Societa` Astronomica G.V. Schiaparelli

La storia della luce

Luca G Molinari

Varese, 13 novembre 2015

Georges de La Tour (1642) - Louvre

2015 ANNO DELLA LUCE

150
ANNI
DELLE LEGGI
DELL'ELETTROMAGNETISMO

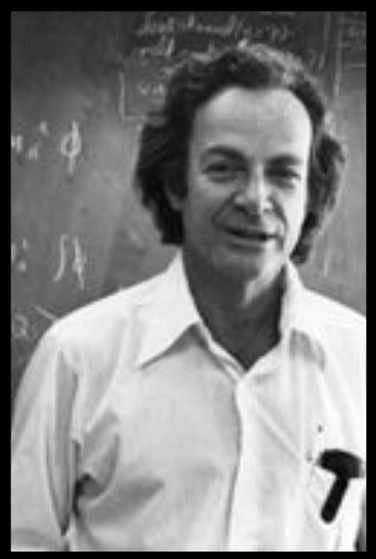
COSA E` LA LUCE?

ESO/H.H. Heyer

DUECENTO ANNI DI STORIA DELLA FISICA

e

DELLA LUCE



Lo spettro della luce

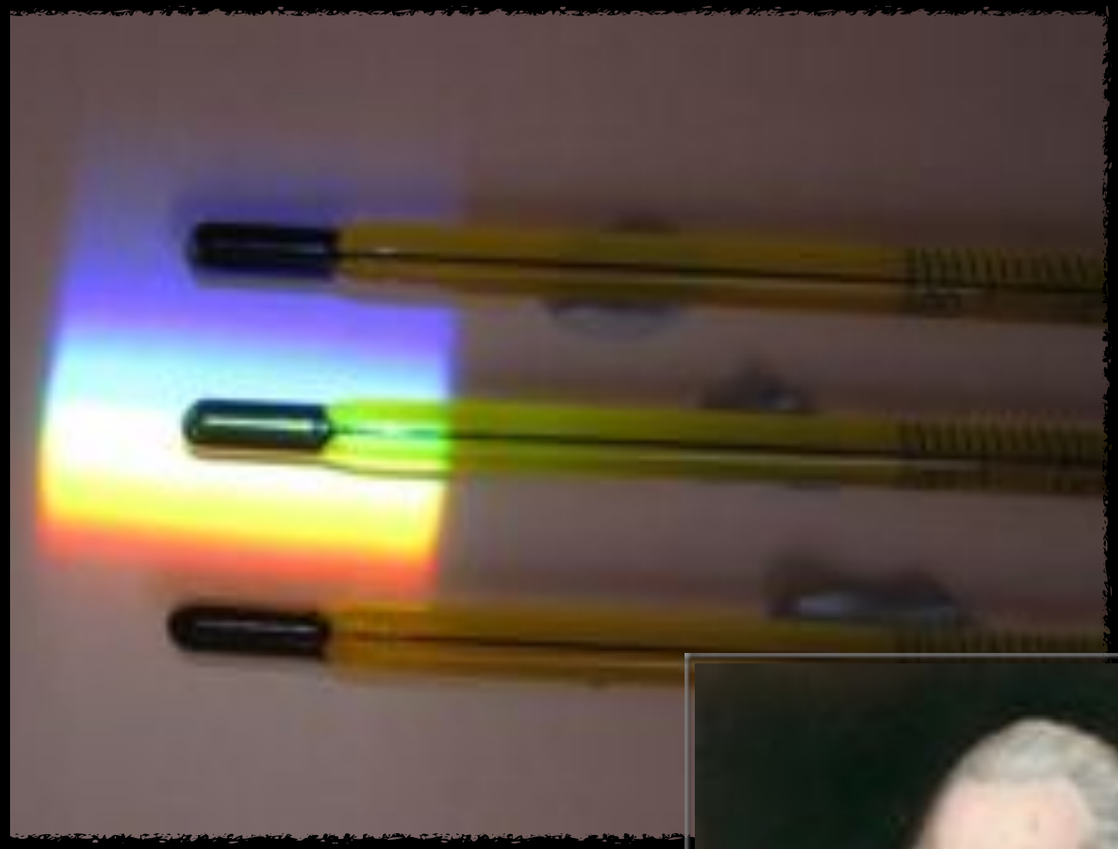
Nel 1666 ISAAC NEWTON dimostro` che la luce bianca del Sole e` scomponibile in un continuo di colori (lo spettro).

(si pensava che i colori fossero dovuti al prisma, e non fossero una proprieta` intrinseca della luce)

Condusse gli esperimenti nella casa di campagna, per sfuggire alla peste.

La radiazione infrarossa

William Herschel - 1800

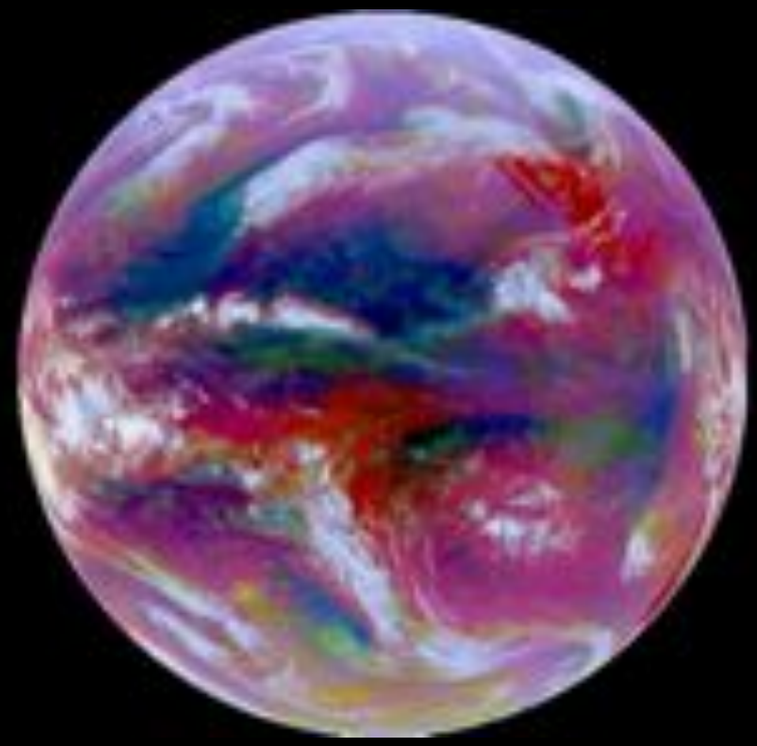


Luce e calore radiante sono forme dello stesso fenomeno

… we are not allowed, by the rules of philosophizing, to admit two different causes to explain certain effects, if they may be accounted for by one.

... non ci e` consentito, dalle regole del ragionamento, ammettere due differenti cause per spiegare certi effetti, se questi possono essere spiegati da una sola.

(1738-1822)



GOES 9 satellite meteo
35,000 km sull’equatore e
Oceano Pacifico orientale
(Genn 1997)

Telescopio spaziale Herschel - IR

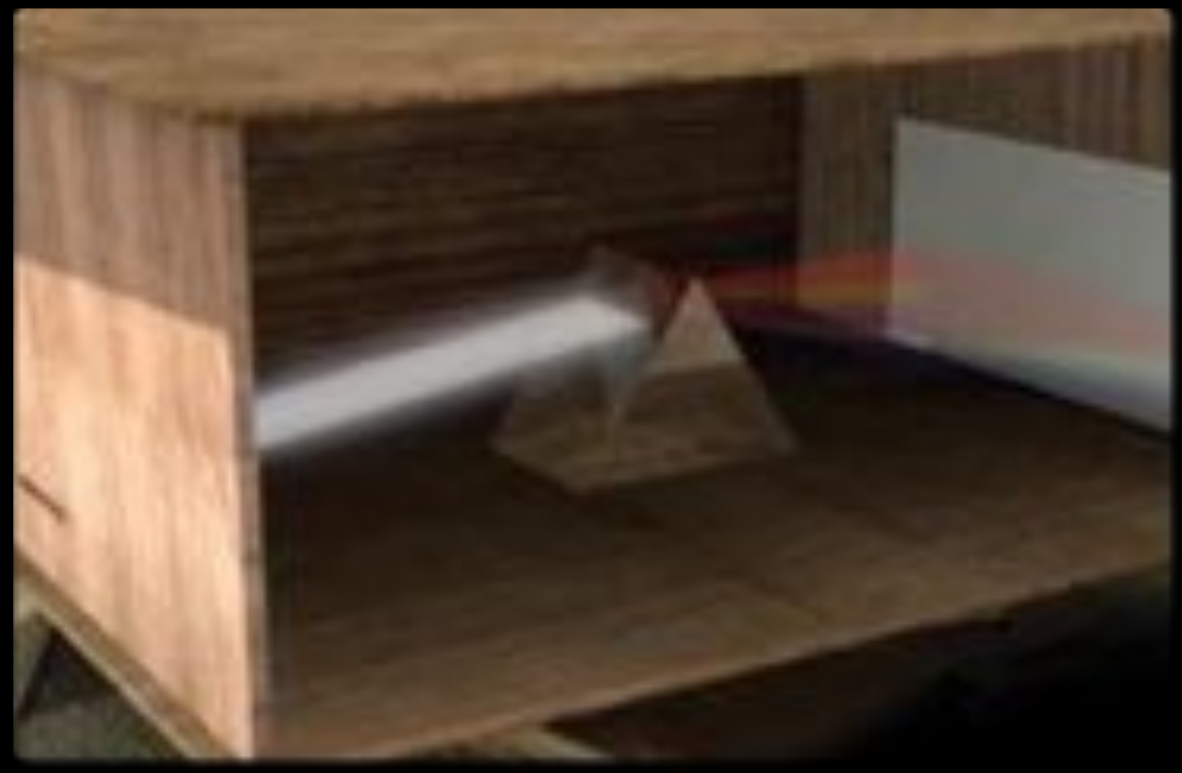
lanciato nel 2009 insieme al satellite Planck

... e della galassia M31

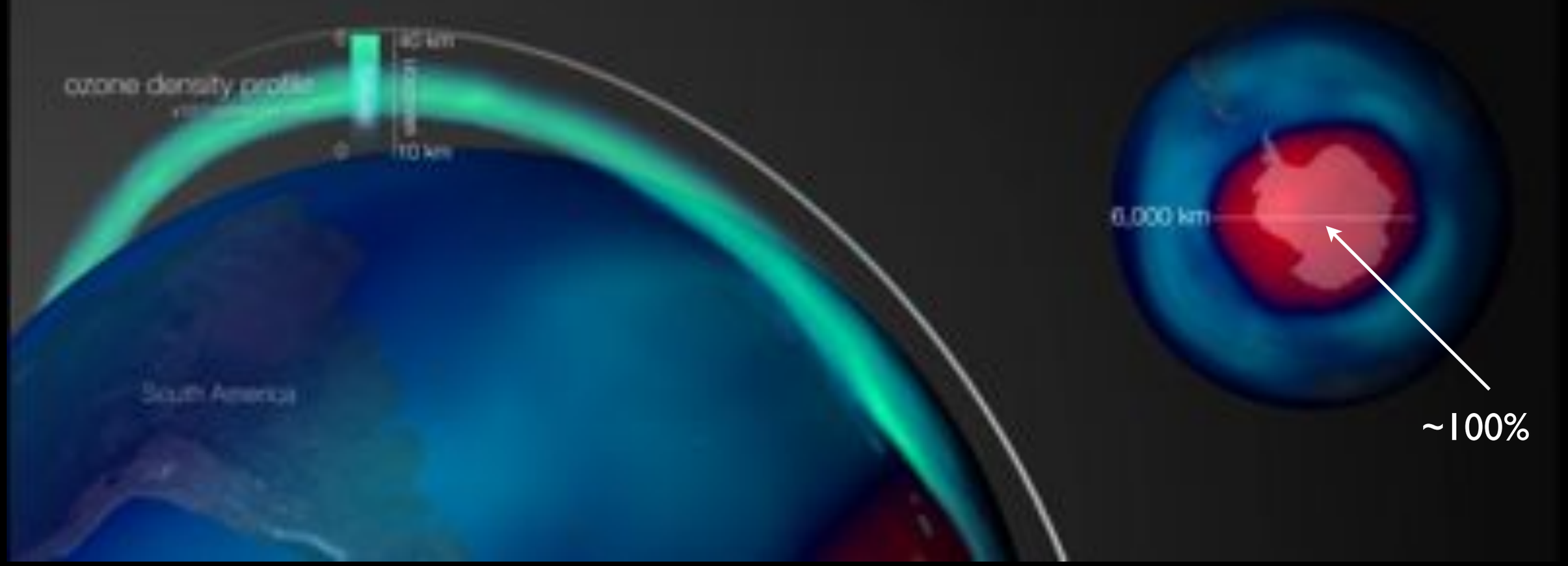
Le polveri della Via Lattea

La radiazione UV (1801)

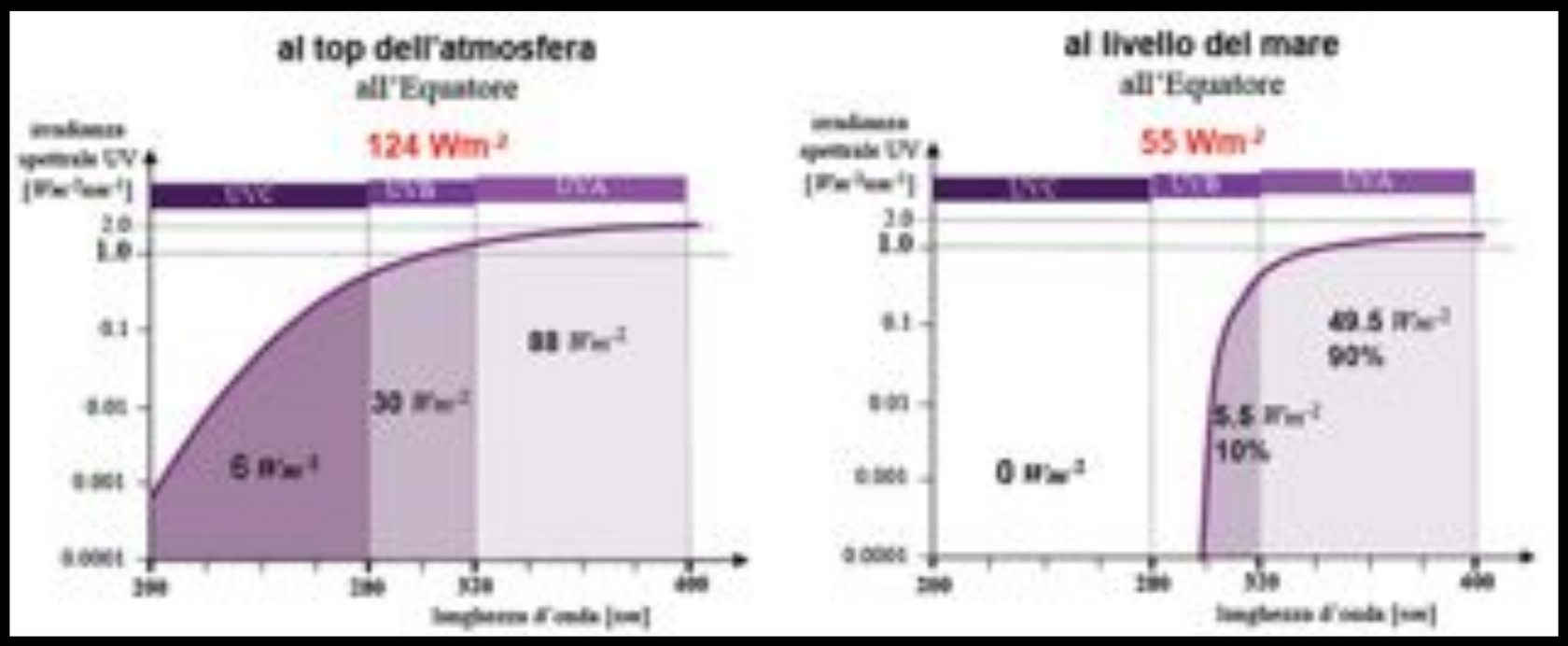
Johann Wilhem Ritter



Una radiazione invisibile oltre il violetto
impressiona carta impregnata con sali d'argento
(piu` che la radiazione violetta)

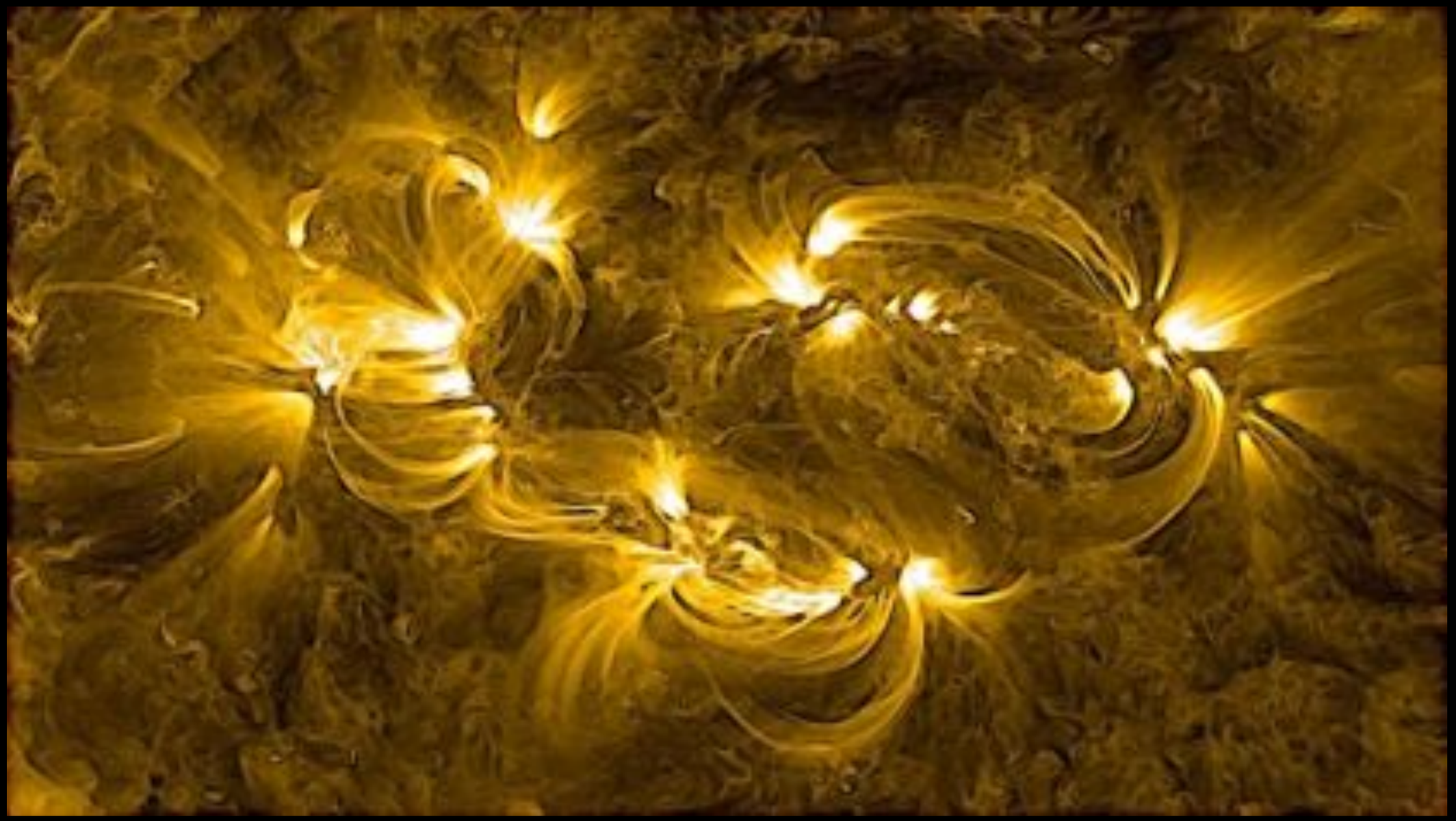


I raggi UVC (e parte dei B) sono bloccati dall'ozono stratosferico tra 10 e 40 km dove la temperatura cresce con la quota (3 molecole O_3 ogni 10 milioni)

