# *Ion Acceleration by Laser: Theory and Simulations*


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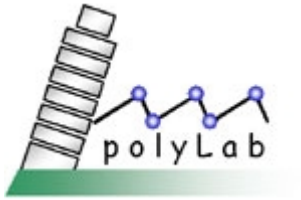
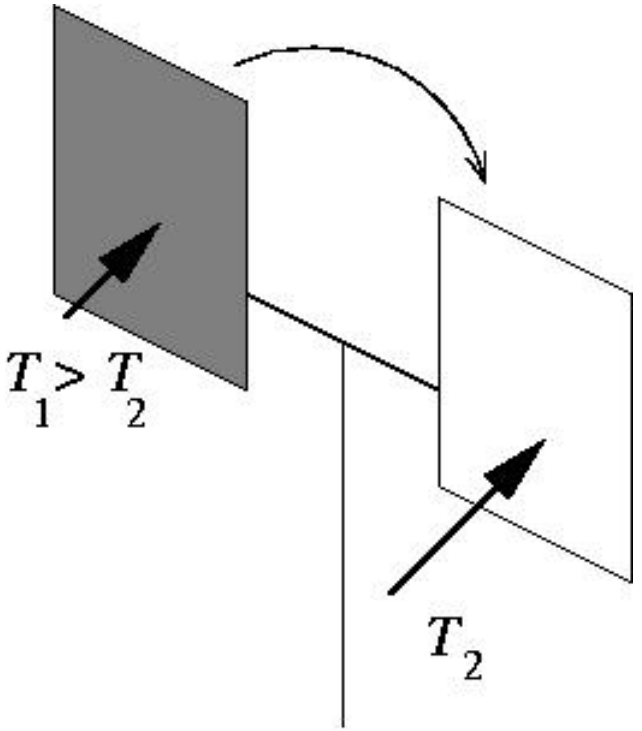





Seminario "La Luce Estrema: Presente e Futuro",
Università di Bologna, 8 gennaio 2008

