

Fisica teorica

a Firenze

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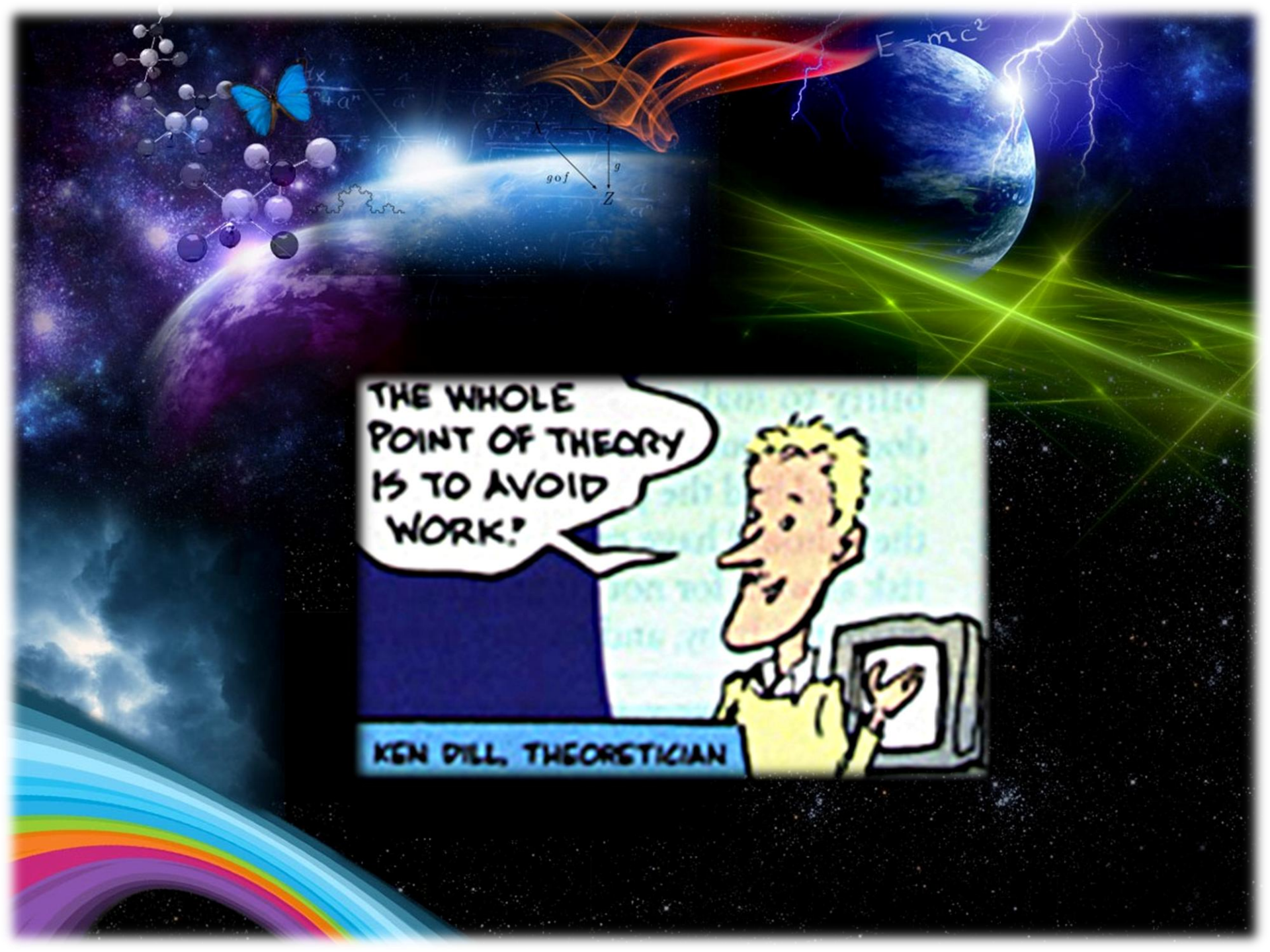


theory.fi.infn.it



per cominciare...

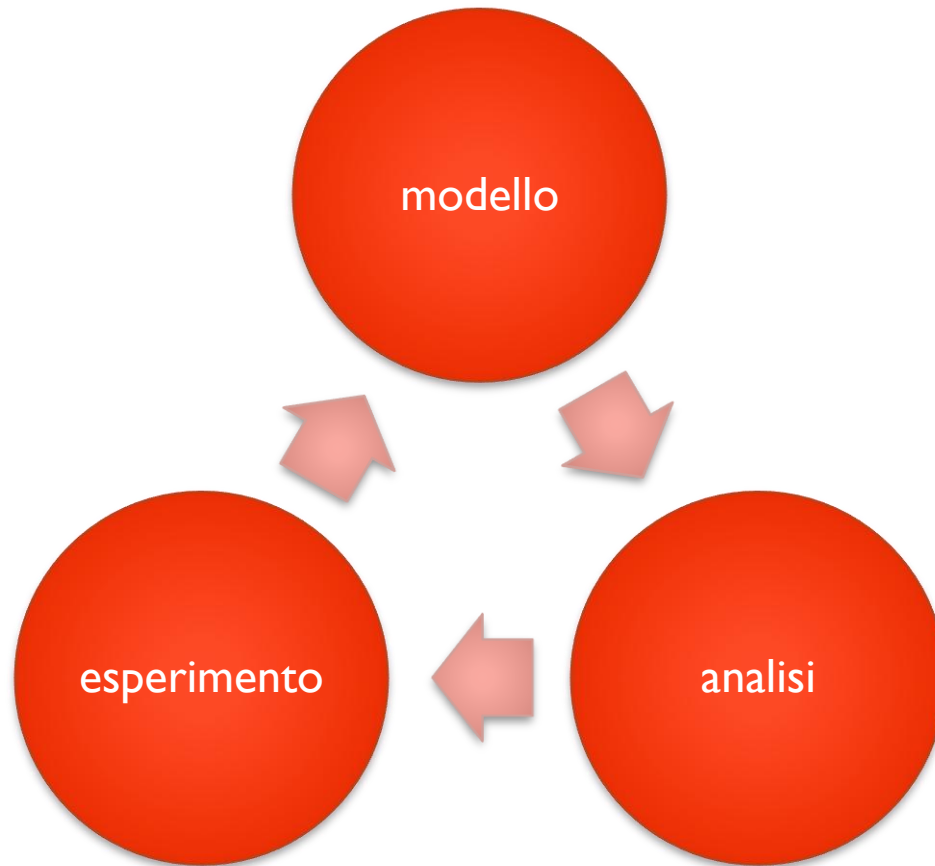
COS'È LA FISICA TEORICA?



THE WHOLE
POINT OF THEORY
IS TO AVOID
WORK!



