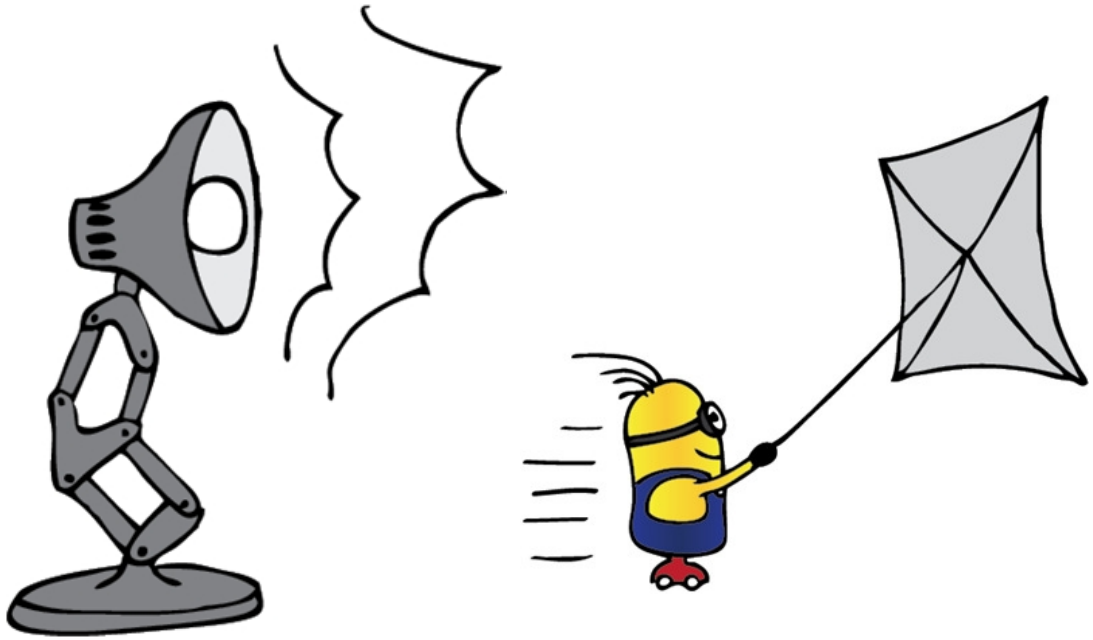
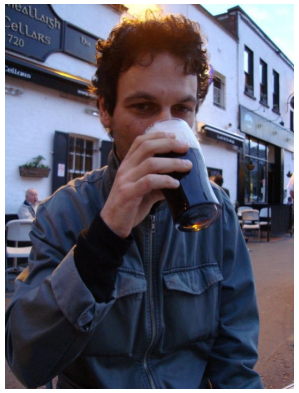
Under Light Pressure

dalle vele solari ai nuovi acceleratori laser





Andrea MACCHI

CNR, Istituto Nazionale di Ottica, Pisa

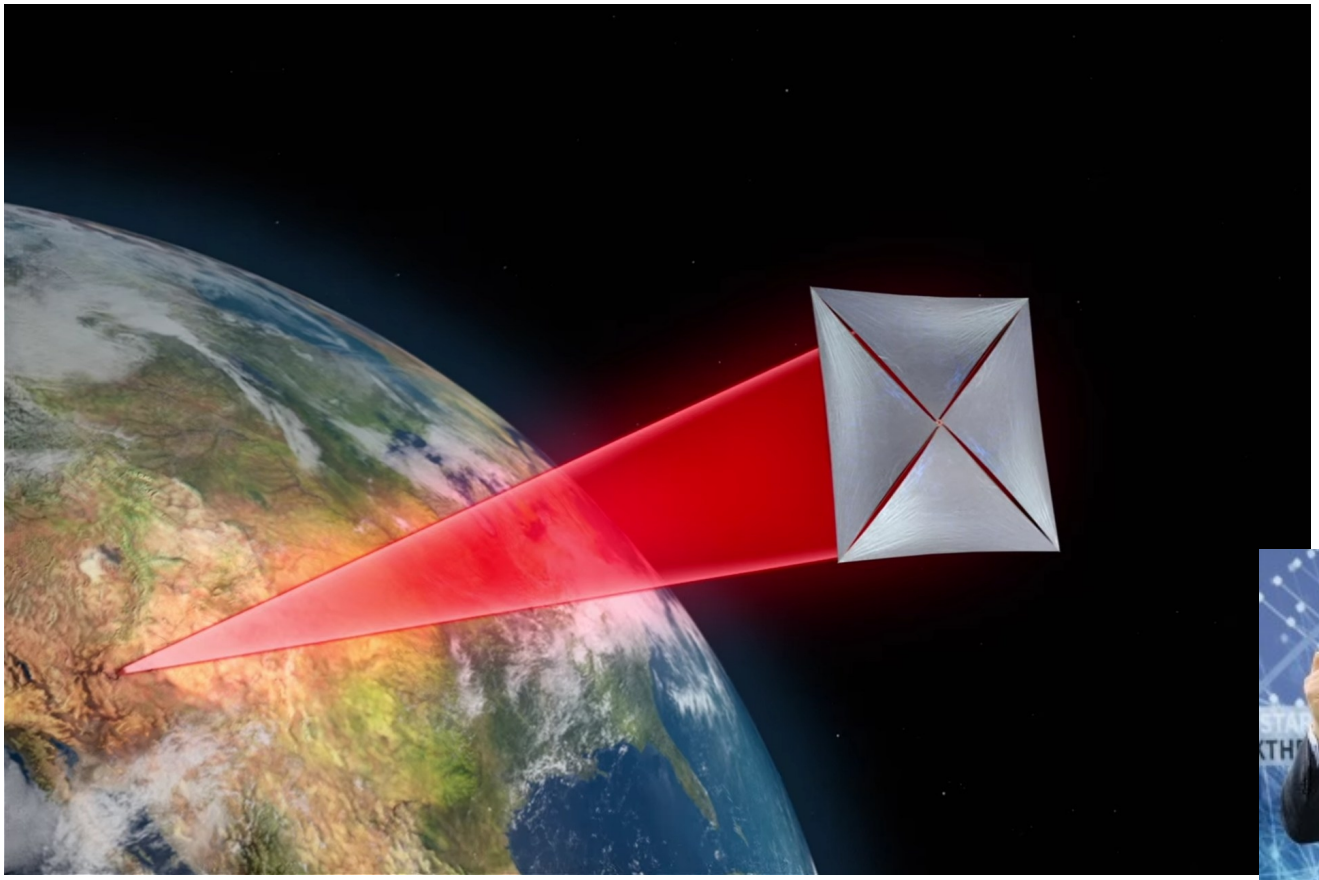
Dipartimento di Fisica, Università di Pisa

23, 24 e 25 Maggio

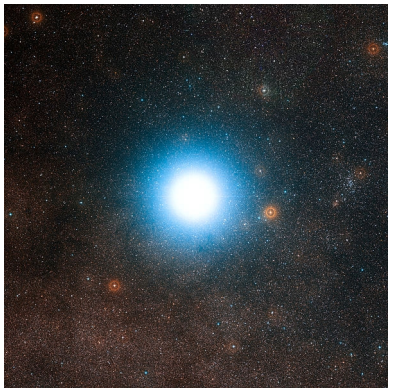
Pint of Science 2016

Solo nei migliori bar

PINT OF SCIENCE



credit: Breakthrough Starshot
breakthroughinitiatives.org



M. Zuckerberg

Y. Milner
S. Hawking
F. Dyson

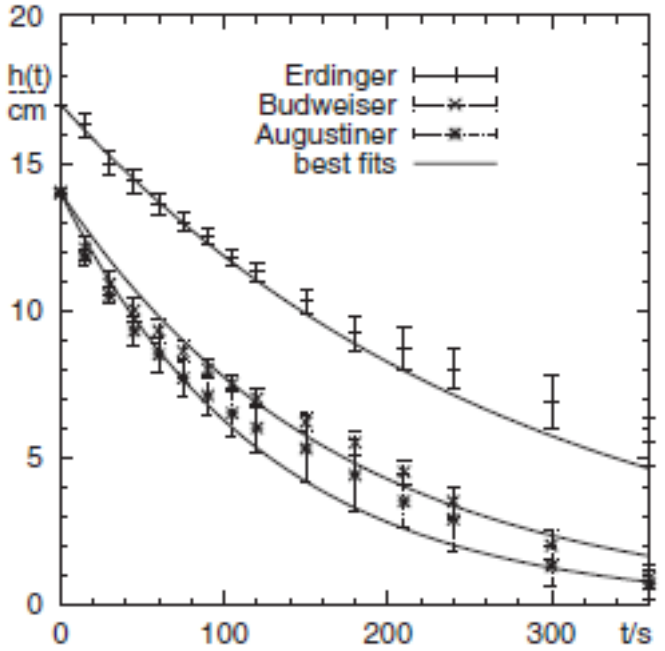
Fisica & Birra

INSTITUTE OF PHYSICS PUBLISHING — EUROPEAN JOURNAL OF PHYSICS
Eur. J. Phys. **23** (2002) 21–26 — PII: S0143-0807(02)26048-1

