical simulations for the propagation of laser beams

- Algorithm -



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Numerical simulations for the propagation of laser beams

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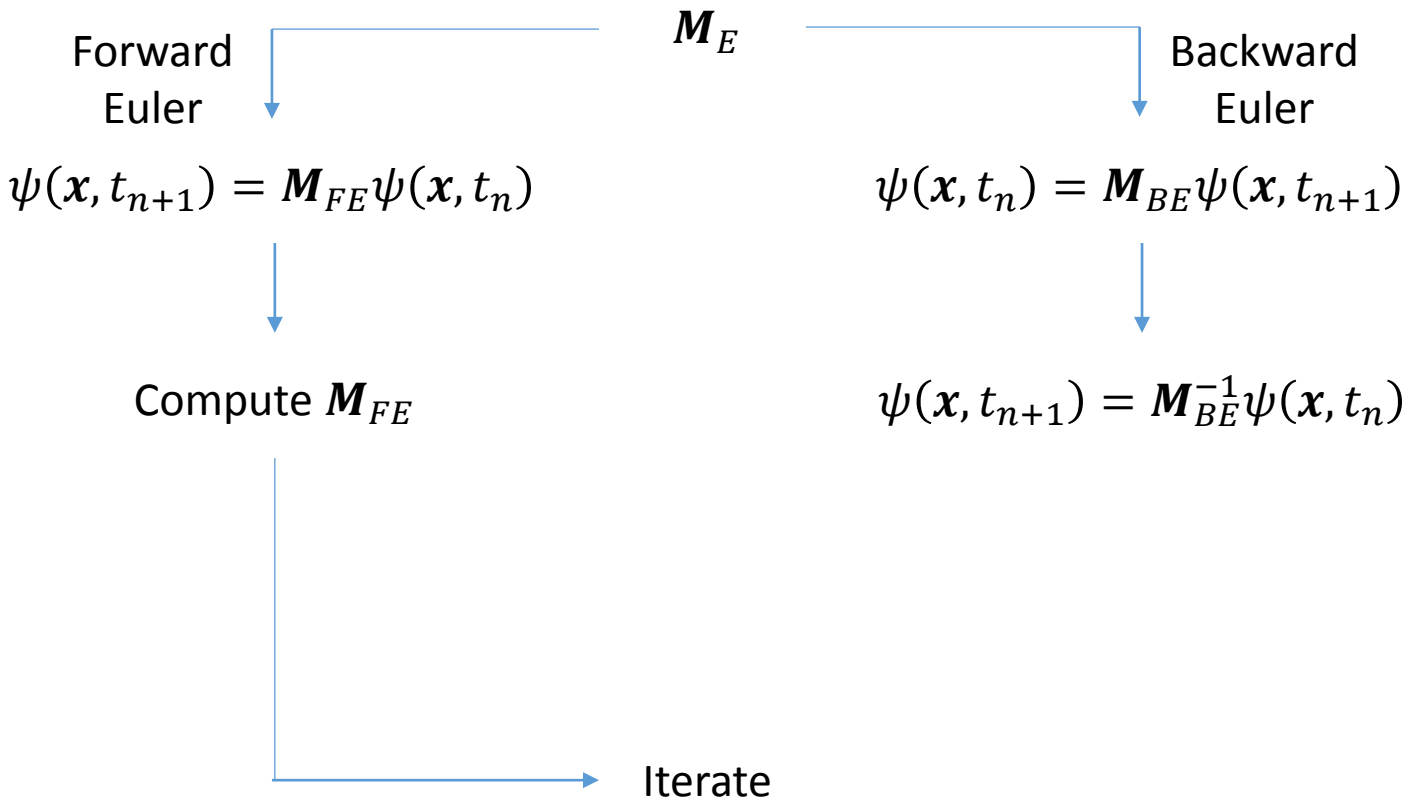

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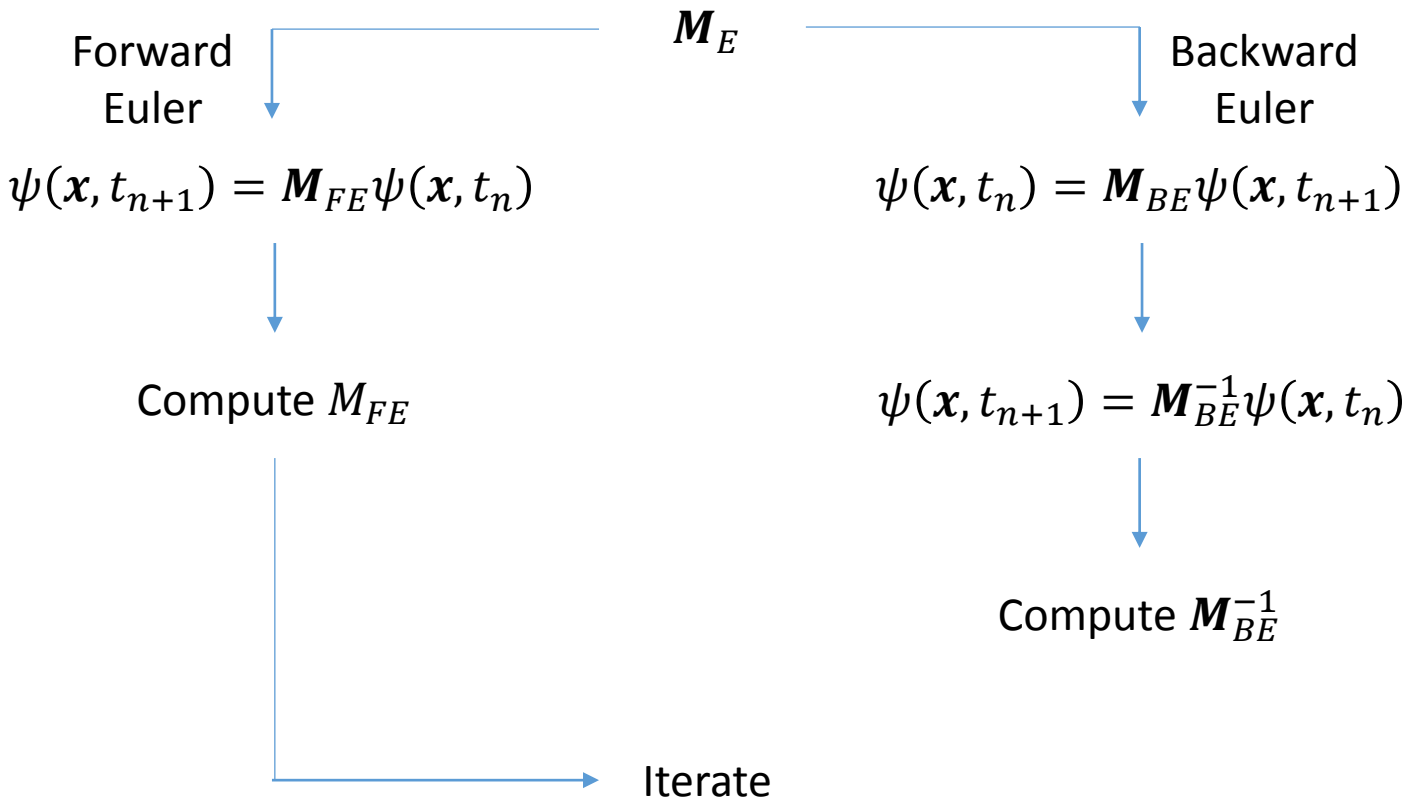