KEN DILL, THEORETICIAN

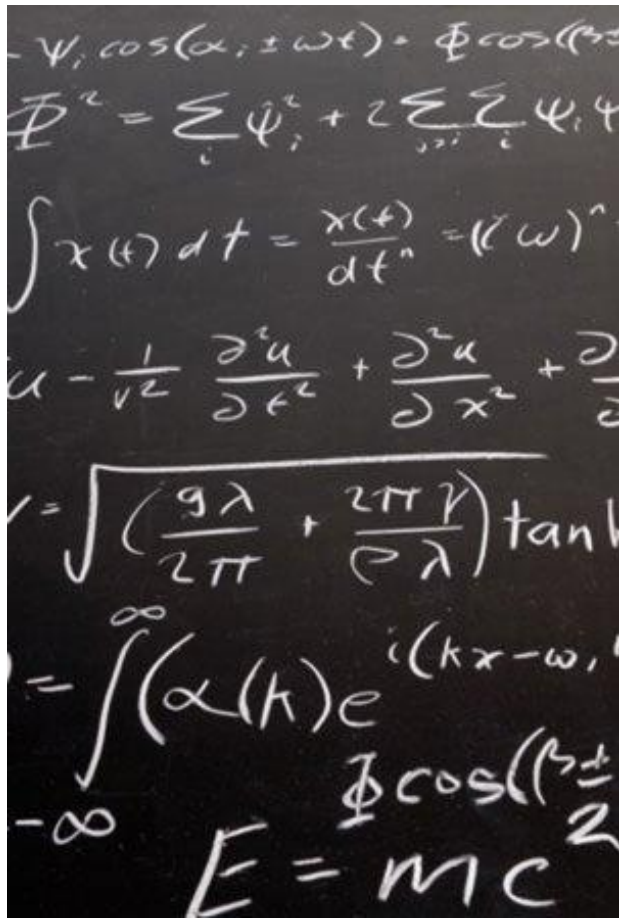


GLI STRUMENTI DELLA FISICA TEORICA



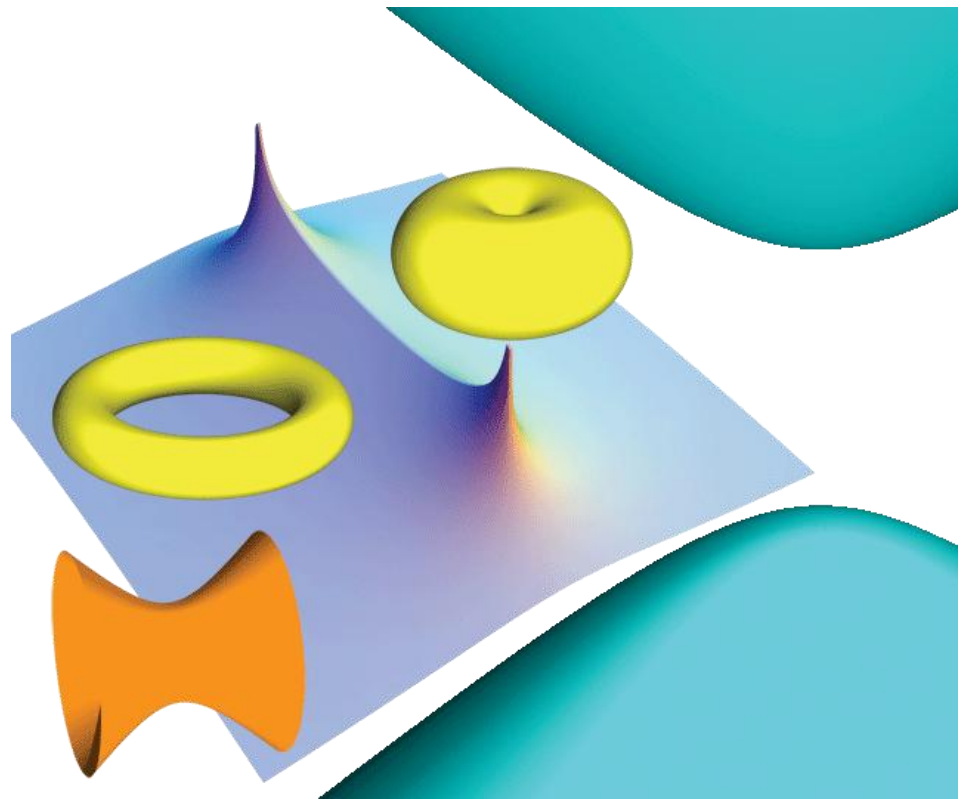
La Natura è il *grandissimo libro* che continuamente ci sta aperto innanzi agli occhi ..., ma non si può intendere se prima non s'impara a *intender la lingua*, e conoscer i caratteri, ne' quali è scritto. Egli è *scritto in lingua matematica*, e i caratteri sono triangoli, cerchi, ed altre figure geometriche, senza i quali mezzi è impossibile a intenderne umanamente parola.

GLI STRUMENTI DELLA FISICA TEORICA



Handwritten mathematical equations on a chalkboard, including:

$$\Psi_i \cos(\alpha_i \pm \omega t) = \Phi \cos(\beta \pm \omega t)$$
$$\Phi^2 = \sum_i \Psi_i^2 + 2 \sum_{i,j} \Psi_i \Psi_j$$
$$\int x(t) dt = \frac{x(t)}{dt} = (v(\omega))^n$$
$$u = \frac{1}{v^2} \frac{\partial^2 u}{\partial t^2} + \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial z^2}$$
$$v = \sqrt{\left(\frac{g\lambda}{2\pi} + \frac{2\pi\gamma}{\rho\lambda}\right) \tan k}$$
$$= \int_{-\infty}^{\infty} (\alpha(k) e^{i(kx - \omega t)})$$
$$\Phi \cos(\beta \pm \omega t)$$
$$E = mc^2$$



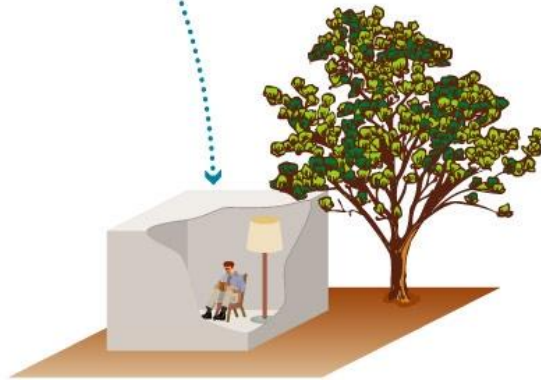
GLI STRUMENTI DELLA FISICA TEORICA



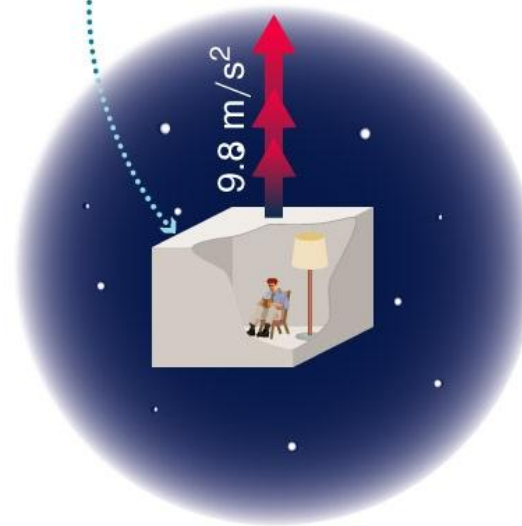
“GEDANKENEXPERIMENTEN”...

The Equivalence Principle

*You cannot tell the difference between
being in a closed room on Earth . . .*

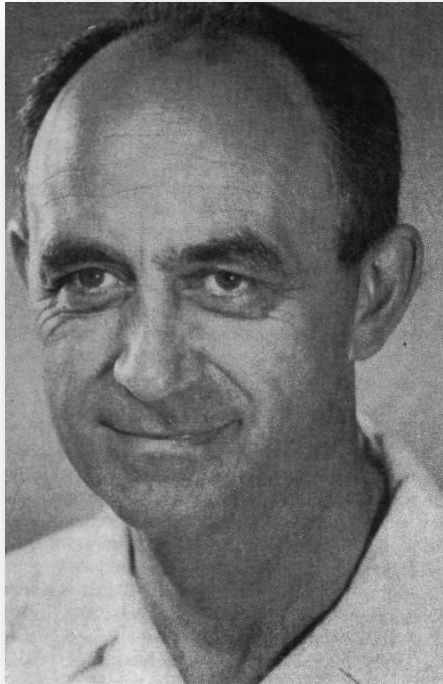


*. . . and being in a closed room
accelerating through space at 1g.*

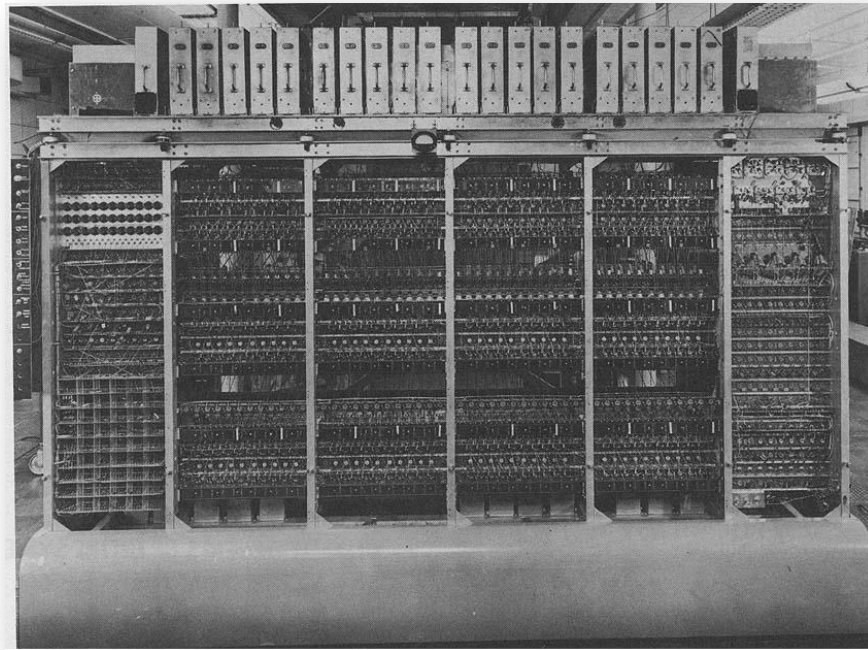


...E SIMULAZIONI NUMERICHE

L'esperimento mentale moderno: un vero e proprio esperimento, condotto però in un ambiente più docile e controllabile, il computer

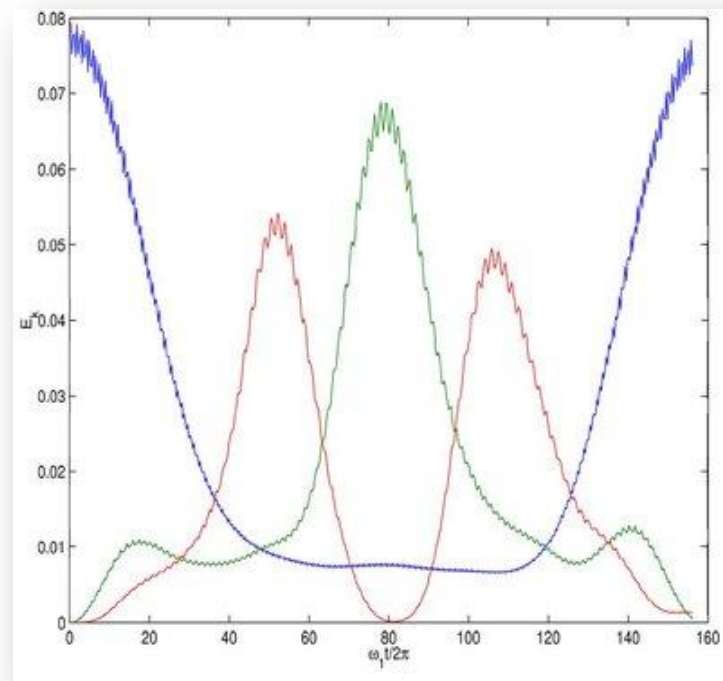
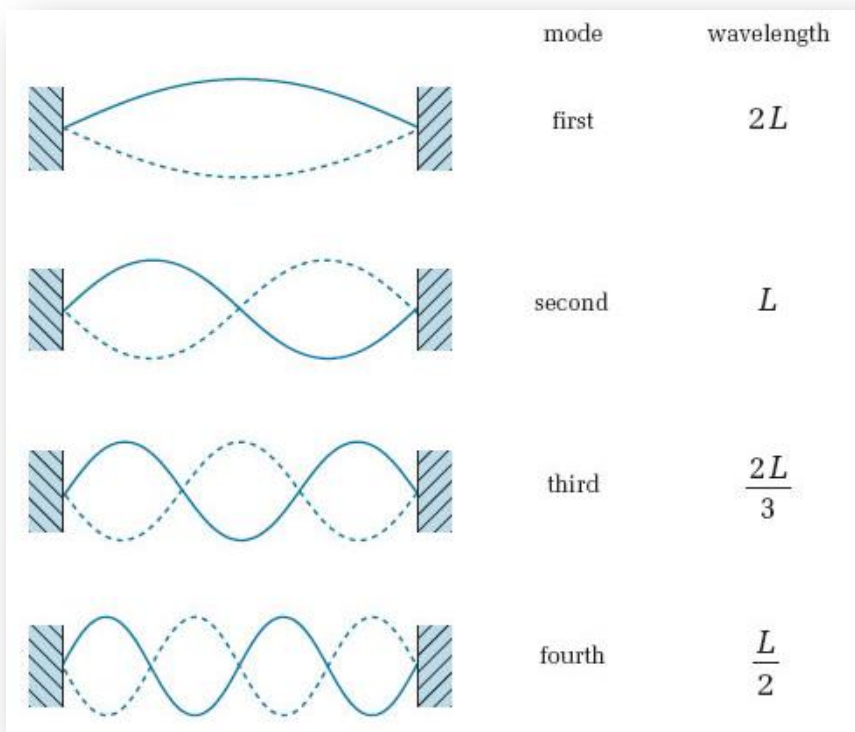