Demonstration of the exponential decay law using beer froth

A Leike

Ludwig–Maximilians-Universität, Sektion Physik, Theresienstr. 37, D-80333 München, Germany



Ricerca vincitrice del premio *IgNobel* in Fisica 2005

http://www.improbable.com/ig/ig-top.html

Foto dalla cerimonia:
la bottiglia è William Lipscomb, premio Nobel 1976 in Chimica

Homepage di
Physical Review Letters
Ottobre 2012:
riconoscimento pari dignità
Nobel/IgNobel

2012 Nobel Prize in Physics: Quantum Mechanics of Photons and Atoms

October 9, 2012

The APS congratulates Serge Haroche and David Wlneland for their 2012 Nobel Prize in Physics. They and their collaborators have made significant advances in the realization of quantum phenomena with many beautiful experiments. Their abilitiy to manipulate atoms and photons to demonstrate fundamental aspects of quantum physics has been documented in many journal articles. We are very pleased that much of this seminal work has been published in the APS journals *Physical Review Letters*, *Physical Review A*, and *Reviews of Modern Physics*. To honor these laureates and their collaborators, we have made freely available five of their many APS publications that demonstrate some of the key insights of their pioneering work.

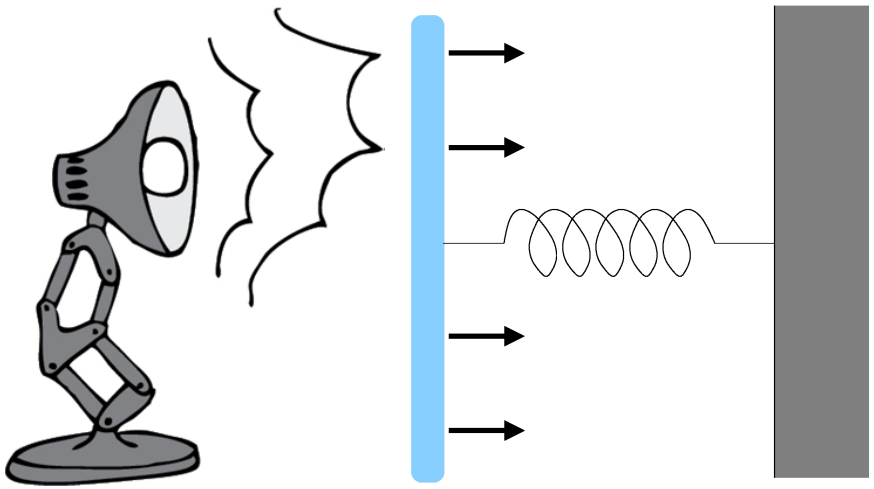
Read More | More News/Announcements

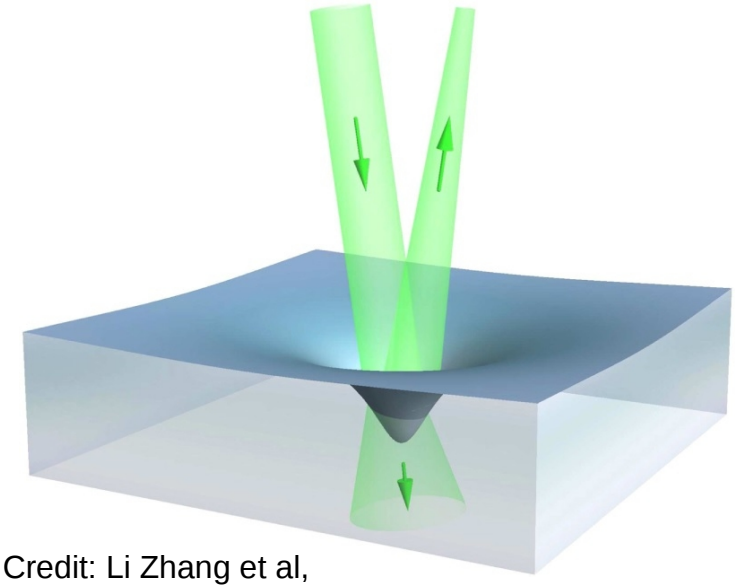
Ponytails and coffee spills lead to a pair of 2012 Ig Nobel Awards

September 25, 2012

Congratulations to the winners of the 2012 Ig Nobel Prizes in Physics and Fluid Dynamics. Raymond E. Goldstein, Patrick B. Warren, and Robin C. Ball received a share of the Physics prize for their work on the shape and motion of human hair when bundled in a ponytail, Phys. Rev. Lett. 108, 078101 (2012). For additional information, see Ponytail Physics for a brief synopsis published in *Physics*. Rebecca Thompson, APS's Head of Public Outreach, wrote on the Physics Central blog about her attempt to duplicate the ponytail research. H.C. Mayer and R. Krechetnikov took home the Fluid Dynamics prize for their study on the dynamics of sloshing coffee, Phys. Rev. E 85, 046117 (2012), which was highlighted in *Physics*, Science of Slosh, back in April 2012. We also note that our very own prognosticator, Brian Jacobsmeyer, predicted both winners back in July (http://physicsbuzz.physicscentral.com/2012/07/who-will-win-ig-nobel-prize.html).

La pressione della Luce





Credit: Li Zhang et al,
New Journal of Physics **17** (2015) 53035

per incidenza perpendicolare
su uno specchio perfettamente riflettente

$$P = 2I/c$$

I : intensità della luce
(flusso di energia incidente per unità di tempo)
c : velocità della luce (≈300000 km/s)

http://www.weatherclipart.net

intensità della radiazione solare sulla Terra

$I \approx 1.4$ kWatt/m^2

$\approx$ 2kCal/(minuto cm^2)

$\rightarrow I/c \approx 10^{-5}$ N/m^2

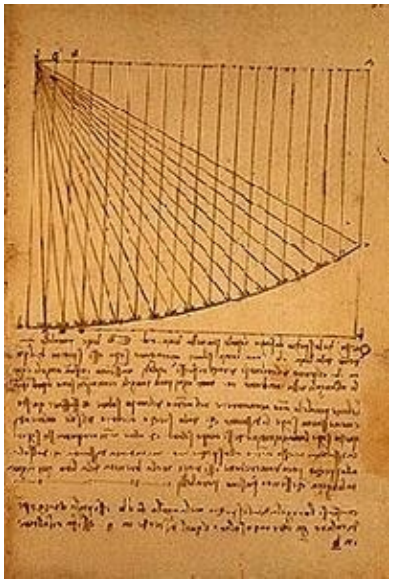
$\approx 10^{-10}$ atmosfere

focalizzando la luce con specchi o lenti si può ottenere

$\approx I \times 1000$

(la pressione rimane debole ...)