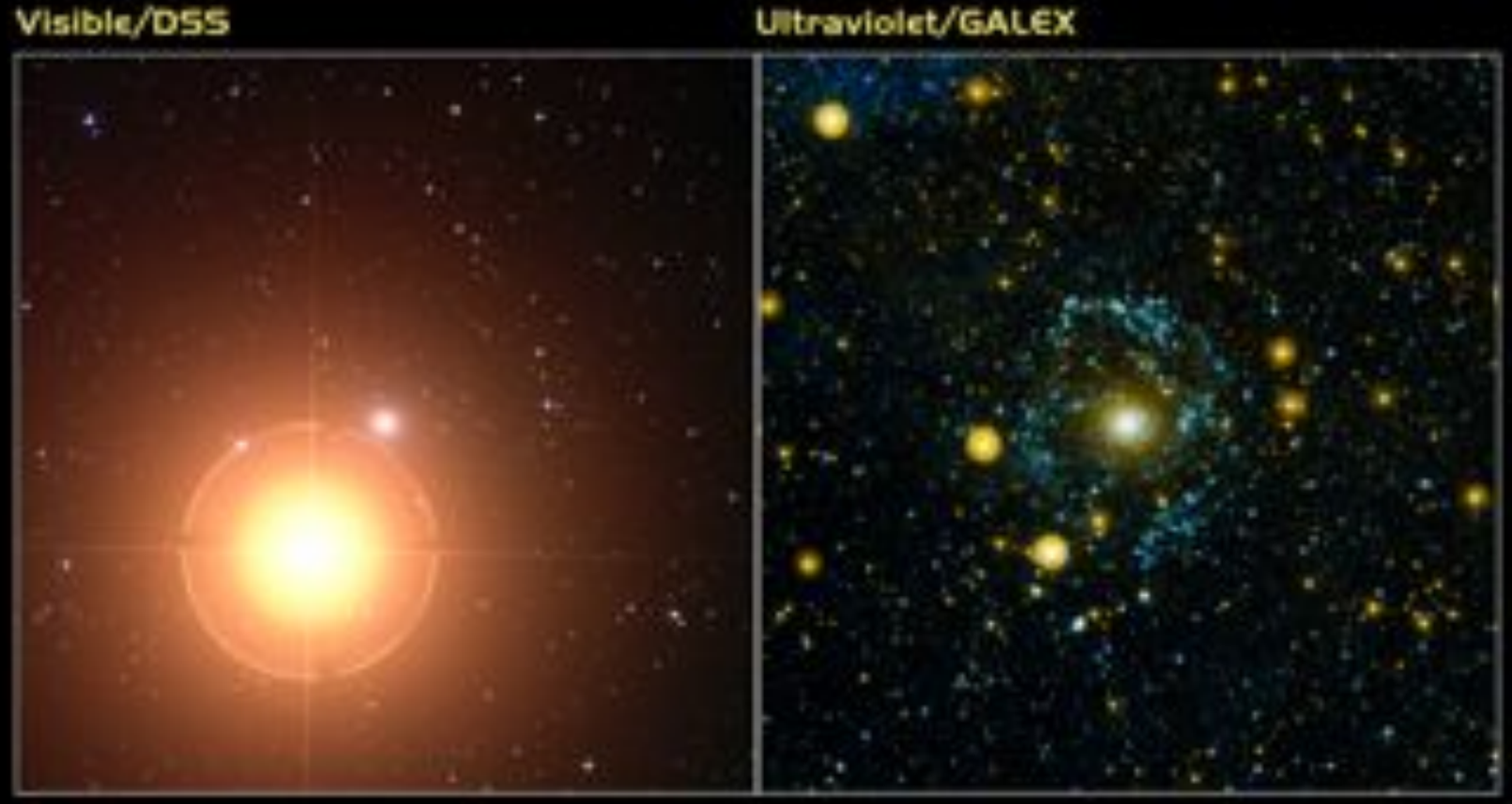


Sole in UV e transito di Venere (2012)

SolarDynamicsObservatory (NASA)



GALEX Galaxy Evolution Explorer



NGC 404: the Ghost of Mirach (Beta And, la schiena)

Cygnus Loop Nebula (d=1500 a.l., SN 5-8mila anni fa)
Galex ultraviolet telescope

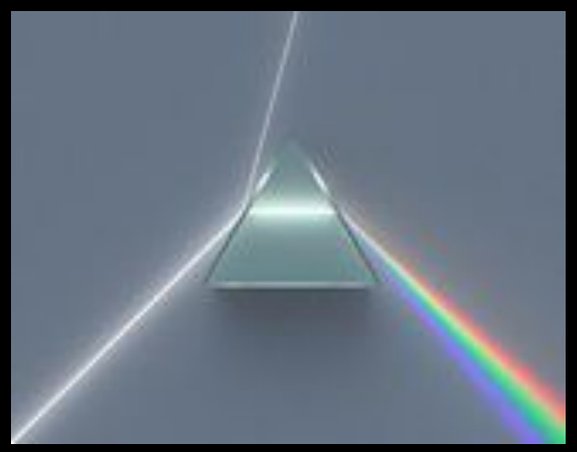
Galex, M33 (d=3milioni a.l.)

LA SPETTROSCOPIA

1814

Joseph Fraunhofer

(Monaco 1787 - 1826)



Le linee di Fraunhofer (1814)

Joseph Fraunhofer osservo`che lo spettro del Sole, quando sufficientemente disperso, e` attraversato da molte sottili linee scure (ne conto` piu` di 500).

W. H. Wollaston le aveva gia`osservate nel 1802, senza attribuirvi significato.

Fraunhofer studio` gli spettri di molti corpi celesti. Quello della Luna mostrava le stesse linee nere del Sole. Noto` che le linee brillanti del Sodio corrispondono alle riga scura D nello spettro solare; ma non fu in grado di darne spiegazione.

Gustav Robert Kirchoff

(1824-1887)

&

Robert Wilhem Bunsen

(1811-1899)

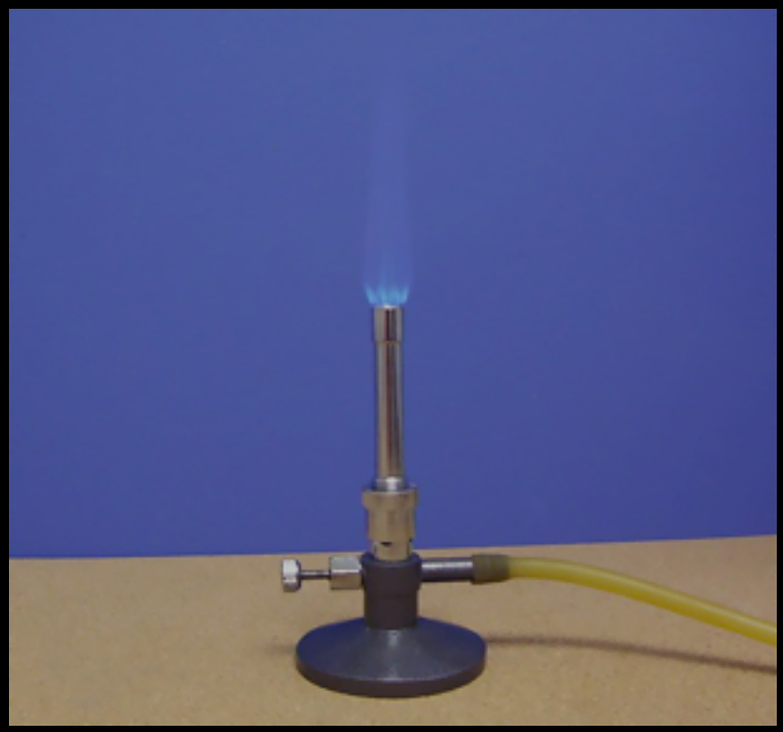
Il sodalizio ebbe inizio nel 1850 a Breslavia dove Kirchhoff insegnava e dove, poco dopo, arrivò Bunsen.
Trasferitosi Bunsen ad Heidelberg, Kirchhoff lo seguì nel 1854.

Kirchhoff e Bunsen posero le basi dell'analisi spettroscopica, scoprendo che ogni riga spettrale è caratteristica dell'elemento chimico che la emette.

Li

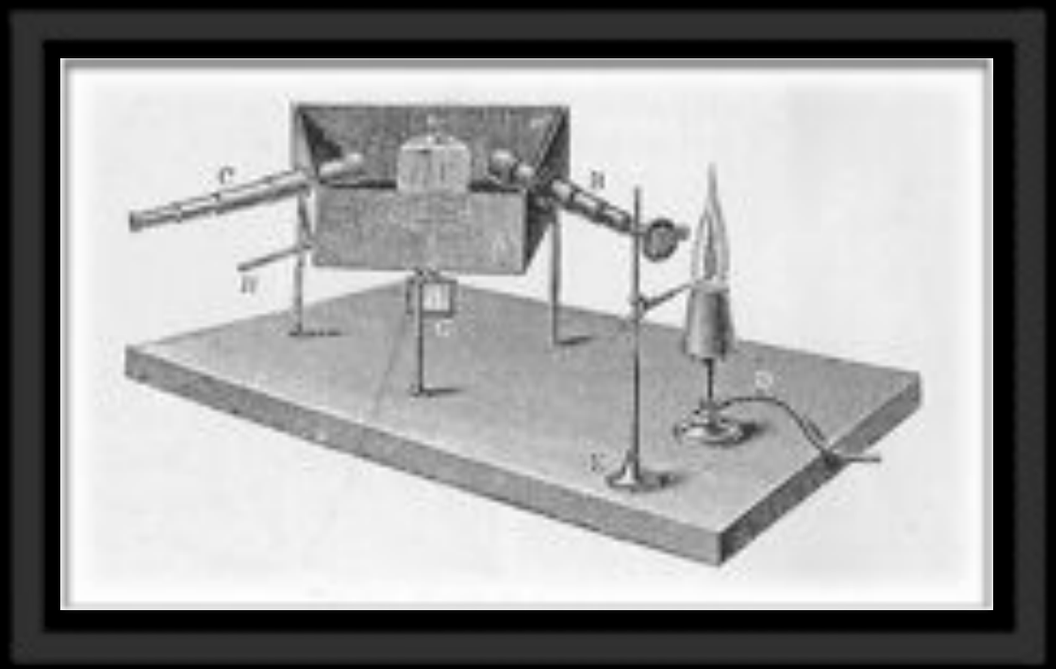
Na

K

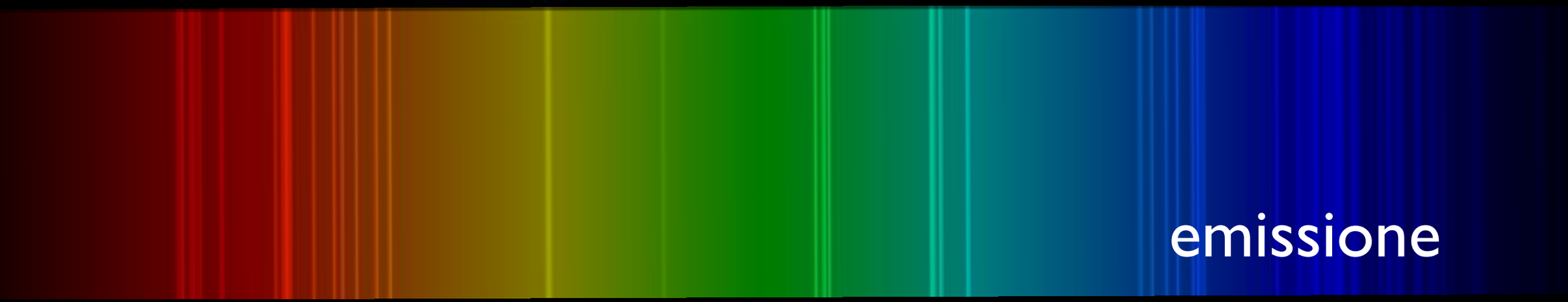


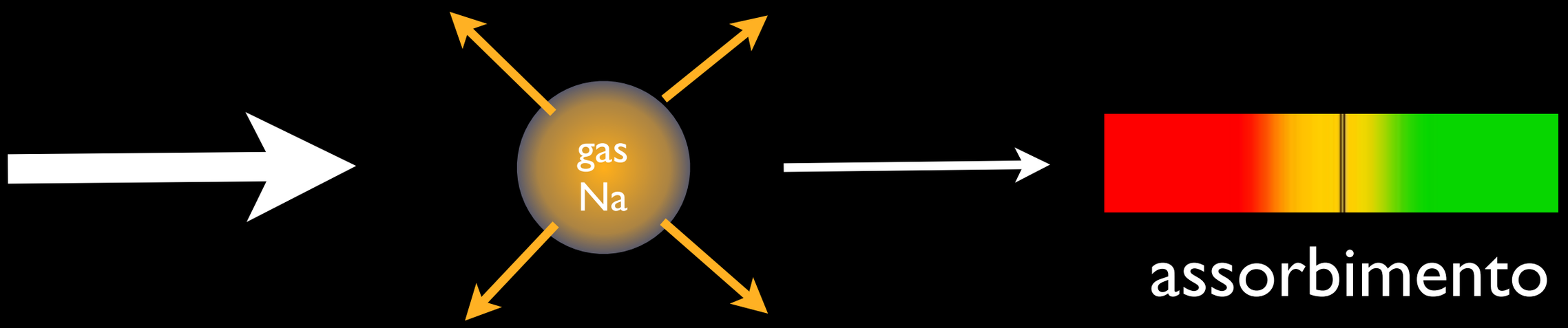
Cu

Ca

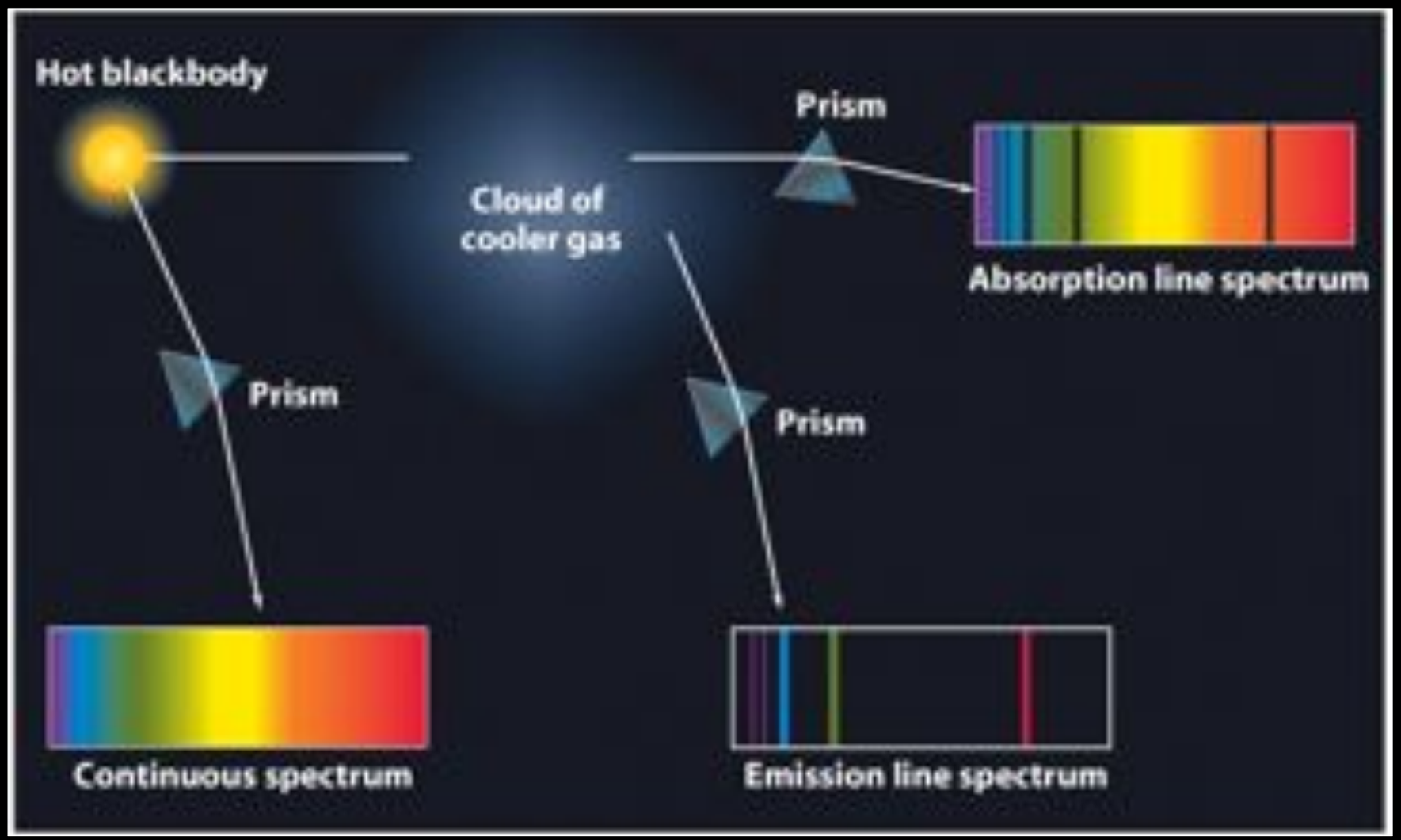


Na - SODIO

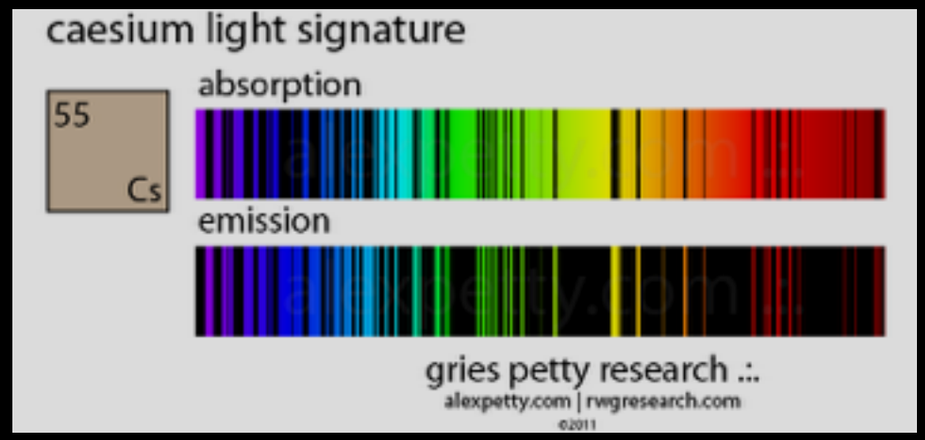




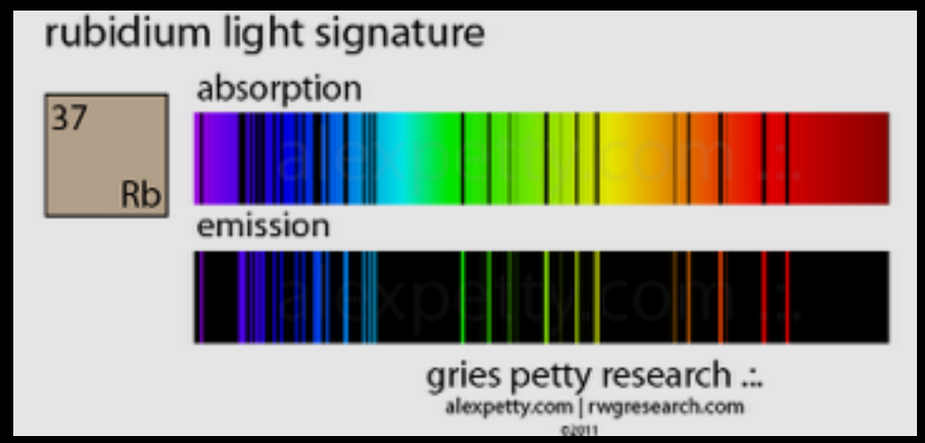
Un gas che emette uno spettro di linee
deve, alla stessa temperatura,
assorbire lo stesso spettro di linee