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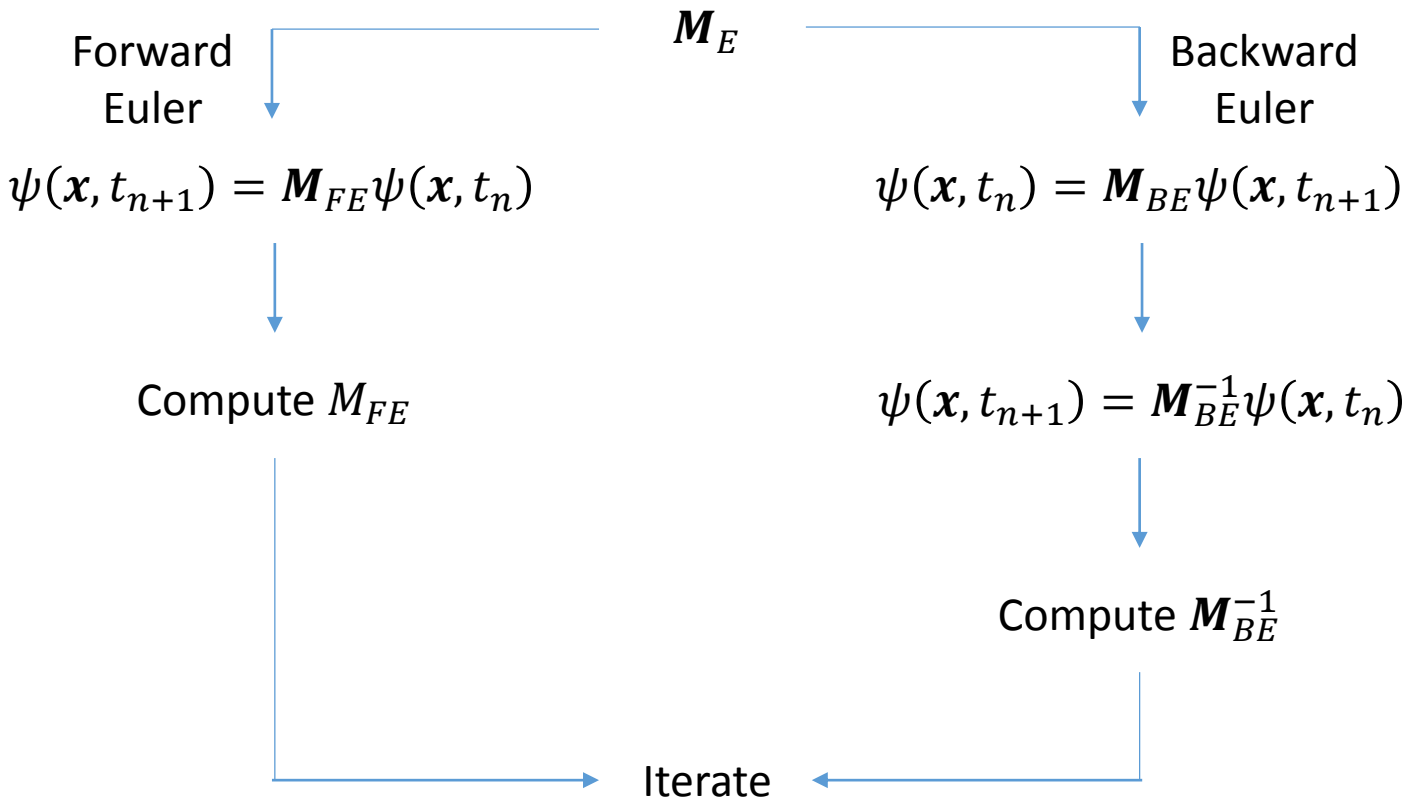

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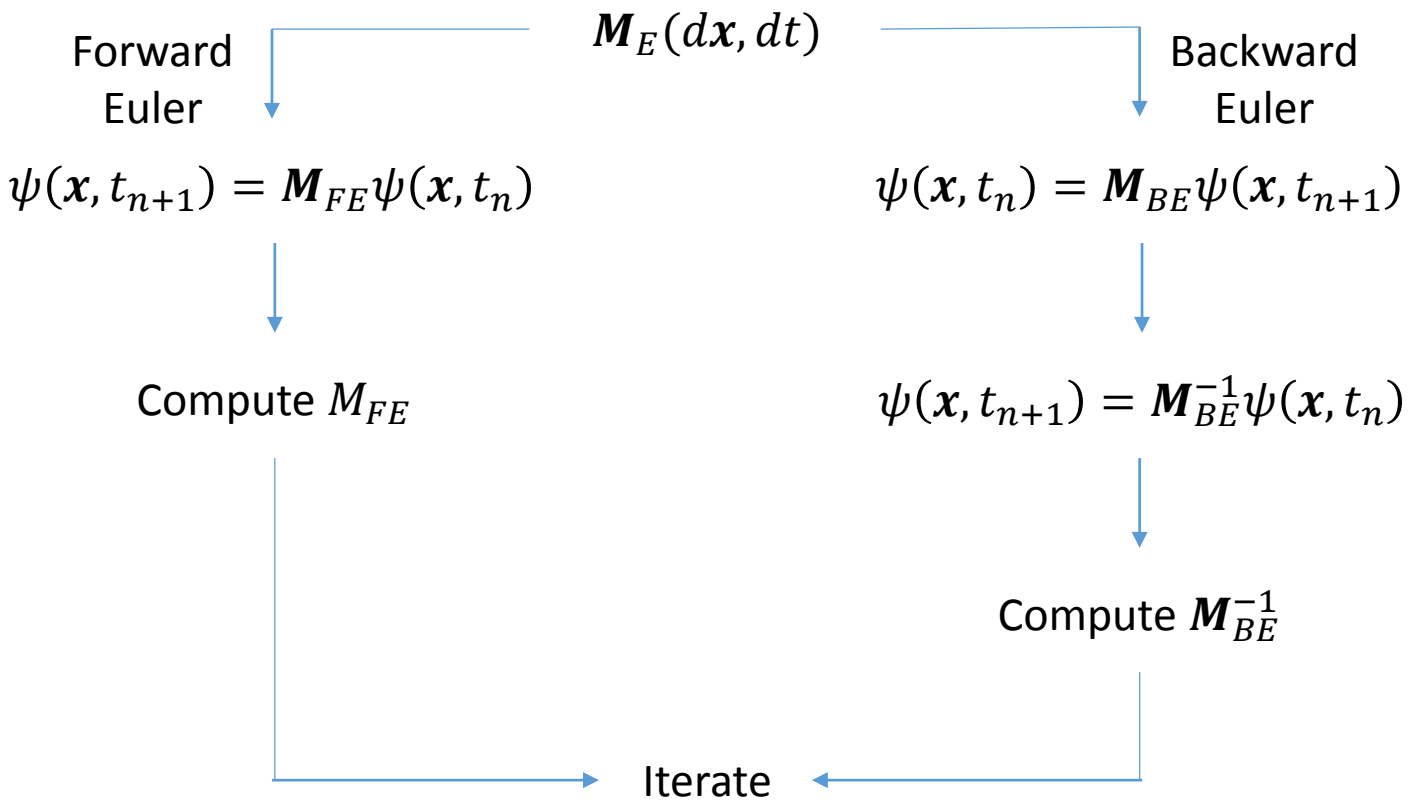

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Numerical simulations for the propagation of laser beams