Specchi ustori di Archimede.
Giulio Parigi, ca. 1600. Museo d. Uffizi, Stanzino delle Matematiche, Firenze

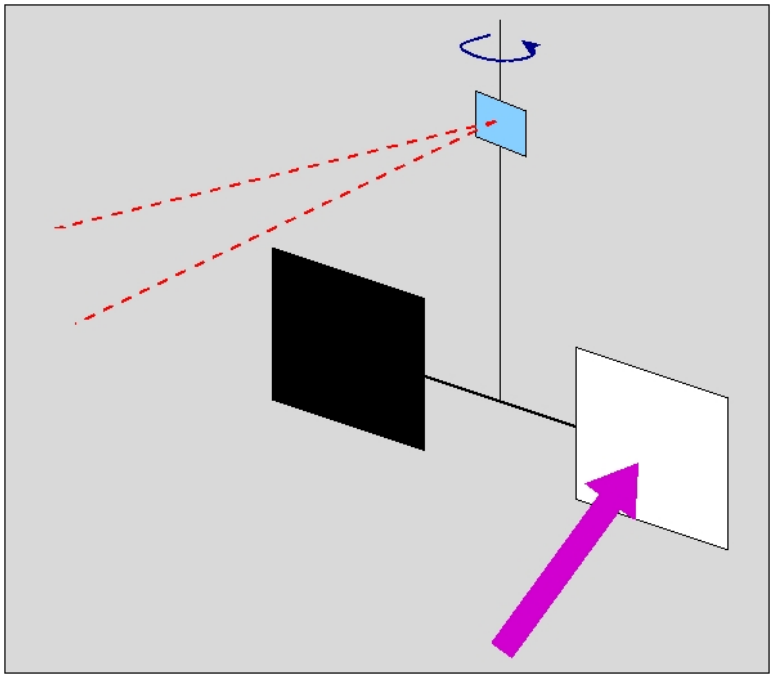


Leonardo da Vinci, Codex Arundel (1480-1518), British Library, London.

Gli scopritori della formula $P=2I/c$:

James Clerk Maxwell, 1874
(teoria elettromagnetica della luce)

Adolfo Bartoli, 1876
(termodinamica della radiazione)

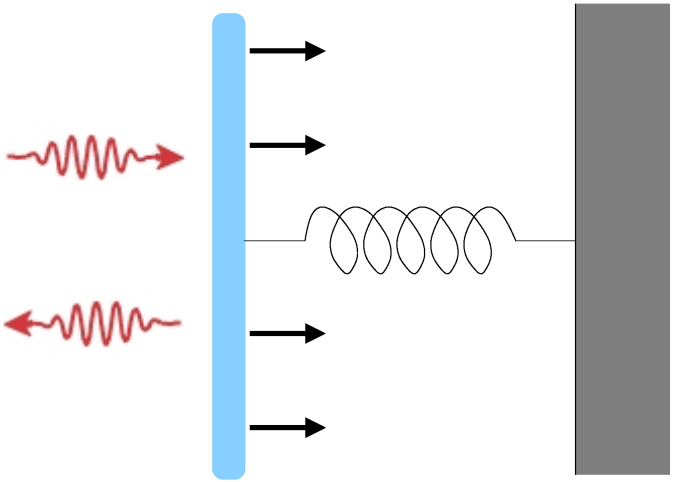


Verifica sperimentale:
Piotr N. Lebedev, 1899
(metodo del pendolo
di torsione)

Pressione dai quanti di luce (fotoni)

relazione tra quantità di moto p ed energia E per particelle a massa nulla

$$p=E/c$$



Se N fotoni “rimbalzano” su uno specchio di area A in un tempo Δt

$$I=NE/(A\Delta t)$$

$$\Delta p=N(2p)=2NE/c$$

forza risultante:

$$F=\Delta p/\Delta t=2(NE/c)/\Delta t$$

pressione:

$$P=F/A=2(NE/A\Delta tc)=2I/c$$

Albert Einstein, 1905

Vele solari

"... *un giorno avremo velocità molto più grandi [dei pianeti e del proiettile], delle quali probabilmente la luce o l'elettricità saranno gli agenti meccanici* ...
e viaggeremo verso la Luna, i pianeti, e le stelle"
Jules Verne, Dalla Terra alla Luna (1865)

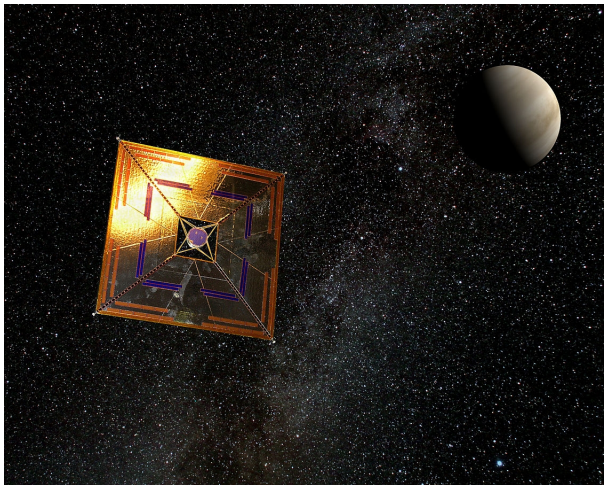
credit: NASA

progetti:

NanoSAIL (NASA)

IKAROS (Giappone)

...



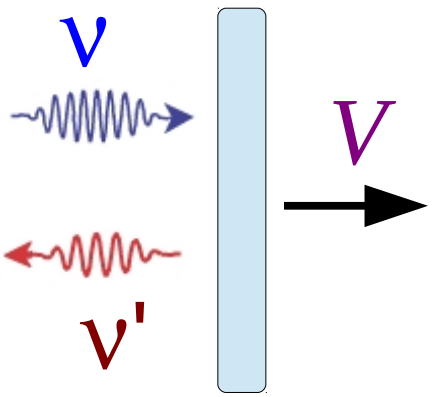
Andrzej Mirecki https://commons.wikimedia.org/w/index.php?curid=14656159

Efficienza della vela a luce (*light sail*)

relazione tra frequenza ν (colore) della luce

e energia E del fotone

$$E=h\nu$$

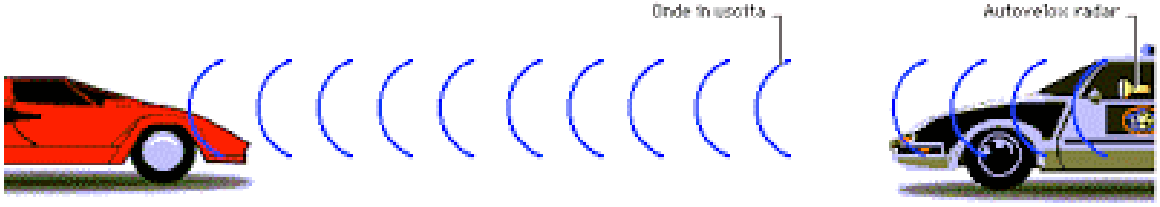


effetto Doppler ("spostamento verso il rosso")

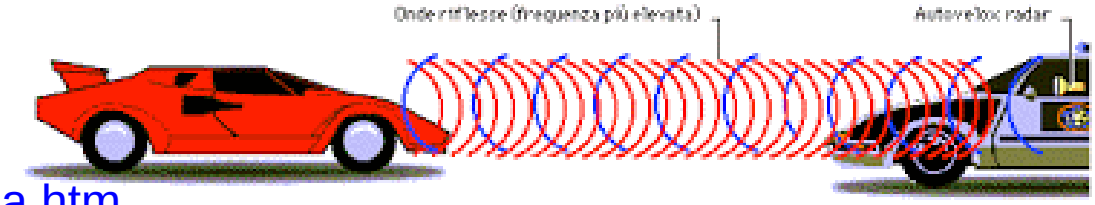
nella riflessione da vela in moto con velocità V

$$\nu'=\nu(1-V/c)/(1+V/c)$$

per $V \rightarrow c$, $\nu' \rightarrow 0$: tutta l'energia viene ceduta alla vela

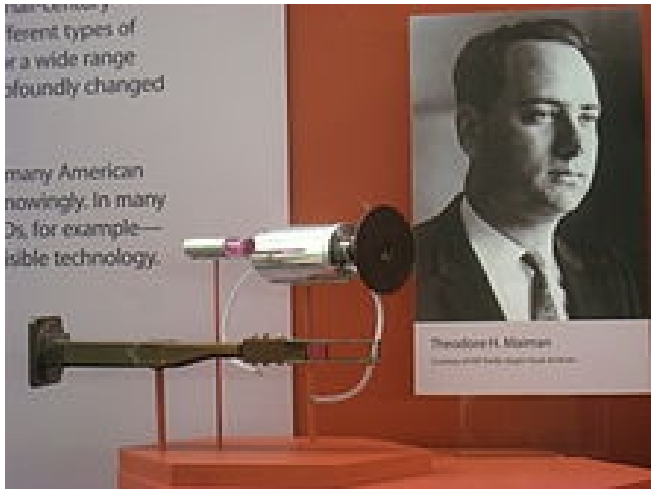


Autovelox Doppler



Fonte:
http://users.libero.it/i3ltt/prova/fisica.htm

"... [*questo laser*] *è una soluzione in cerca di un problema*"
I. d'Haenens a T. H. Maiman (1960)



