NUMERICAL METHODS FOR SOLVING COMPLEX PLASMA PHYSICS PHENOMENA

Fluid codes

- Solve Poisson equation $$\nabla^2\Phi = \frac{en_0}{\epsilon_0}\left(\frac{\delta n}{n_0} + \frac{n_b}{n_0}\right)$$

- Solve fluid equations $$\frac{\partial n}{\partial t} + \nabla \cdot (n\mathbf{v}) = 0$$

$$\left(\frac{\partial}{\partial t} + \mathbf{v} \cdot \nabla\right)\mathbf{p} = e\left(\nabla\Phi + \frac{\partial \mathbf{A}}{\partial t} - \mathbf{v} \times \nabla \times \mathbf{A}\right)$$

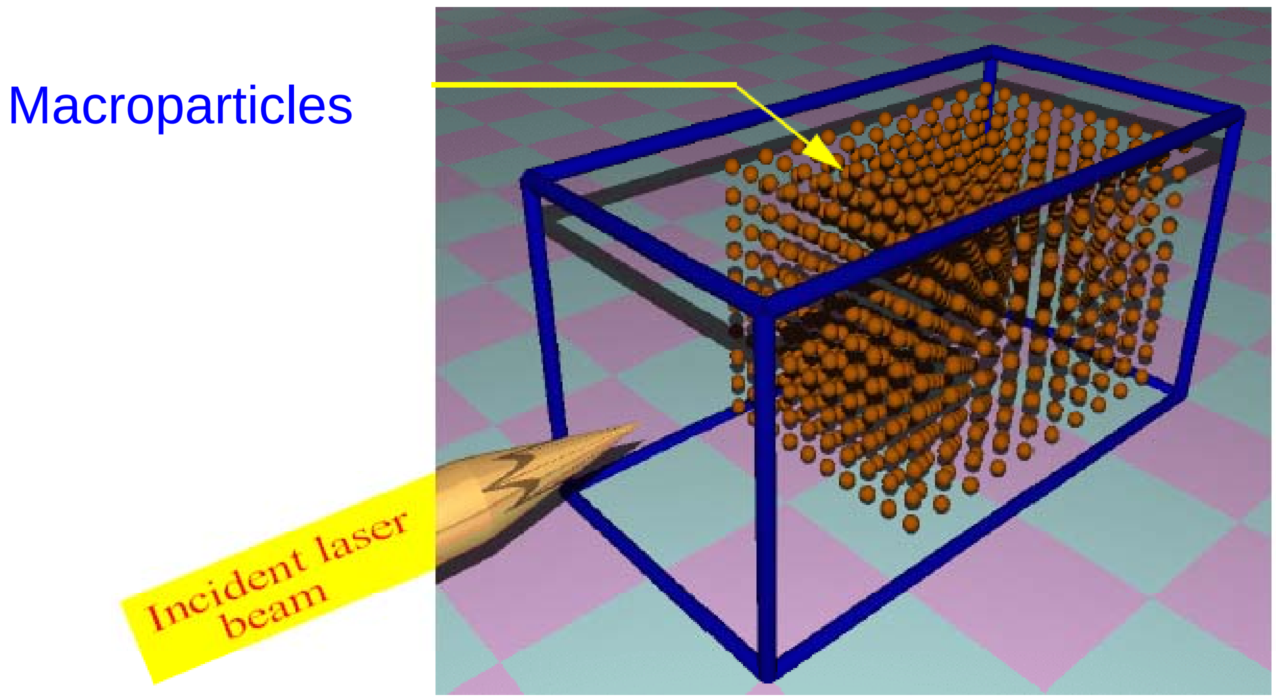
- Solve wave equation $$\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right) a = k_p^2\left(1 + \frac{\delta n}{n_0} - \frac{\langle a^2 \rangle}{2}\right) a$$

Fast computation but not enough physics:

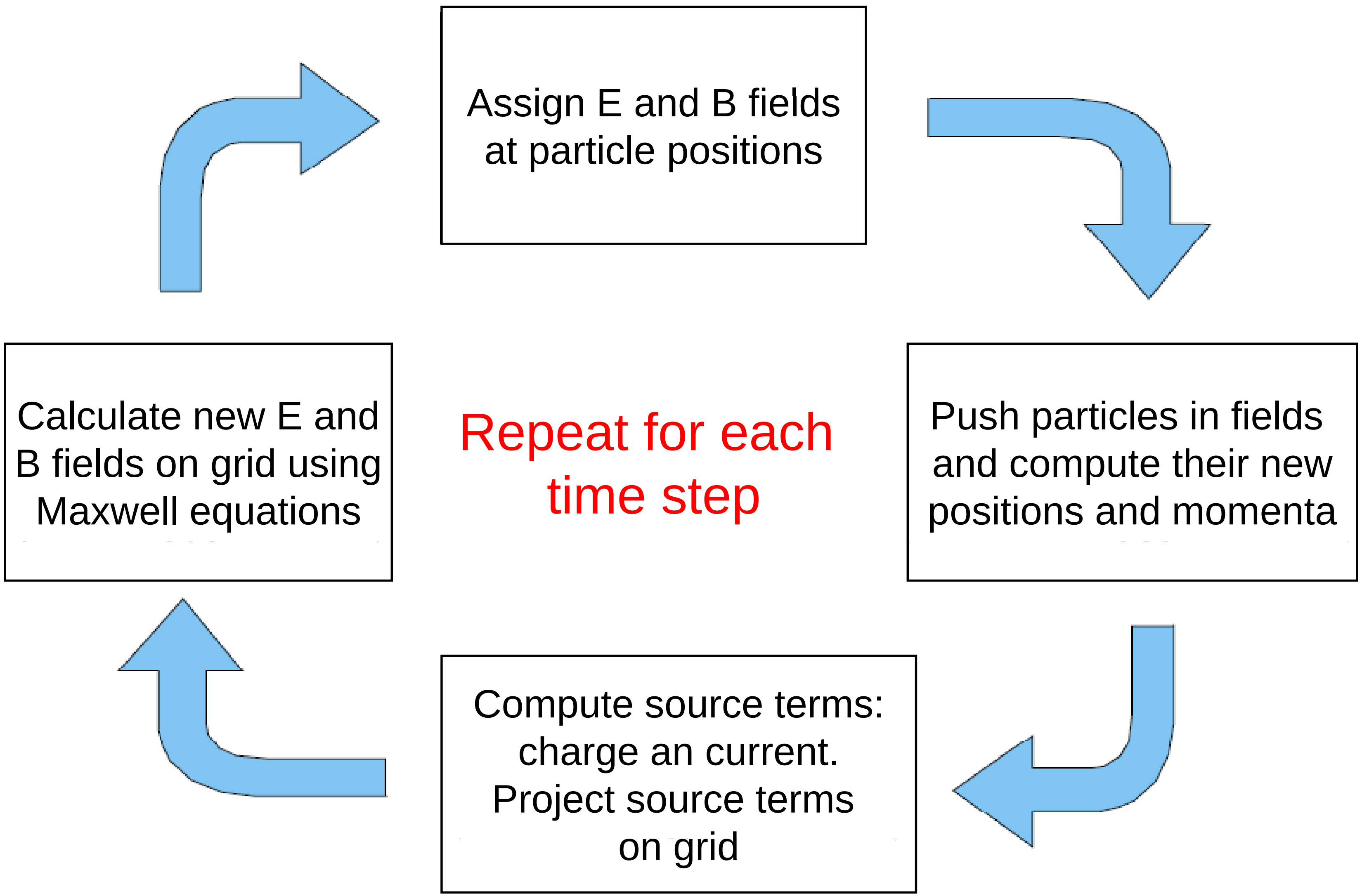
no trapping, no injection

PIC codes

- Brute force method: represent plasma electrons and ions by macro particles scattered on a grid (the simulation box)
- Push electrons and ions in fields



PIC code scheme



PIC code: advantages / limitations

- Able to model *most of the physics of interest*:
  - Plasma waves
  - Nonlinear effects
  - Kinetic effects (injection, trapping…)