- Method stability -

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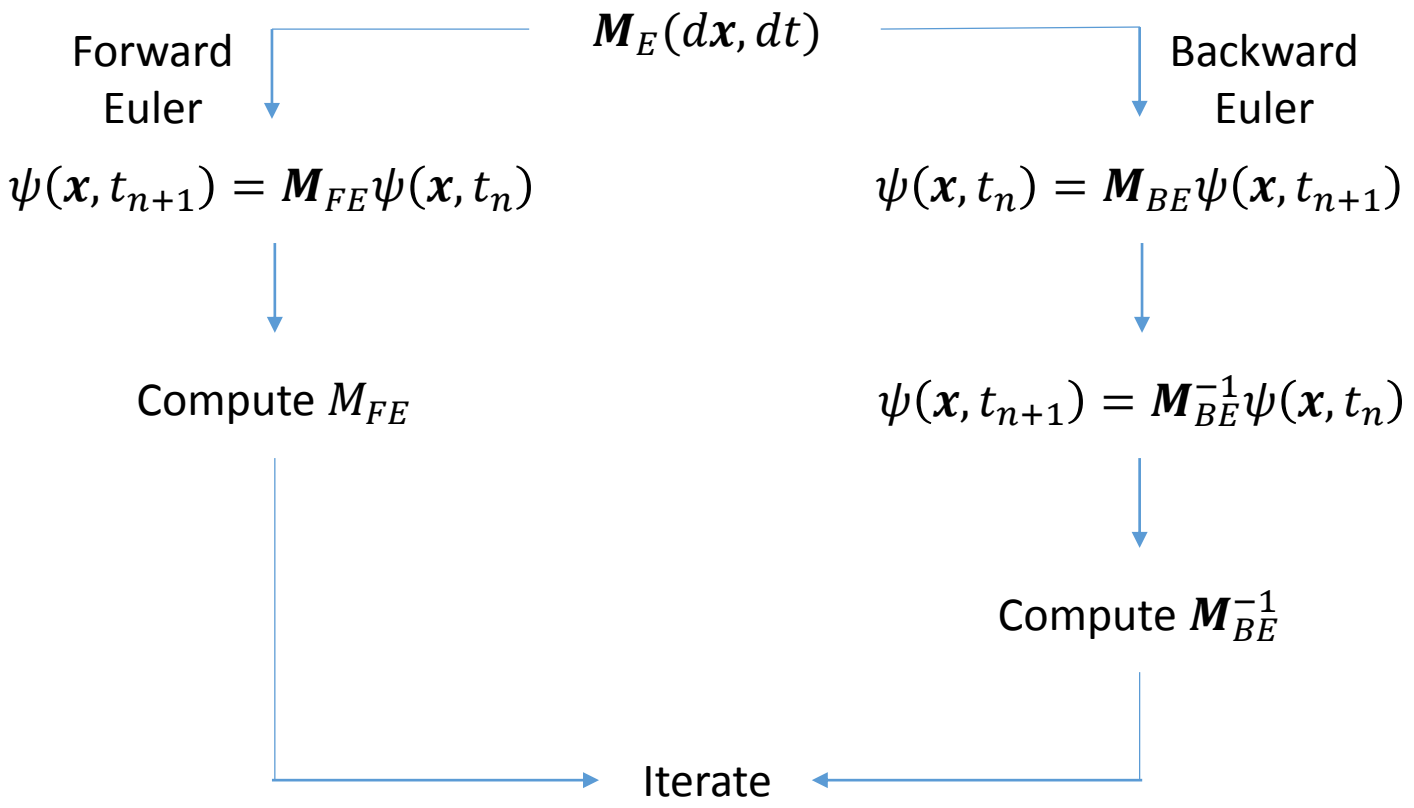

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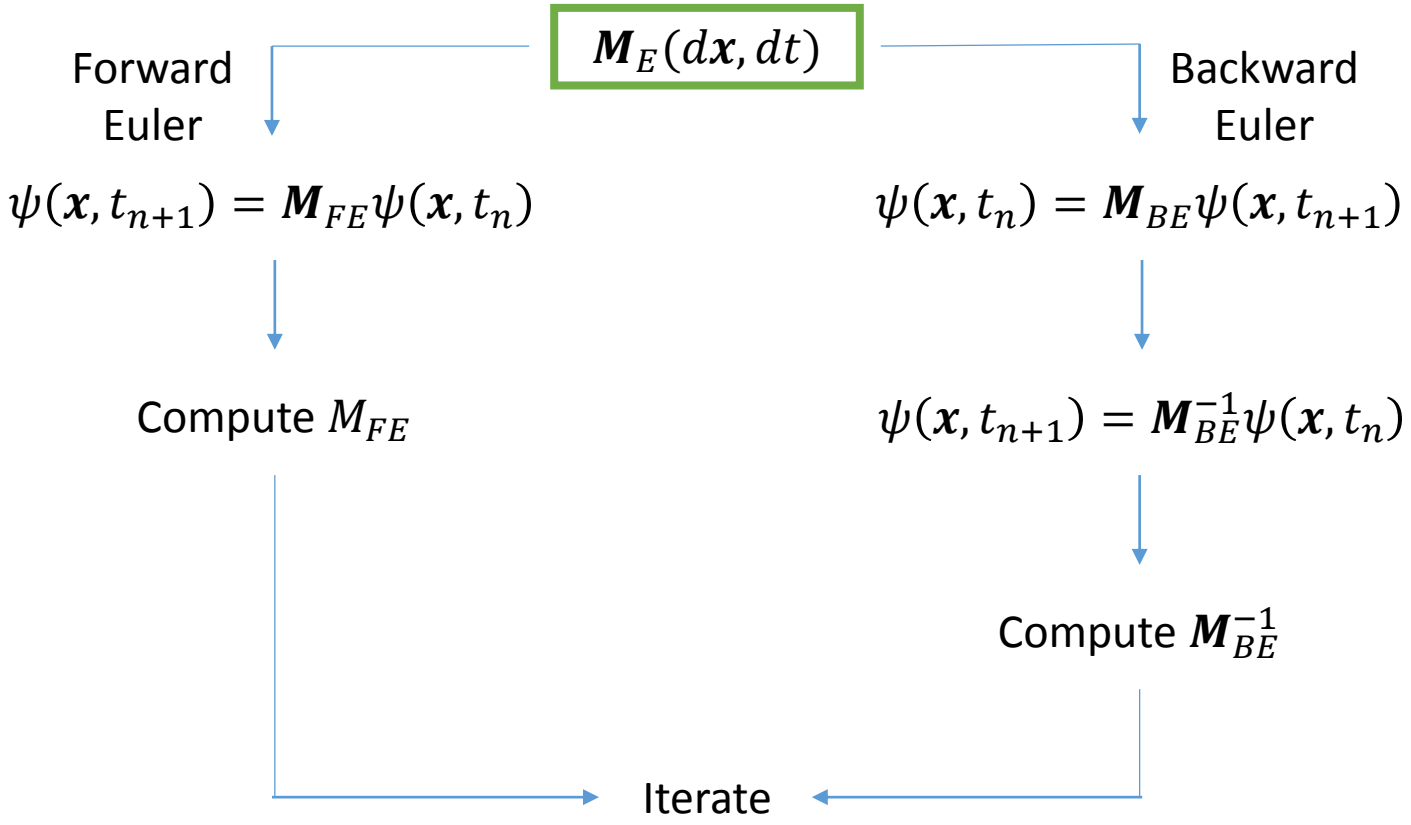