# Accelerating Matter by Electromagnetic Radiation: the “Optical Mill” (Solar Radiometer)

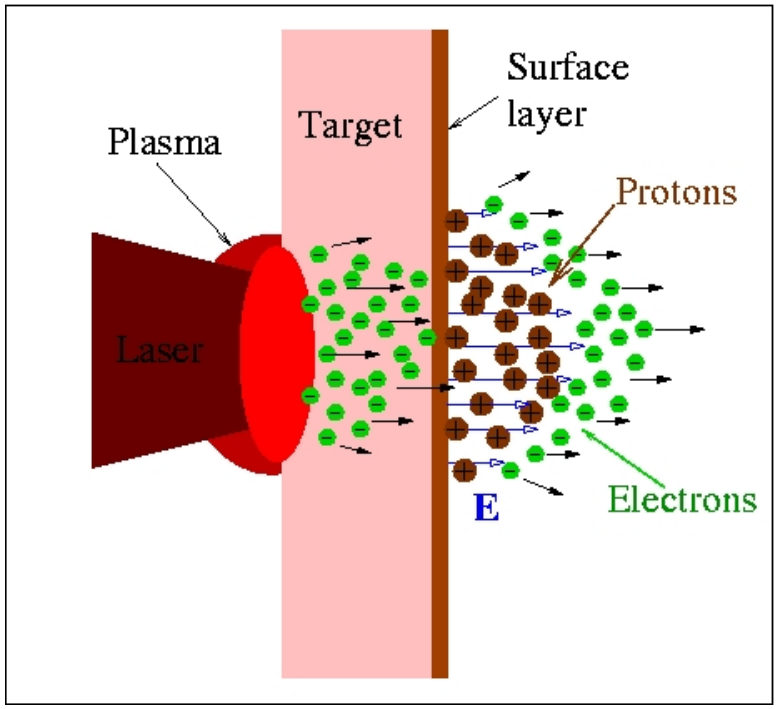




The **black** face is more absorbing than the white one

the background air is heated to larger temperatures

the mill is pushed by the **thermal pressure** of the air

# Ion Acceleration in Current Experiments is due to Target Heating (to 100 Billions of degrees...)



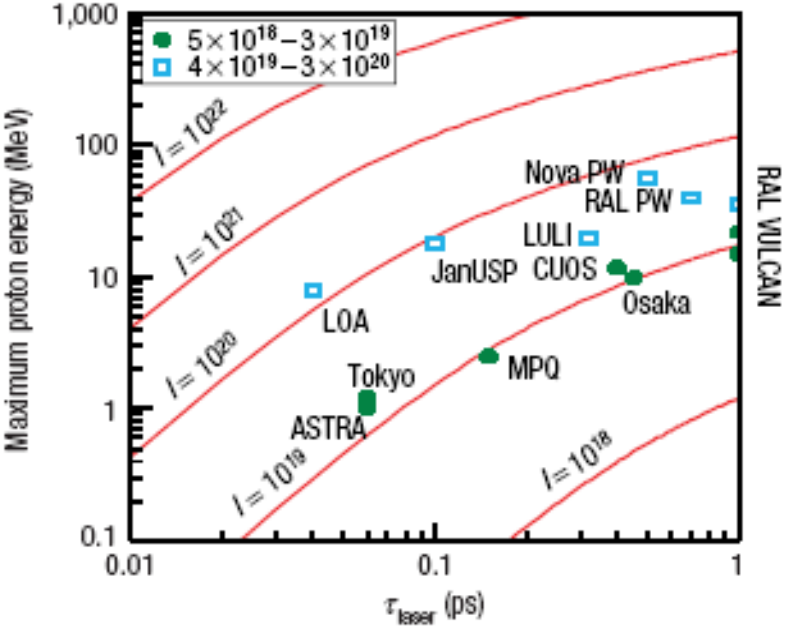

The ultraintense laser pulse accelerates **electrons** to tens of MeV energies

**Electrons** escaping in vacuum drag **ions** which are accelerated by electric fields exceeding

$10^{11}$ V/m

The **plasma expansion** model provides the theoretical basis to interpretate present experiments and to infer **scaling laws** towards **higher energies**

[picture from J.Fuchs et al, Nature Physics **2** (2005) 48



# Simulations suggest transition to a new acceleration regime at intensities ~ $10^{21}$ W/cm$^2$

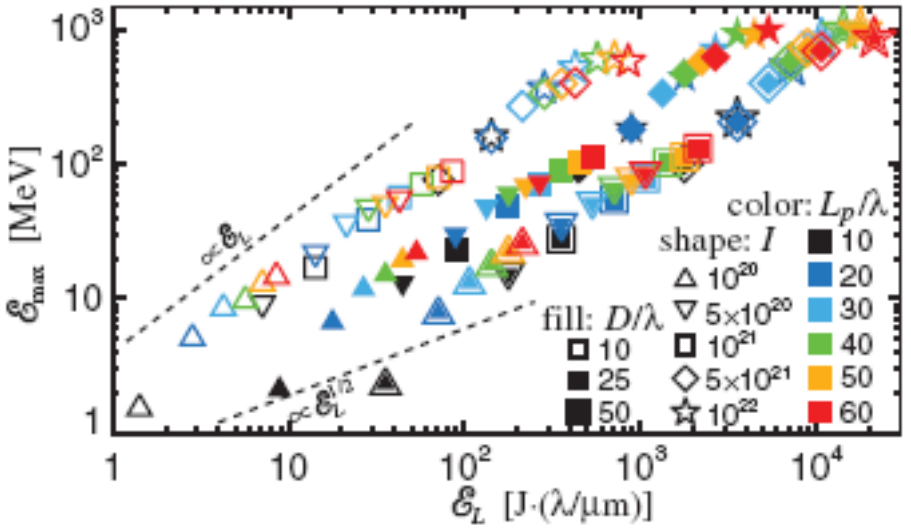
Scaling inferred from
"multi-parametric"
2D PIC simulations
(up to 400 simultaneous runs!)

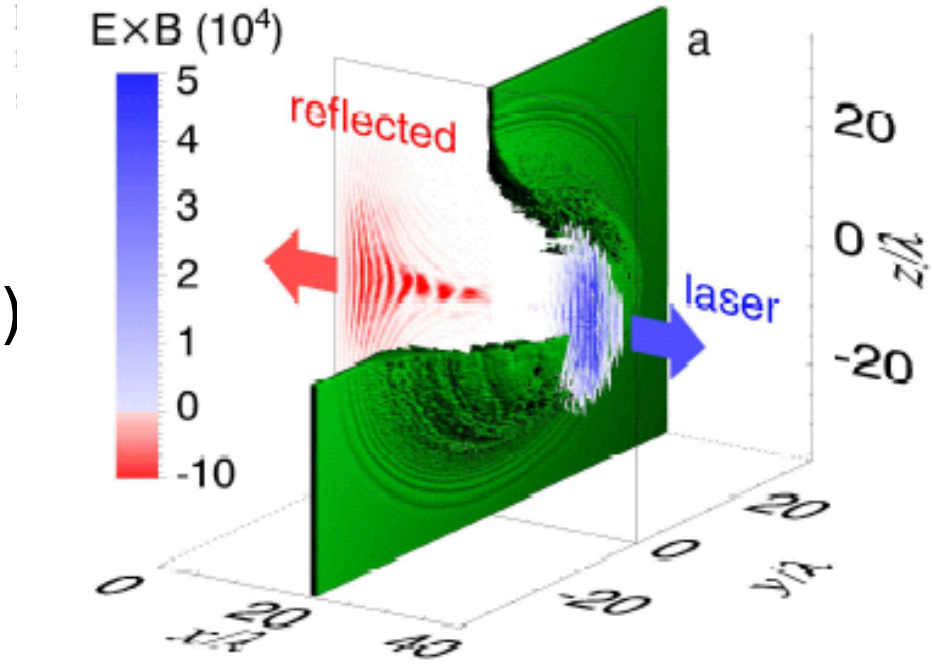
3D massively parallel simulations show relativistic (GeV) ions at
$I \geq 10^{23}$ W/cm$^2$ (foreseeable!)

