Elementaire deeltjes

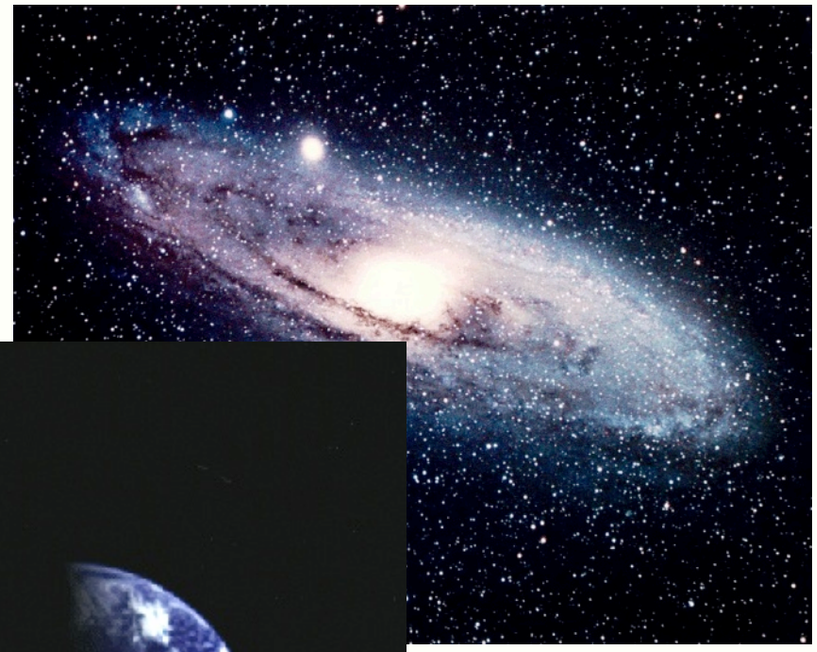
Docenten: J.W. van Holten
K. Gaemers
B. van Eijk
M. de Jong