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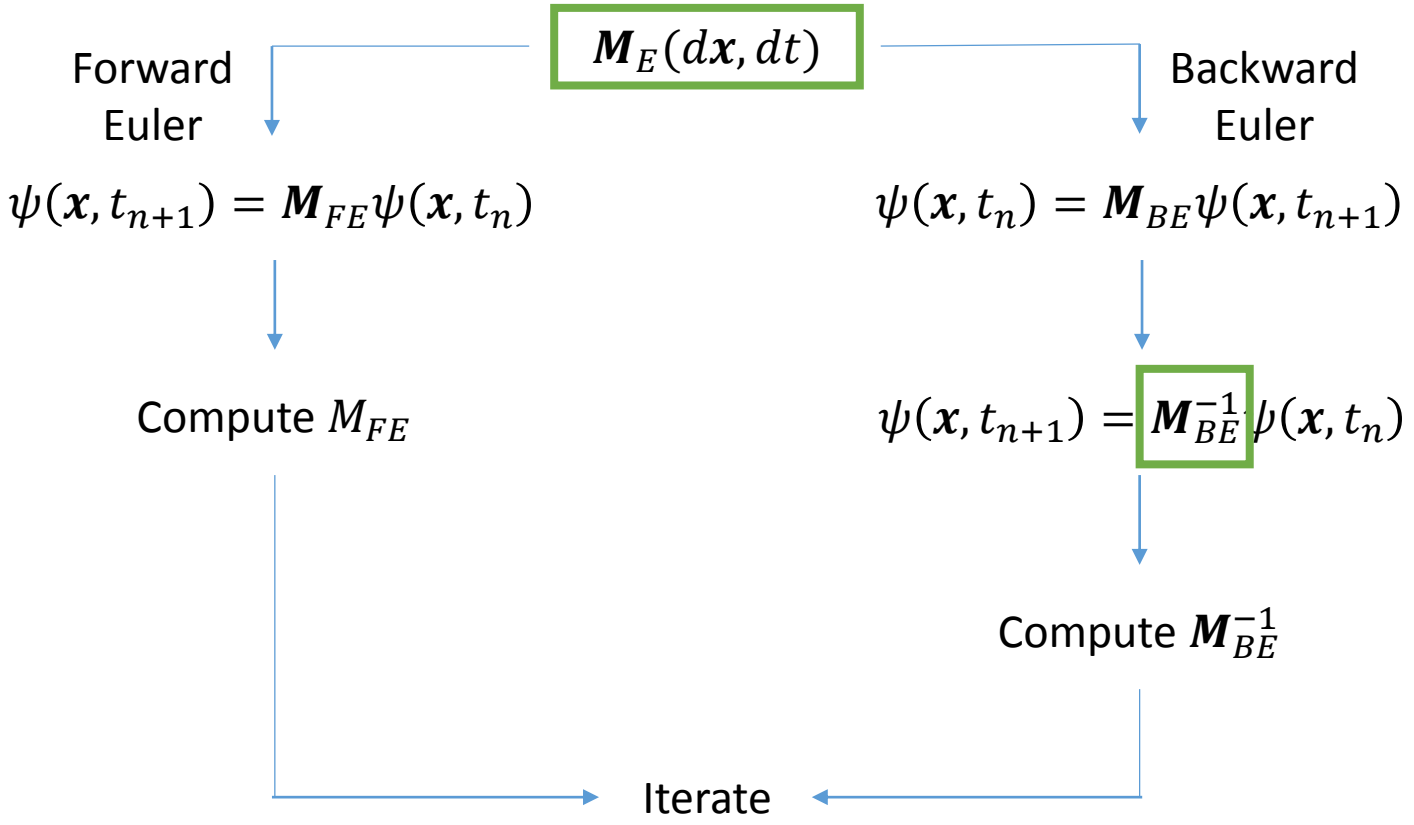

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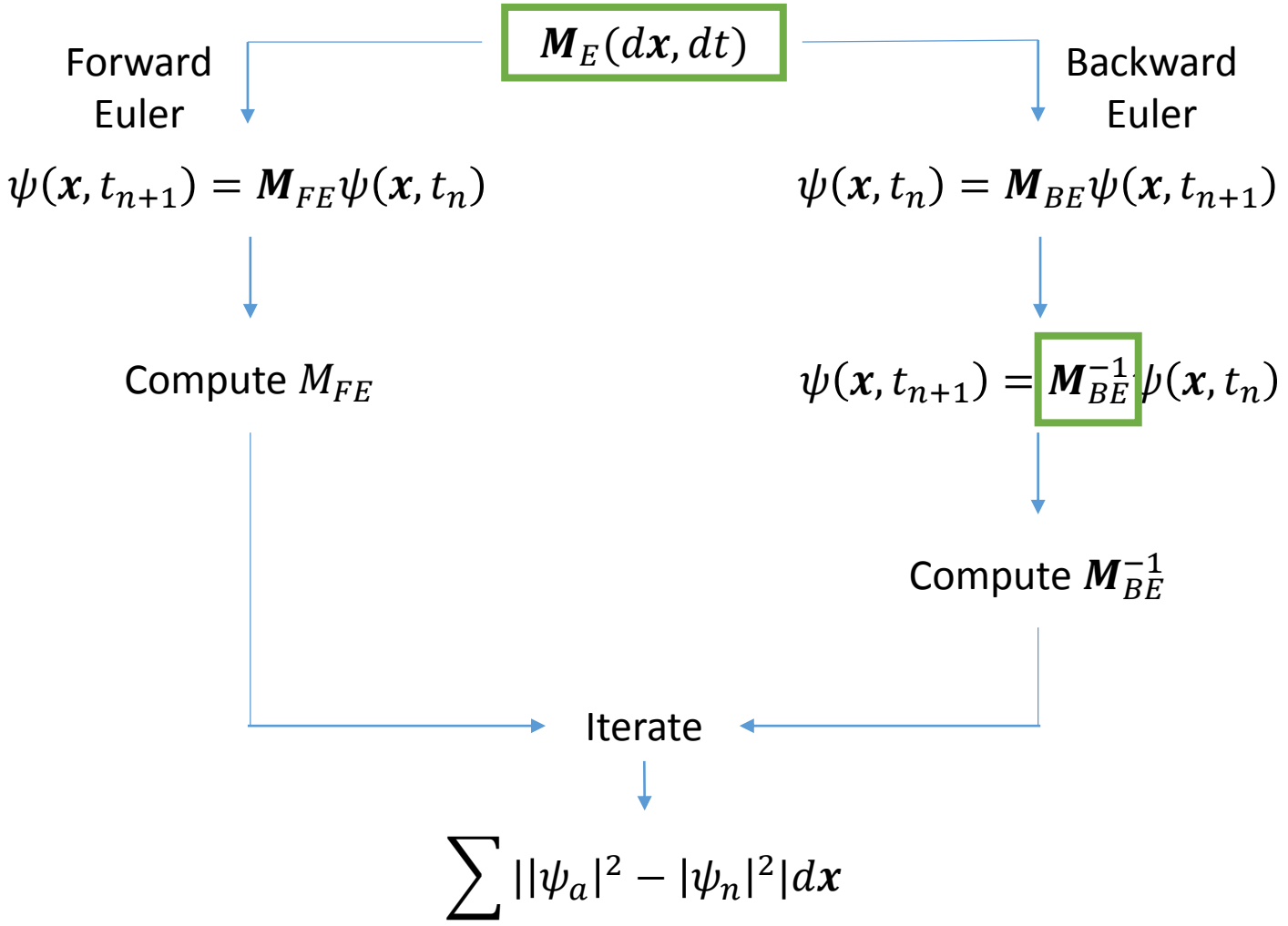