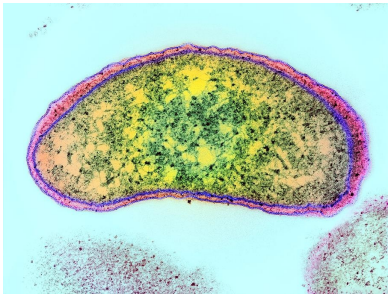
LASER: luce artificiale coerente, monocromatica, direzionale, amplificabile, "concentrabile" nello spazio nel tempo

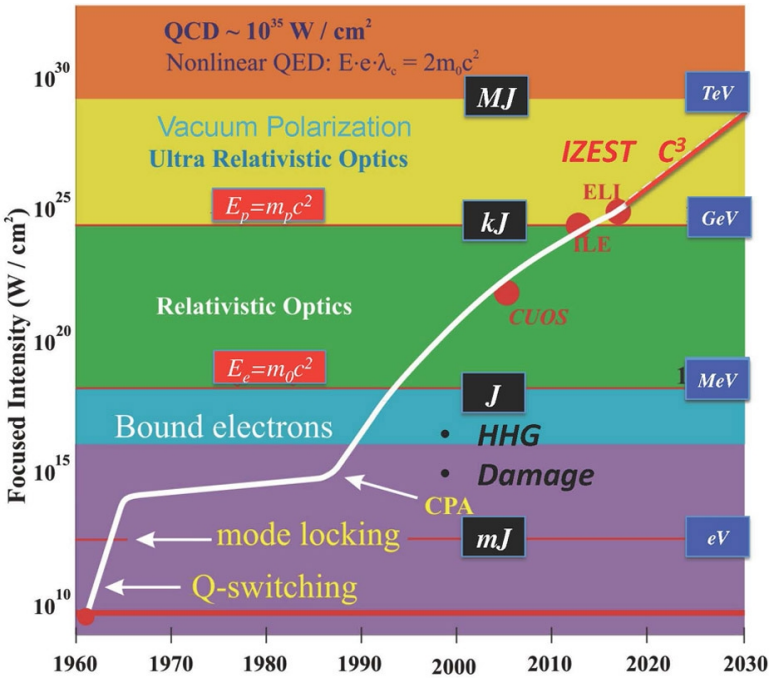
Record attuale di intensità

$I \approx 10^{27}$ Watt/m^2

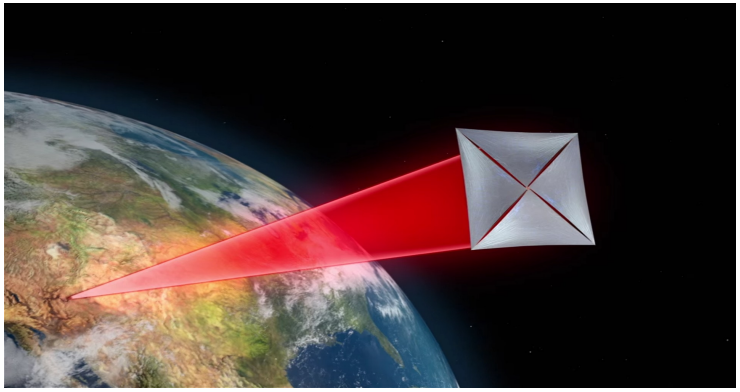
$\rightarrow I/c \approx 3 \times 10^{18}$ N/m^2

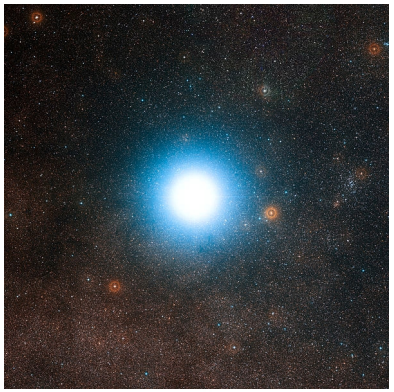
$\approx 3 \times 10^{13}$ atmosfere





Vele laser





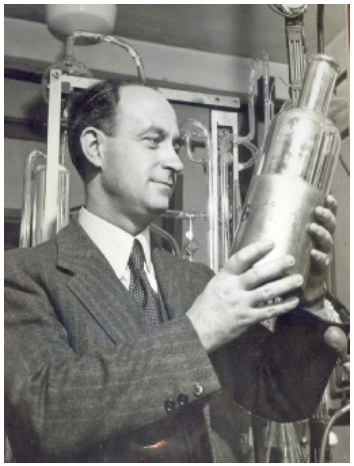
R. L. Forward (1964)

G. Marx (1966)
Nature **211**, 22

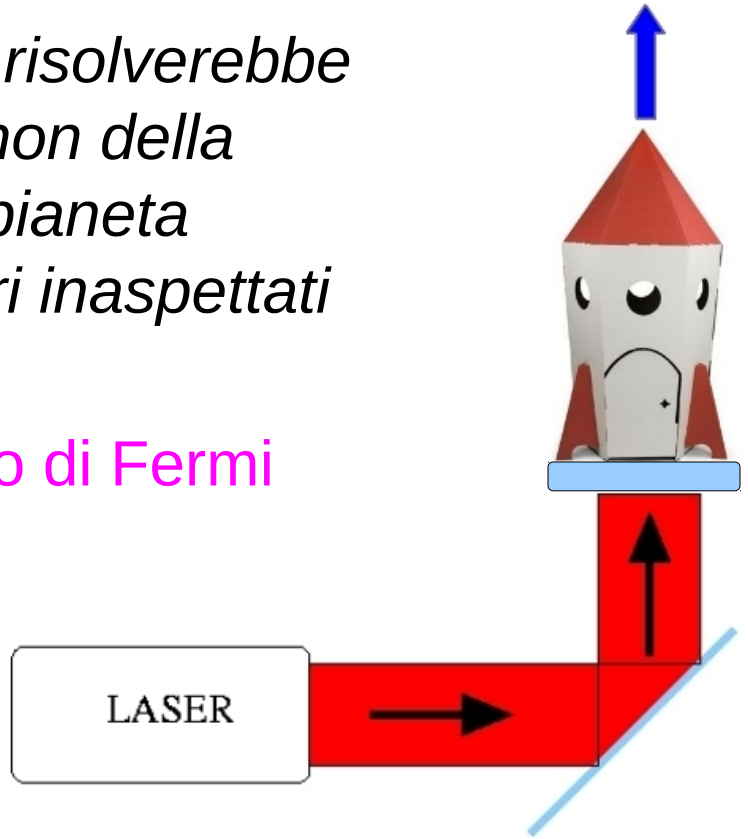
"*La propulsione laser dalla terra ... risolverebbe il problema dell'accelerazione ma non della decelerazione all'arrivo ... nessun pianeta potrebbe essere invaso da visitatori inaspettati dallo spazio esterno*"

Ovvero una soluzione al Paradosso di Fermi

"*Se l'Universo pullula di alieni, dove sono tutti quanti?*"

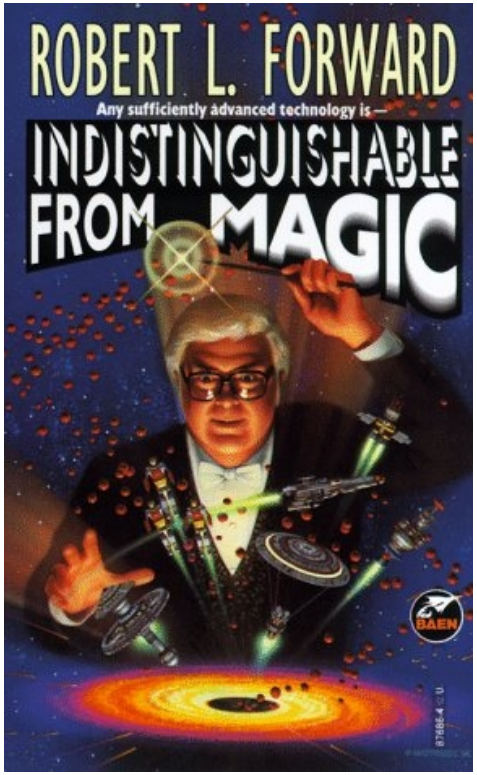


Enrico Fermi (1950)