Teyler Museum, Haarlem

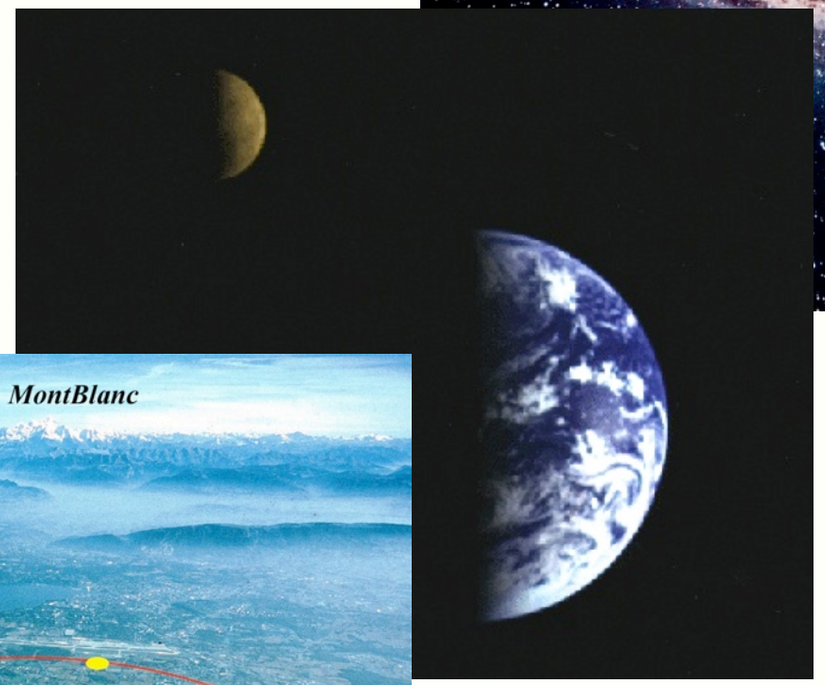
voorjaar 2012

Afstanden

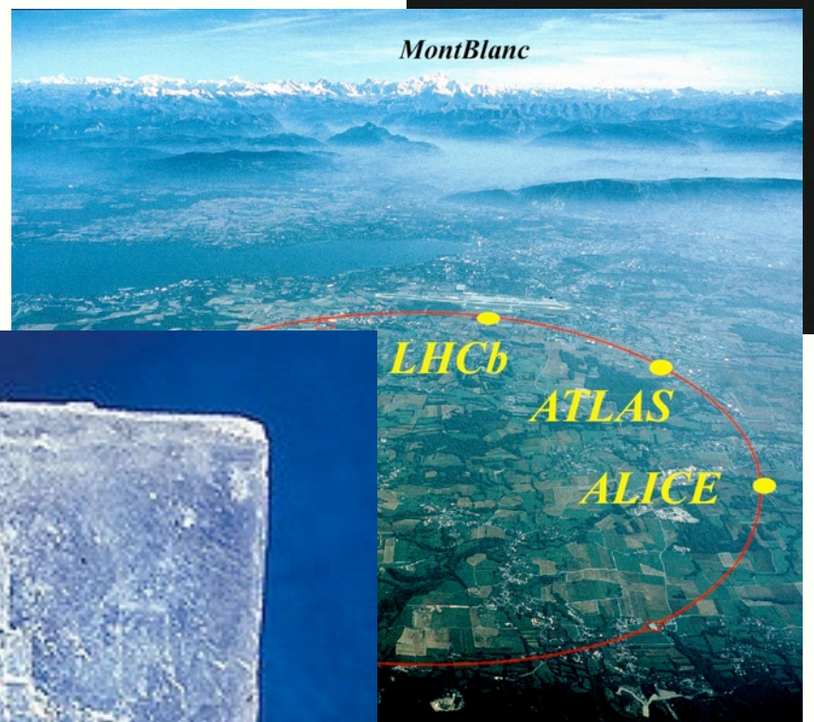
2.000.000 lichtjaar



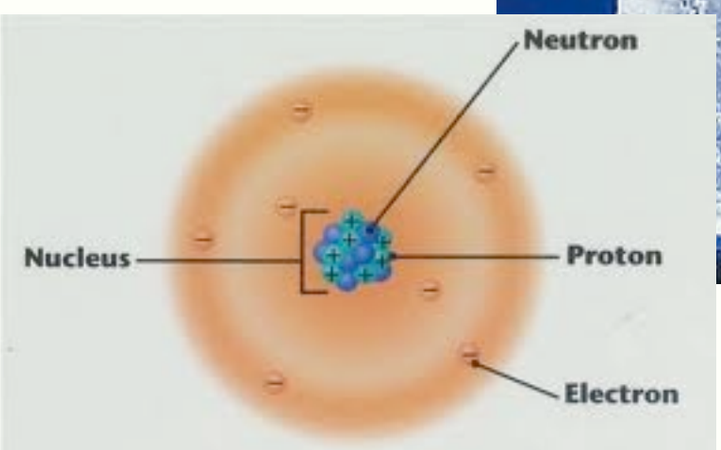
300.000 km



30 km

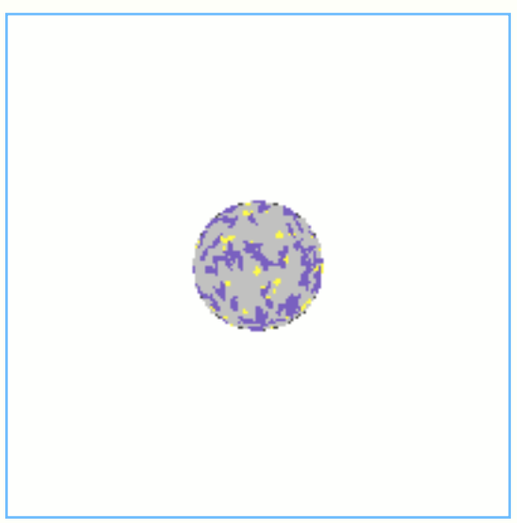


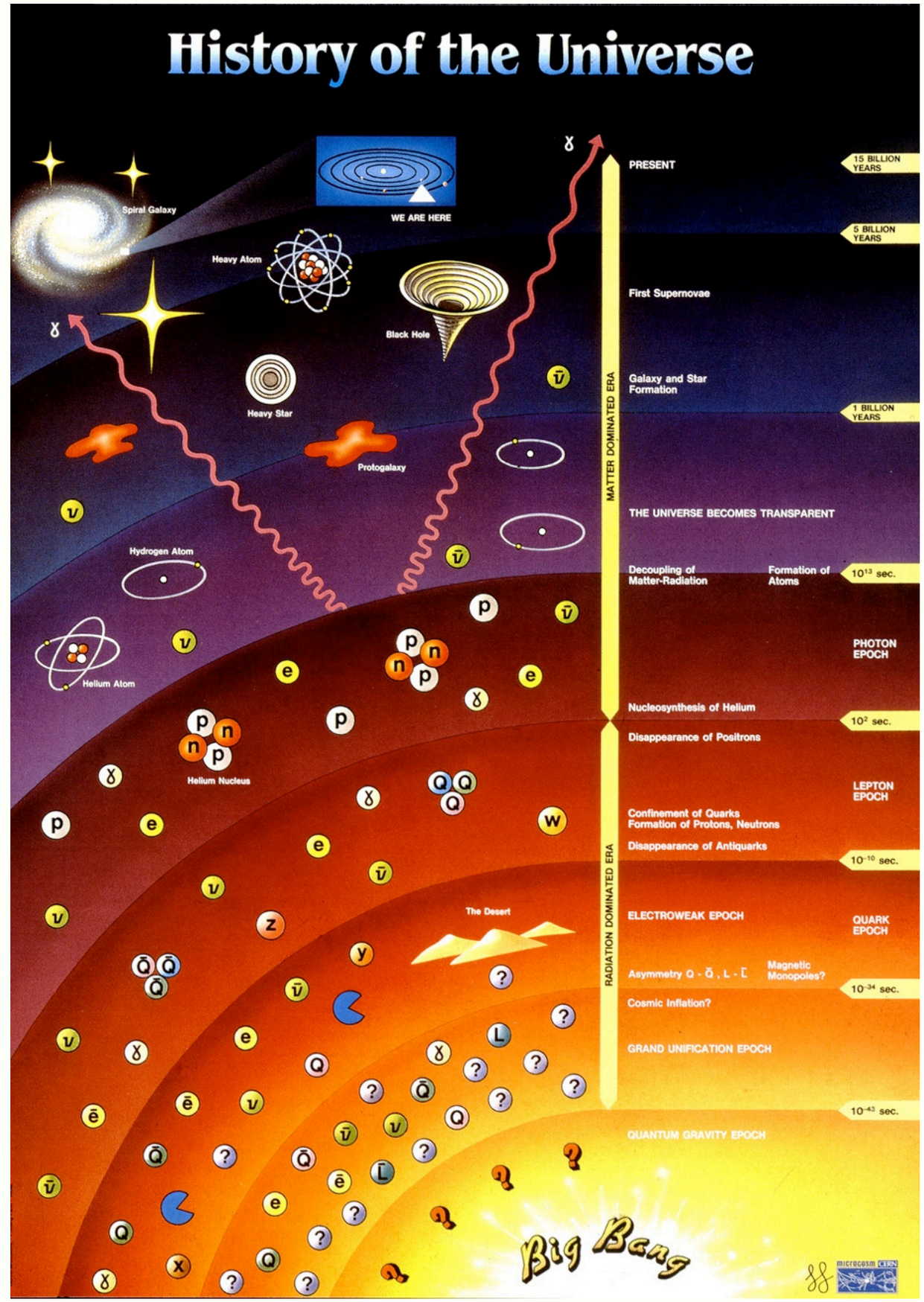
1 mm



0,000.000.1 mm

Tijden




History of the Universe
Spiral Galaxy
WE ARE HERE
Heavy Atom
Black Hole
Heavy Star
Protogalaxy
Hydrogen Atom
Helium Atom
Helium Nucleus
The Desert
PRESENT
15 BILLION YEARS
5 BILLION YEARS
First Supernovae
Galaxy and Star Formation
1 BILLION YEARS
MATTER DOMINATED ERA
THE UNIVERSE BECOMES TRANSPARENT
Decoupling of Matter-Radiation
Formation of Atoms
10^13 sec.
PHOTON EPOCH
Nucleosynthesis of Helium
10^2 sec.
Disappearance of Positrons
LEPTON EPOCH
Confinement of Quarks
Formation of Protons, Neutrons
Disappearance of Antiquarks
10^-10 sec.
RADIATION DOMINATED ERA
ELECTROWEAK EPOCH
QUARK EPOCH
Asymmetry Q - Q̄ , L - L̄
Magnetic Monopoles?
10^-34 sec.
Cosmic Inflation?
GRAND UNIFICATION EPOCH
10^-43 sec.
QUANTUM GRAVITY EPOCH
Big Bang
microcosm CERN