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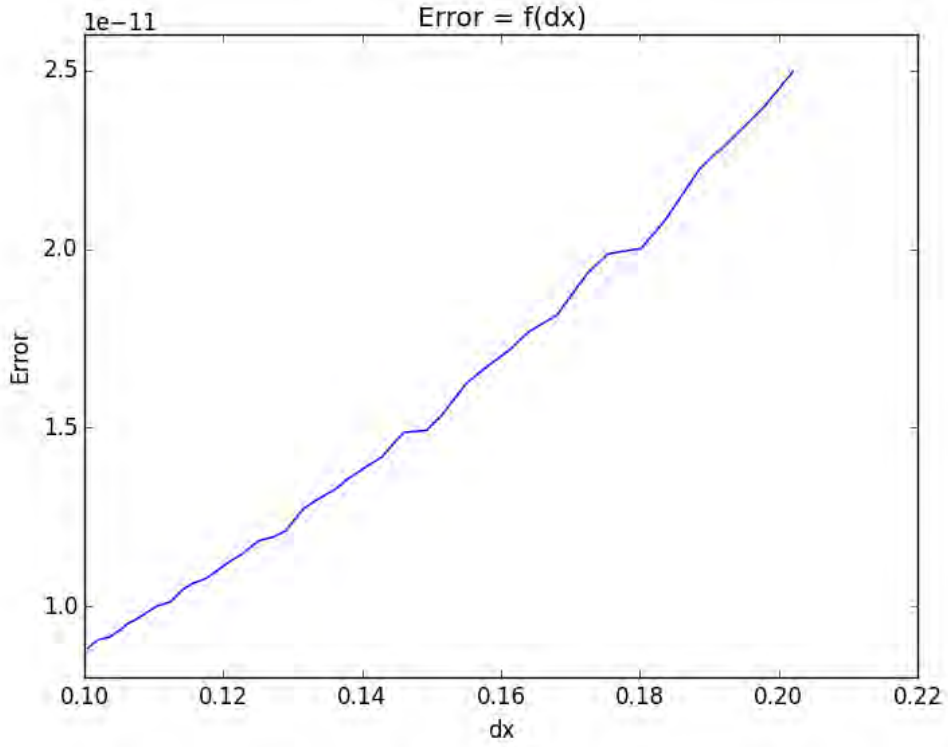
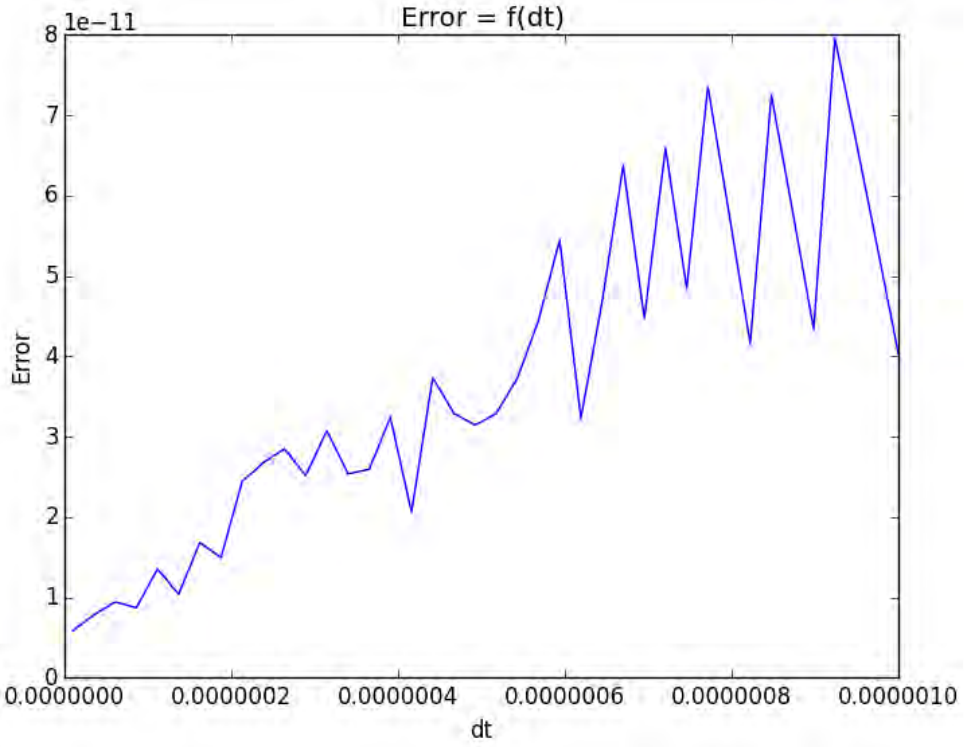
Numerical simulations for the propagation of laser beams

- Method stability -

dx ← $\boldsymbol{M}_{FE}(dx, dt)$ → dt

Case 1D





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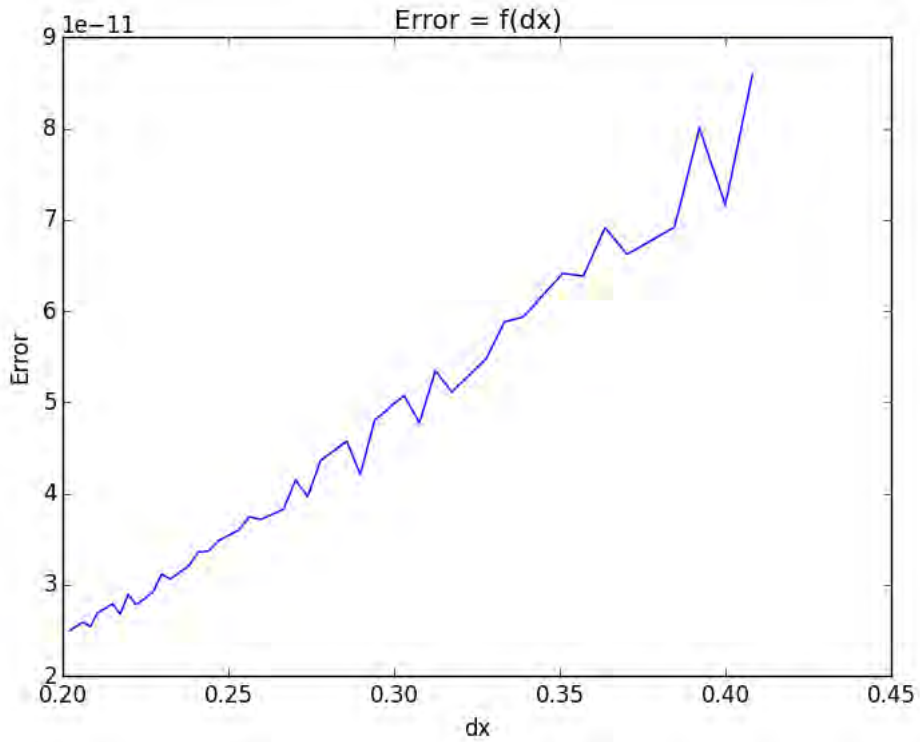
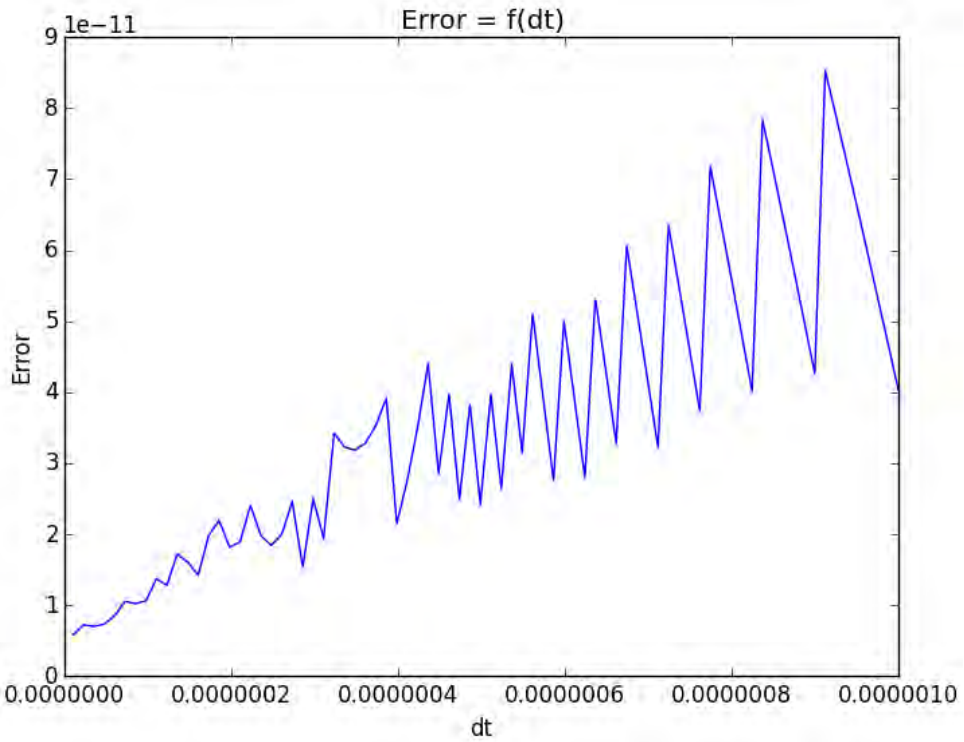
Numerical simulations for the propagation of laser beams