T.Esirkepov et al, Phys.Rev.Lett.
**92**, 175003 (2004); **96** (2006) 105001;

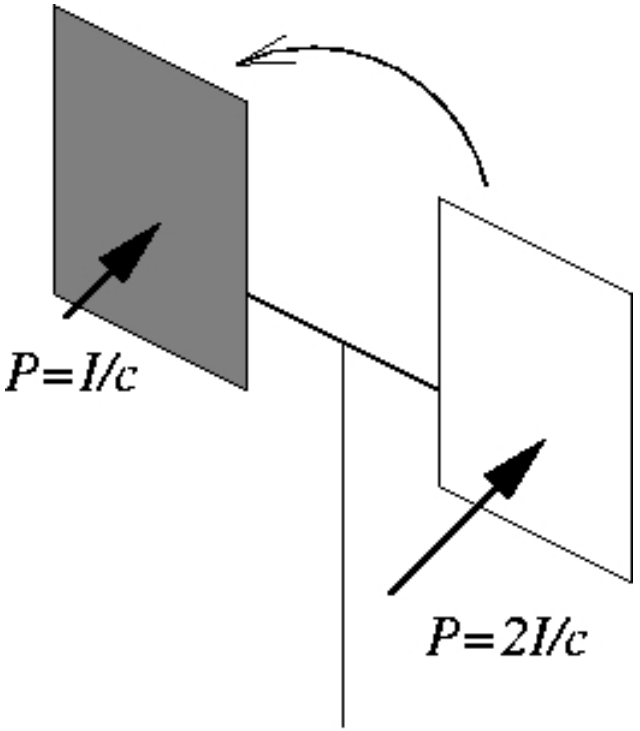
(this opens perspectives for
High-Energy physics experiments!)

from the theory point of view
the transition is explained by
the dominance of
Radiation Pressure Acceleration



# Radiation Pressure Acceleration: transfering the momentum of light to matter


The **pressure of the light** is stronger on the white face than on the **black** one: the radiometer would turn in the direction **opposite** to the usual one in perfect vacuum (i.e. with the background gas heatingsuppressed)

# Radiation Pressure Acceleration: transfering the momentum of light to matter

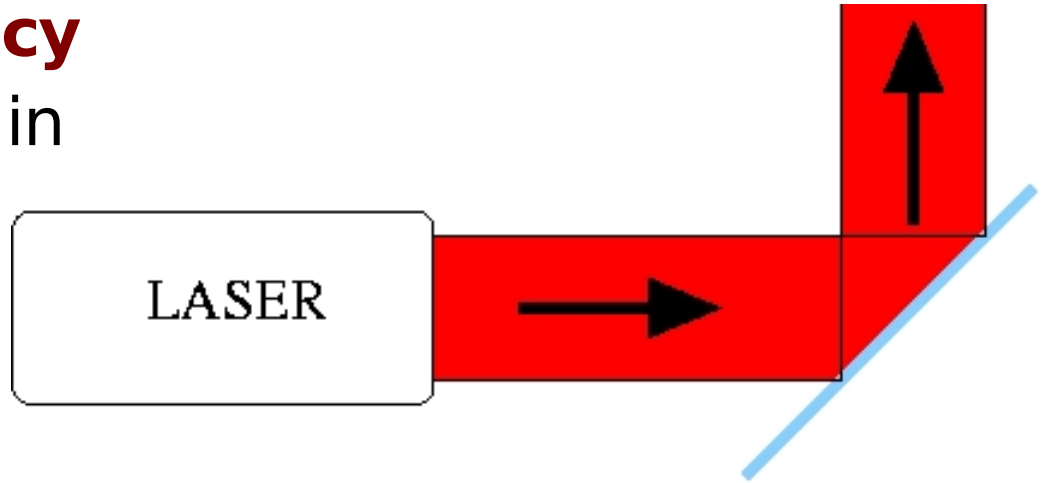
The **acceleration of a massive mirror** by light pressure is particularly efficient when the velocity becomes close to the speed of light (this suggested the “visionary” application of a **laser-propelled rocket** 42 years ago:)