Natuurkrachten

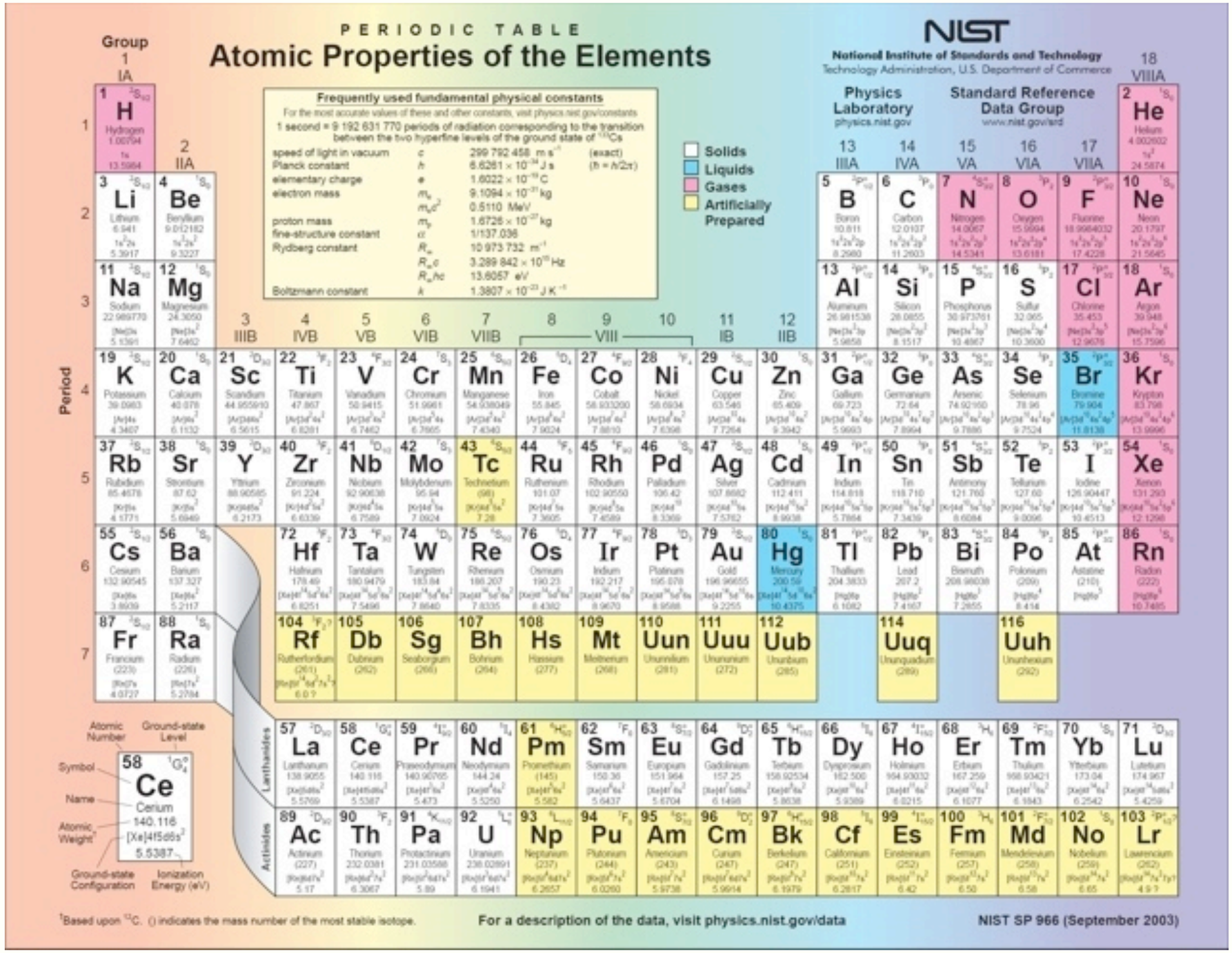
Zwaartekracht
- uitdijing en grootschalige structuur van het heelal

Elektriciteit en magnetisme:
- straling: radio, licht, röntgen- en gammastraling
- magnetisme van mineralen
- atomen en moleculen: structuur en chemie

Sterke kernkracht en kleurkrachten:
- kernen en kerndeeltjes: quarks, baryonen en mesonen

Zwakke krachten:
- transmutaties, radioactiviteit
- kernfusie
- neutrino's

Elementen

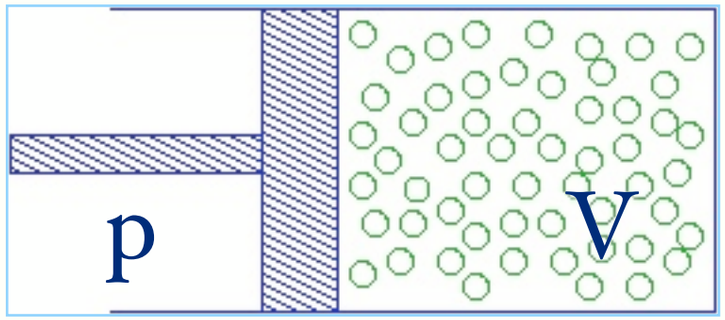


D. Mendeleev

atomaire bouwstenen van de chemie

Atomen en gassen

Gaswet: $\boxed{pV = N\,k\,T}$



⟶ bij dezelfde (p, T) is het
aantal deeltjes per volume-eenheid
voor verschillende gassen gelijk

Loschmidt (1865):

$N_0 = 2{,}687 \times 10^{22}$ deeltjes/liter
bij 273 K en 1 atm

of $k = 1{,}381 \times 10^{-23}$ J/K
(constante van Boltzmann)

Atoommassa's

		relatief
H:	1,68	1
He:	6,65	4
C:	19,95	12
O:	26,6	16
Fe:	92,3	56
U:	399,7	238

$\times 10^{-24}$ g

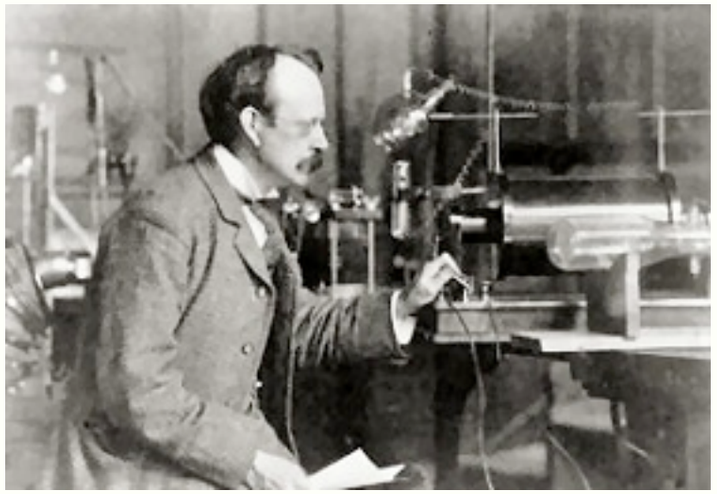
Atomaire afmetingen

d(H) = 0,11 nm
d(He) = 0,06 nm
d(O) = 0,15 nm
d(Fe) = 0,25 nm

van der Waals:

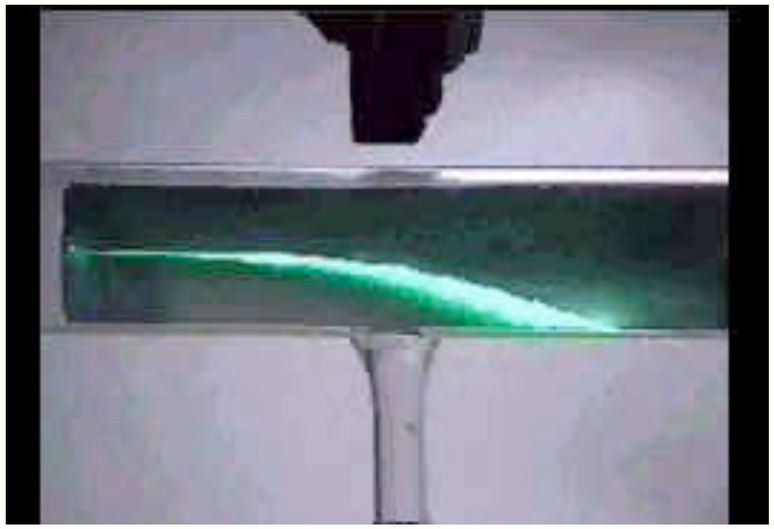
$$(p + aN^2/V^2)(V - Nb) = NkT$$

Elektronen

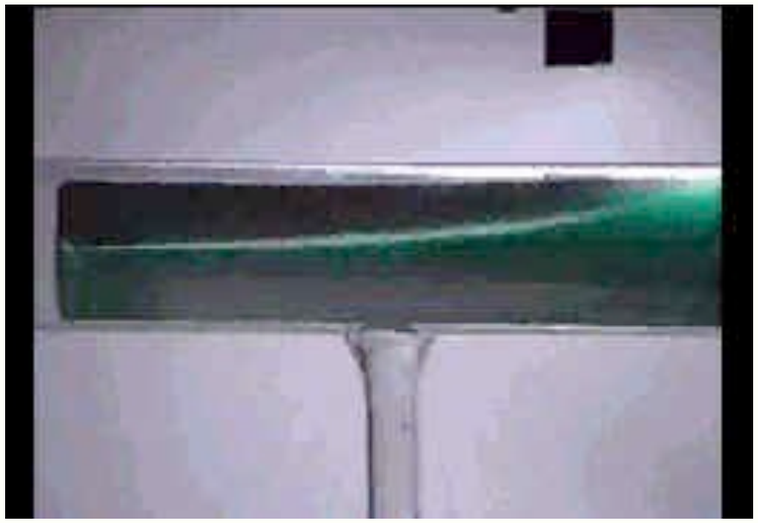


J.J. Thomson (1897)