- Method stability -

dx ← $\boldsymbol{M}_{BE}(dx, dt)$ → dt

Case 1D





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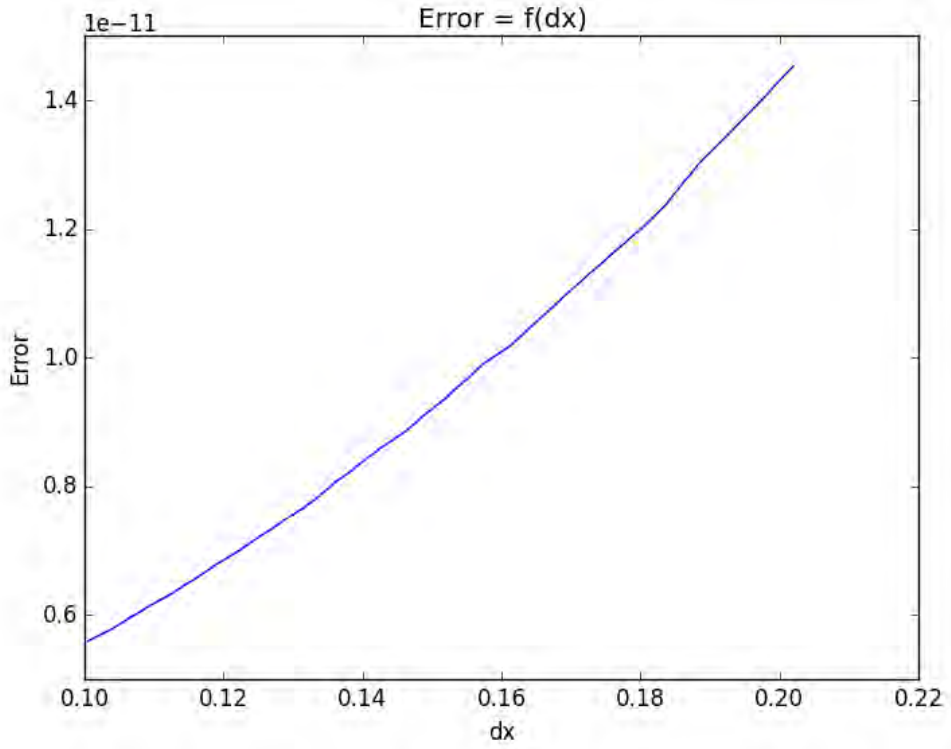
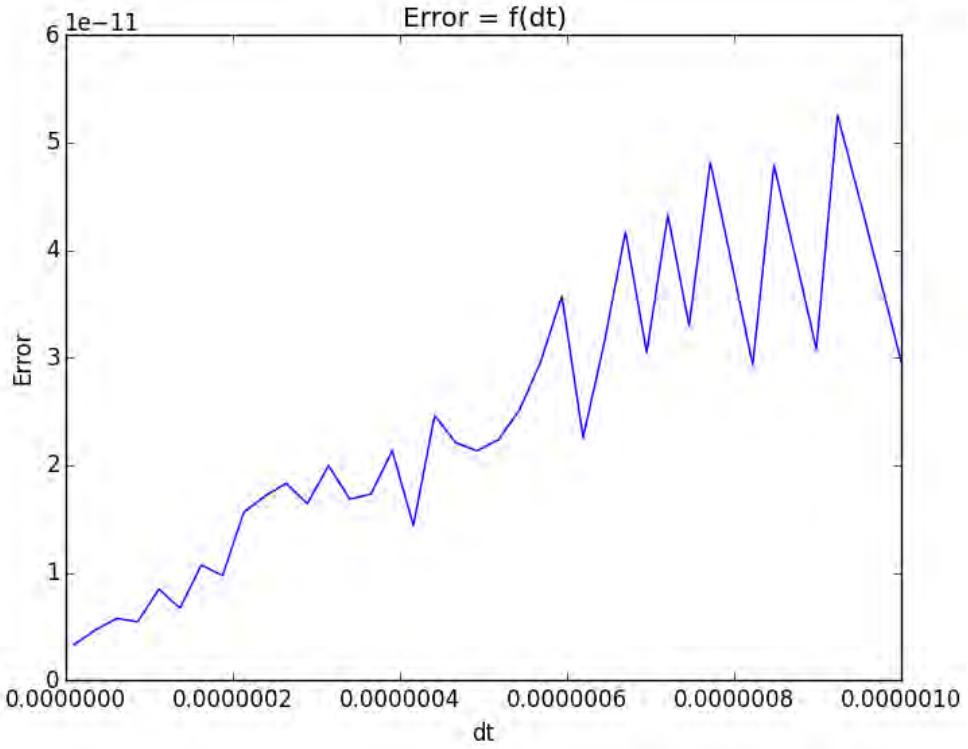
Numerical simulations for the propagation of laser beams