Enrico Fermi (1901 - 1954)

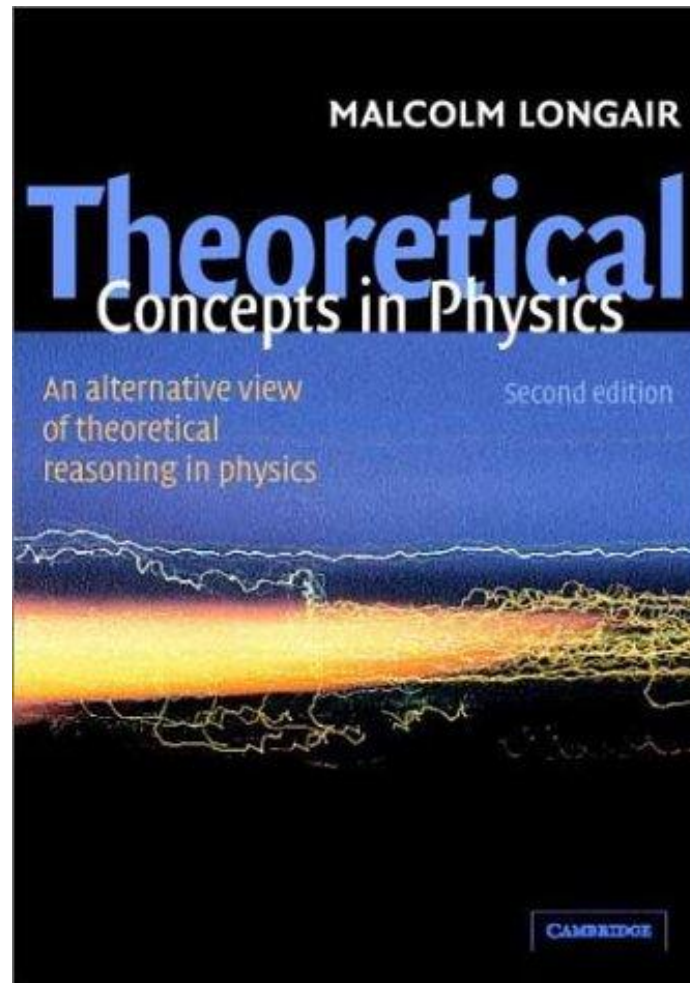


Il calcolatore MANIAC I a Los Alamos

...E SIMULAZIONI NUMERICHE



UN BUON LIBRO...



**fisica
matematica**

**teoria delle
interazioni
fondamentali**

**meccanica
statistica e
sistemi
complessi**

GEOMETRIA NONCOMMUTATIVA, QUANTUM GROUPS...

FISICA MATEMATICA – TEORIA DELLE INTERAZIONI FONDAMENTALI

F. Bonechi, R. Giachetti, D. Seminara, M. Tarlini...



Qual è la struttura dello spazio a piccolissime scale?

GEOMETRIA NONCOMMUTATIVA, QUANTUM GROUPS...

FISICA MATEMATICA – TEORIA DELLE INTERAZIONI FONDAMENTALI

F. Bonechi, R. Giachetti, D. Seminara, M. Tarlini...

$$[x_i, x_j] \neq 0$$

$$\ell_P = \sqrt{\frac{\hbar G}{c^3}} \approx 1.616252(81) \times 10^{-35} \text{ meters}$$

RELATIVITÀ GENERALE, GRAVITÀ QUANTISTICA, STRING THEORY

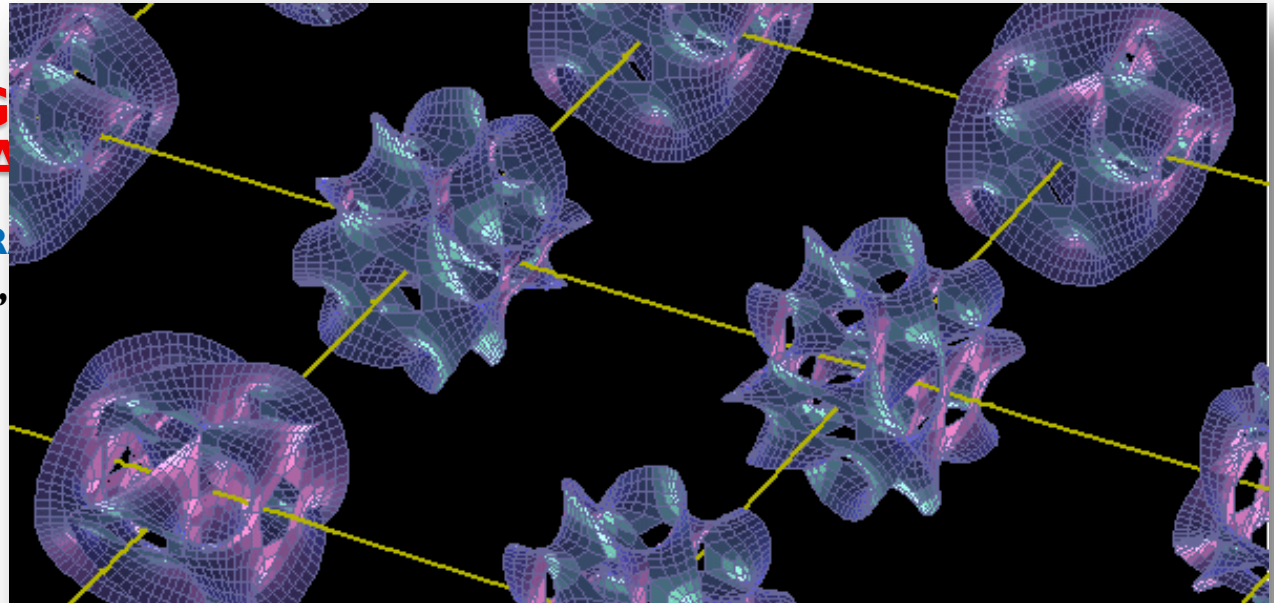
TEORIA DELLE INTERAZIONI FONDAMENTALI

F. Becattini, M. Ciafaloni, L. Lusanna, D. Seminara...

- ✓ Supergravità e string theory
- ✓ Formulazione hamiltoniana della relatività generale
- ✓ Fluidodinamica relativistica
- ✓ Meccanica statistica dei sistemi relativistici

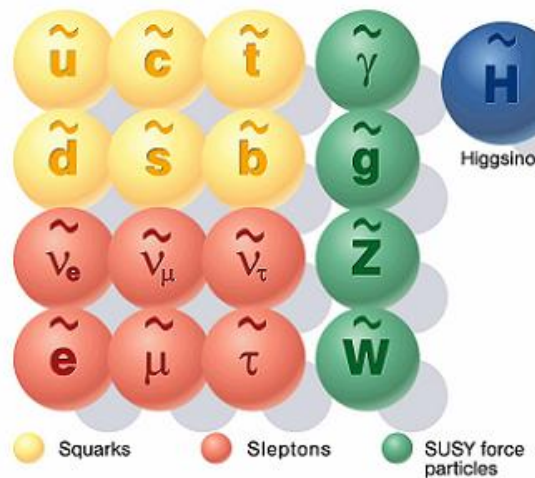
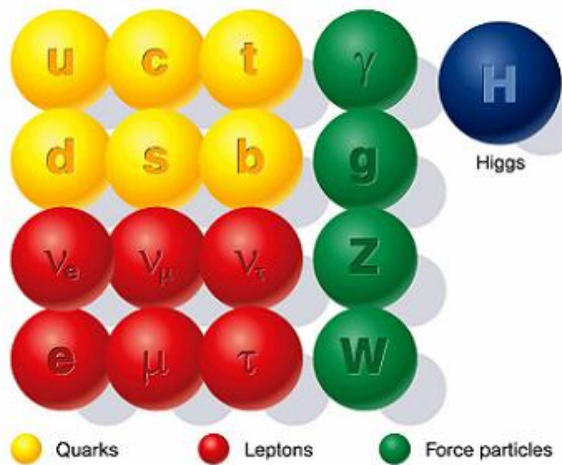
RELATIVITÀ G QUANTISTICA