CESIO (1860) *caesius = azzurro cielo*



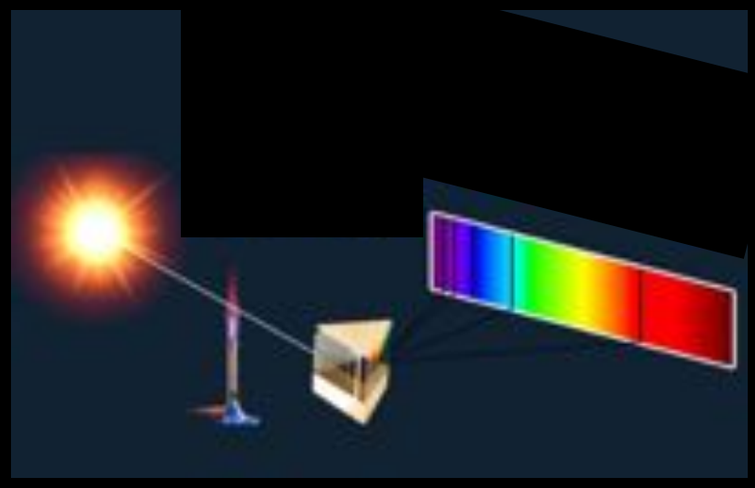
RUBIDIO (1861) *rubidus = rosso cupo*

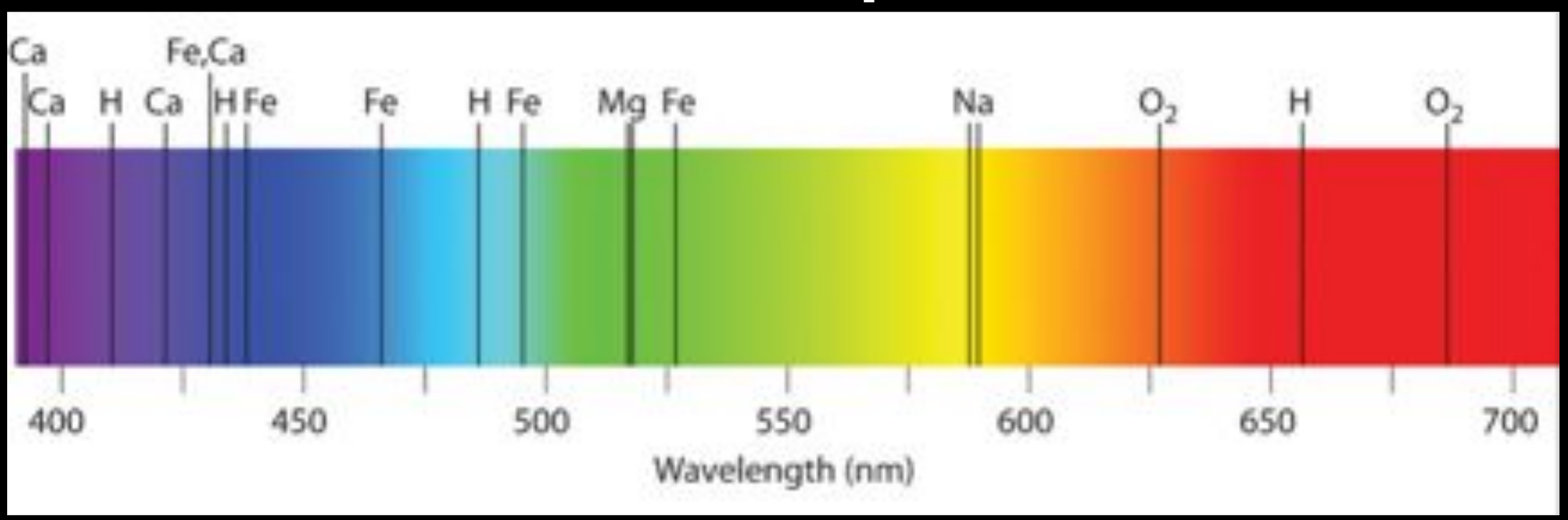


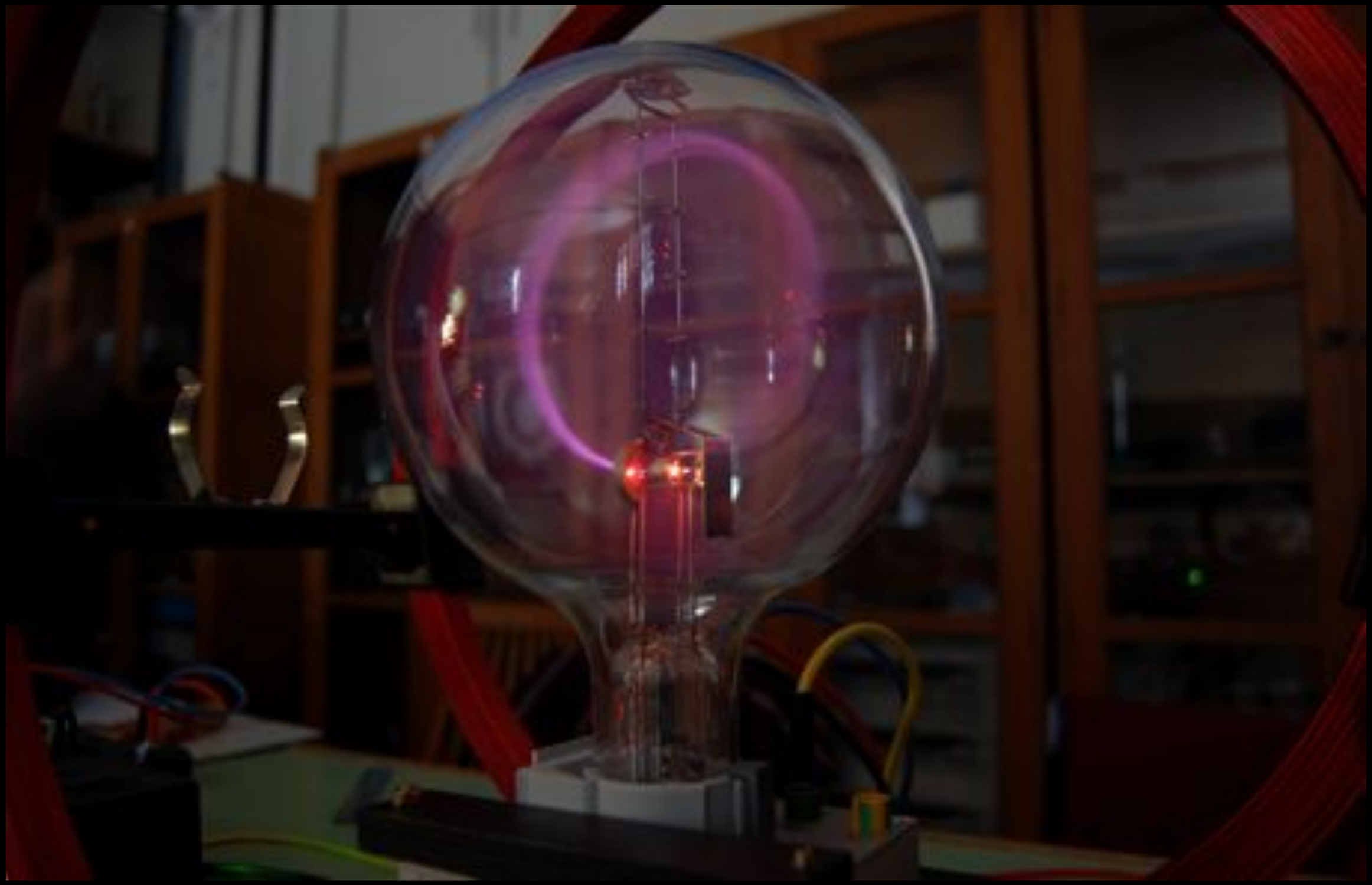
Lo spettro del Sole

Le linee di Fraunhofer nello spettro solare
sono dovute all'assorbimento dello spettro
continuo (emesso dall'interno del Sole)
da parte degli elementi presenti
nell'atmosfera solare piu` fredda.

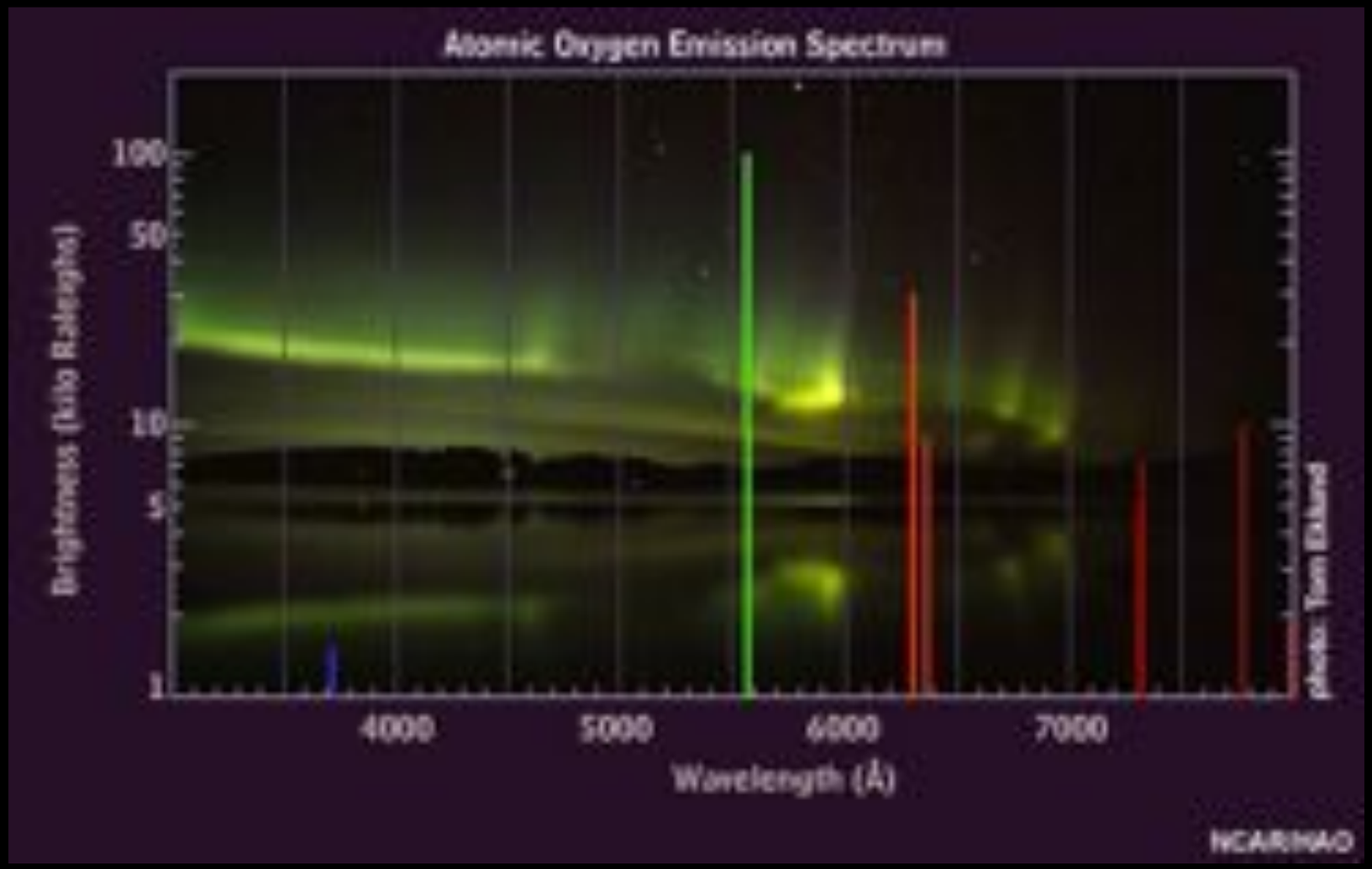
Über die fraunhoferschen Linien
Annalen der Physik (1860)

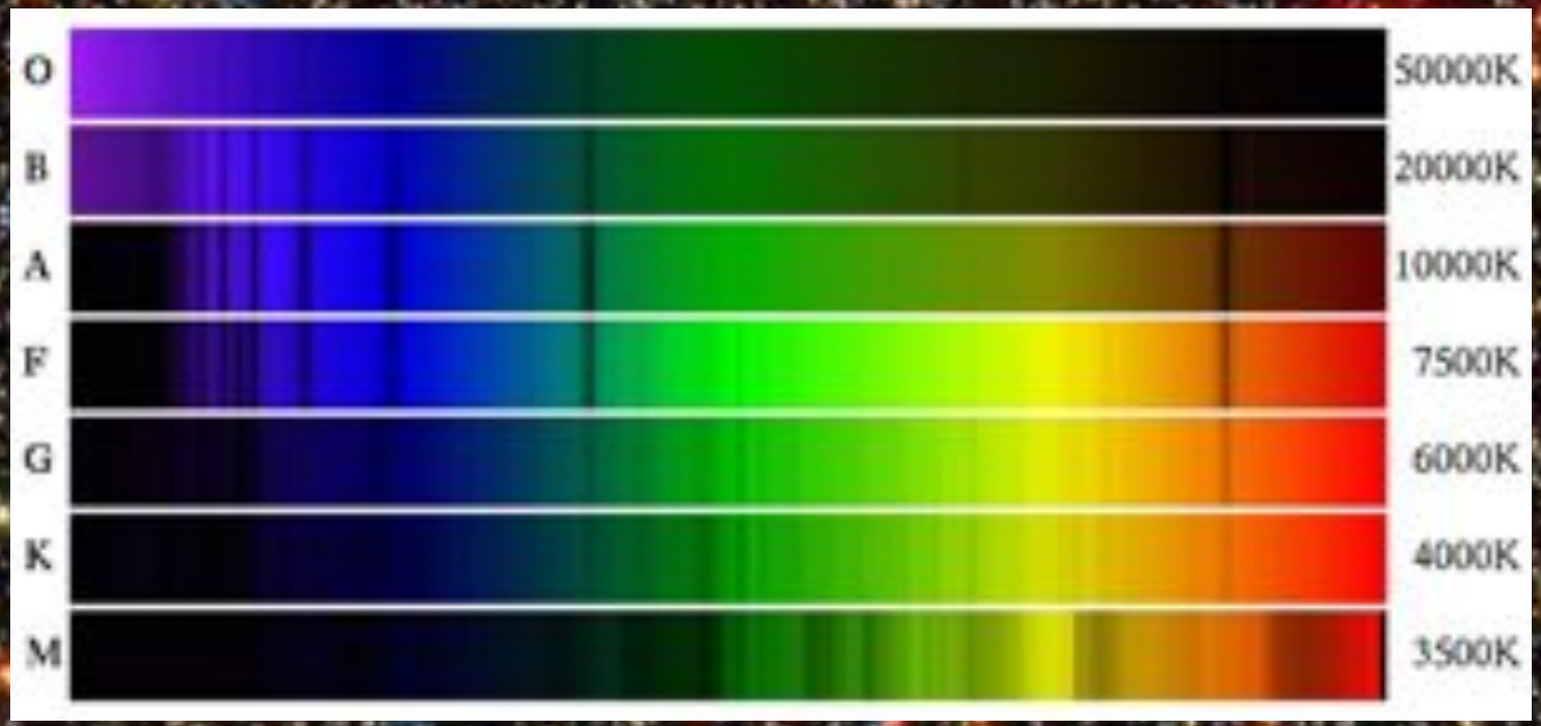






Gli elettroni in campo magnetico compiono moto circolare
e collidono con le molecole del gas nell'ampolla, che emettono luce


Atomic Oxygen Emission Spectrum
100
50
10
5
1
Brightness (kilo Rayleighs)
4000
5000
6000
7000
Wavelength (Å)
photo: Tom Eklund
NCAR/HAO



Oh Be A Fine Girl Kiss Me

Padre Angelo Secchi

Si distinse per l'invenzione di nuovi strumenti (eliospettroscopio, spettroscopio stellare) e soprattutto nell'individuazione di 5 classi stellari (di Secchi) dedotti da quasi 4000 spettri, studiati a partire da 1863.