- Method stability -

dx ← $\boldsymbol{M}_{FE}(dx, dy, dt)$ → dt

Case 2D





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- Results -

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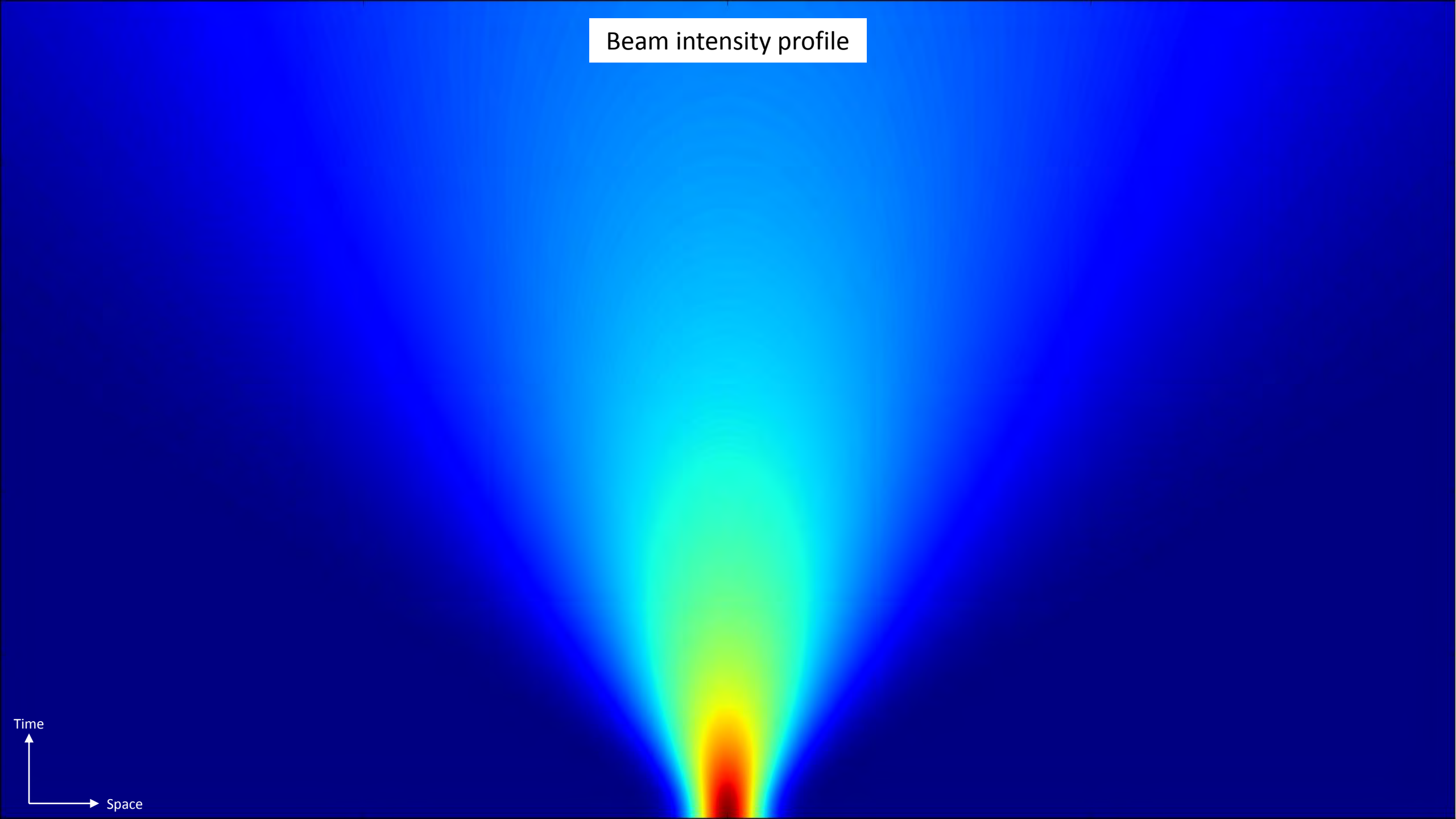
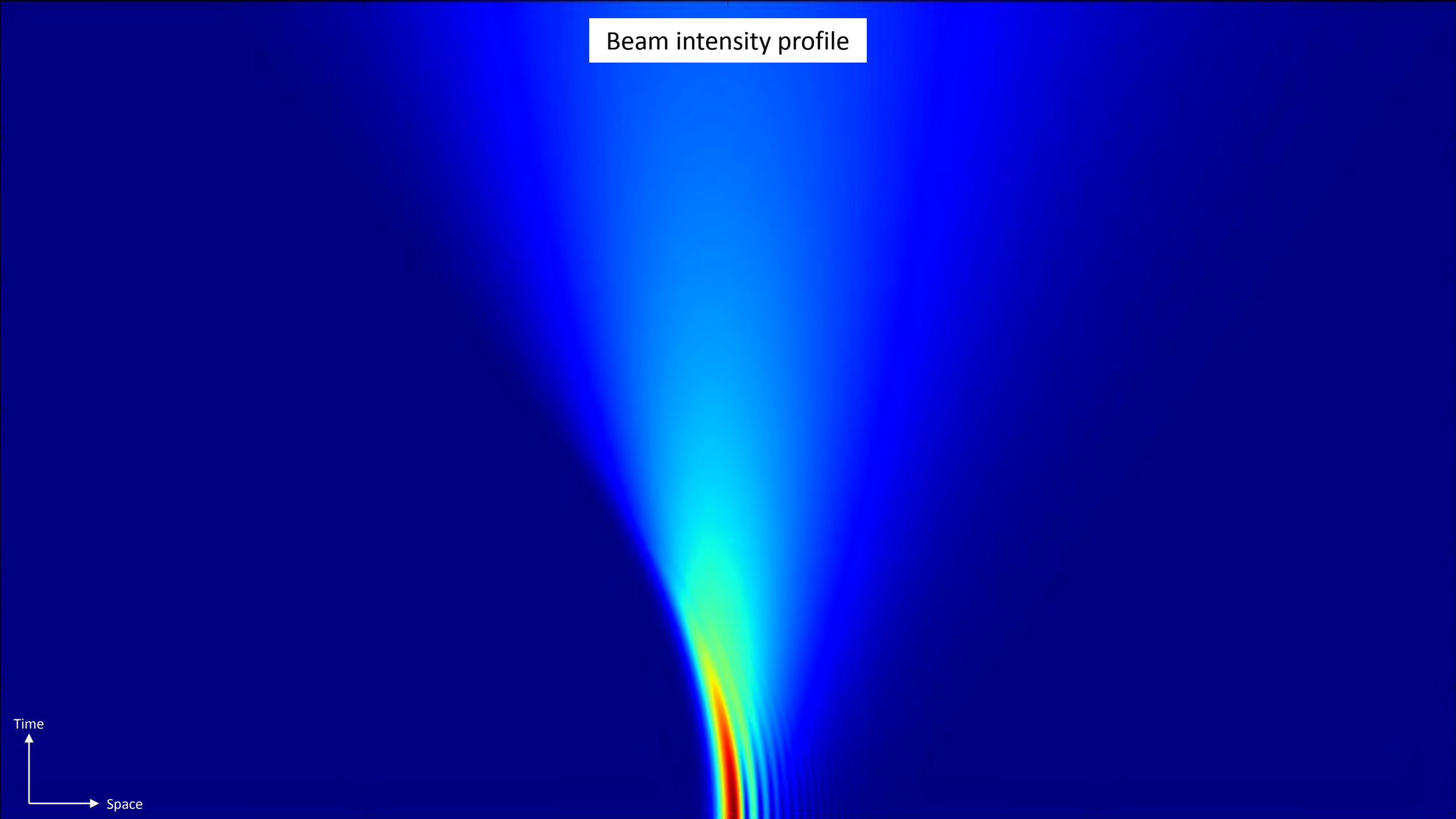
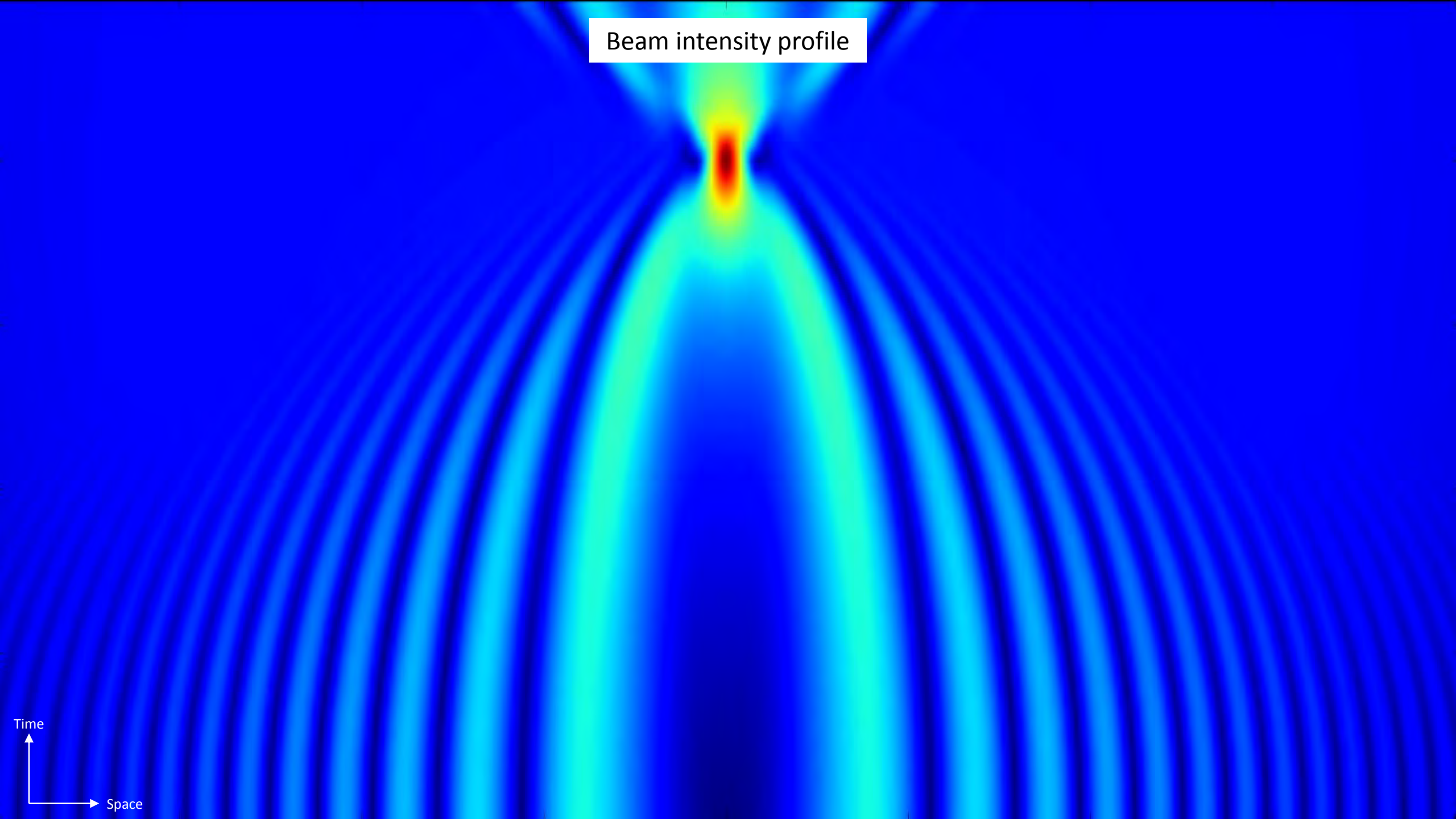