TEORIA DELLE INTER
F. Becattini, M.Ciafaloni,



Standard particles

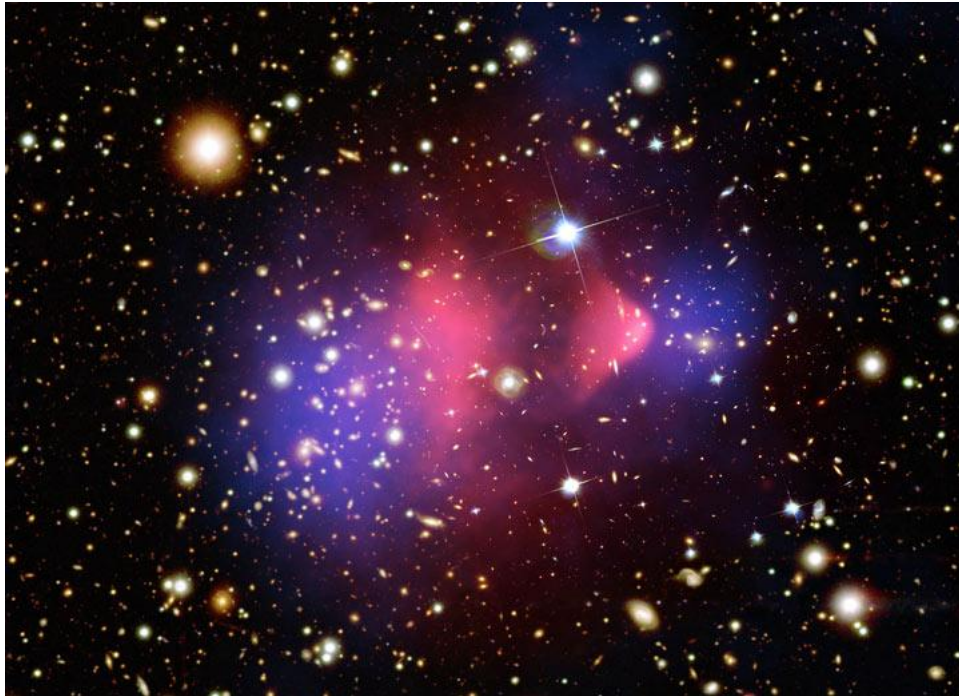
SUSY particles



RELATIVITÀ GENERALE, GRAVITÀ QUANTISTICA, STRING THEORY

TEORIA DELLE INTERAZIONI FONDAMENTALI

F. Becattini, M. Ciafaloni, L. Lusanna, D. Seminara...



TEORIE DI CAMPO

TEORIA DELLE INTERAZIONI FONDAMENTALI – FISICA MATEMATICA

A. Cappelli, F. Colomo...

- ✓ Teoria di campo conforme
- ✓ Teorie di campo in bassa dimensione
- ✓ Applicazioni alla fisica della materia condensata (effetto Hall quantistico)
- ✓ Entanglement in teoria dei campi e meccanica quantistica

TEORIE DI CAMPO

TEORIA DELLE INTERAZIONI FONDAMENTALI – FISICA MATEMATICA

A. Cappelli, F. Colomo...

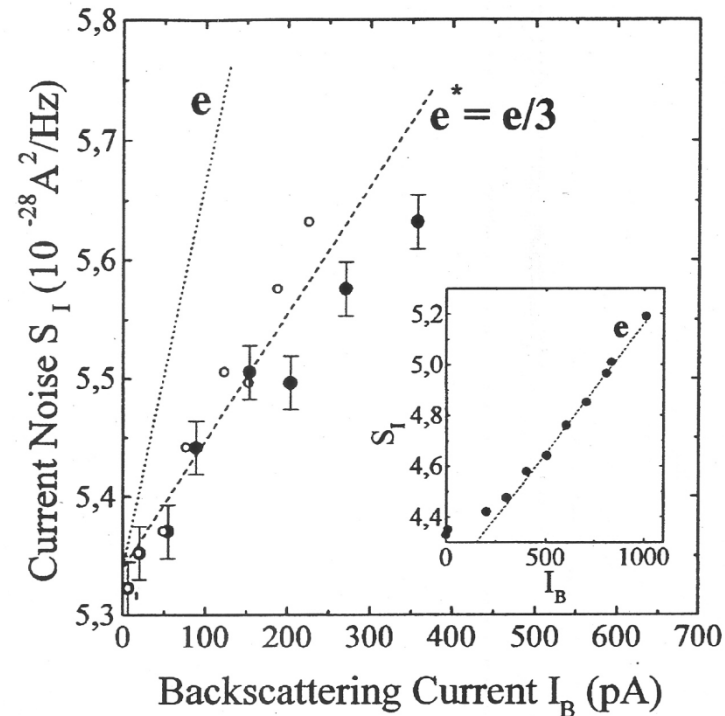
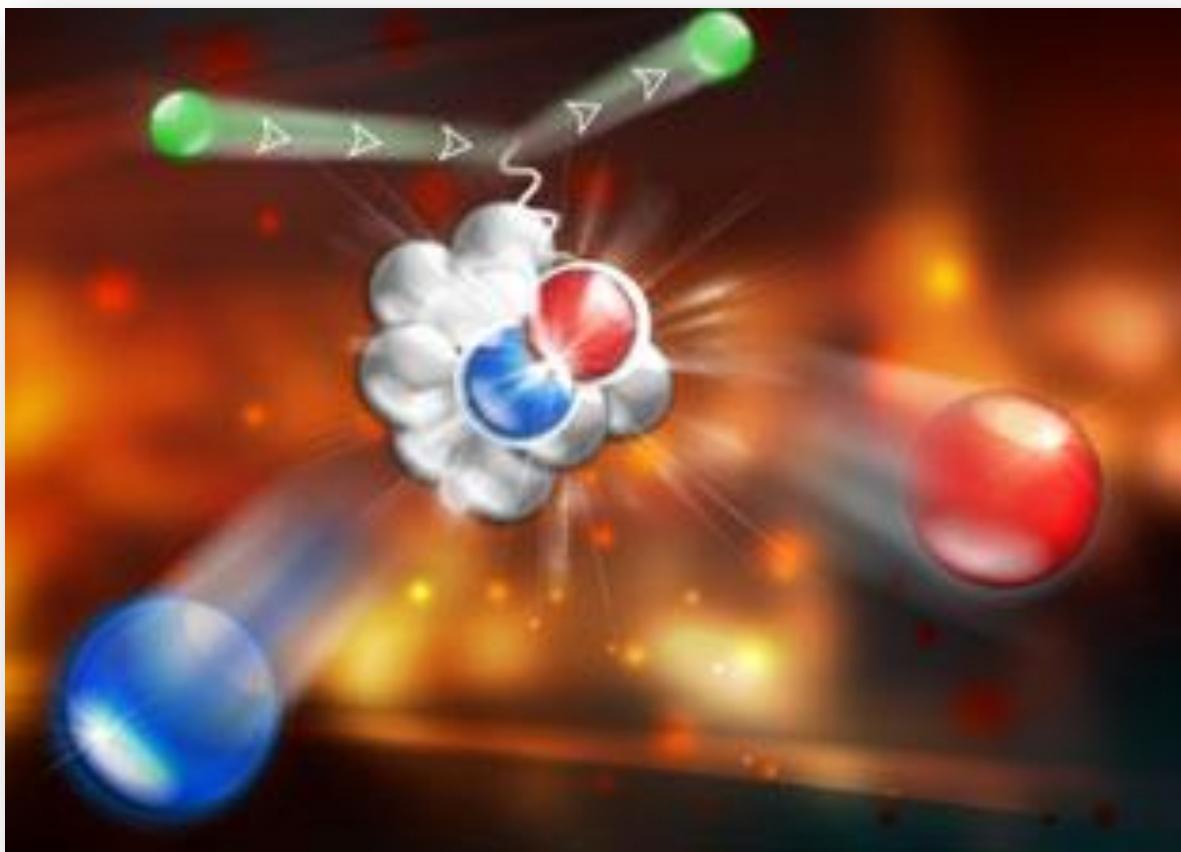


FIG. 2. Tunneling noise at $\nu = 1/3$ ($\nu_L = 2/3$) when following path A and plotted versus $I_B = (e^2/3h)V_{ds} - I$ (filled circles) and $I_B(1 - R)$ (open circles). The slopes for $e/3$ quasiparticles (dashed line) and electrons (dotted line) are shown. $\Theta = 25$ mK. Inset: data in same units showing electron tunneling for similar $G = 0.32e^2/h$ but in the IQHE regime ($\nu_L = 4$). The expected slope for electrons $2eI_B(1 - R)$ [$R = 0.68$, $I_R = (e^2/h)V_{ds} - I$] is shown. $\Theta = 42$ mK.

NUCLEI E MATERIA NUCLEARE

TEORIA DELLE INTERAZIONI FONDAMENTALI

A. Dellafiore, F. Matera, B. Mosconi, P. Ricci...



NUCLEI E MATERIA NUCLEARE

TEORIA DELLE INTERAZIONI FONDAMENTALI

A. Dellafiore, F. Matera, B. Mosconi, P. Ricci...

- ✓ Interazioni elettrodeboli nei nuclei
- ✓ Tecniche semiclassiche e statistiche per la materia nucleare
- ✓ Fisica degli ioni pesanti

TEORIA E FENOMENOLOGIA DELLE PARTICELLE ELEMENTARI

TEORIA DELLE INTERAZIONI FONDAMENTALI

A. Barducci, F. Becattini, R. Casalbuoni, S. Catani, M. Ciafaloni, D. Colferai, S. De Curtis, D. Dominici, M. Grazzini, G. Pettini...