1) Cupola equatoriale di Merz
3) Cupola circolo meridiano
6) Antenna con il globo in vimini che, sganciato al mezzogiorno, dava il segnale per lo sparo del cannone sul Castel S. Angelo.
7) Cavi elettrici per la trasmissione dei segnali dei sensori meteorologici al Meteorografo registratore.

Montecitorio.

Osservatorio del Collegio Romano

JAMES CLERK MAXWELL

1831-1879

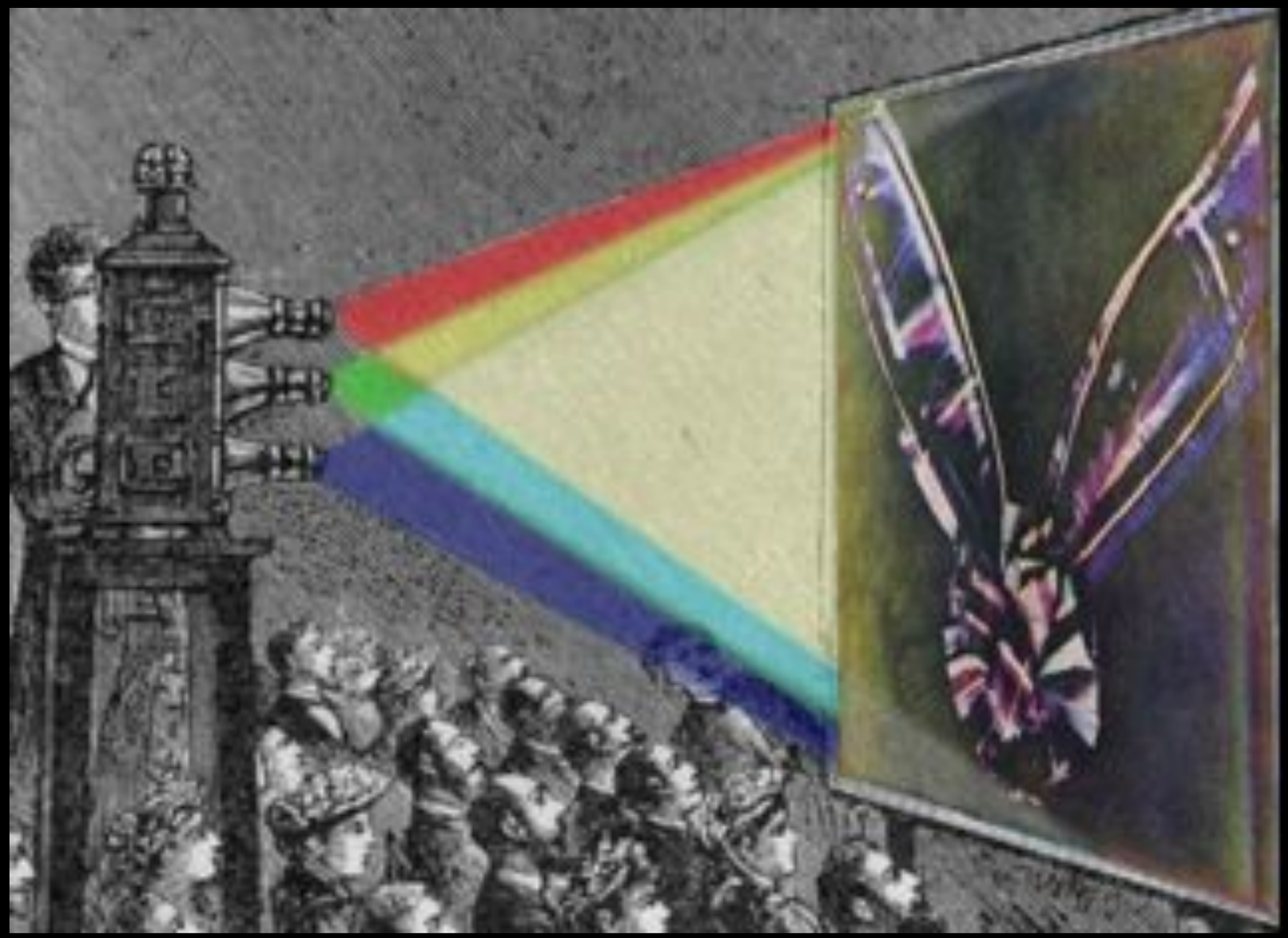
Diametro: 270 mila km
Spessore: 10 m - 1 Km
polveri ghiacciate che
collidono e polverizzano

On the stability of the motion of Saturn's rings

Premio Adams 1856 (Cambridge)

Gli anelli sono composti da particelle

La prima fotografia a colori



TARTAN RIBBON (1861)
eseguita da un fotografo
in tre filtri rosso verde blu

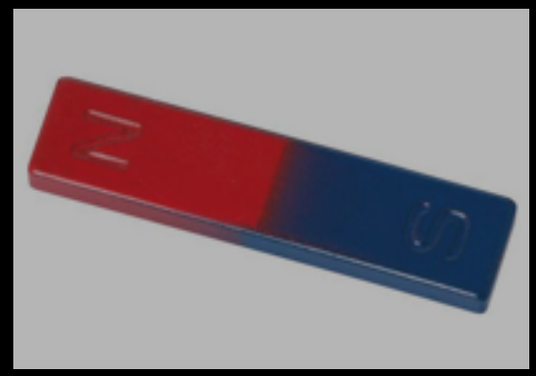
LE EQUAZIONI DI MAXWELL (1865)

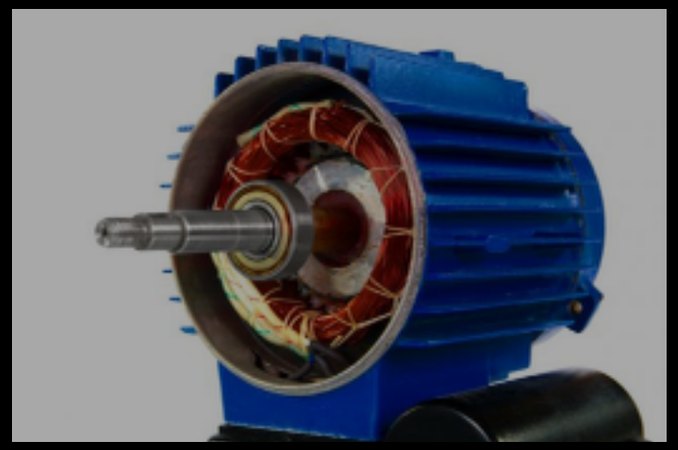
$$\nabla \cdot E = 4\pi\rho$$

$$\nabla \cdot B = 0$$

$$\nabla \times E = -\frac{1}{c}\frac{\partial B}{\partial t}$$

$$\nabla \times B = 4\pi J - \frac{1}{c}\frac{\partial E}{\partial t}$$





$$\nabla \cdot E = 4\pi\rho$$

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$$\nabla \times E = -\frac{1}{c}\frac{\partial B}{\partial t}$$

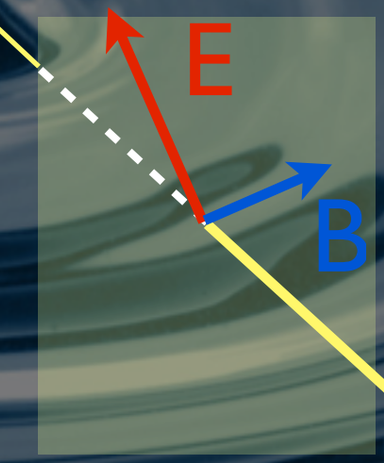
$$\nabla \times B = 4\pi J - \frac{1}{c}\frac{\partial E}{\partial t}$$

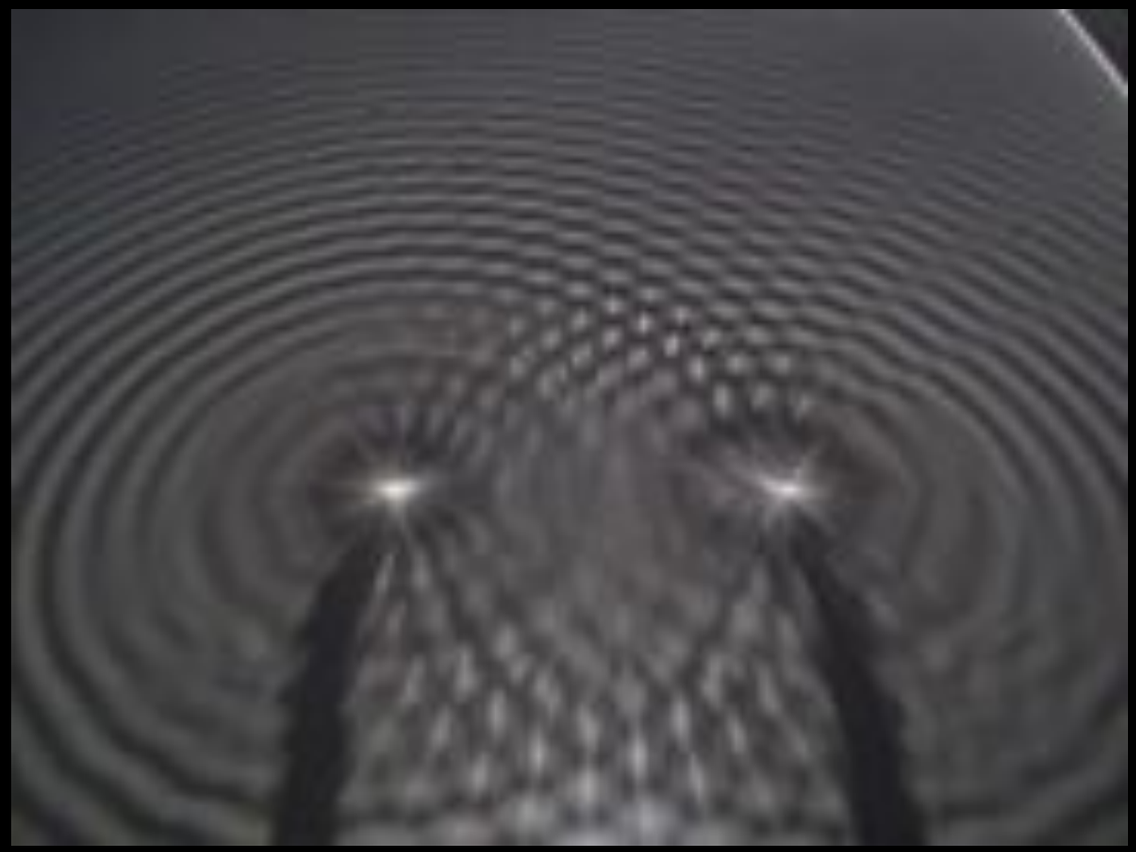
Gilbert
Coulomb
Volta
Gauss
Ampere
Franklin
Faraday
Biot
Savart
Ohm
Oersted
Neumann
Lenz
...

La teoria unificata dell’elettricita` e del magnetismo

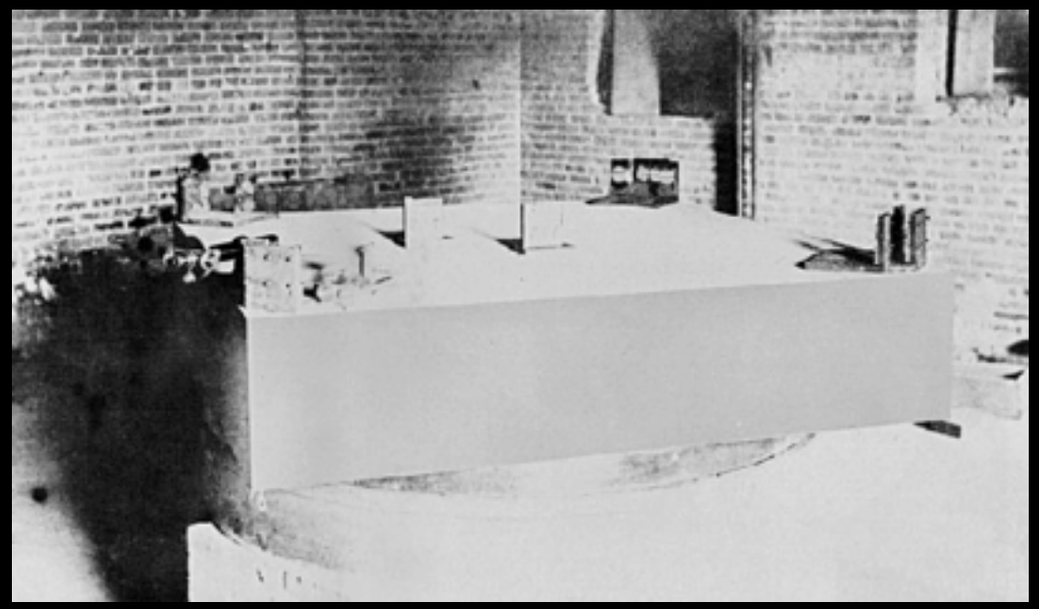
Soluzioni delle equazioni di Maxwell senza sorgenti:

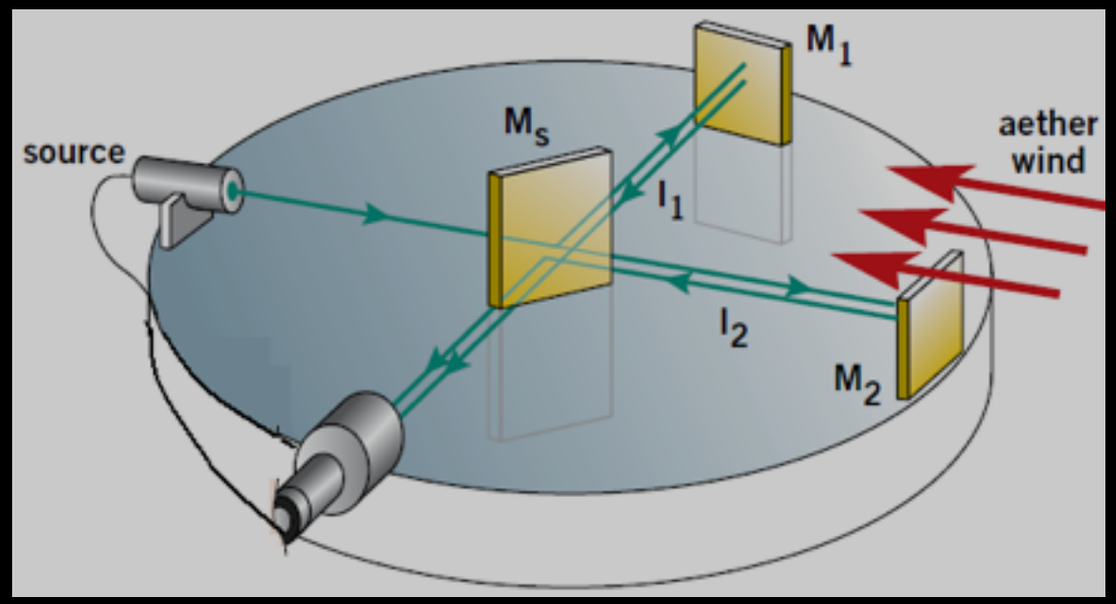
LE ONDE ELETTROMAGNETICHE





Il problema dell'etere





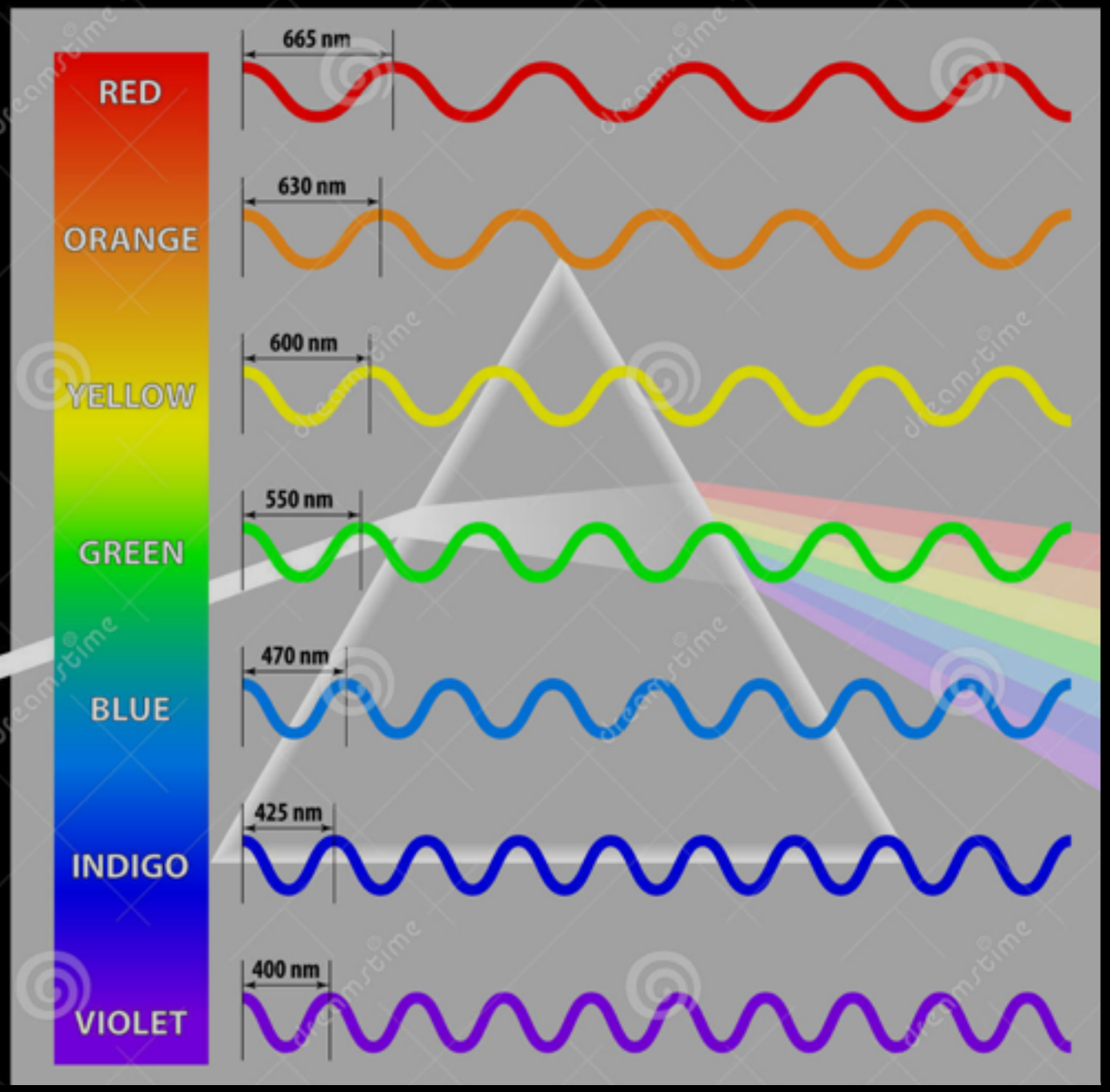
L'esperimento di Michelson e Morley (1887)