- Laser propagation: requires *small grid size* ($\ll \lambda_0$)
- *Large number of particles* are necessary for reasonable results

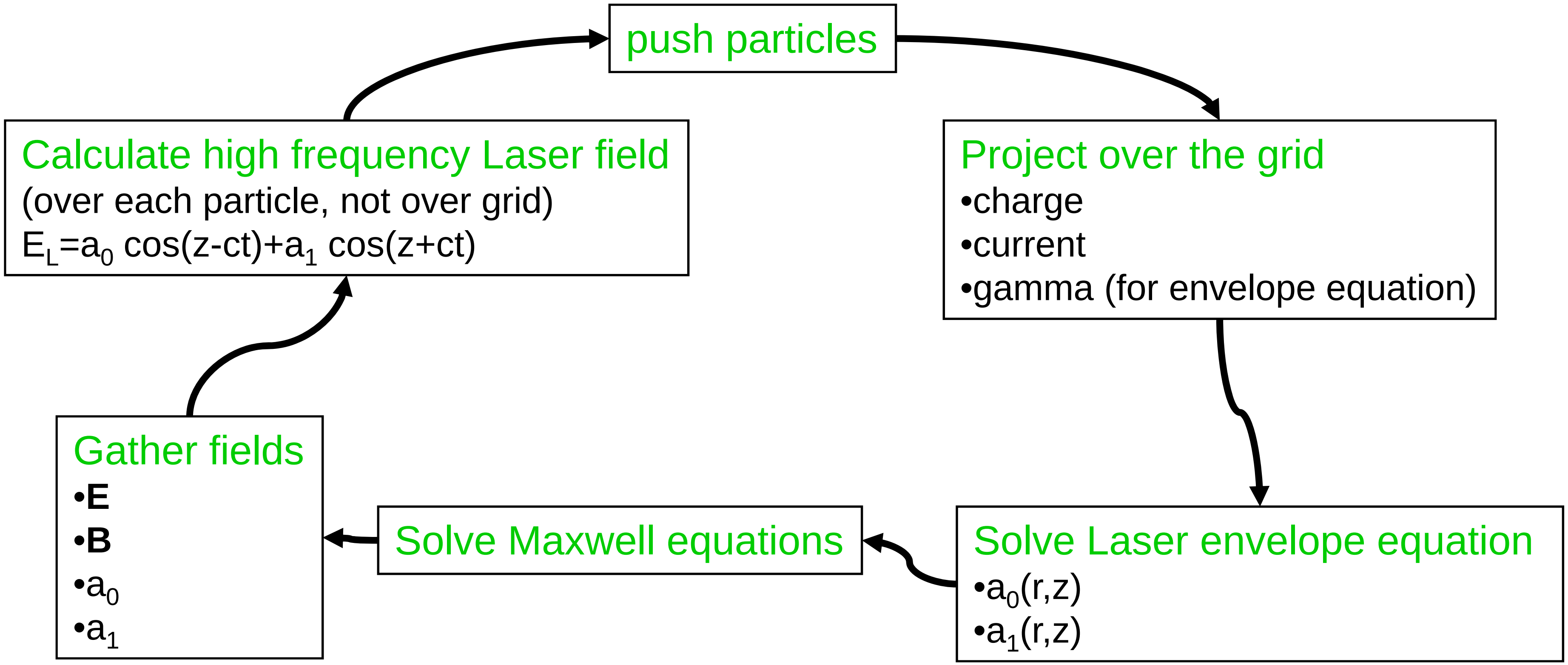
- 3D laser-plasma interaction:
  - 1 mm propagation: a few days on a super-computer (100s of nodes)

→ Long runtime, hard to do long scale propagation

Hybrid codes

*A. Lifschitz et al

- Particle-in-Cell code in cylindrical coordinates (r,z)
- Laser evolution calculated using the envelope equation



→ Considerable gain (10^3) in CPU time (10-20 hours CPU for one case)

Example of hybrid PIC code run