- ✓ QCD perturbativa
- ✓ Teoria elettrodebole
- ✓ Estensioni del modello standard
- ✓ QCD a temperatura e densità finite

Standard Model of FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

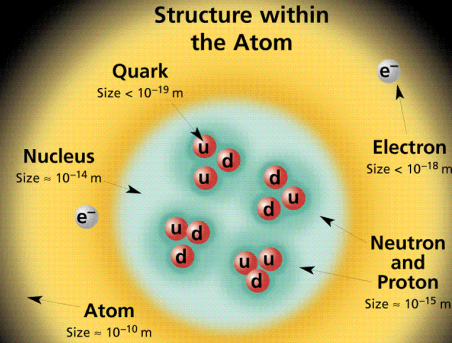
Leptons spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge
ν_e electron neutrino	$<1 \times 10^{-8}$	0
e electron	0.000511	-1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	-1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	-1

Quarks spin = 1/2		
Flavor	Approx. Mass GeV/c ²	Electric charge
u up	0.003	2/3
d down	0.006	-1/3
c charm	1.3	2/3
s strange	0.1	-1/3
t top	175	2/3
b bottom	4.3	-1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of \hbar , which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58 \times 10^{-25} \text{ GeV s} = 1.05 \times 10^{-34} \text{ J s}$.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The **energy** unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c² (remember $E = mc^2$), where $1 \text{ GeV} = 10^9 \text{ eV} = 1.60 \times 10^{-10} \text{ joule}$. The mass of the proton is $0.938 \text{ GeV}/c^2 = 1.67 \times 10^{-27} \text{ kg}$.



BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1		
Name	Mass GeV/c ²	Electric charge
γ photon	0	0
W^-	80.4	-1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1		
Name	Mass GeV/c ²	Electric charge
g gluon	0	0

Color Charge
Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically-charged particles interact by exchanging photons, in strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and W and Z bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons
One cannot isolate quarks and gluons; they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge. Two types of hadrons have been observed in nature: **mesons** $q\bar{q}$ and **baryons** qqq .

Residual Strong Interaction
The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$					
Baryons are fermionic hadrons. There are about 120 types of baryons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c ²	Spin
p	proton	uud	1	0.938	1/2
\bar{p}	anti-proton	$\bar{u}\bar{u}\bar{d}$	-1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	-1	1.672	3/2

Property	Interaction	Gravitational	Weak (Electroweak)		Strong	
		Mass - Energy	Flavor	Electric Charge	Fundamental	Residual
Acts on:		All	Quarks, Leptons	Electrically charged	Quarks, Gluons	See Residual Strong Interaction Note
Particles experiencing:		All (not yet observed)	W^+, W^-, Z^0	γ	Gluons	Hadrons
Particles mediating:		Graviton (not yet observed)				Mesons
Strength relative to electromag for two u quarks at:	10^{-18} m $3 \times 10^{-17} \text{ m}$	10^{-41}	0.8	1	25	Not applicable to quarks
for two protons in nucleus		10^{-41}	10^{-4}	1	60	Not applicable to hadrons
		10^{-36}	10^{-7}	1	Not applicable to hadrons	20

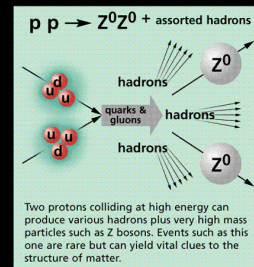
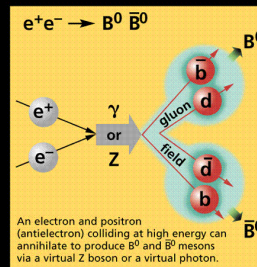
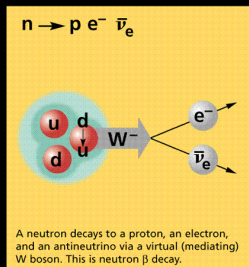
Mesons $q\bar{q}$					
Mesons are bosonic hadrons. There are about 140 types of mesons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c ²	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	-1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2.980	0

Matter and Antimatter

For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or - charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0 , γ , and $\eta_c = c\bar{c}$, but not $K^0 = d\bar{s}$) are their own antiparticles.

Figures

These diagrams are an artist's conception of physical processes. They are **not** exact and have **no** meaningful scale. Green shaded areas represent the cloud of gluons or the gluon field, and red lines the quark paths.



The Particle Adventure

Visit the award-winning web feature *The Particle Adventure* at <http://ParticleAdventure.org>

This chart has been made possible by the generous support of:

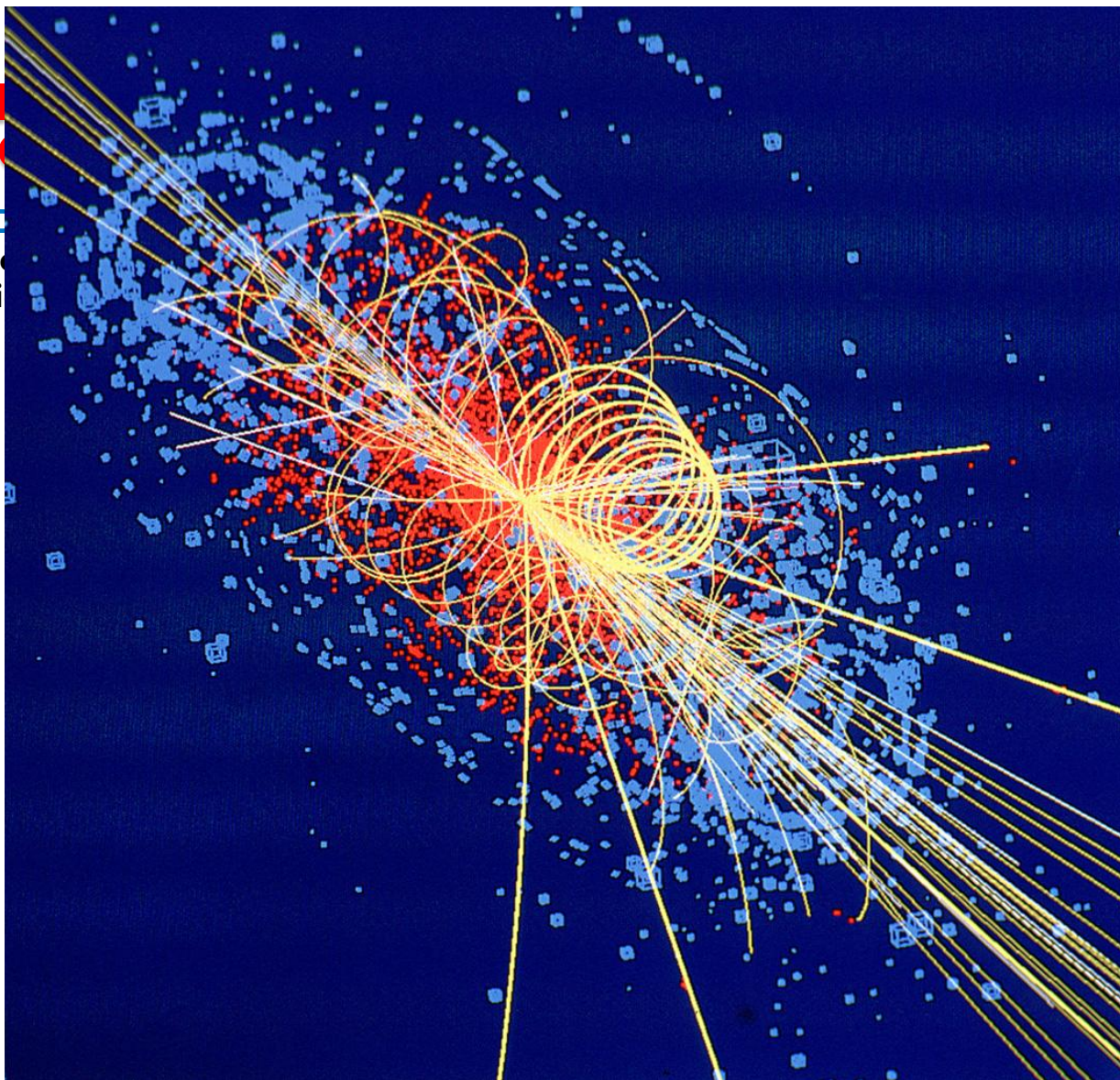
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<http://CPEPweb.org>

TEORIA PARTICELLE

TEORIA D
A. Barducci
D. Domini



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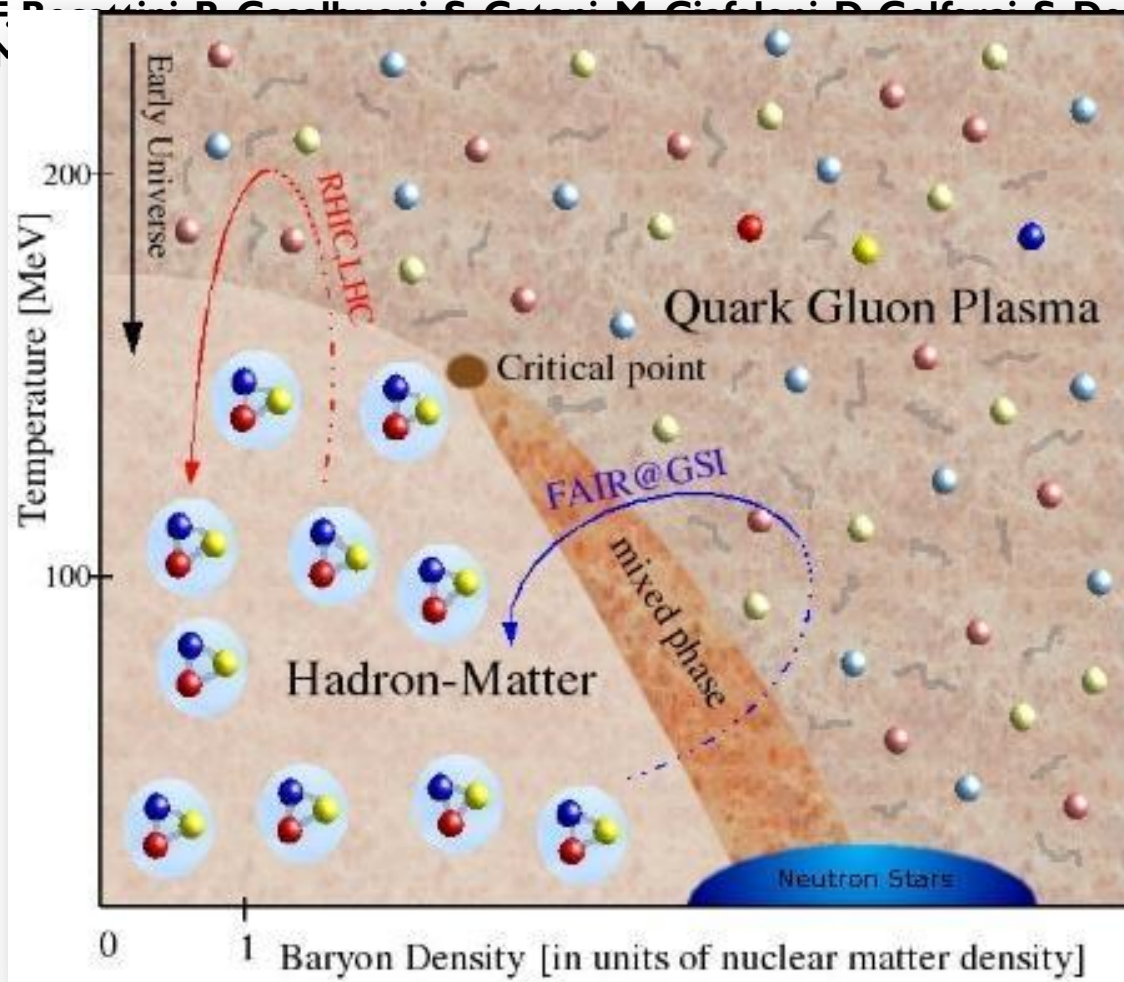
Evento di produzione di una particella di Higgs a LHC