The special theory of relativity
owes its origins to Maxwell's equations
of the electromagnetic field
(Albert Einstein)

UNA LUMINOSA SCOPERTA

" The speed of electromagnetic waves is nearly that of light ... which gives a good reason to conclude that light is somehow itself, an electromagnetic disturbance that propagates under the laws of electromagnetism "

1864, "Dynamical theory of the electromagnetic field"
discorso alla Royal Society, pubblicato nel 1865

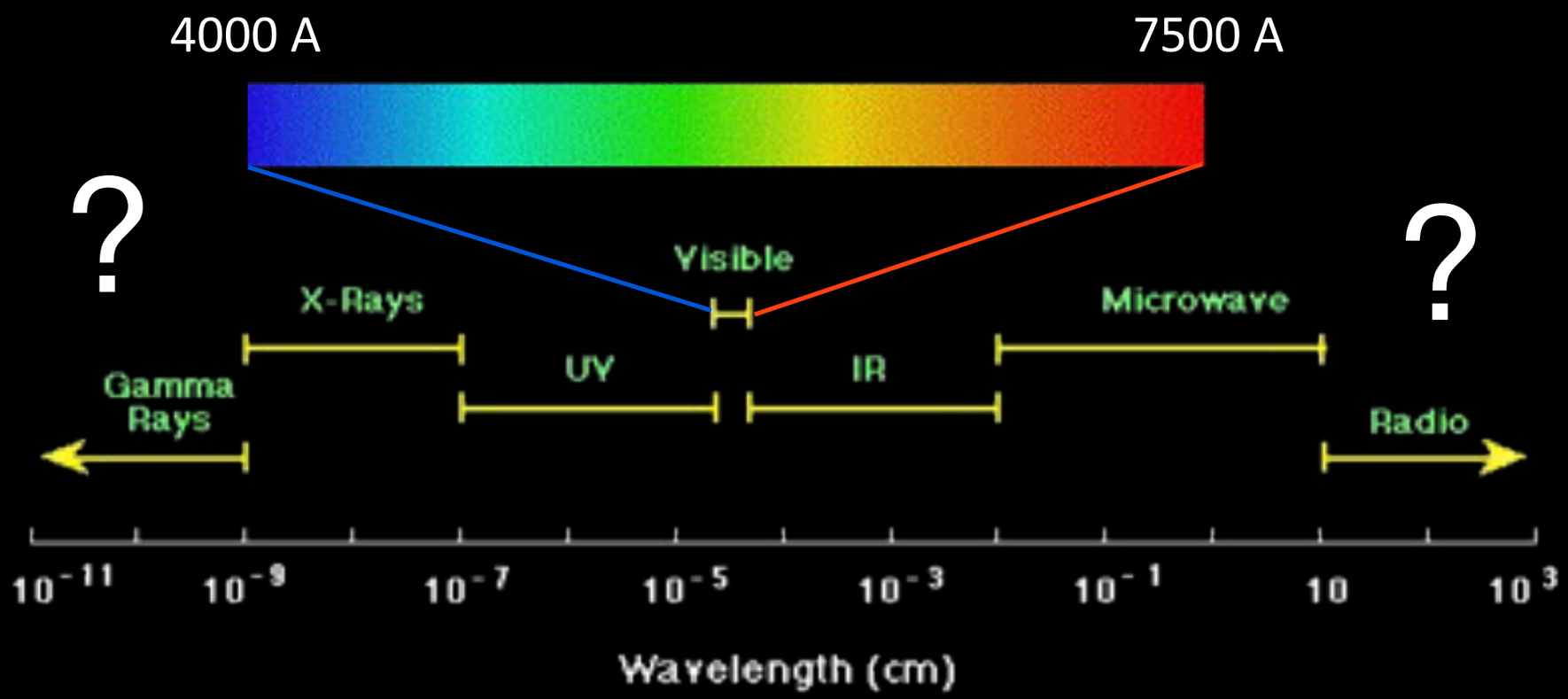


I colori che compongono la luce visibile sono onde e.m.

Le onde e.m. sono caratterizzate da una lunghezza d'onda.
Trasportano energia e hanno nel vuoto la stessa velocita`
c =300mila km/s

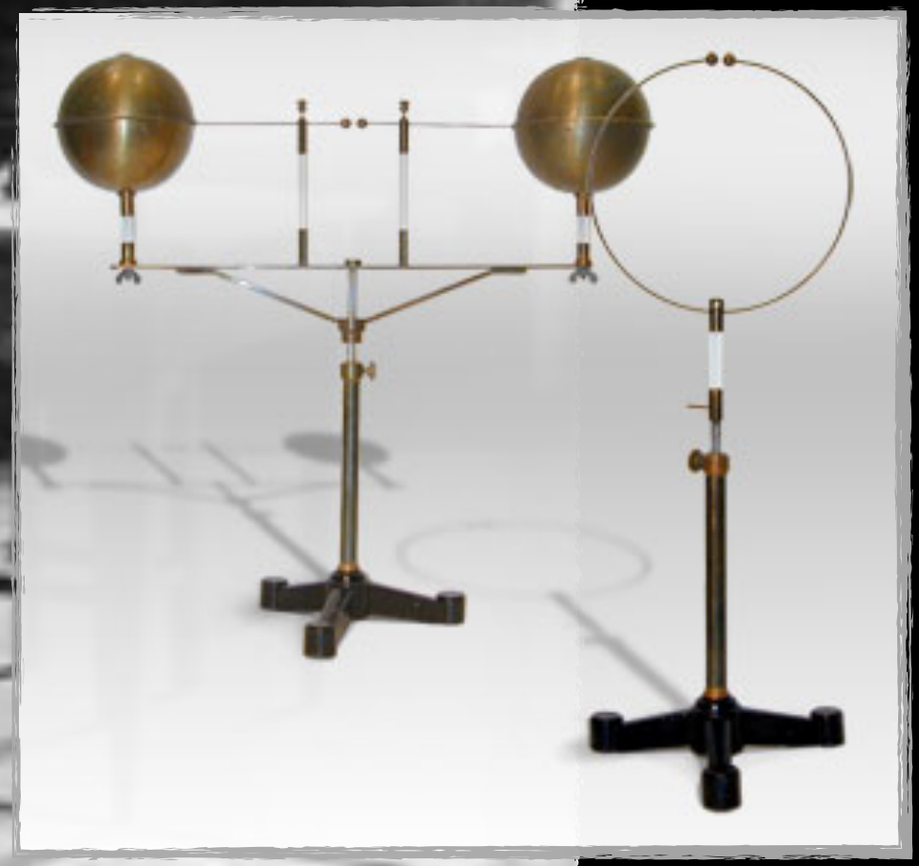
Ogni elemento chimico emette e assorbe un proprio spettro di righe (onde e.m.)

Lo spettro elettromagnetico



Gli esperimenti di Hertz

Negli anni 1885 -1889, al Politecnico di Karlsruhe,
Heinrich Hertz fu il primo a produrre e studiare le onde radio,
previste matematicamente da Maxwell

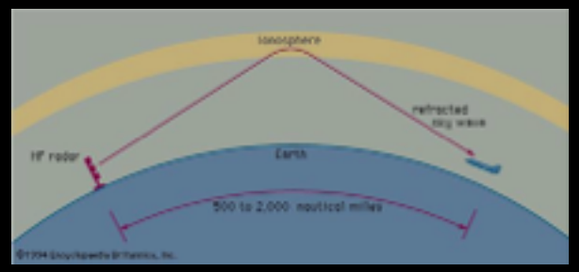


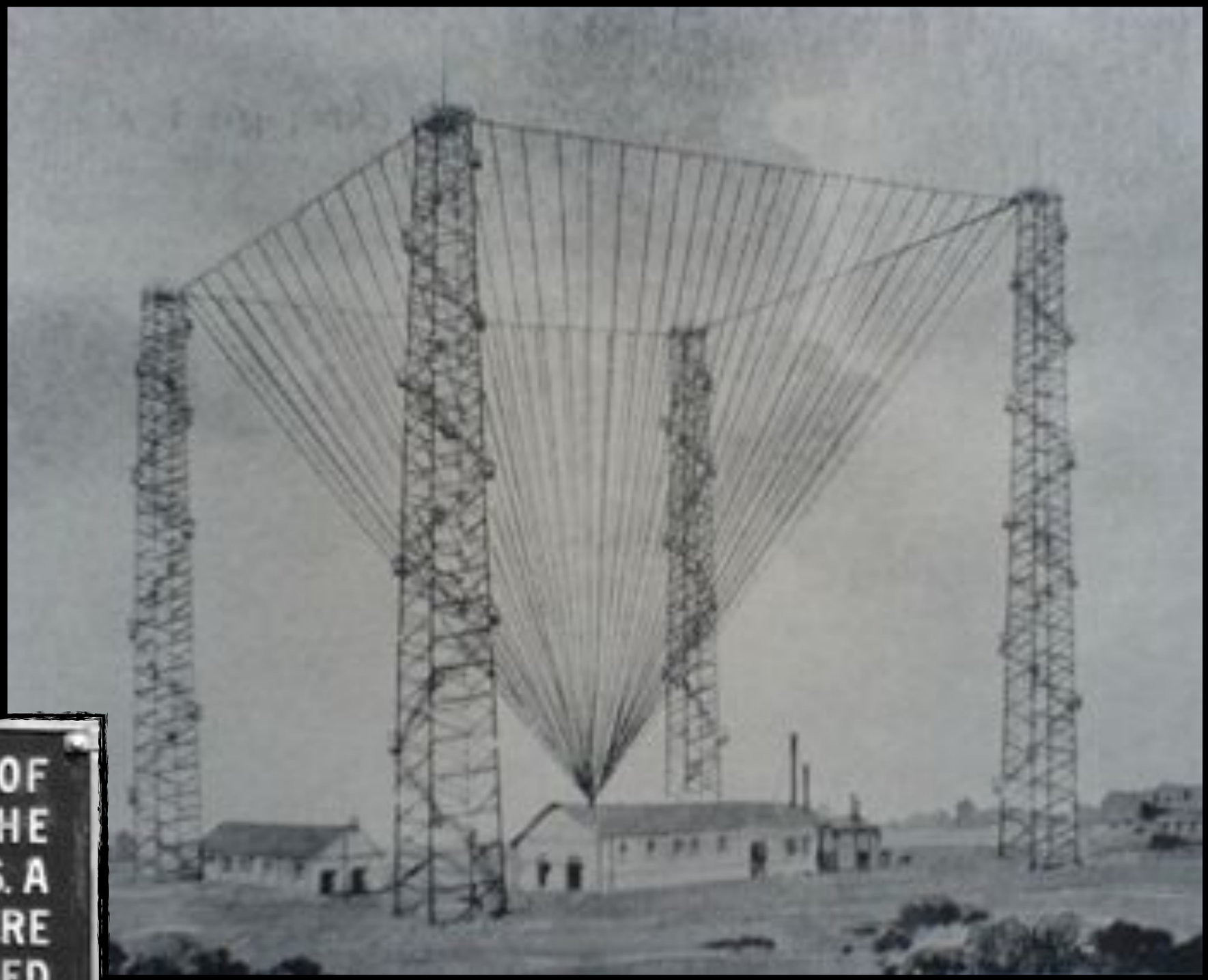
Guglielmo Marconi

Premio Nobel per la Fisica 1909

Nel novembre 1901 costruì a Poldhu (Cornovaglia) un grande trasmettitore.
Poi attraverso l'Atlantico per St. Johns in Terranova, a oltre 3.000 chilometri.

Il 12 dicembre 1901 fu trasmesso il primo segnale radio transoceanico,
Il messaggio era composto da tre punti (la *S* in codice Morse) e giunse dopo due riflessioni sulla ionosfera (100-400 km).





Wireless Telegraph & Signal Company.

Ingegneri del British Post Office esaminano un apparecchio di radio-telegrafia di Marconi (1897)

LA NAVE ELETTRA

Nel 1930 Marconi, invio' dal porto di Genova gli impulsi elettrici che illuminarono il Municio di Sydney, Australia, distante 20,000 chilometri.

"My father loved the sea and loved the yacht Elettra"
(Princess Elettra Marconi Giovanelli)

1931, Pio XI e Marconi per la prima trasmissione radio dal Vaticano

PRESIDENT SENDS WIRELESS MESSAGE TO KING EDWARD.

England's Ruler Returns the Compliment by Means of the Marconi System.

SOUTH WELLFLEET, Mass., Jan. 19.—The following messages were transmitted today by the Marconi system of wireless telegraphy between Cape Cod and Cornwall, England, between President Roosevelt and King Edward: His Majesty, Edward VII.

London, Eng.

In taking advantage of the wonderful triumph of scientific research and ingenuity which has been achieved in perfecting a system of wireless telegraphy, I extend on behalf of the American people most cordial greetings and good wishes to you and to all the people of the British Empire.

THEODORE ROOSEVELT

Wellfleet, Mass., Jan. 19, 1903.

Sandringham, Jan. 19, 1903

The President,

White House, Washington, America

I thank you most sincerely for the kind message which I have just received from you, through Marconi's trans-Atlantic wireless telegraphy. I sincerely reciprocate in the name of the people of the British Empire the cordial greetings and friendly sentiment expressed by you on behalf of the American Nation and I heartily wish you and your country every possible prosperity.

EDWARD R. and I.

deplored the lack of convenience.

MARCONI MOURNED BY ENTIRE WORLD

Body Lies in State in Royal Academy in Rome—50,000 Pay Tributes to Inventor

FUNERAL CEREMONY TODAY

Important Radio Experiments on the Yacht Elettra Were Halted by Death

By ARNALDO COSTESI

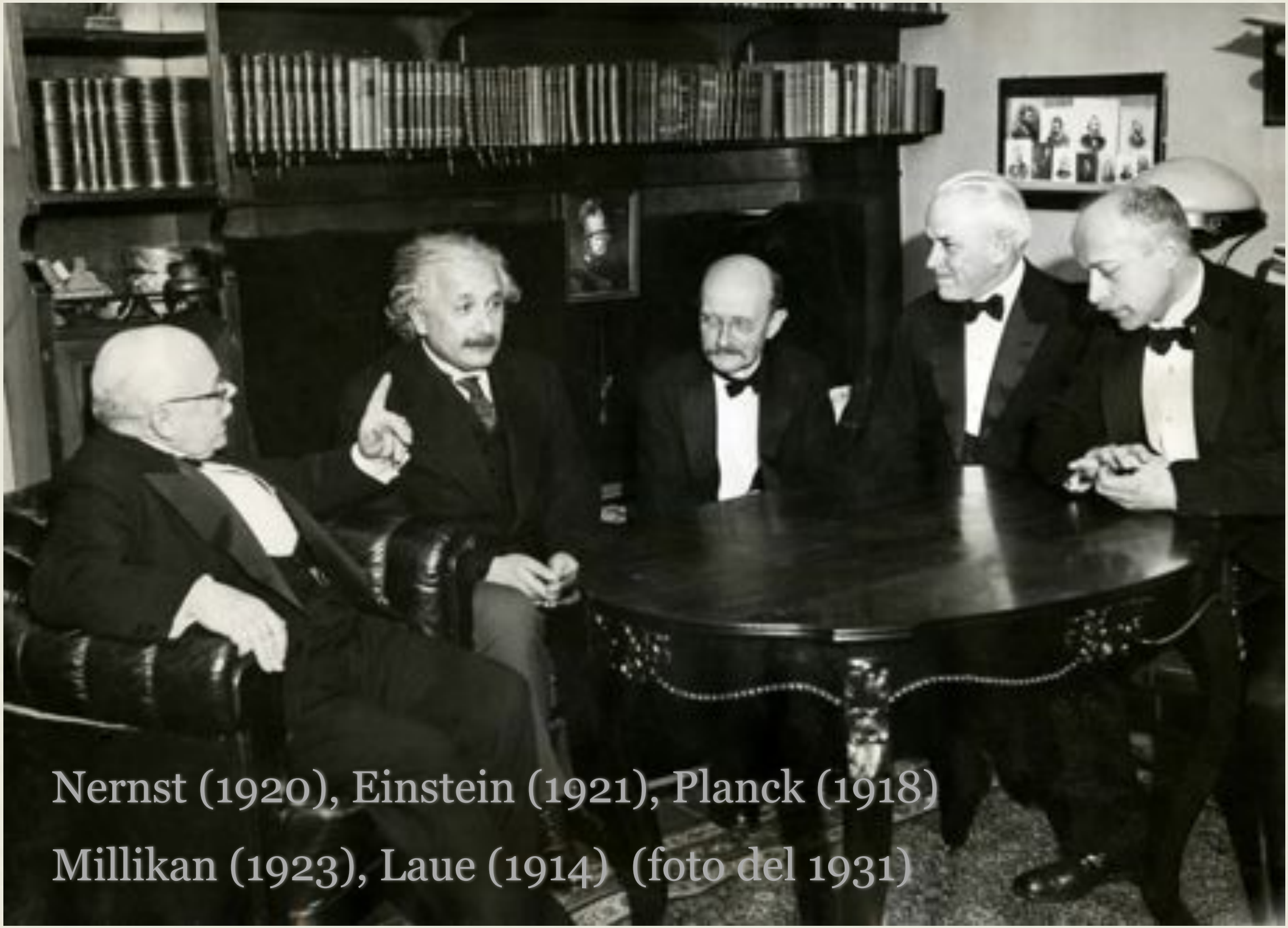
Special to The New York Times.

ROME, July 20.—Marquis Guglielmo Marconi died of a heart attack

The Marconi International Marine Communication Company, Ltd.