Viaggio ε-Eridani A/R

R. L. Forward (1984)
J. Spacecraft **21**, 187



"*Ogni tecnologia sufficientemente avanzata è indistinguibile dalla magia*"

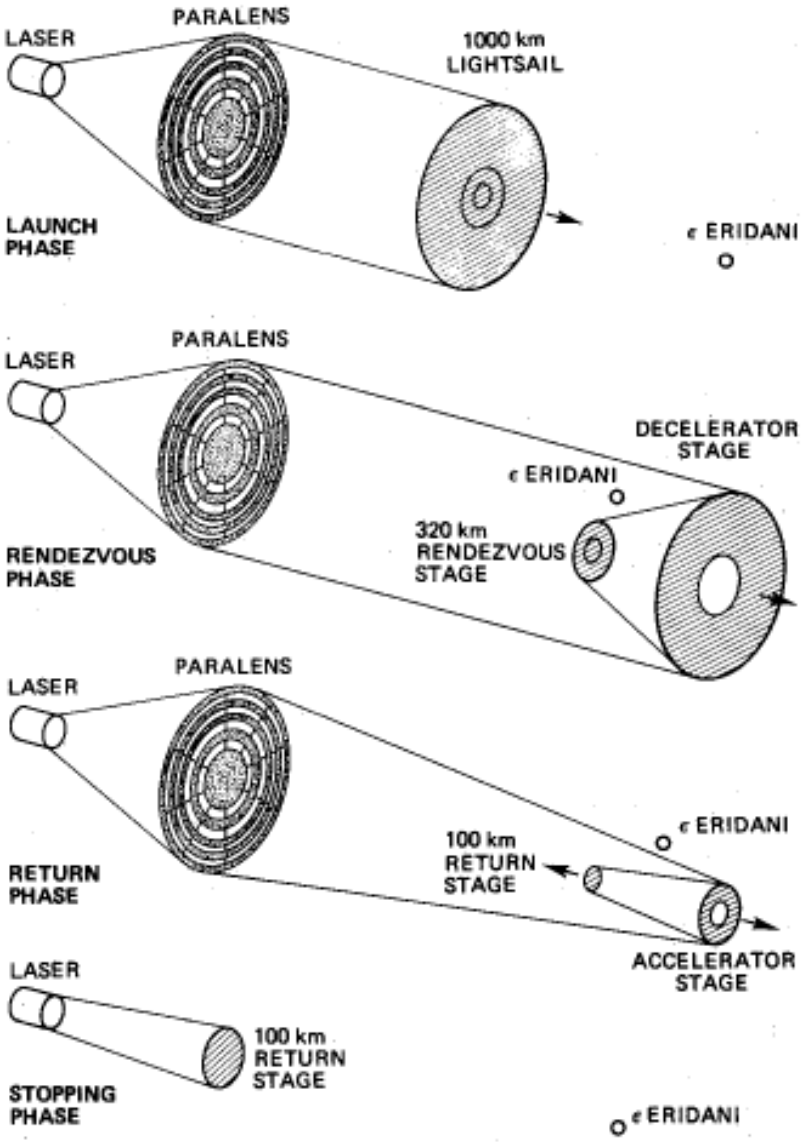
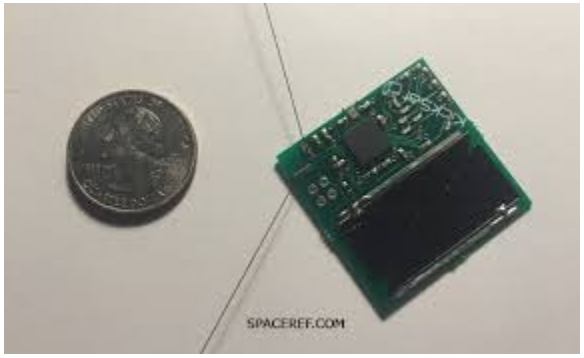
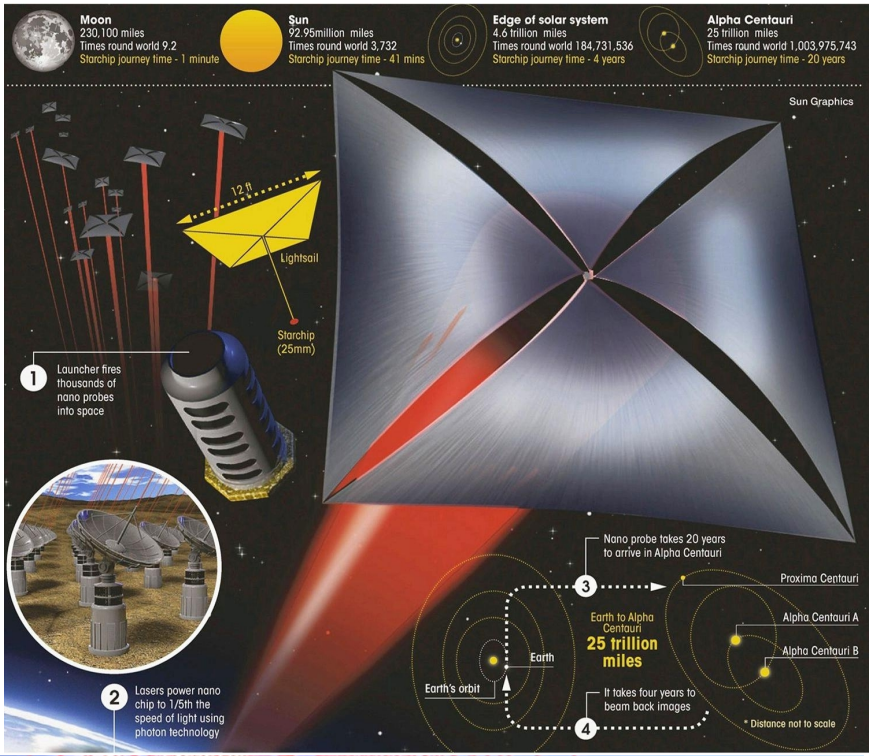


Fig. 5 Propulsion phases of roundtrip interstellar travel using laser-pushed lightsails.

2016: Breakthrough Starshot

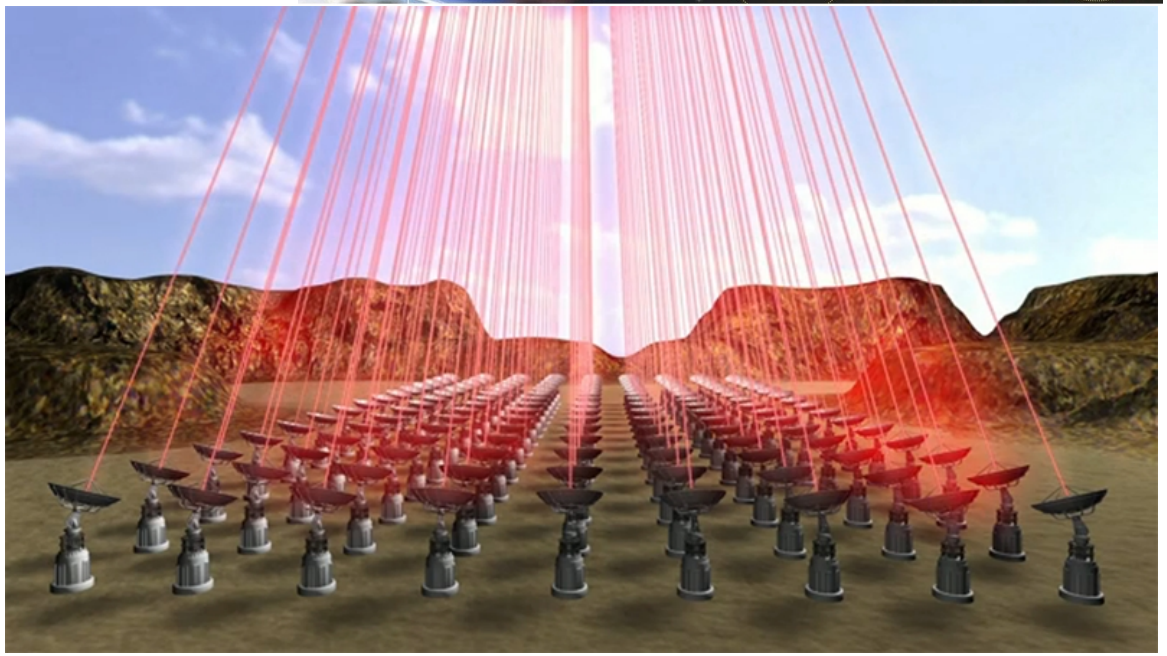
Obiettivo: raggiungere
α-Centauri in 20 anni accelerando
≈1000 vele sonda (“StarChip”)
di (4 X 4)m^2 e 1 g a $V=0.2c$