Esclusione di Higgs fra 160 e 170 GeV al Tevatron basata su risultati teorici di Firenze

TEORIA E FENOMENOLOGIA DELLE PARTICELLE ELEMENTARI

TEORIA DELLE INTERAZIONI FONDAMENTALI

A. Barducci, F. Becattini, P. Colangelo, G. Giacalone, M. Giannini, D. Greife, S. D. Curtis,
D. Dominici, M. H. Thoma



TRANSIZIONI DI FASE E MODELLI RISOLUBILI IN MECCANICA STATISTICA

**MECCANICA STATISTICA E SISTEMI COMPLESSI - FISICA MATEMATICA -
TEORIA DELLE INTERAZIONI FONDAMENTALI**

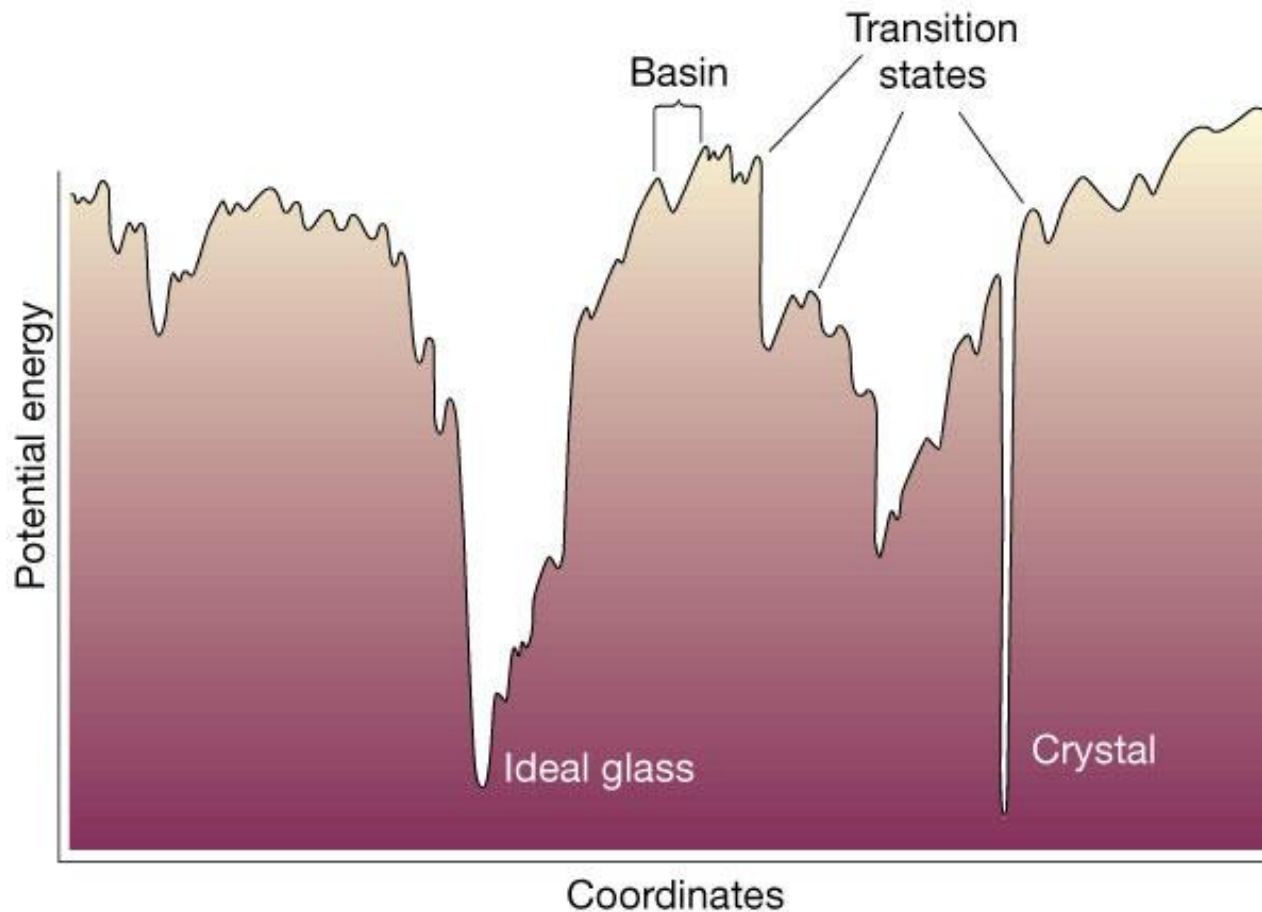
A. Cappelli, L. Casetti, F. Colomo, R. Livi...

- ✓ Singolarità termodinamiche
- ✓ Energy landscapes
- ✓ Modelli esattamente risolubili in meccanica statistica
- ✓ Sistemi integrabili classici e quantistici

TRANSIZIONI DI FASE E MODELLI RISOLUBILI IN MECCANICA STATISTICA

MECCANICA STATISTICA E SISTEMI COMPLESSI - FISICA MATEMATICA -
TEORIA DELLE INTERAZIONI FONDAMENTALI

A. Cappelli, L. Casetti, F. Colomo, R. Livi...



Il Modello di Ising

$$\sigma_i = \pm 1$$

$$H[\sigma] = -J \sum_{\langle i,j \rangle} \sigma_i \sigma_j - h \sum_i \sigma_i$$

$$Z[\beta, h] = \sum_{\{\sigma_i\}} e^{-\beta H[\sigma]}$$

- perfetto "toy model":
- integrabile & non banale
- paradigma dei fenomeni critici

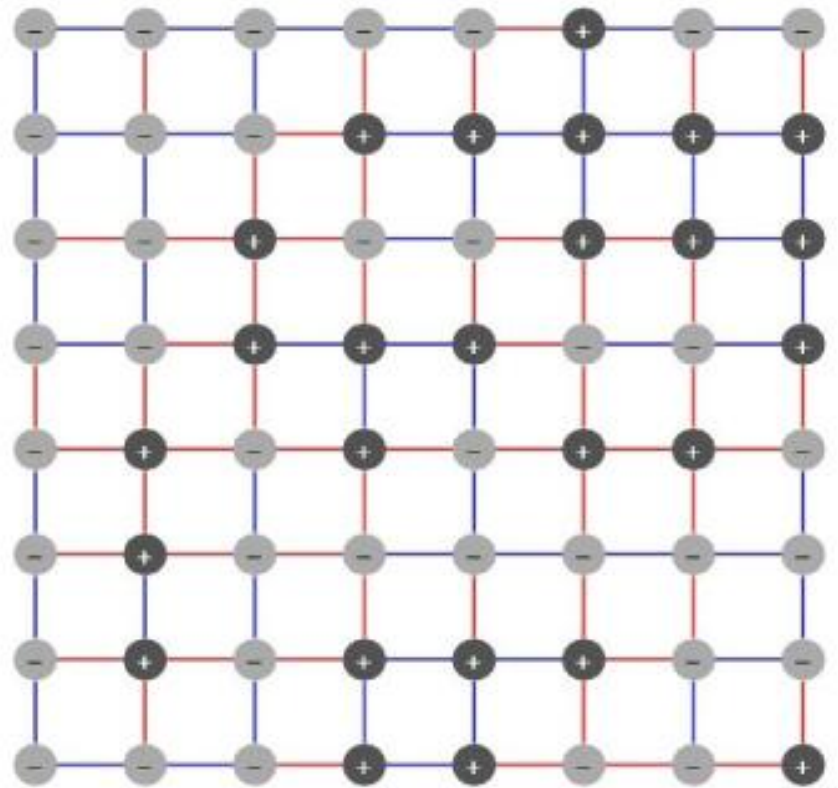


Diagramma delle fasi

asse $h = 0$:
fermione libero

$$\psi(x) = \hat{\sigma}_x \hat{\sigma}_{x+a} \hat{\sigma}_{x+2a} \cdots \hat{\sigma}_\infty$$