Beam intensity profile
Time
Space


Beam intensity profile
Time
Space


Beam intensity profile
Time
Space

Numerical simulations for the propagation of laser beams

- Future work -

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Numerical simulations for the propagation of laser beams

- Future work -

Numeric Package

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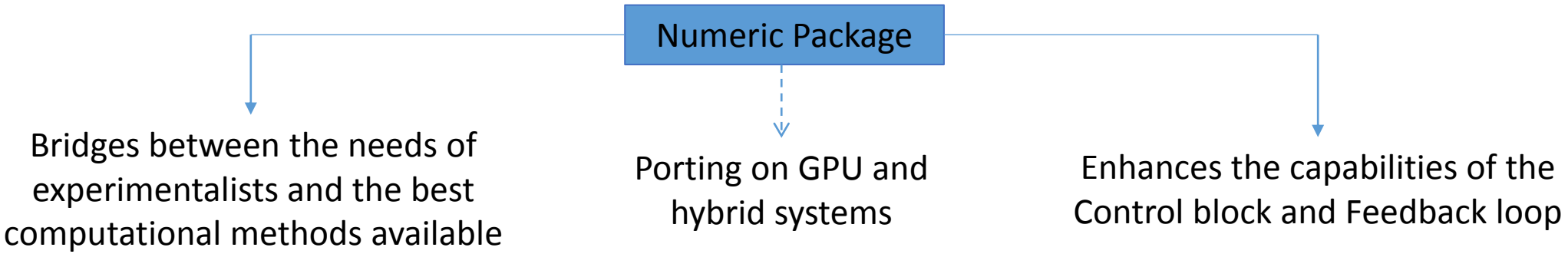
Numerical simulations for the propagation of laser beams

- Future work -



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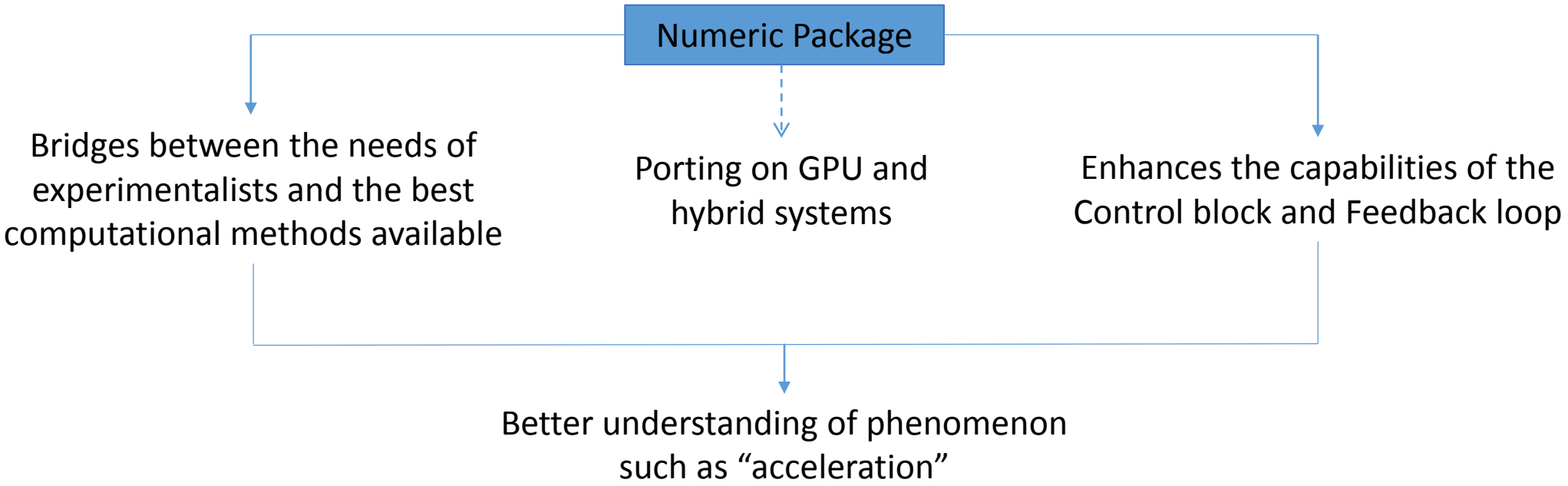

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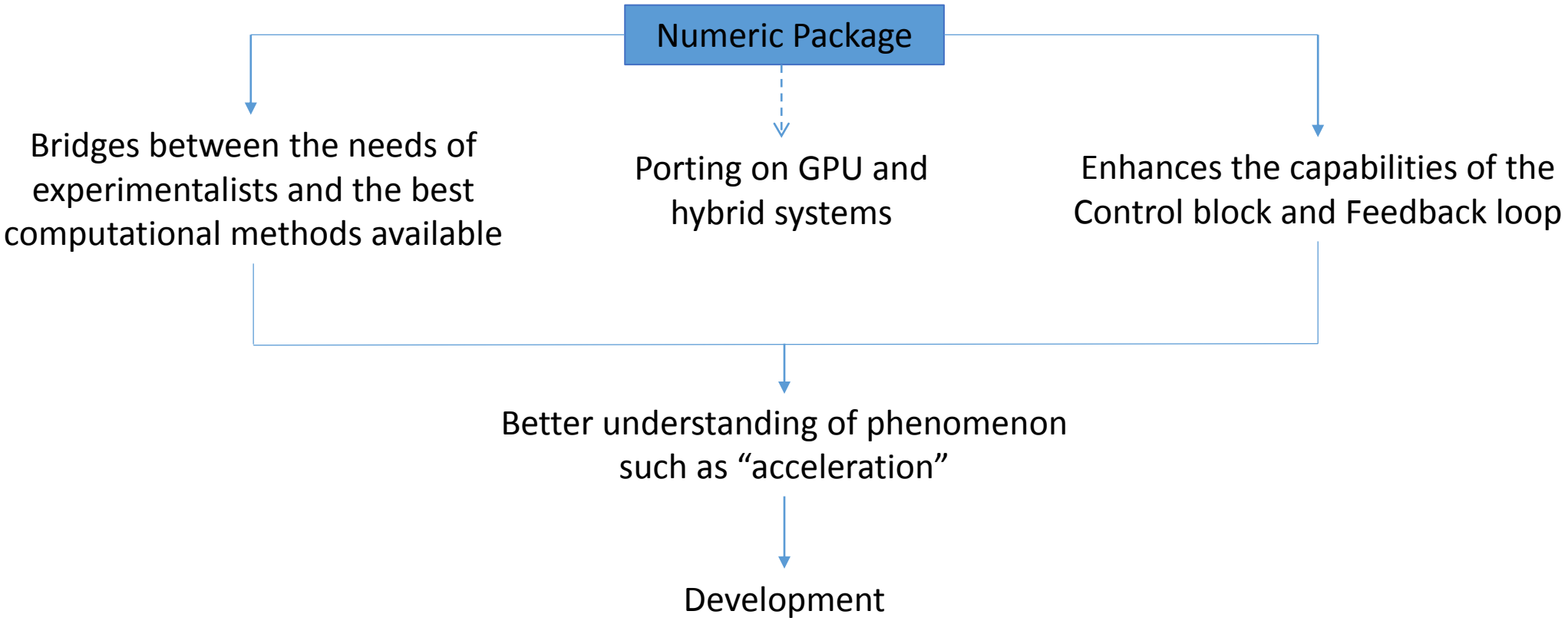

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Thank you for your attention!

Questions | Comments