N



Z



Afbuiging van kathodestraal door een magneet

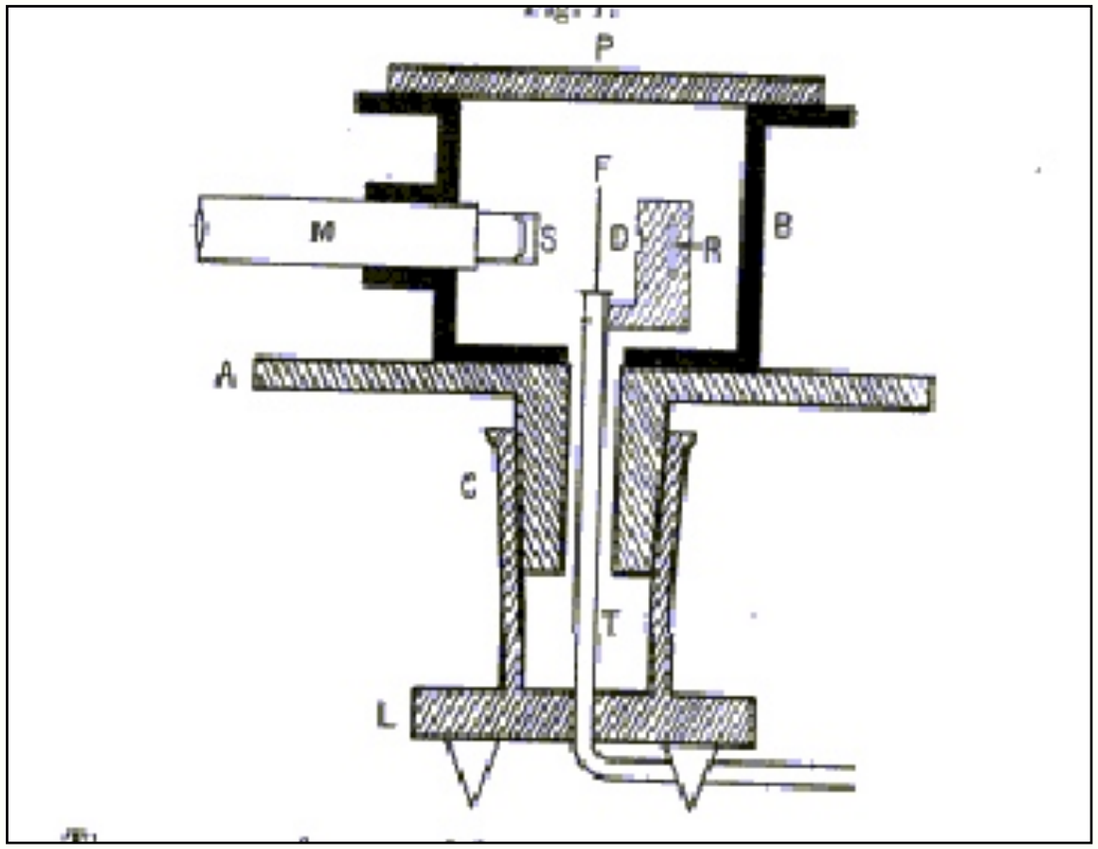
$\longrightarrow$ bepaling van e/m:

$m_e/m_H = 1/1837$

Het Geiger -Rutherford experiment

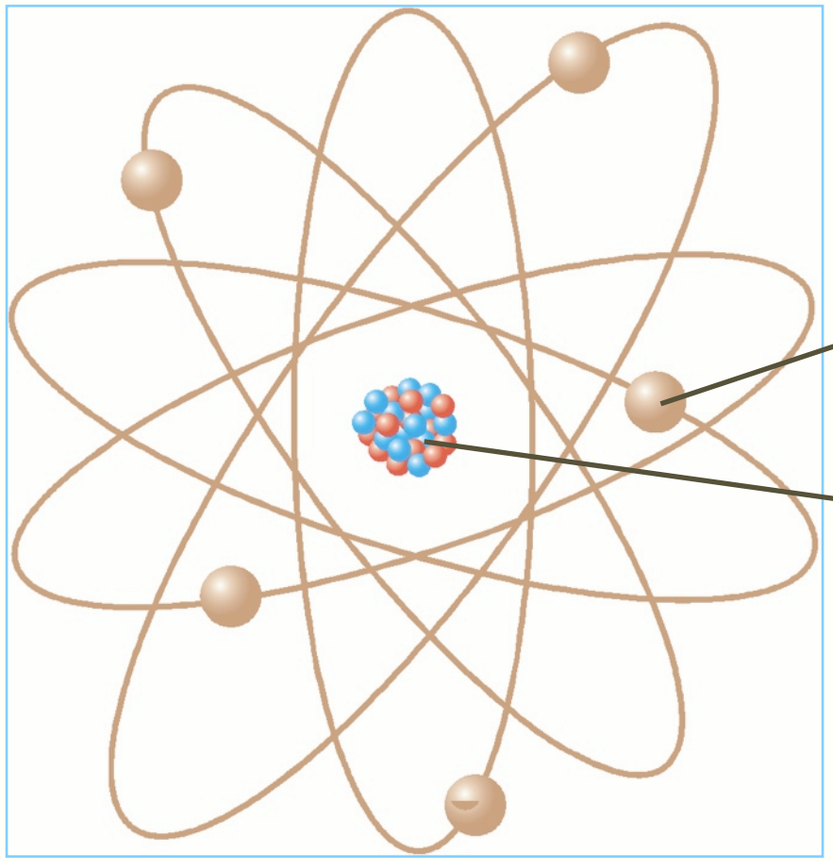
E. Rutherford

H. Geiger



R - α-radioactieve bron
F - folie（goud）
S - scintillatorplaatje
M - microscoop

Rutherford Experiment:
Nuclear Atom



elektron

lading -e

kern

lading Ze

Z = aantal protonen

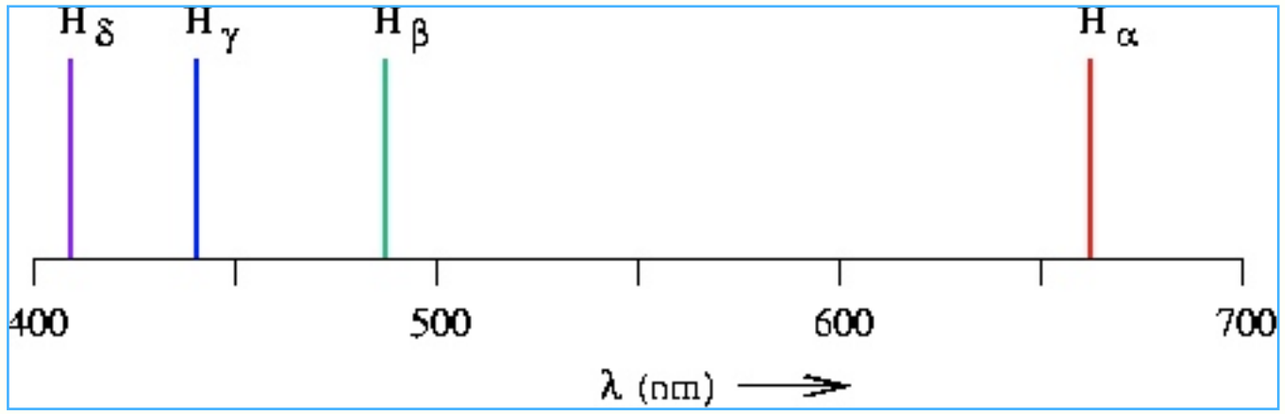
atoomgetal

A = aantal kerndeeltjes

$e = 1{,}602 \times 10^{-19}$ C

A - Z = aantal neutronen

Atoomspectra



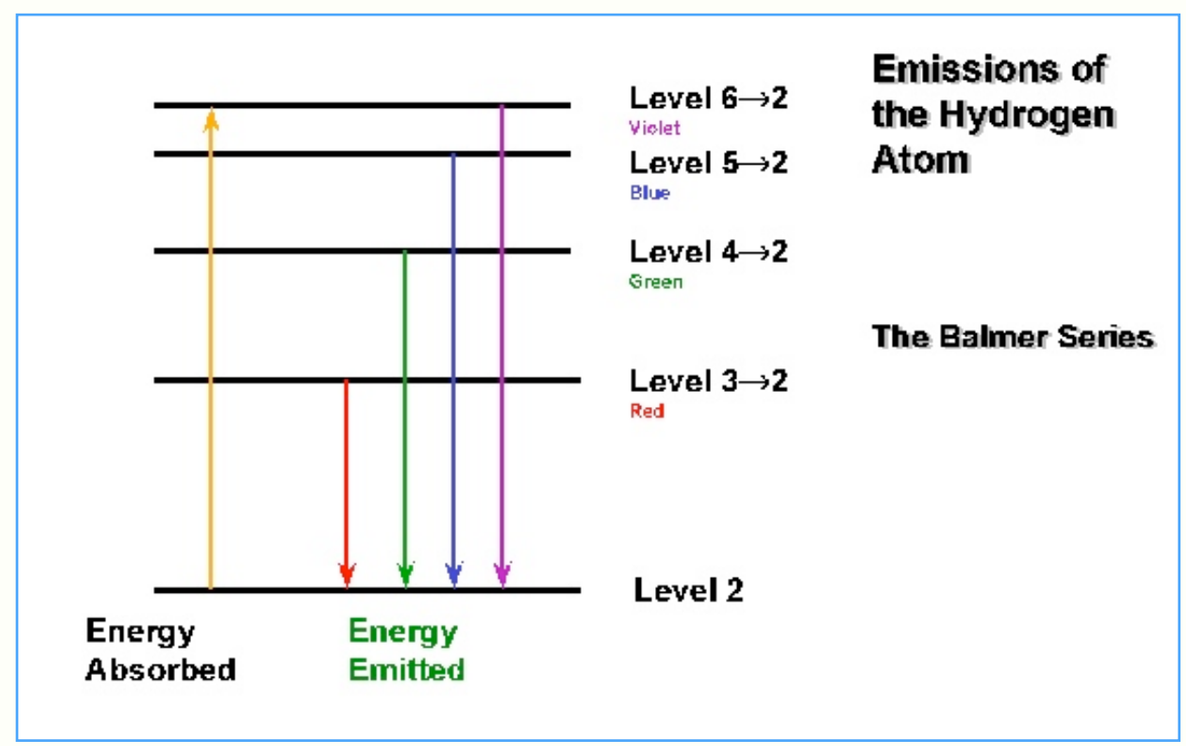
N. Bohr

Waterstofspectrum: Balmer lijnen

Energieniveaus van het elektron in het waterstofatoom

$$E_n = \frac{E_{ion}}{n^2}$$

$$E_m - E_n = h\, f_{mn} = \frac{hc}{\lambda_{mn}}$$



Fotonen

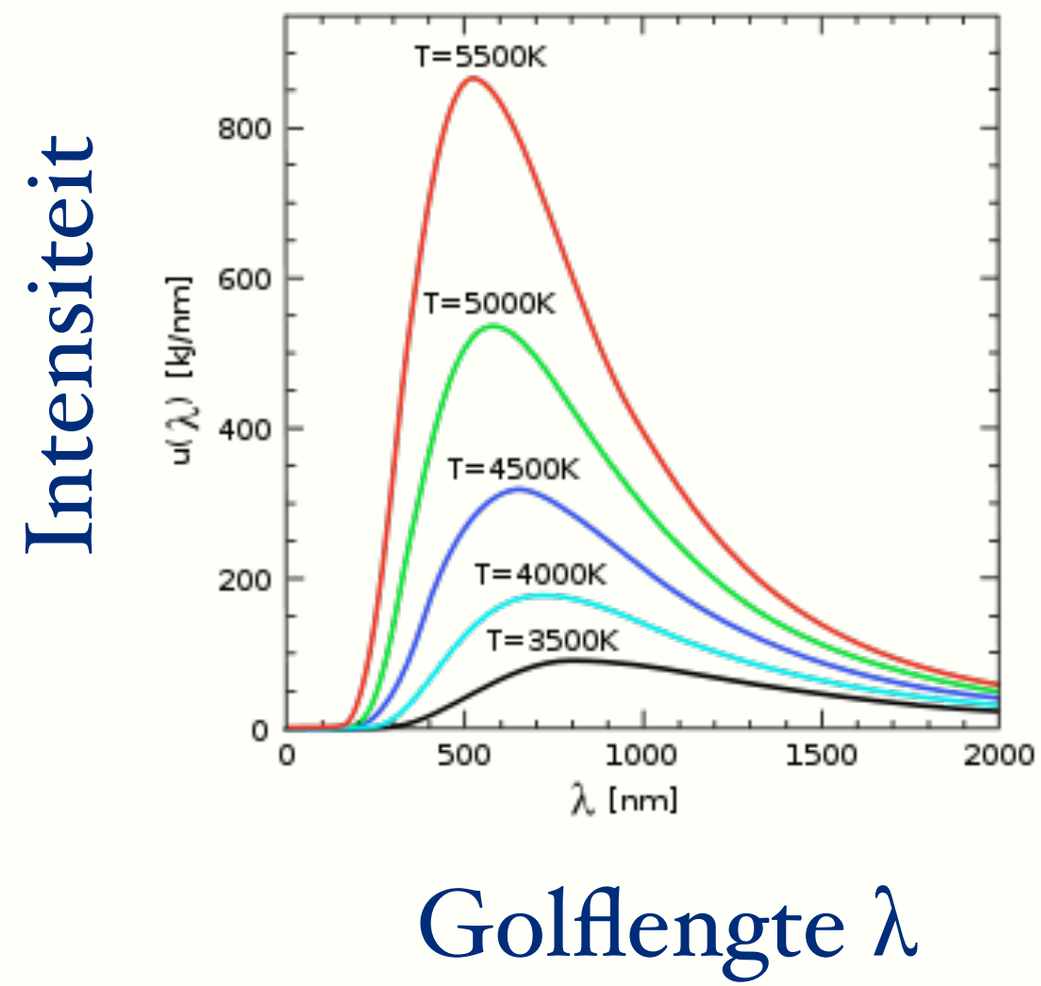
Stralingswet van Planck:

Straling van een perfect absorberend voorwerp gedraagt zich als een gas van deeltjes met energie

M. Planck

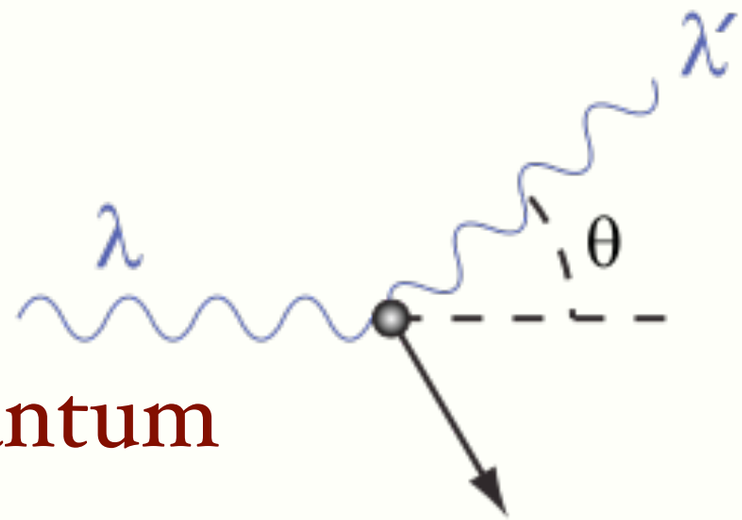
$$E = h f = h c / \lambda$$

constante van Planck:
$h = 6{,}63 \times 10^{-34}$ Js
$= 4{,}14 \times 10^{-15}$ eV/ Hz



Comptonverstrooiing

A. Compton

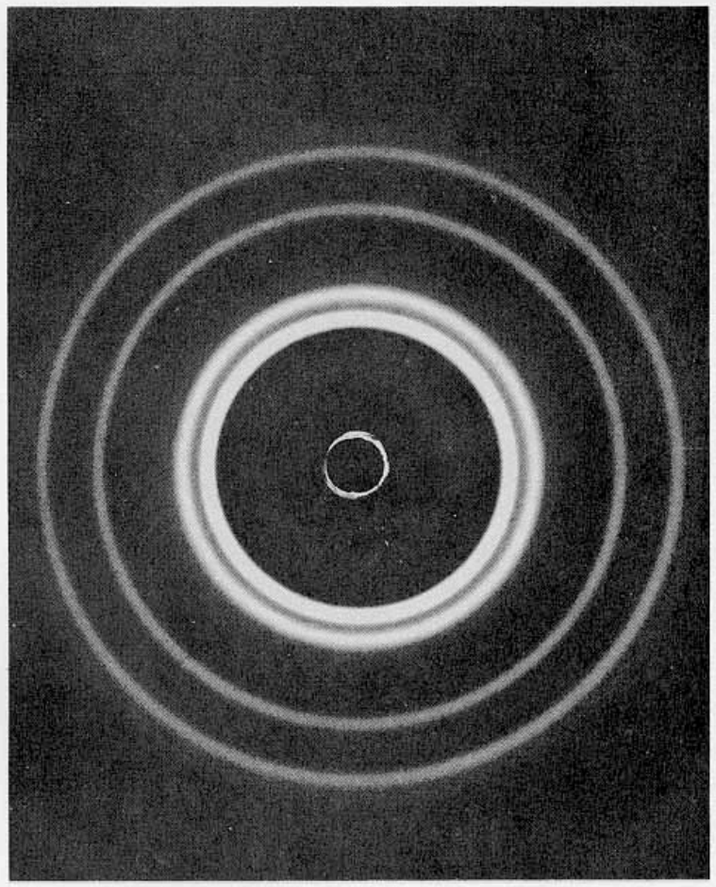


lichtquantum

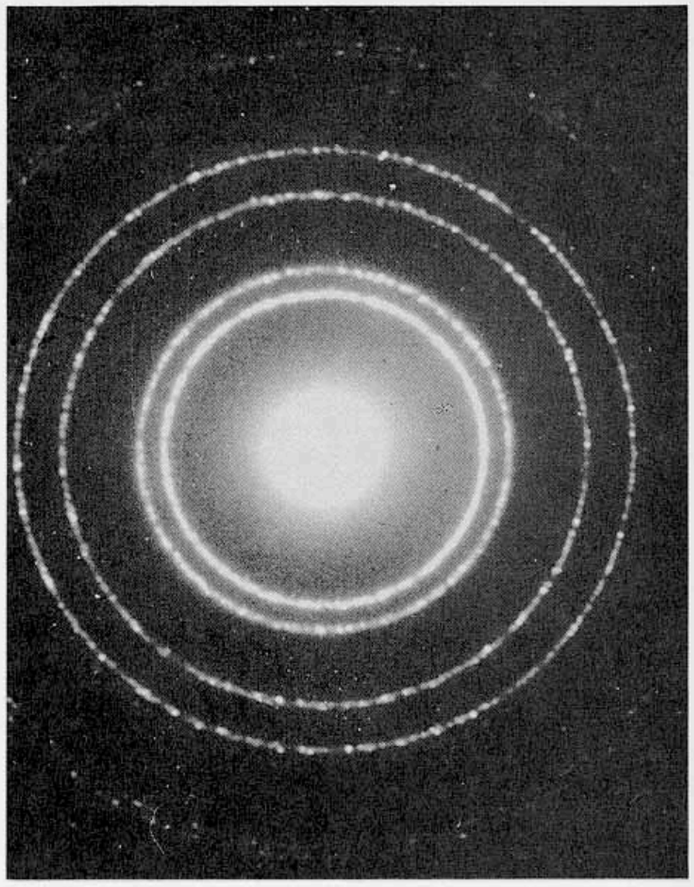
elektron

Materiegolven

The diffraction pattern on the left was made by a beam of x rays passing through thin aluminum foil. The diffraction pattern on the right was made by a beam of electrons passing through the same foil.