$$m \sim |\beta - \beta_c|$$

asse $\beta = \beta_c$: teoria integrabile
8 particelle massive interagenti

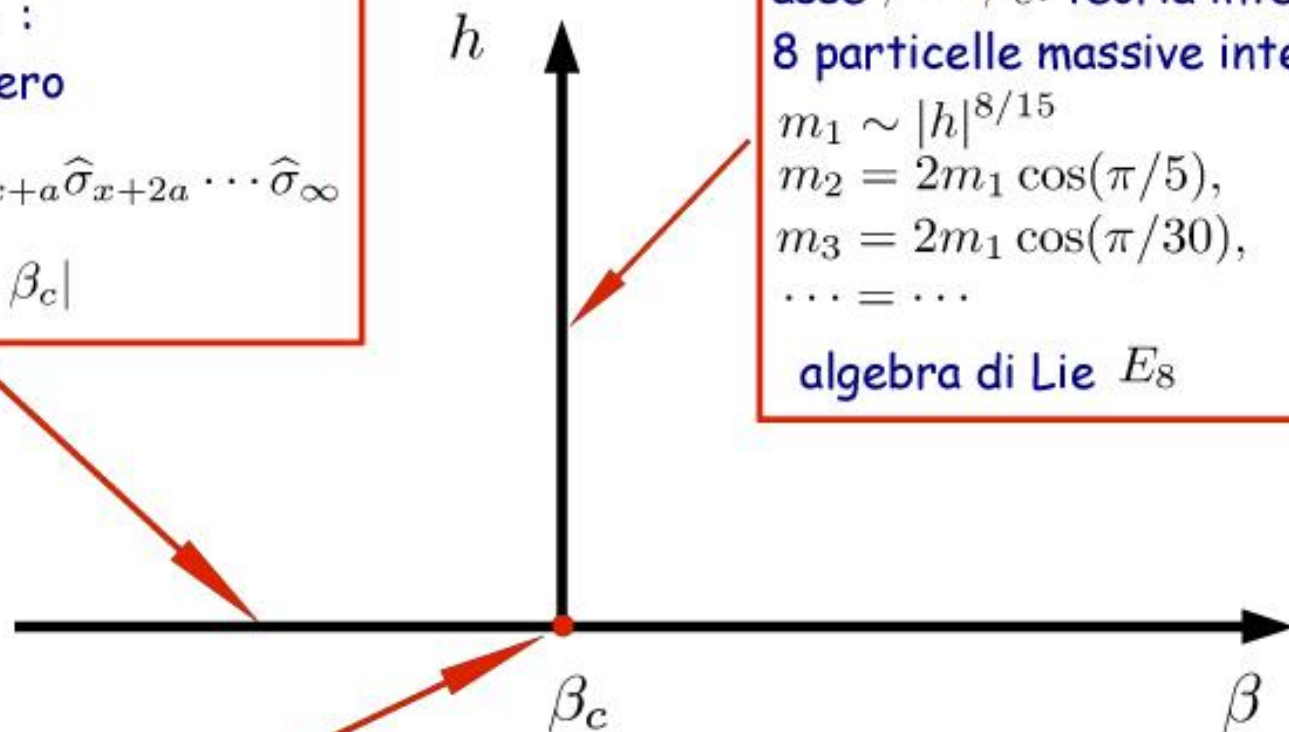
$$m_1 \sim |h|^{8/15}$$

$$m_2 = 2m_1 \cos(\pi/5),$$

$$m_3 = 2m_1 \cos(\pi/30),$$

$$\cdots = \cdots$$

algebra di Lie E_8



punto critico:

- invarianza di scala e conforme
- soluzione esatta

$$\langle \sigma(x) \sigma(0) \rangle = \frac{1}{|x|^{1/4}}$$

TEORIA DEI SISTEMI DINAMICI

MECCANICA STATISTICA E SISTEMI COMPLESSI - FISICA MATEMATICA

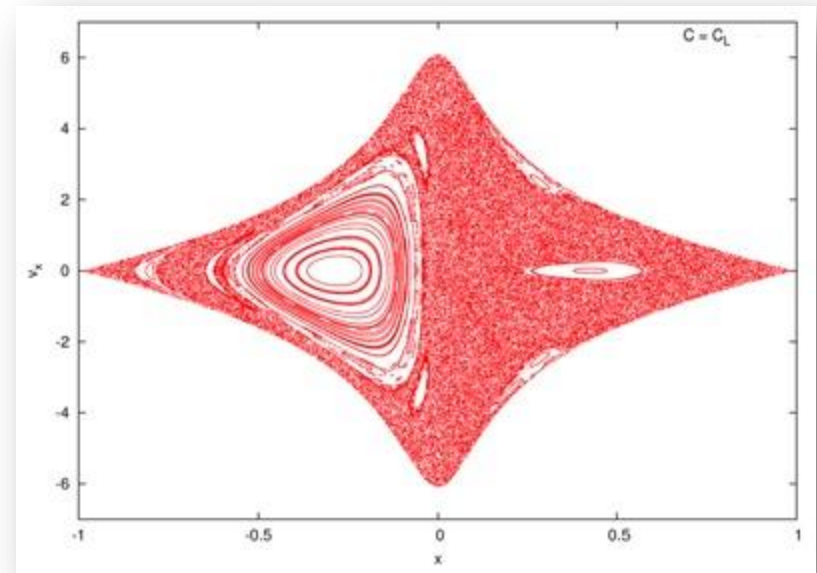
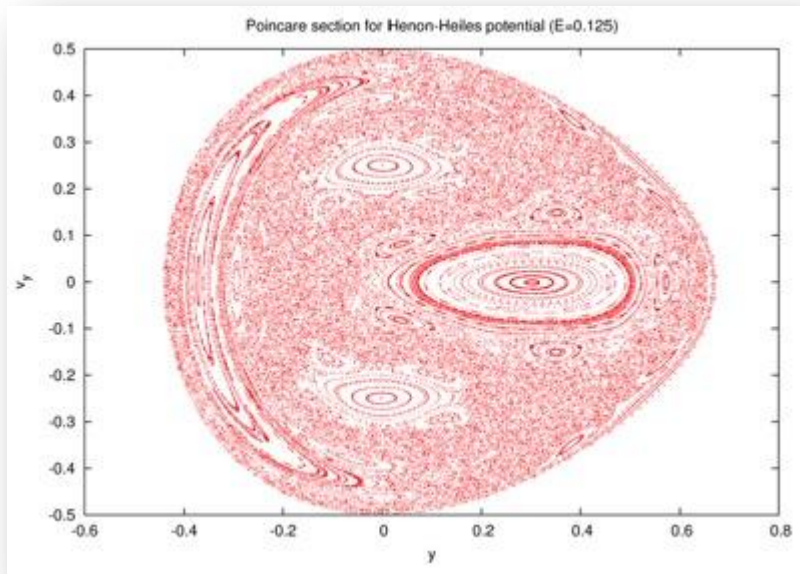
F. Bagnoli, L. Casetti, D. Fanelli, S. Lepri, R. Livi, A. Politi, P. Politi, S. Ruffo...

- ✓ Caos deterministico nei sistemi hamiltoniani
- ✓ Caos deterministico nei sistemi dissipativi
- ✓ Automi cellulari
- ✓ Applicazioni: dalle dune di sabbia ai plasmi

TEORIA DEI SISTEMI DINAMICI

MECCANICA STATISTICA E SISTEMI COMPLESSI - FISICA MATEMATICA

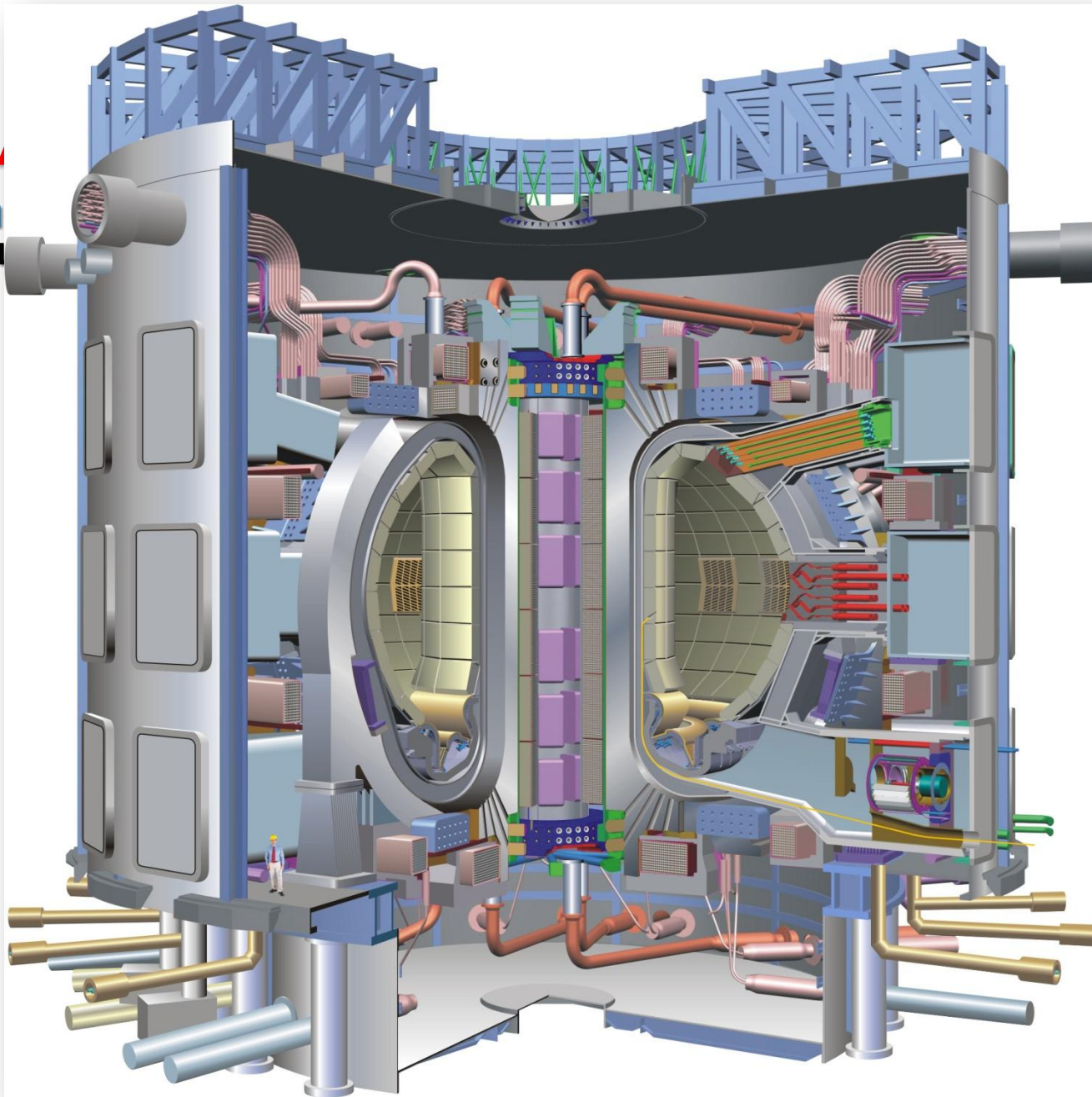
F. Bagnoli, L. Casetti, D. Fanelli, S. Lepri, R. Livi, A. Politi, P. Politi, S. Ruffo...