Curie, Marconi, Bohr, Fermi, Majorana, Como 1931

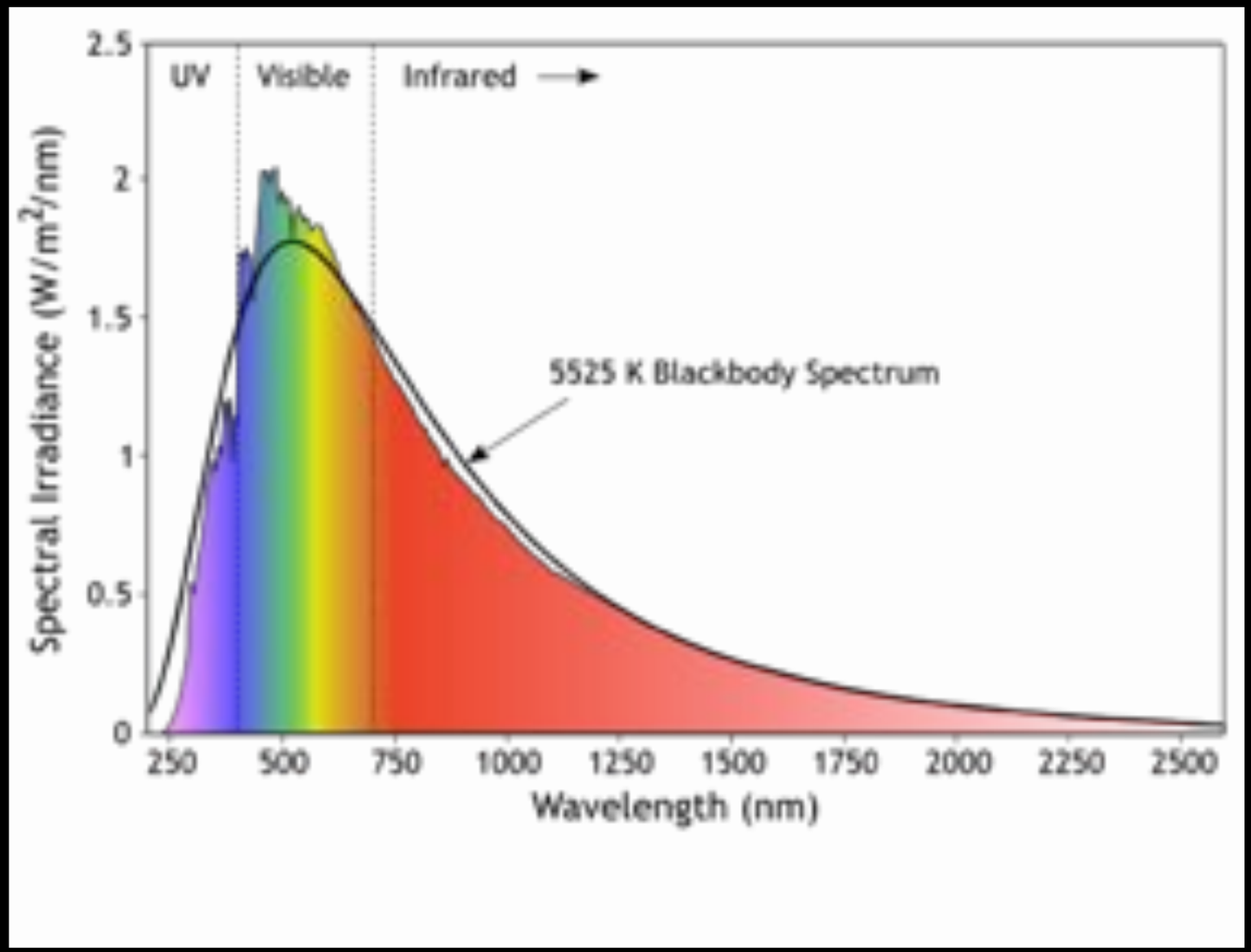
Marconi Memorial a Washington



Nernst (1920), Einstein (1921), Planck (1918)

Millikan (1923), Laue (1914) (foto del 1931)

LA RADIAZIONE DEL CORPO NERO (1900)
(Legge di Planck, dopo una lunga ricerca)

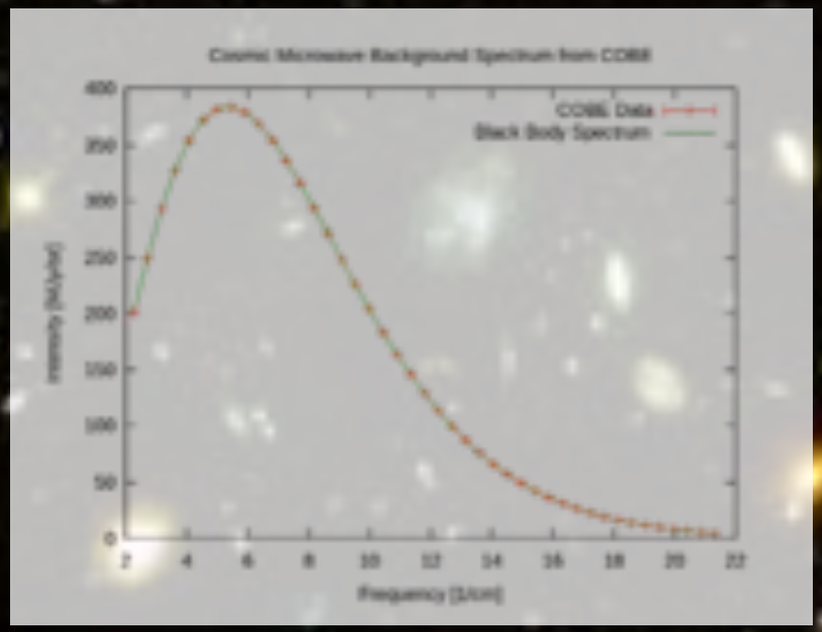


Kirchoff:

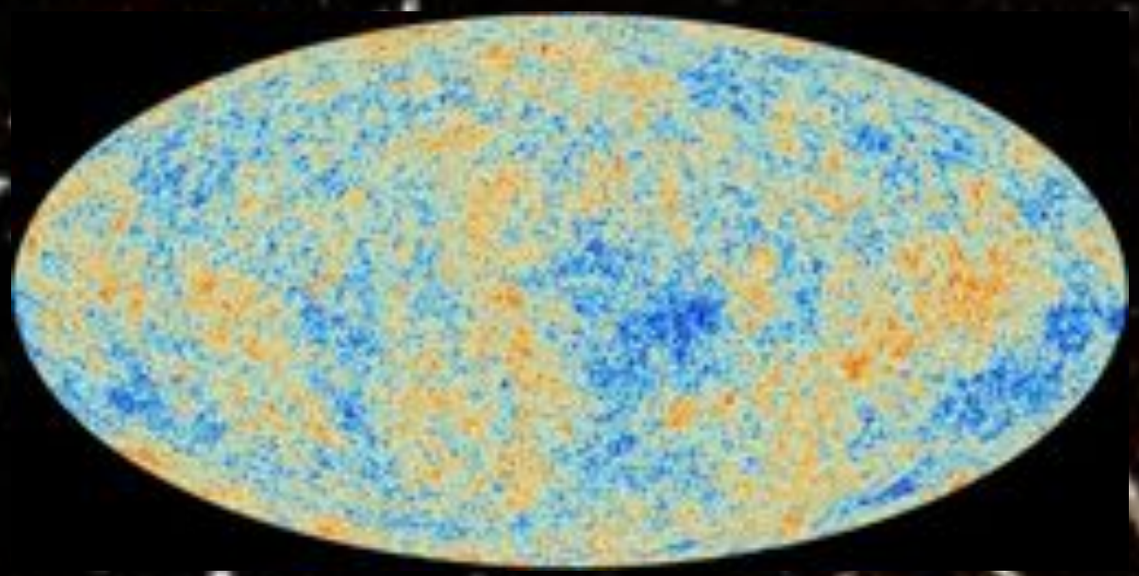
$$\frac{E(\lambda,T)}{A(\lambda,T)} = f(\lambda, T)$$

funzione universale, corrispondente all'emissione di un corpo ideale con $A=1$ (corpo nero)

h



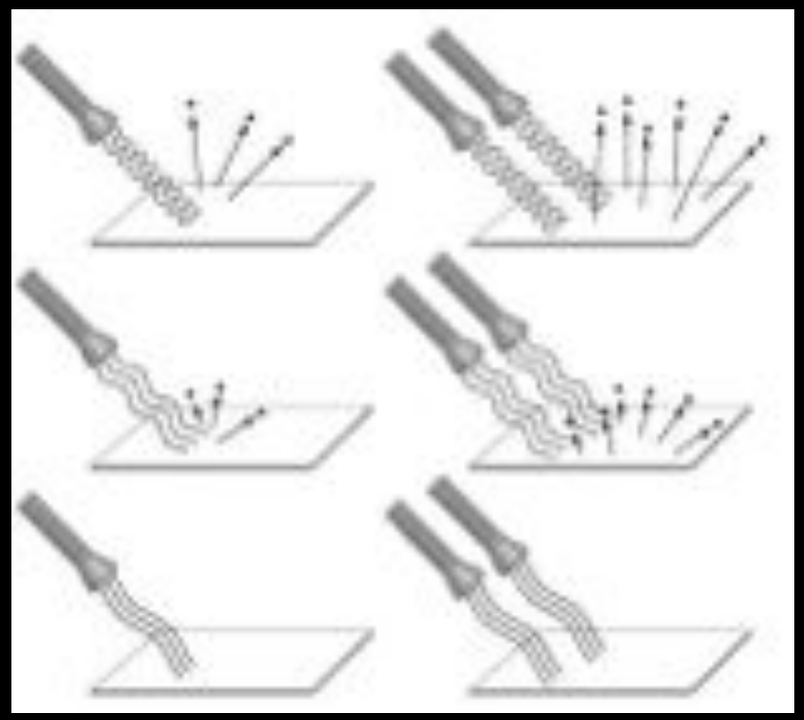
Il fondo cosmico di microonde



L'effetto fotoelettrico

UV

IR



Le onde e.m. cedono energia alla materia in forma di particelle senza massa:

I FOTONI

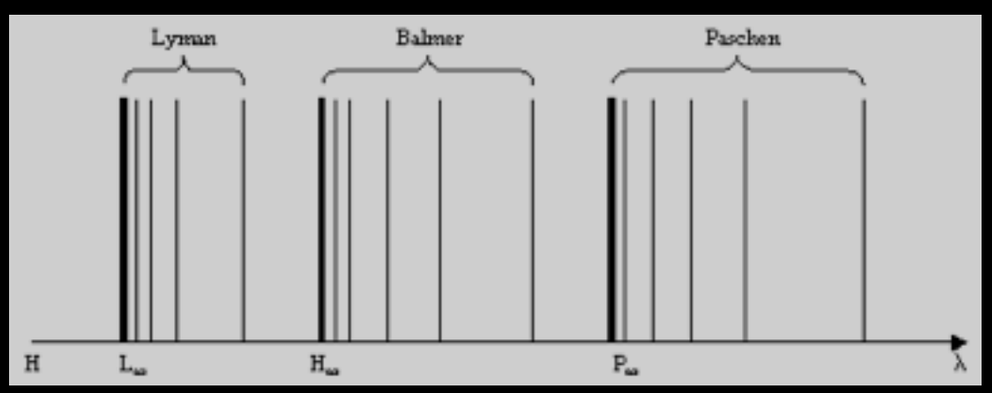
Ogni fotone ha energia $E = h\,\nu$ (Einstein 1905)

Max Planck medal - Berlino, 1929,

Le serie spettrali dell'idrogeno

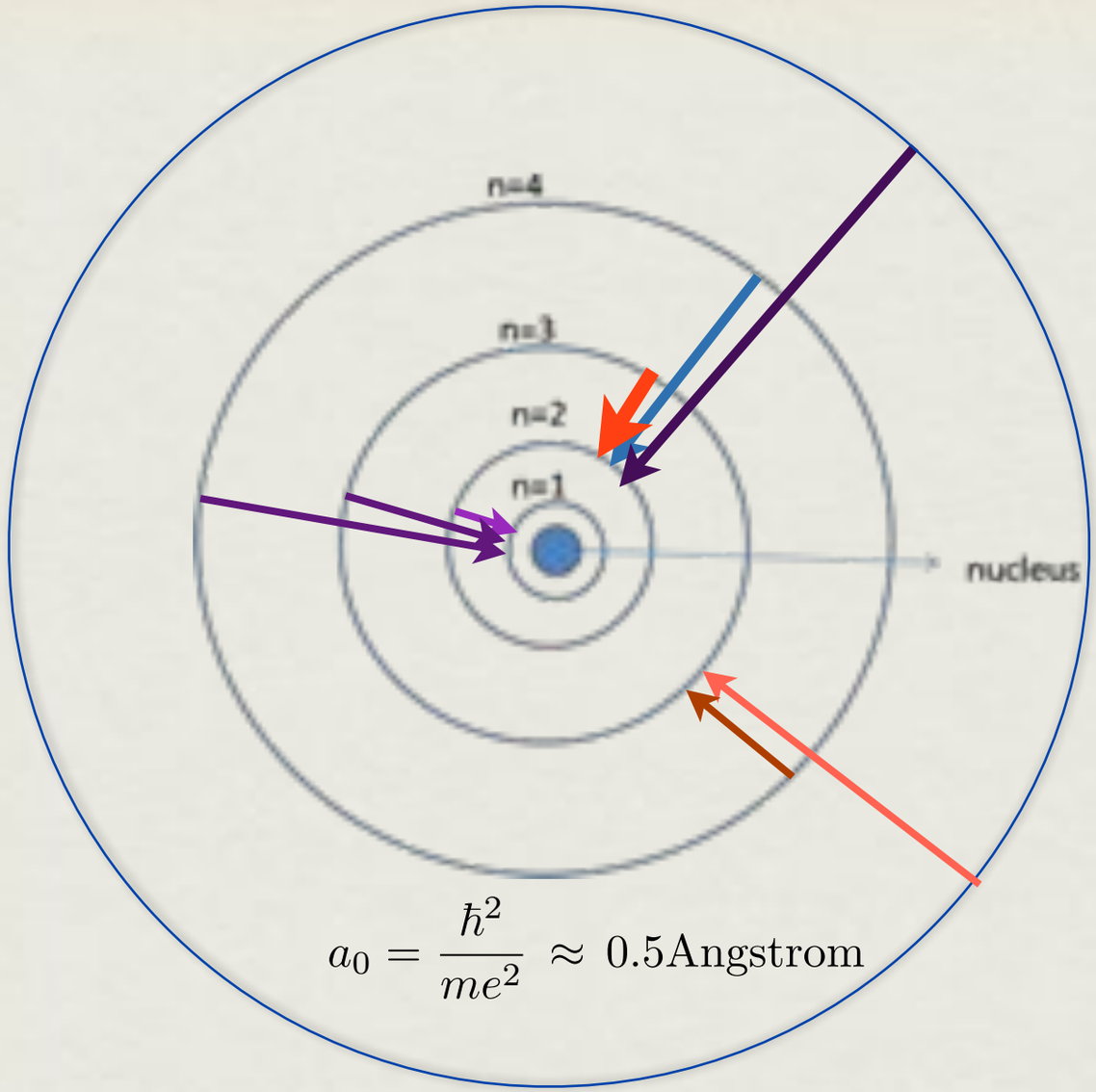
Balmer (1885)

$$\frac{1}{\lambda} = R_H \left[\frac{1}{2^2} - \frac{1}{n^2} \right] \qquad n = 3, 4, 5, \ldots$$



Lyman UV (1906)
Paschen IR (1908)

L'ATOMO DI BOHR



$$a_0 = \frac{\hbar^2}{me^2} \approx 0.5\text{Angstrom}$$

Niels Bohr
Premio Nobel 1922

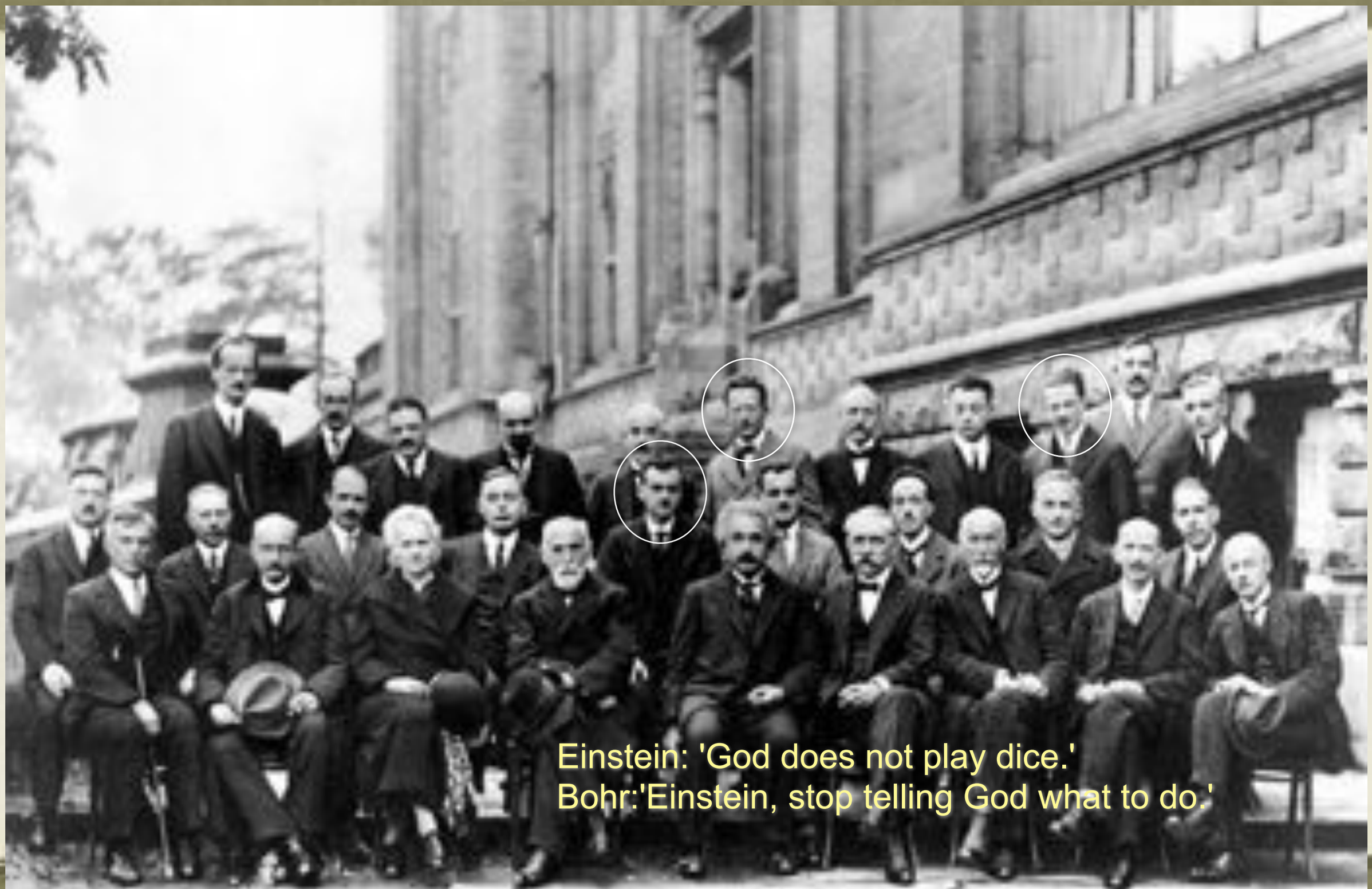
Rutherford: come fa un elettrone
a sapere su quale orbita saltare?