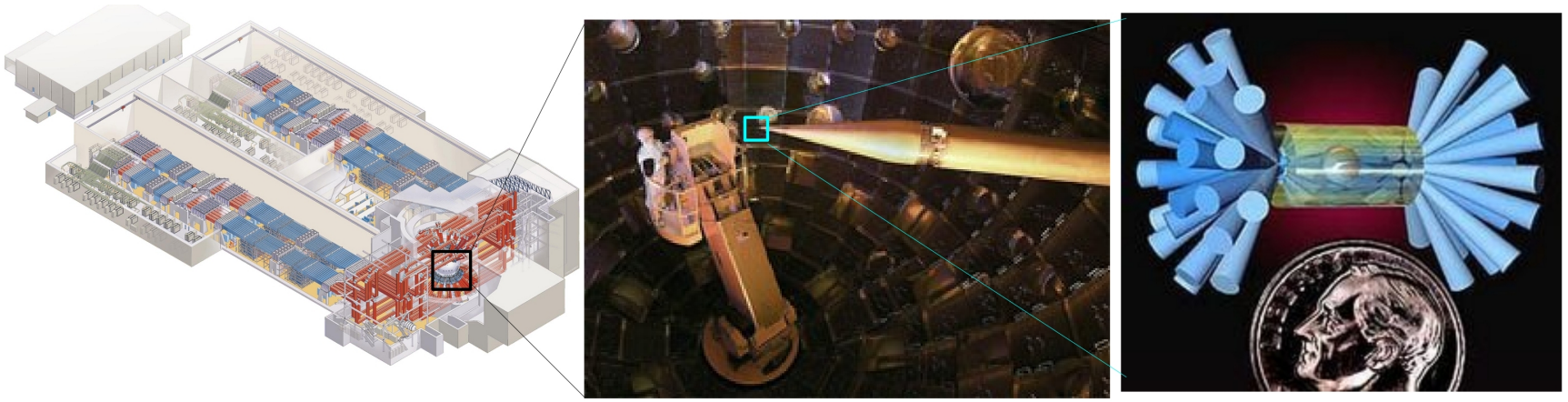


Potenza richiesta:
≈100 GigaWatt
(≈100 centrali nucleari)
per ≈10 minuti
(>10^{14} Joule di energia)
da uno schieramento
di Laser su ≈1 km^2

breakthroughinitiatives.org

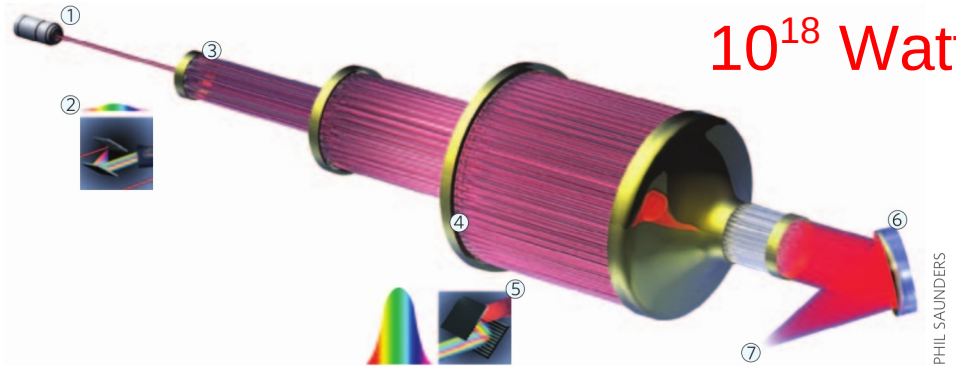


Laser superintensi (impulso ultrabreve: 10^{-8} - 10^{-14} sec)

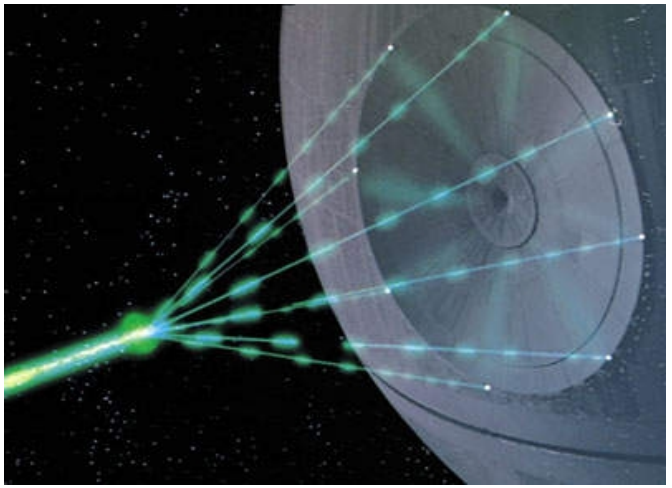


National Ignition Facility (USA) per fusione nucleare (2012):
$\approx 10^{6}$ Joule in $\approx 10^{-9}$ secondi ($\approx 10^{15}$ Watt) , uno sparo al giorno

Idea del laser “multifibra”: sincronizzazione in fase di $\approx 10^{3}$ fasci



10^{18} Watt?



[Mourou et al, Nature Photonics **7** (2013) 258]

Vela laser come acceleratore “da tavolo”

Miniaturizzazione in laboratorio:

Impulso laser: energia ≈10 J
durata ≈10 femtosecondi=10^{-14} sec

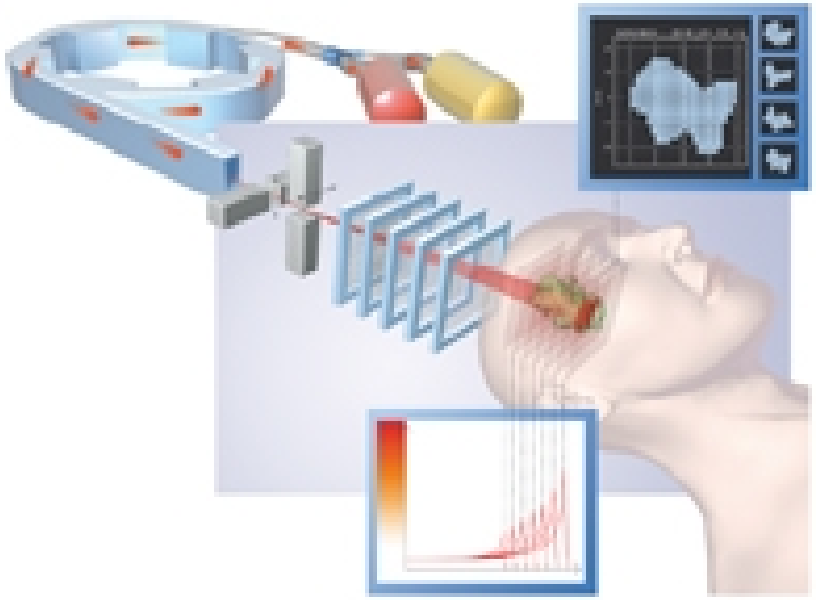
Vela: pellicola ultrasottile
(≈10 nanometri=10^{-8} m)