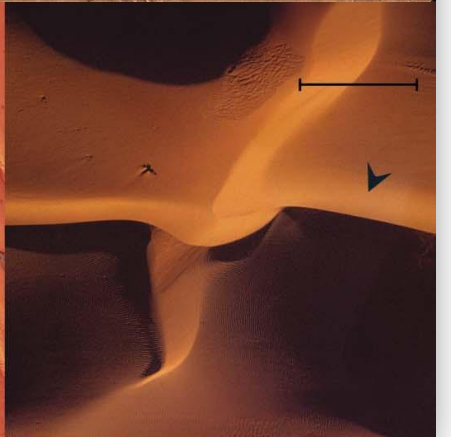
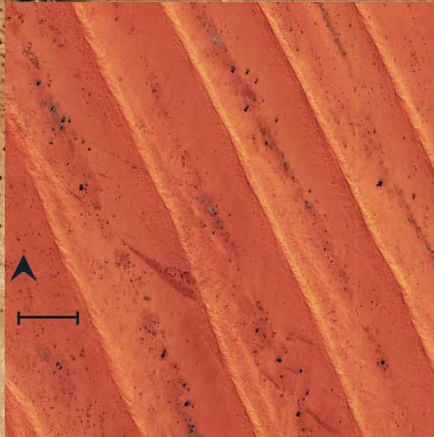
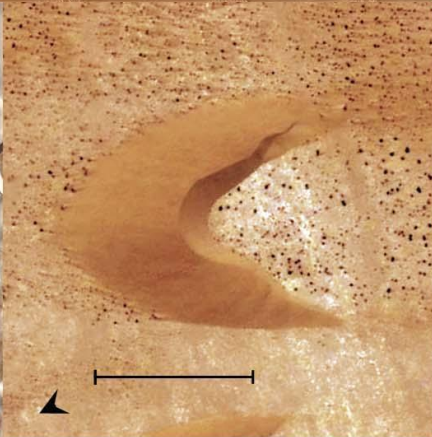
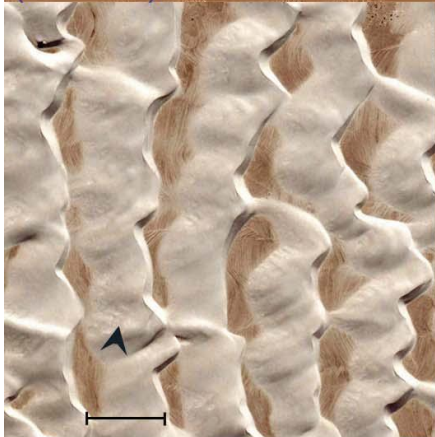
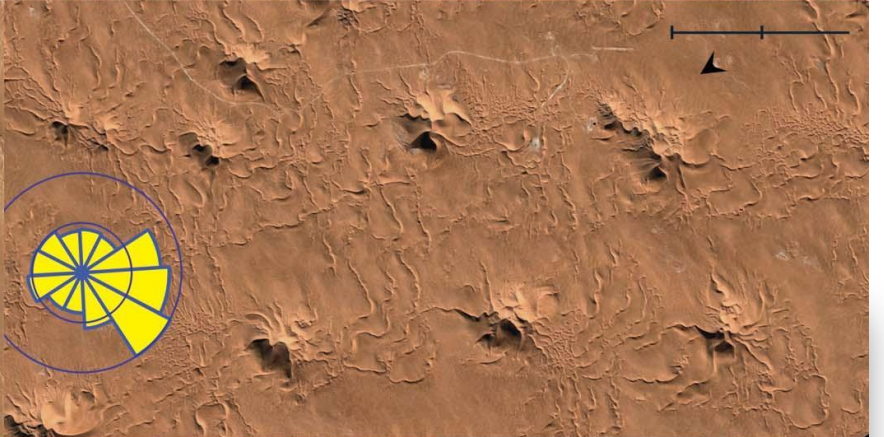
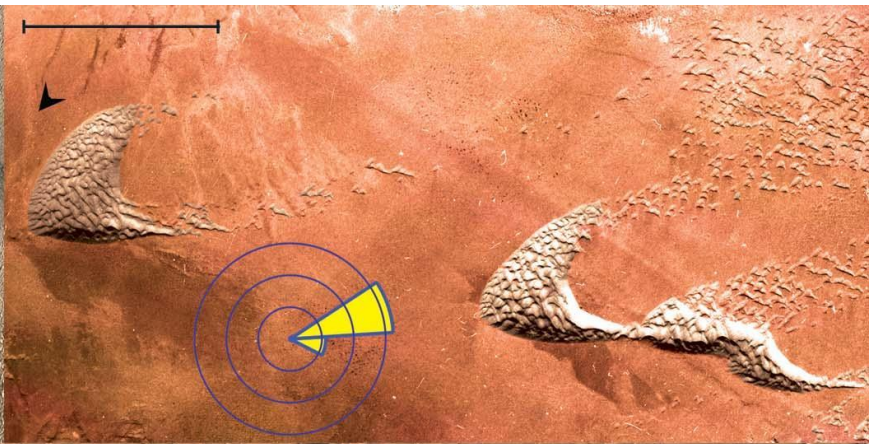


TEORIA

MECCANICA

F. Bagnoli, I





ASPETTI FONDAMENTALI DELLA MECCANICA STATISTICA

MECCANICA STATISTICA E SISTEMI COMPLESSI

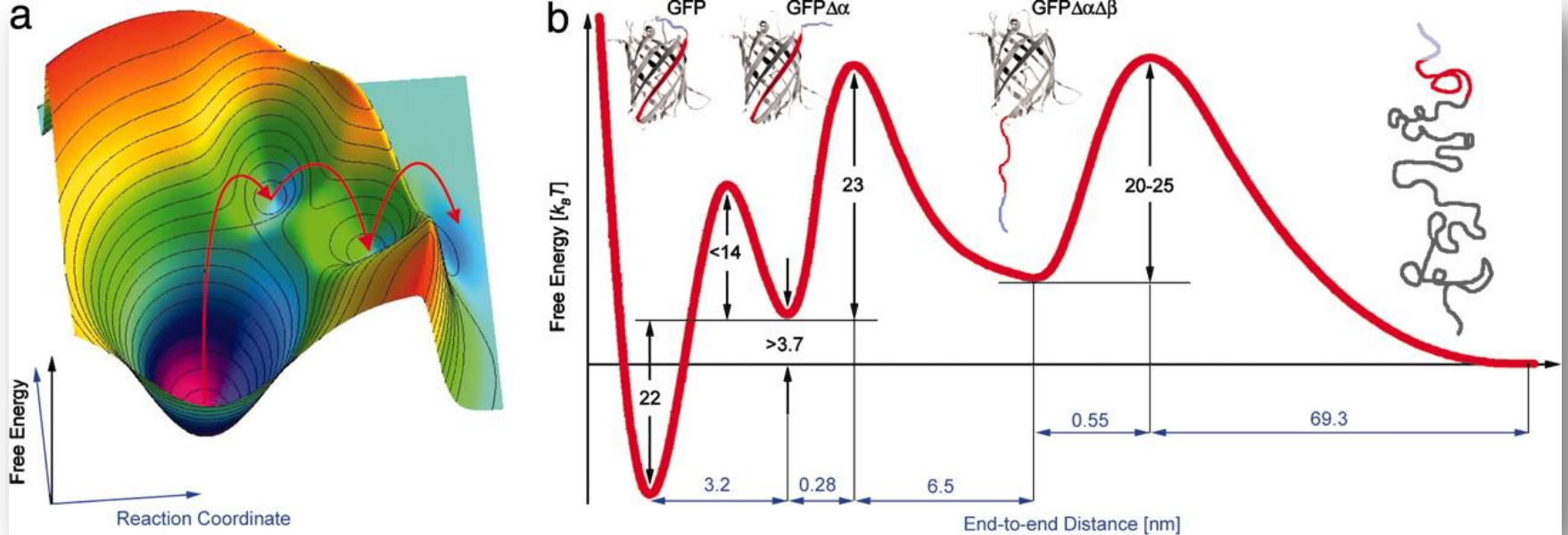
L. Casetti, D. Fanelli, S. Lepri, R. Livi, A. Politi, P. Politi, S. Ruffo...

- ✓ Equivalenza e non-equivalenza fra insiemi statistici
- ✓ Interazioni a lungo raggio
- ✓ Meccanica statistica fuori dall'equilibrio
- ✓ Fenomeni di trasporto

BIOFISICA TEORICA

MECCANICA STATISTICA E SISTEMI COMPLESSI

F. Bagnoli, D. Fanelli, R. Livi, A. Politi, A. Torcini...





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Dipartimento di Fisica

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...e molti altri...