Röntgenstraling



elektronen

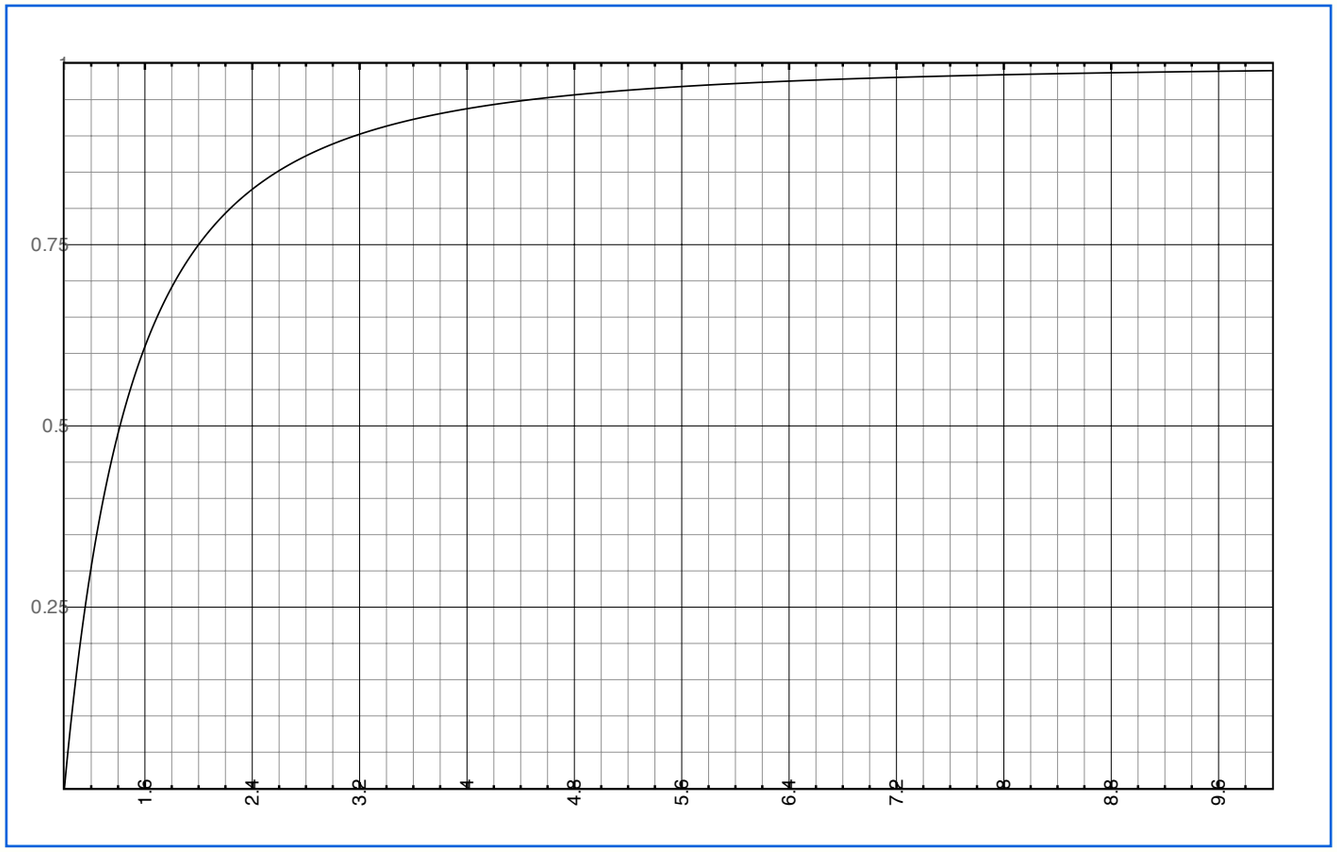
Comptongolflengte

$$\lambda = \frac{h}{mc} \longrightarrow mc^2 = \frac{hc}{\lambda} = hf$$

Equivalentie van massa en energie

A. Einstein

Versnelling



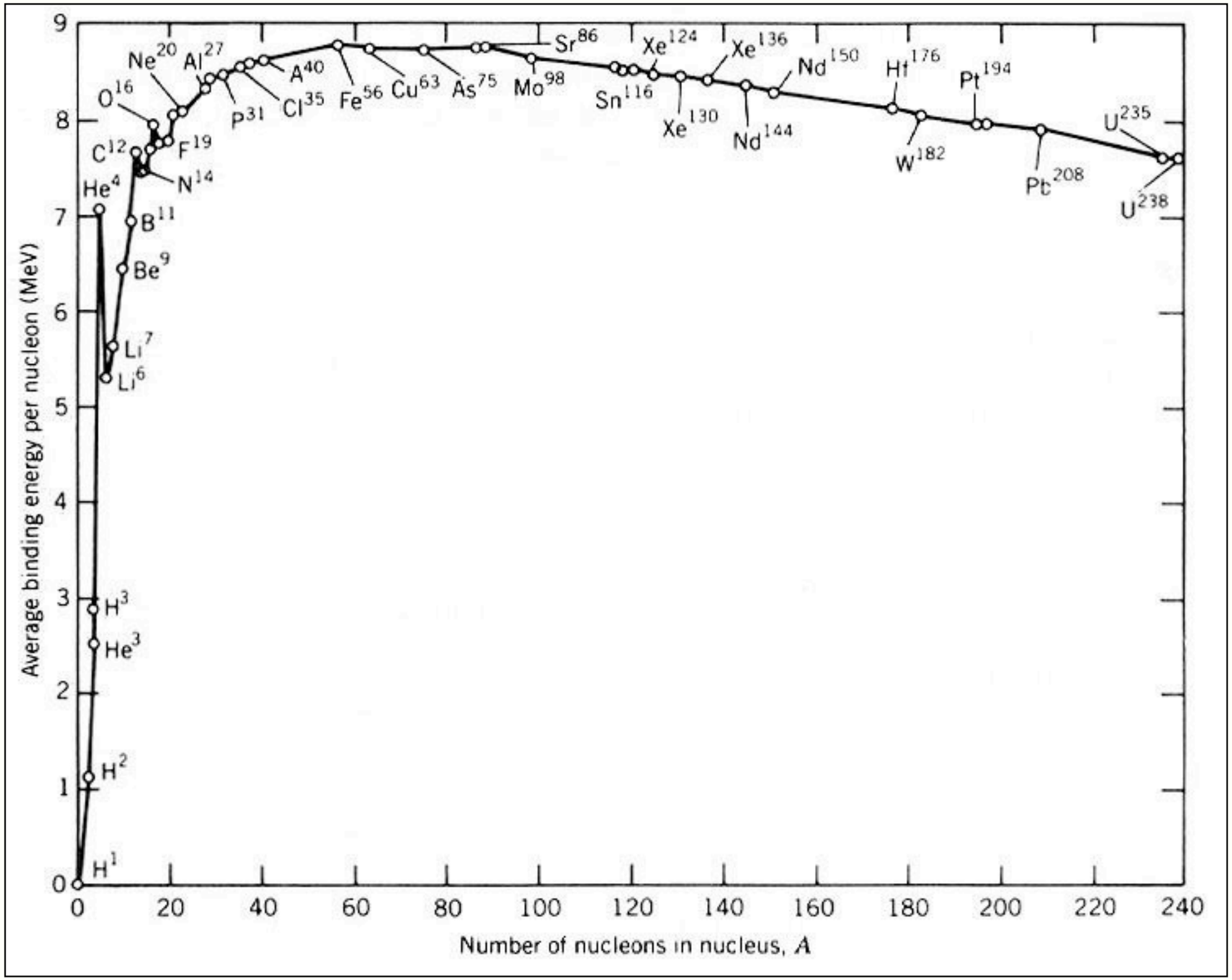
v^2/c^2

E/mc^2