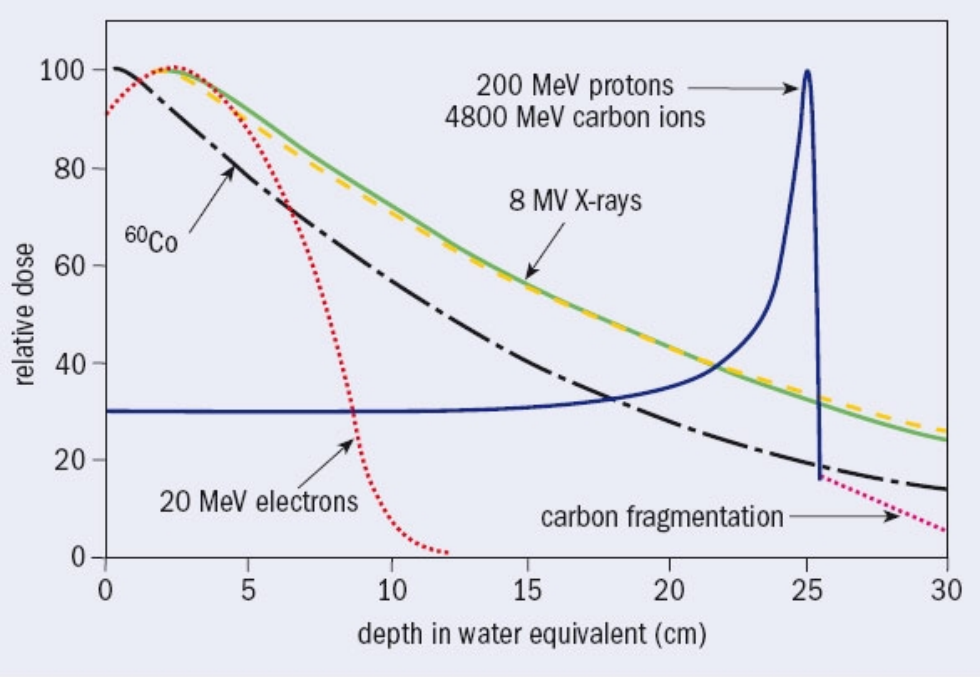
→ possibile accelerare a $V=0.3c$
≈10^{-14} g di materia (≈10^{14} protoni)
ad alta ripetizione (>10 impulsi/sec)
su una lunghezza di ≈100 micron=0.1 mm

LHC al CERN (Ginevra):
27 km di circonferenza...

Perché un acceleratore di ioni?

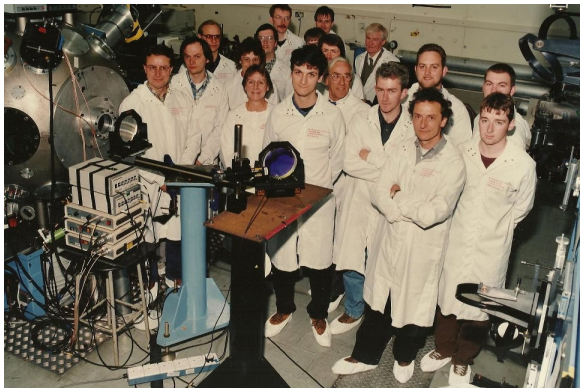
Un fascio di ioni (protoni, ioni Carbonio, ...) deposita la propria energia nella materia in una regione estremamente più localizzata di raggi X, γ o elettroni



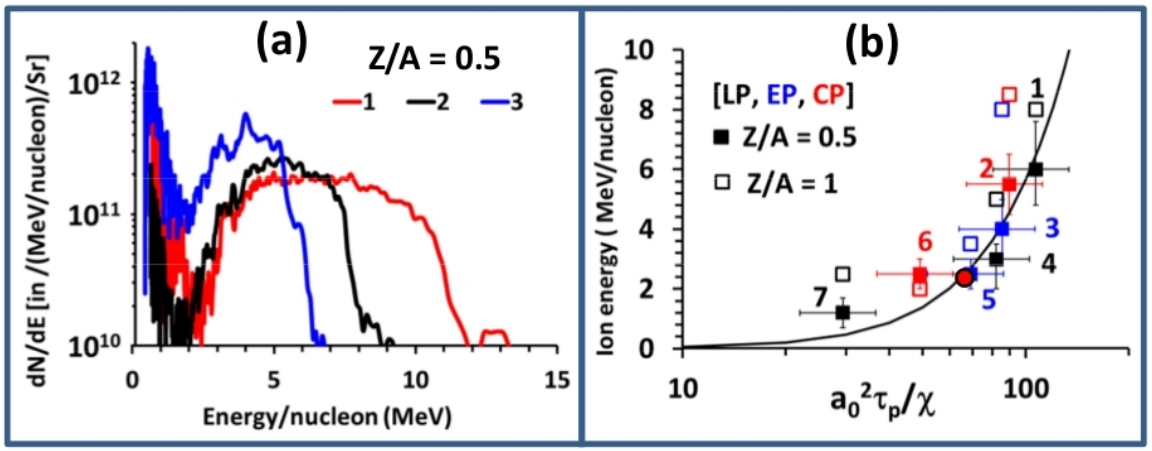


L'adroterapia usa fasci di ioni per distruggere tumori non operabili annidati in profondità in organi vitali

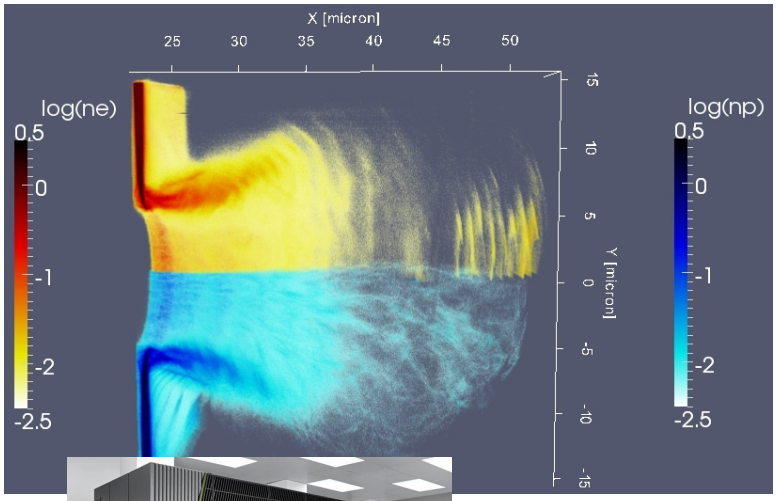
I nostri strumenti



esperimenti

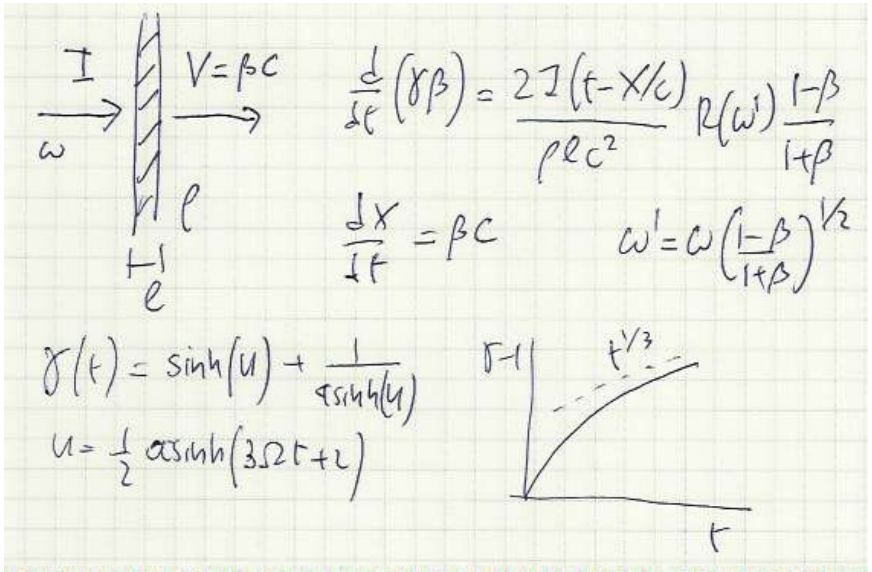


S. Kar et al, Phys. Rev. Lett. **109** (2012) 185006



simulazioni numeriche

carta e penna

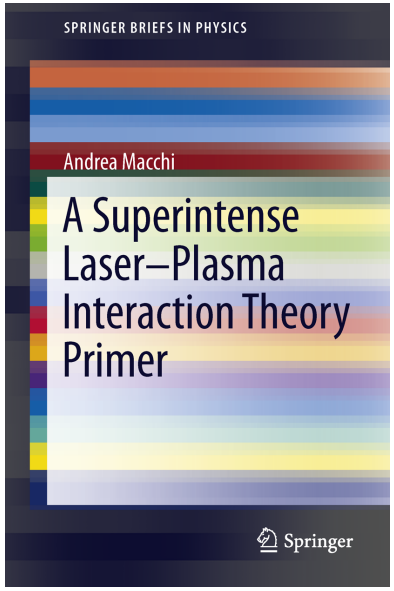


I nostri prodotti (carta, carta, carta ...)