L'Istituto Niels Bohr a Copenhagen

E' tutt'oggi finanziato dalla Carlsberg

Il modello di Bohr - Sommerfeld non spiegava correttamente il MOMENTO ANGOLARE

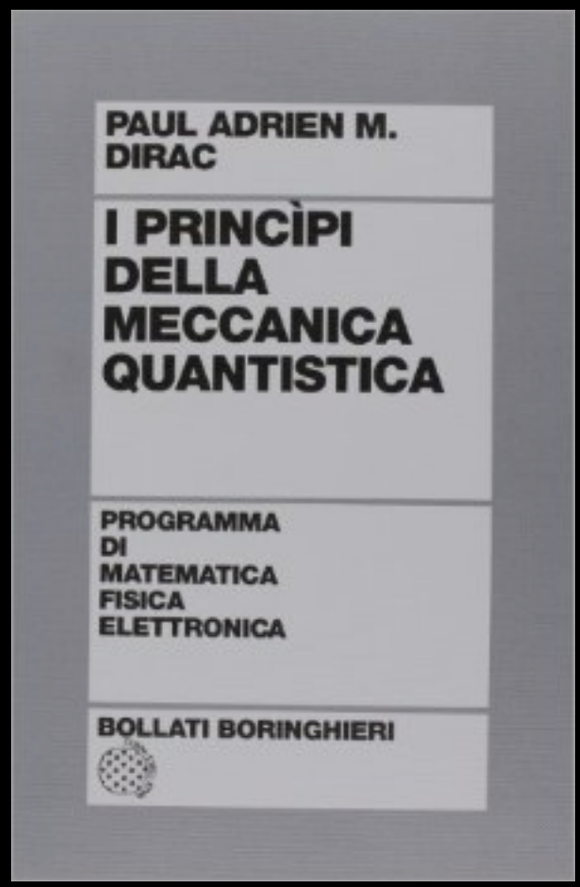
LA CONFERENZA SOLVAY 1927
LA NUOVA MECCANICA QUANTISTICA



LA NUOVA MECCANICA QUANTISTICA

I fondatori Heisenberg (1932) Dirac e Schrodinger (1933) vanno a Stoccolma a ricevere i premi Nobel

Paul A. M. Dirac
1902-1984



La quantizzazione del campo elettromagnetico (1927)
L'equazione relativistica per l'elettrone (eqz. di Dirac, 1928)

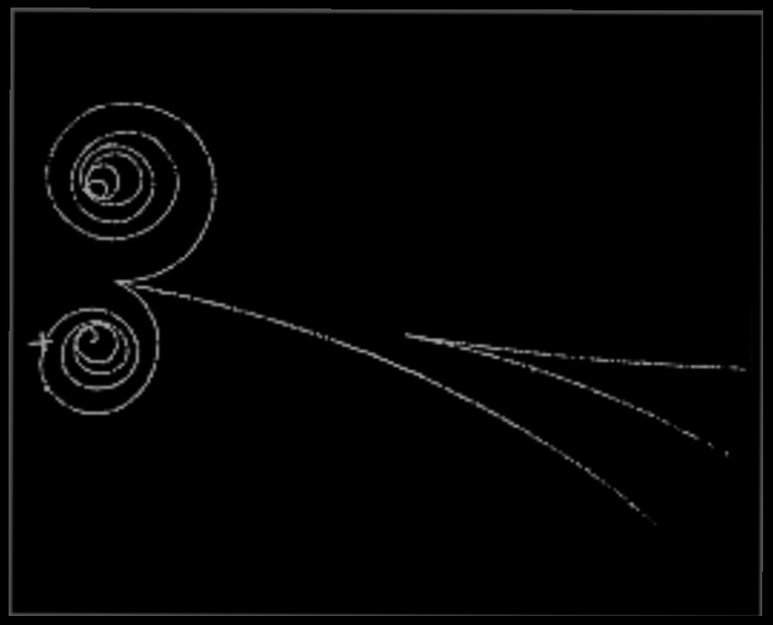
L'equazione di Dirac

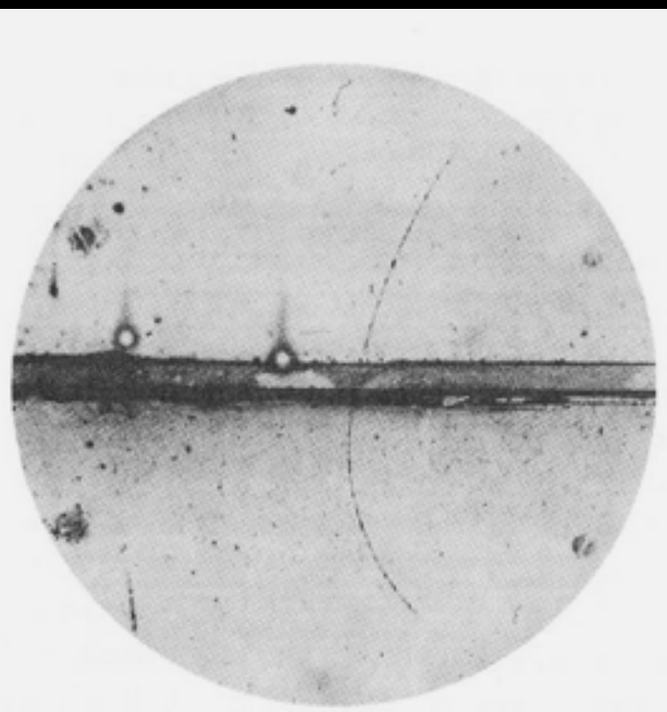
una delle formule piu' eleganti e sorprendenti della fisica

Westminster Abbey

IL POSITRONE (1932)

(Carl D. Anderson - Nobel 1936)





Anderson's prize. This photograph alone established the existence of a positive electron. The direction of motion gives the sign of the charge. Since the particle loses energy as it passes through the plate across the cloud chamber, its curvature is greater afterward. Thus, the particle is moving from top to bottom. That it is a very low mass particle is deduced from the thinness of the ionization along the track.

positroni da raggi cosmici,
in camera a nebbia

K_{40} P=19 N=21 19 e

Ar_{40} P=18 N=22 18 e

I positroni sono emessi nel decadimento radioattivo

$p \rightarrow n$ + antineutrino + positrone

Il Potassio K_{40} emette positroni (emivita = 1,3 miliardi di anni) ed e` il radioisotopo piu` abbondante nel corpo umano.
(circa 4400 decadimenti al secondo in un uomo di 70 kg. Il positrone si annichila con l'elettrone e produce due fotoni da 511 keV, in un processo simile - ma di intensita` assai minore - rispetto a quanto avviene in una PET)

Il Potassio costituisce il 2,4% della massa della crosta terrestre,
1 parte su 10mila e` l'isotopo K_{40}

Le banane sono ricche di potassio.
La radioattività di un grosso carico di banane può far scattare l'allarme degli scanner per la radioattività.
(-->banana equivalent dose)

IL LAMB SHIFT

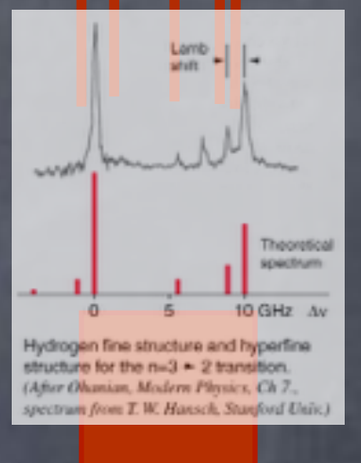
(Lamb, 1947)

n=3

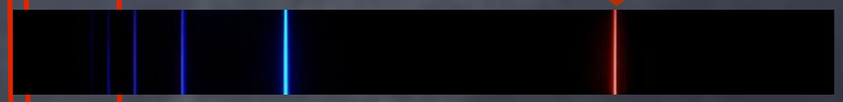
n=2

riga H-alpha

riga H-alpha
alta risoluzione



Hydrogen fine structure and hyperfine structure for the n=3 → 2 transition.
(After Ohanian, Modern Physics, Ch 7., spectrum from T. W. Hansch, Stanford Univ.)



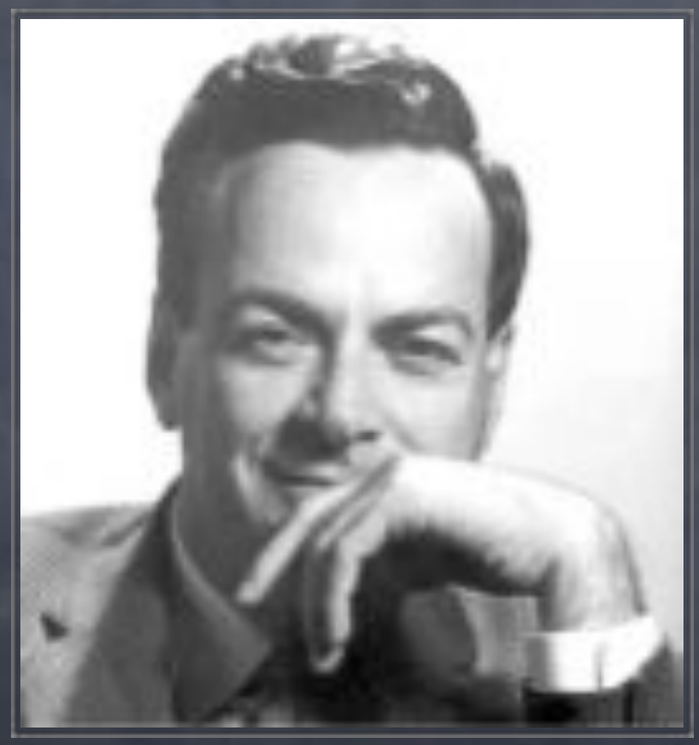
interazione
e-vuoto

QED

Q.E.D.

(quantum electrodynamics)
Premi Nobel della fisica 1965

Sin Itiro Tomonaga



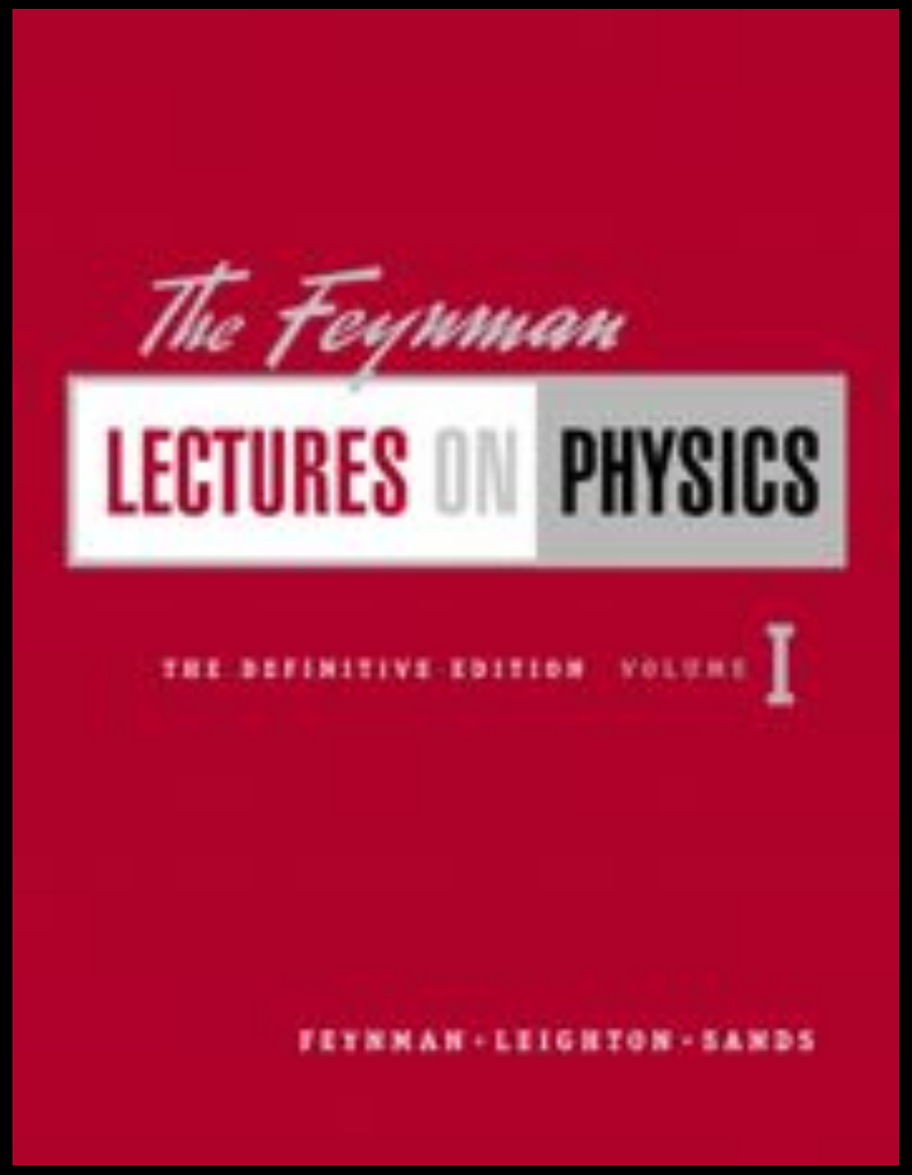
Richard Feynman

Julien Schwinger

RICHARD FEYNMAN 1918-1988

Principio di Fermat (1662)

Il raggio di luce compie il tragitto con tempo minimo



I diagrammi di Feynman

PHYSICAL REVIEW VOLUME 76, NUMBER 6 SEPTEMBER 15, 1949

Space-Time Approach to Quantum Electrodynamics

R. P. FEYNMAN
Department of Physics, Cornell University, Ithaca, New York
(Received May 9, 1949)

In this paper two things are done. (1) It is shown that a considerable simplification can be attained in writing down matrix elements for complex processes in electrodynamics. Further, a physical point of view is available which permits them to be written down directly for any specific problem. Being simply a restatement of conventional electrodynamics, however, the matrix elements diverge for complex processes. (2) Electrodynamics is modified by altering the interaction of electrons at short distances. All matrix elements are now finite, with the exception of those relating to problems of vacuum polarization. The latter are evaluated in a manner suggested by Pauli and Bethe, which gives finite results for these matrices also. The only effects sensitive to the modification are changes in mass and
Such changes could not be directly observ
observable, are insensitive to the details
(except at extreme energies). For such
be taken as the range of the modification
then agree with those of Schwinger. A

THIS paper should be conside
tinuation of a preceding on
motion of electrons, neglecting in
lyzed, by dealing directly with
Hamiltonian differential equations.
nique is applied to include interacti
to express in simple terms the solu
quantum electrodynamics.

For most practical calculations
dynamics the solution is ordinarily
of a matrix element. The matrix
expansion in powers of $e^2/\hbar c$, the s
responding to the inclusion of an i
virtual quanta. It appears that a
cation can be achieved in writing
elements for complex processes. Fu
in the expansion can be written d
directly from a physical point of
space-time view in I. It is the pur
describe how this may be done. We shall also discuss methods of handling the divergent integrals which appear in these matrix elements.

The simplification in the formulae results mainly from the fact that previous methods unnecessarily separated into individual terms processes that were closely related physically. For example, in the exchange of a quantum between two electrons there were two terms depending on which electron emitted and which absorbed the quantum. Yet, in the virtual states considered, timing relations are not significant. Olny the order of operators in the matrix must be maintained. We have seen (I), that in addition, processes in which virtual pairs are

and presumably consistent, method is therefore available for the calculation of all processes involving electrons and photons.

The simplification in writing the expressions results from an emphasis on the over-all space-time view resulting from a study of the solution of the equations of electrodynamics. The relation of this to the more conventional Hamiltonian point of view is discussed. It would be very difficult to make the modification which is proposed if one insisted on having the equations in Hamiltonian form.

The methods apply as well to charges obeying the Klein-Gordon equation, and to the various meson theories of nuclear forces. Illustrative examples are given. Although a modification like that

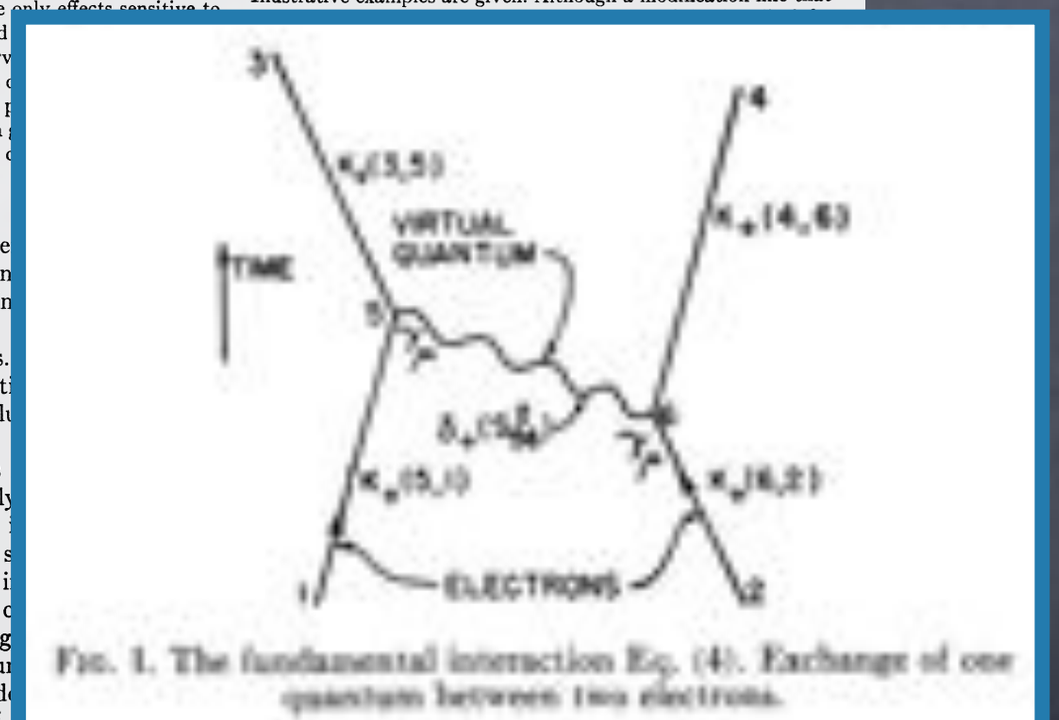
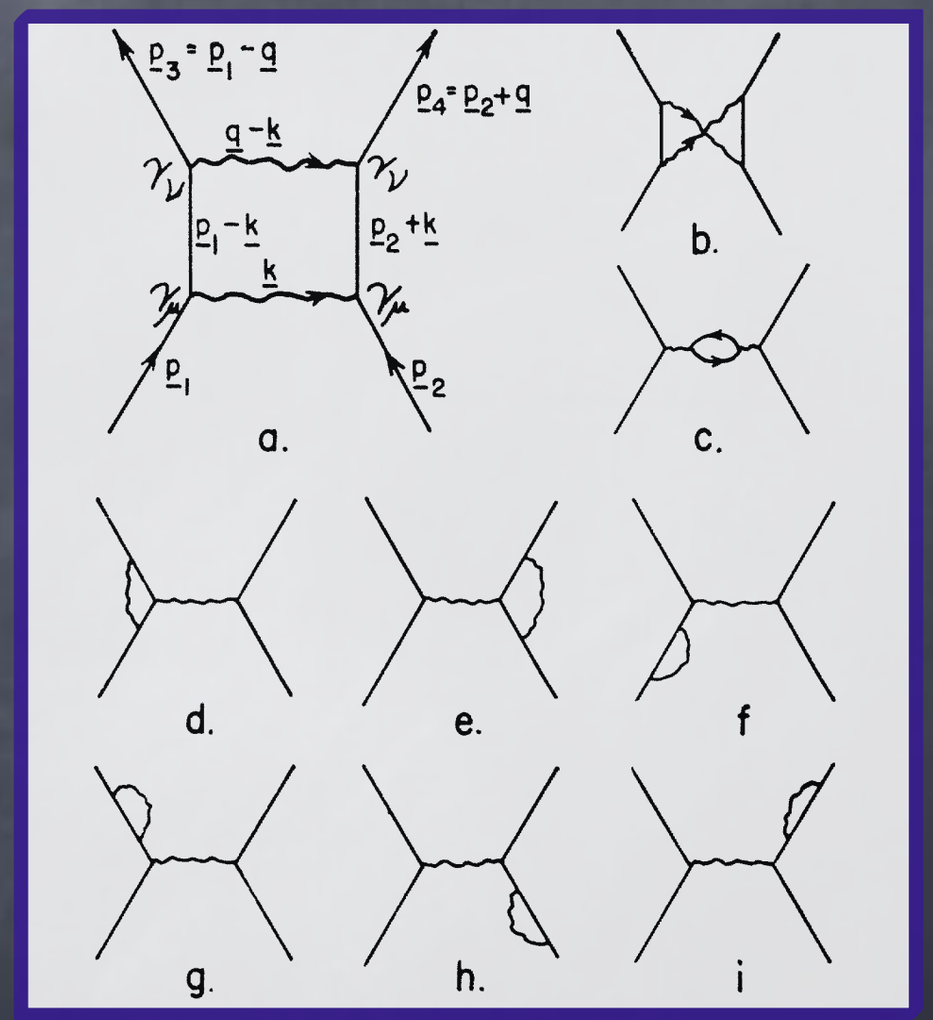