22 NATURE JULY 2, 1966 VOL. 211

INTERSTELLAR VEHICLE PROPELLED BY TERRESTRIAL LASER BEAM

By PROF. G. MARX
Institute of Theoretical Physics, Roland Eötvös University, Budapest

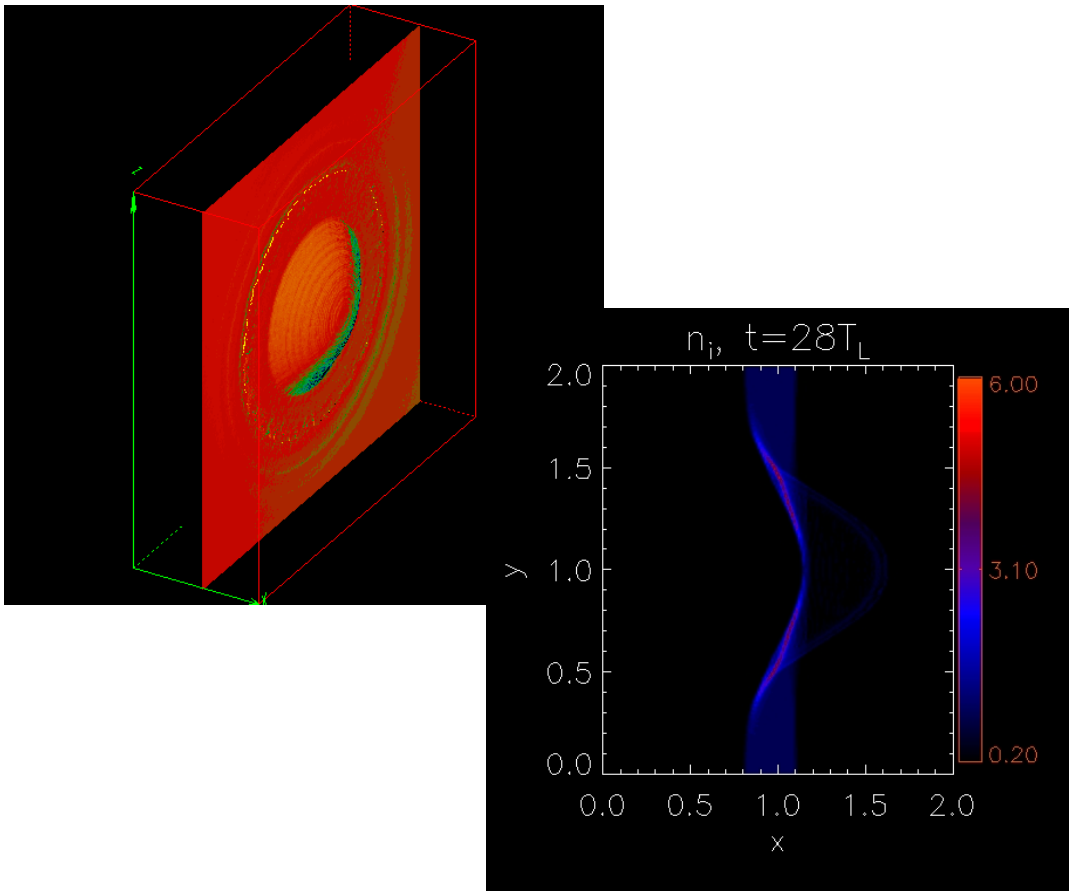
A **breakthrough in efficiency** is thus expected as we enter in the **relativistic regime** (**GeV** ions moving at the speed of light)



# Optimization of Radiation Pressure Acceleration by changing the polarization of the pulse

The **microscopic theory of electron acceleration** by laser interaction with a solid target shows that the latter is inhibited when the **light polarization is circular**: the **effect of radiation pressure is maximized**

Macchi et al,
Phys.Rev.Lett. **94** (2005) 165003




Simulations by three other groups show that use of circular polarization and ultrathin targets may produce GeV ions already at $I \sim 10^{21}$ W/cm$^2$

3D PIC simulations performed at CINECA facility (Bologna) Dec 2007/Jan 2008

(T.V.Liseikina and A.Macchi) sponsored by CNR-INFM supercomputing initiative

# Conclusions

Theoretical and simulation work is essential to unfold the mechanisms of ion acceleration in present-day experiments and to **infer scalability to foreseen applications**

A **breakthrough in ion acceleration is expected** as we enter the **radiation-pressure dominated regime** (and circularly polarized light may make the process even more efficient...)

To support the design of new experiments and explore future regimes the **access to supercomputing facilities** (at the frontier of Terabyte power) is essential:

- powering up local facilities

- strenghten collaborations and promote National and European projects for access to supercomputing