PRL 103, 085003 (2009) PHYSICAL REVIEW LETTERS week ending 21 AUGUST 2009

"Light Sail" Acceleration Reexamined

Andrea Macchi,[1,2,*] Silvia Veghini,[2] and Francesco Pegoraro[2]
[1]*CNR/INFM/polyLAB, Pisa, Italy*
[2]*Dipartimento di Fisica "Enrico Fermi," Università di Pisa, Largo Bruno Pontecorvo 3, I-56127 Pisa, Italy*
(Received 13 May 2009; published 18 August 2009)



APPLIED PHYSICS LETTERS 105, 084105 (2014)

High energy gain in three-dimensional simulations of light sail acceleration

A. Sgattoni,[1,2,a)] S. Sinigardi,[2,3,4] and A. Macchi[2,5]
[1]*Dipartimento di Energia, Politecnico di Milano, Milano, Italy*
[2]*CNR, Istituto Nazionale di Ottica, u.o.s. "Adriano Gozzini," Pisa, Italy*
[3]*Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy*
[4]*INFN sezione di Bologna, Bologna, Italy*
[5]*Dipartimento di Fisica "Enrico Fermi," Università di Pisa, Pisa, Italy*

High Power Laser Science and Engineering, (2014), Vol. 2, e10, 6 pages.

doi:10.1017/hpl.2014.13

Theory of light sail acceleration by intense lasers: an overview

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National Institute of Optics, National Research Council (CNR/INO), Research Unit 'Adriano Gozzini', Department of Physics 'Enrico Fermi', University of Pisa, largo Bruno Pontecorvo 3, I-56127 Pisa, Italy

REVIEWS OF MODERN PHYSICS, VOLUME 85, APRIL–JUNE 2013

Ion acceleration by superintense laser-plasma interaction

Andrea Macchi*
Istituto Nazionale di Ottica, Consiglio Nazionale delle Ricerche (CNR/INO), U.O.S. "Adriano Gozzini," Pisa, Italy, and Department of Physics "Enrico Fermi," University of Pisa, Largo Bruno Pontecorvo 3, I-56127 Pisa, Italy

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IOP Publishing Plasma Physics and Controlled Fusion
Plasma Phys. Control. Fusion **50** (2008) 124033 (9pp) doi:10.1088/0741-3335/50/12/124033

Radiation pressure acceleration by ultraintense laser pulses

Tatiana V Liseykina[1,2], Marco Borghesi[3], Andrea Macchi[3,4,5] and Sara Tuveri[5]

[1] Max Planck Institute for Nuclear Physics, Heidelberg, Germany
[2] Institute of Computational Technologies SD RAS, Novosibirsk, Russia
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[4] polyLab, CNR-INFM, Pisa, Italy
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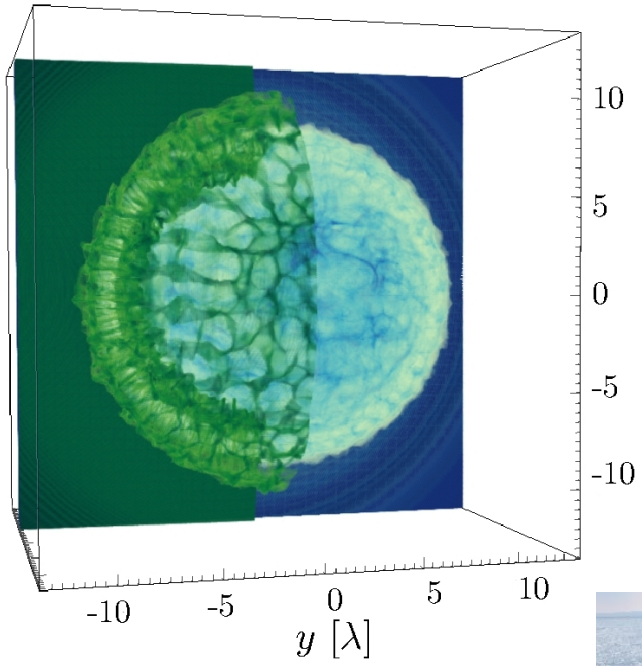
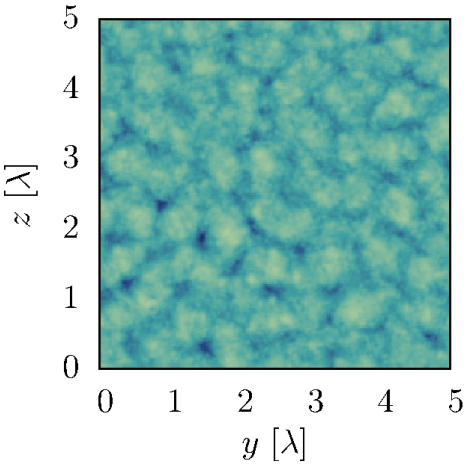
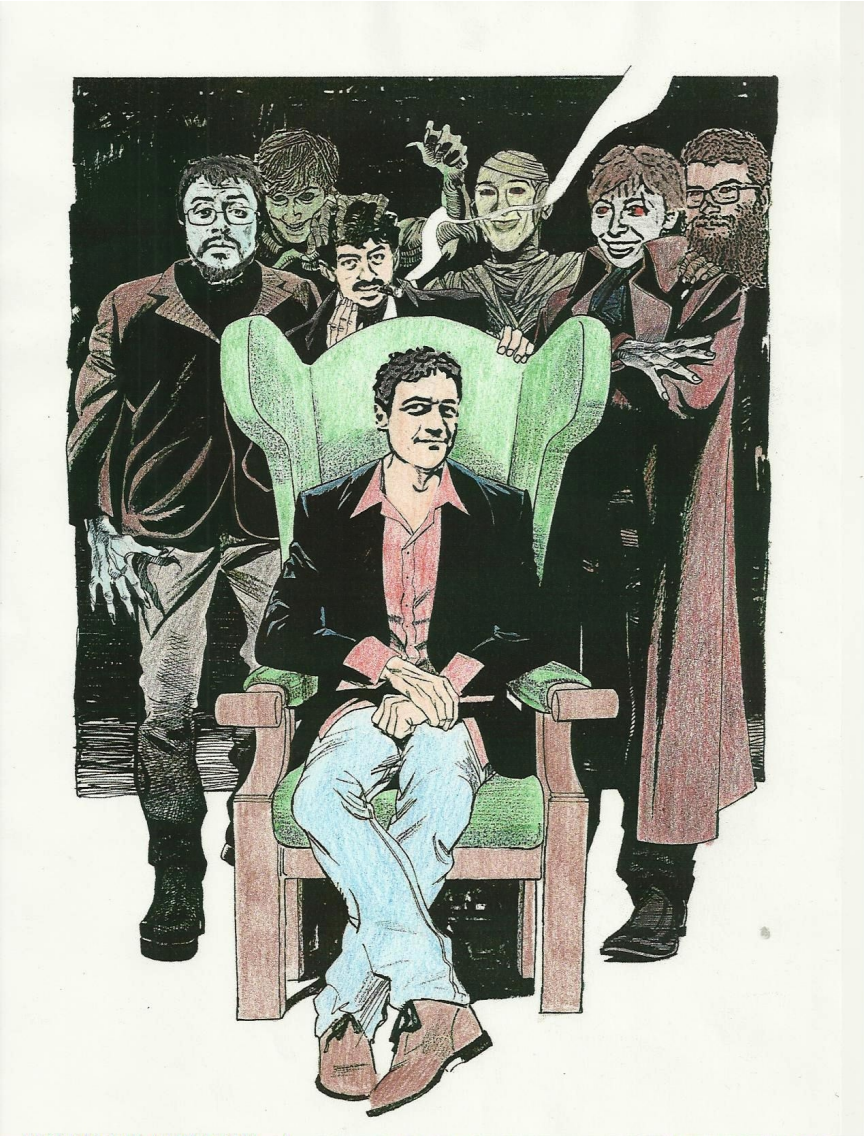
Un problema solo fra tanti ...



"Rottura" della vela a causa dell'instabilità di Rayleigh-Taylor con formazione di strutture esagonali



A. Sgattoni et al, Phys. Rev. E **91** (2015) 013106



Il mio gruppo di ricerca (2014)

Luca Fedeli, Giada Cantono, Andrea Sgattoni, Marta D'Angelo, Anna Grassi, Giannandrea Inchingolo

"*Lei è cattivo!*" (Marta D'Angelo, 2012)

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"*Teamwork is essential - it allows you to blame someone else"* (Anonimo)