FIG. 1. The fundamental interaction Eq. (4). Exchange of one quantum between two electrons.

interaction between charges is next made, and it is shown that the self-energy is made convergent and corresponds to a correction to the electron mass. After the mass correction is made, other real processes are finite and insensitive to the "width" of the cut-off in the interaction.[3]

Unfortunately, the modification proposed is not completely satisfactory theoretically (it leads to some difficulties of conservation of energy). It does, however, seem consistent and satisfactory to define the matrix

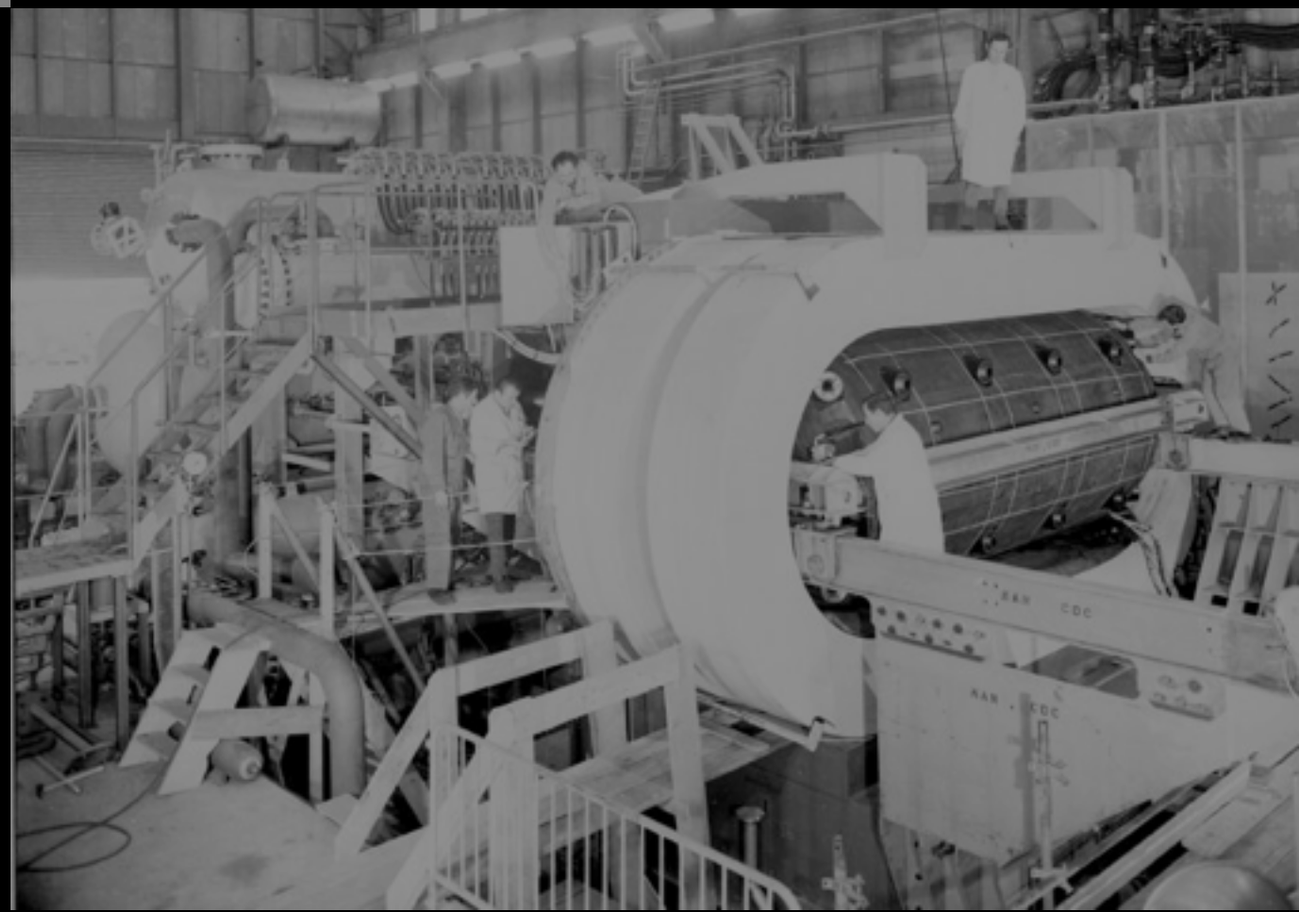
[2] For a discussion of this modification in classical physics see R. P. Feynman, Phys. Rev. 74 939 (1948), hereafter referred to as A.



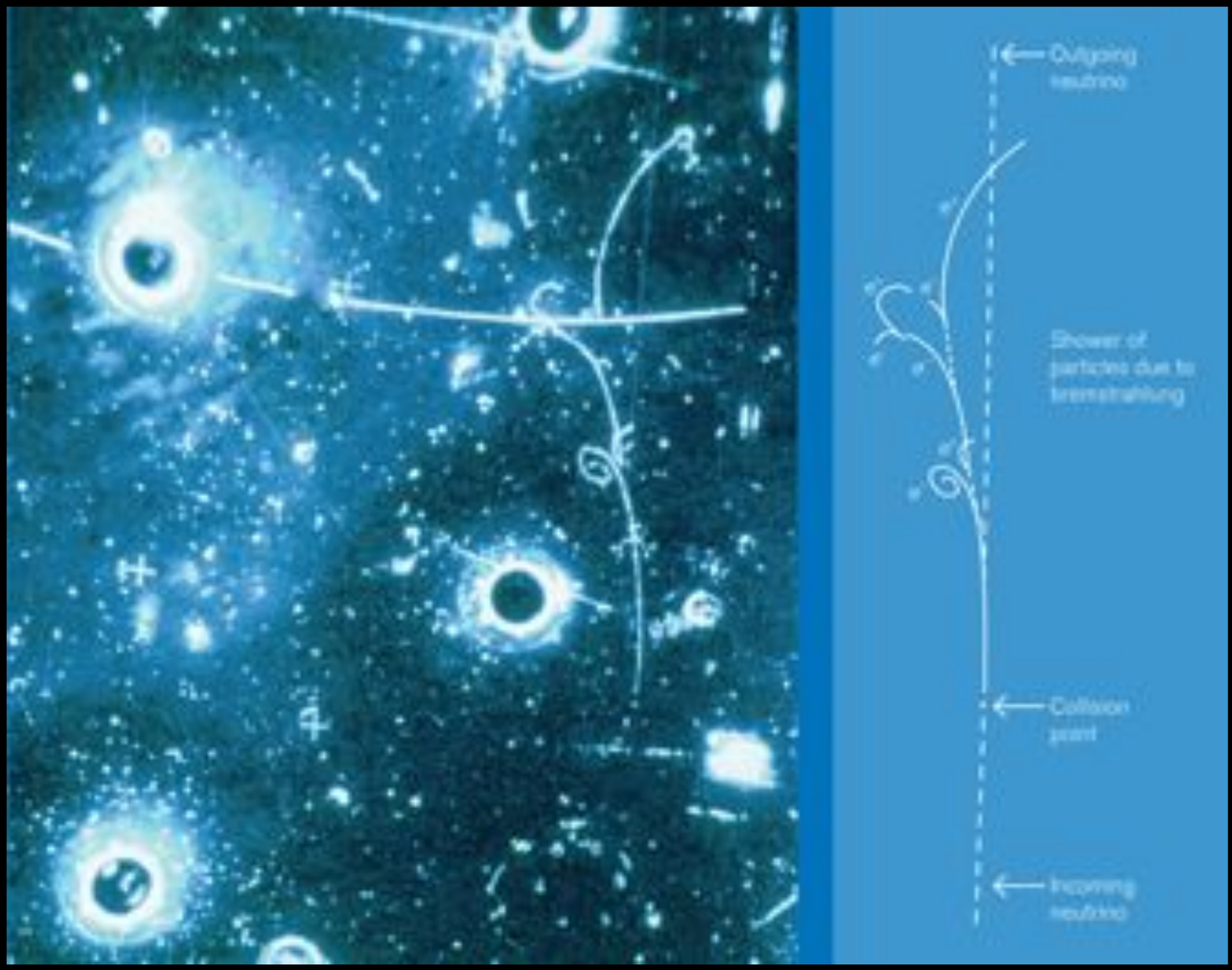
Proton
Synchroton

CERN

Gargamelle



Le correnti deboli neutre 1973

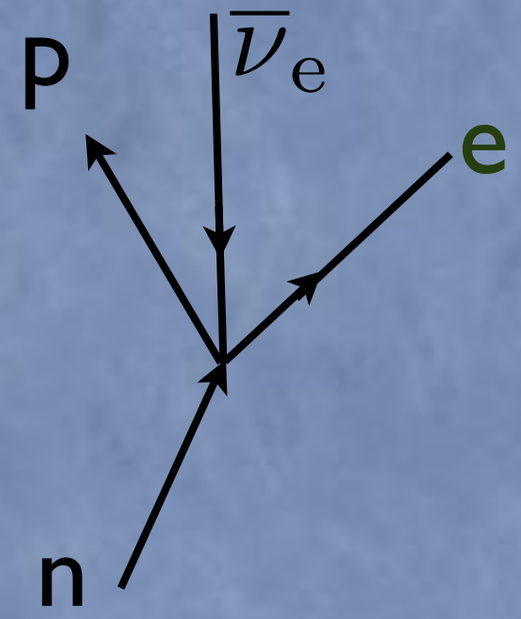


Osservazione interazione diretta neutrino-elettrone
(camera a bolle Gargamelle, SPS - CERN)

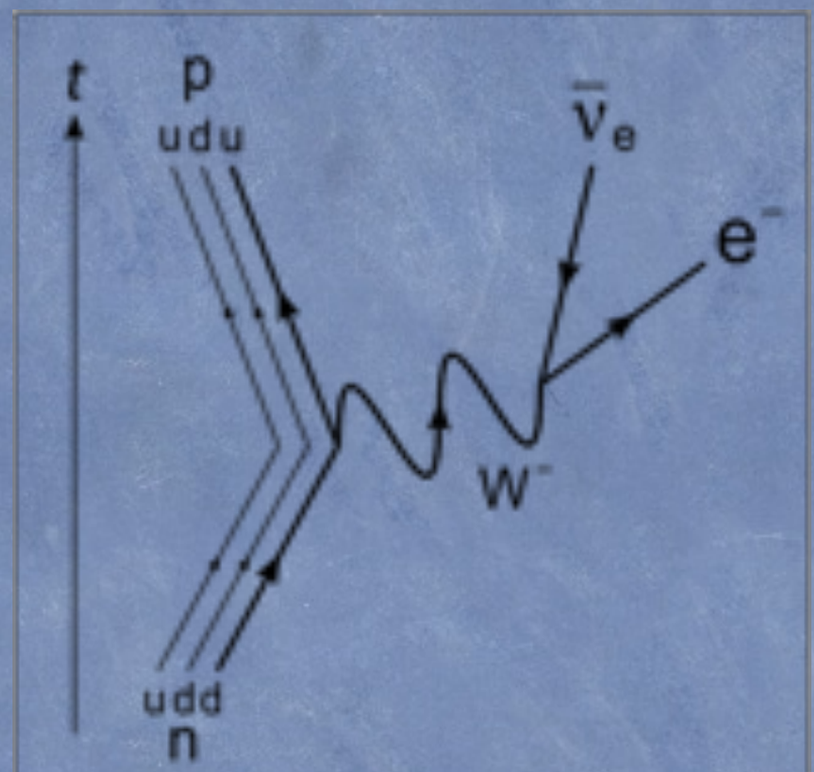
LA TEORIA ELETTRO-DEBOLE

Glashow- Salam - Weinberg (Nobel 1979)

Un processo (elettro)debole: il decadimento radioattivo



Teoria di Fermi



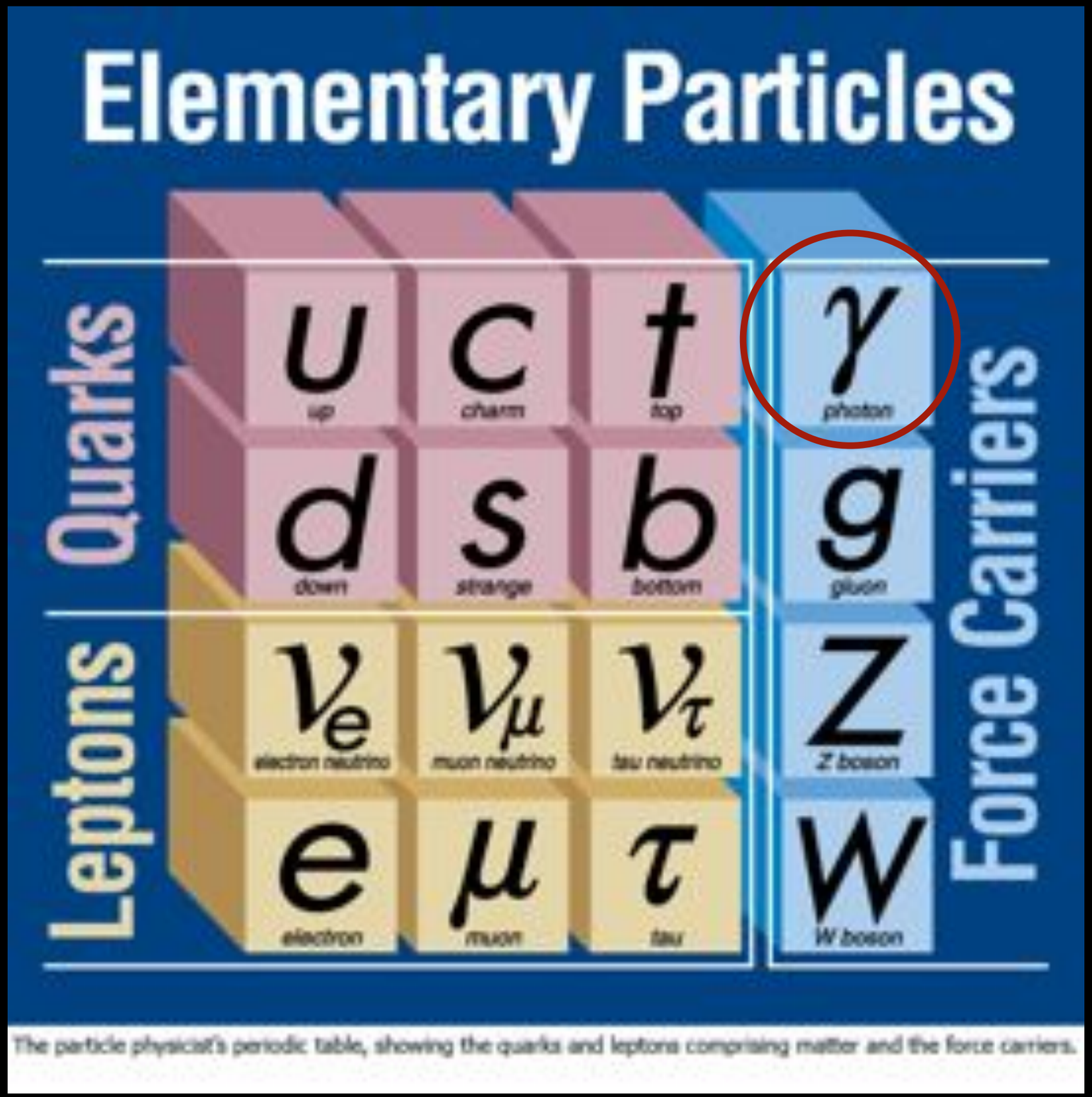
Modello Standard

FOTONE, W+, W-, Z sono i bosoni delle interazioni elettrodeboli, determinate da un unico principio di simmetria che li lega assieme

Nel modello standard un analogo principio di simmetria descrive le interazioni forti (quark-gluoni)

Carlo Rubbia apprende del premio Nobel durante la visita all'ICTP (1984)

Rubbia modifico` l'acceleratore SPS del CERN in un collisionatore di protoni e antiprotoni. A capo del gruppo UA1 di cento fisici, scopri` nel 1983 i bosoni vettoriali W^+, W^- e Z, confermando la teoria elettrodebole.



The particle physicist's periodic table, showing the quarks and leptons comprising matter and the force carriers.

HIGGS

non abbiamo definitivamente capito

cosa e` la luce

ma ogni passo compiuto (sintesi di Maxwell, M.Q. e fotoni, Q.E.D., ottica quantistica ...) ha aggiunto qualcosa per descriverla, produrla, misurarla ...