$$\frac{v^2}{c^2} = 1 - \frac{m^2 c^4}{E^2}$$

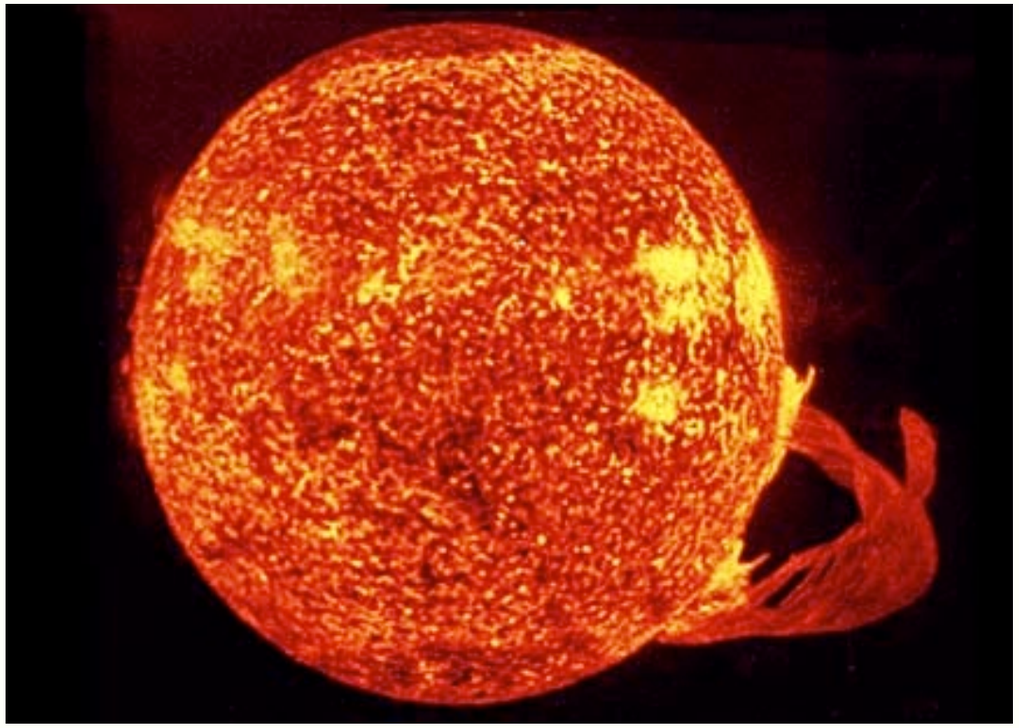
of

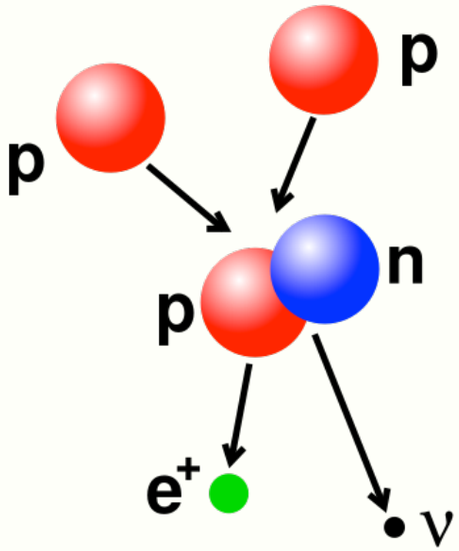
$$E = \frac{mc^2}{\sqrt{1 - v^2/c^2}}$$



M. Goeppert - Mayer

Bindingsenergie van kernen



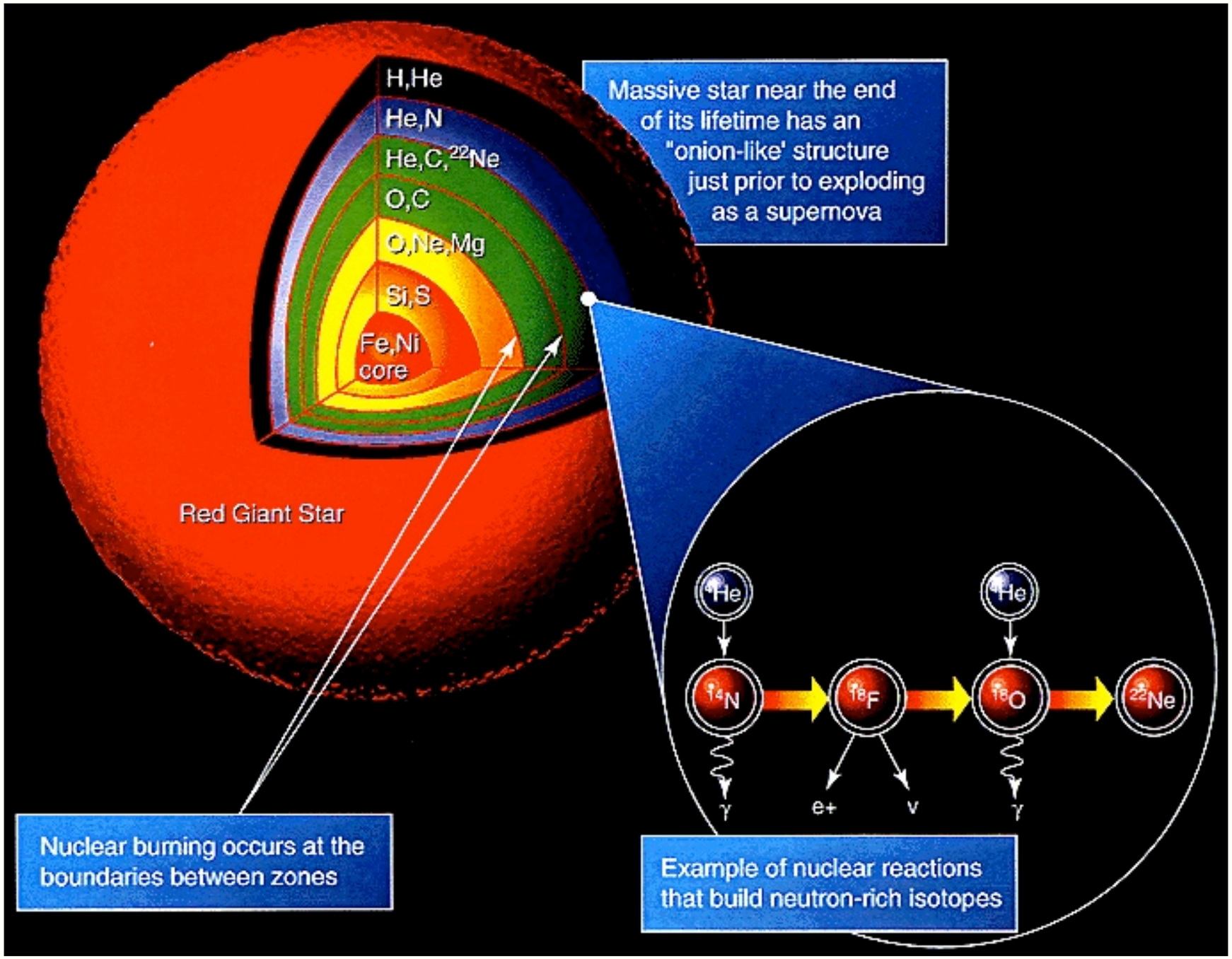


Kernfusie:

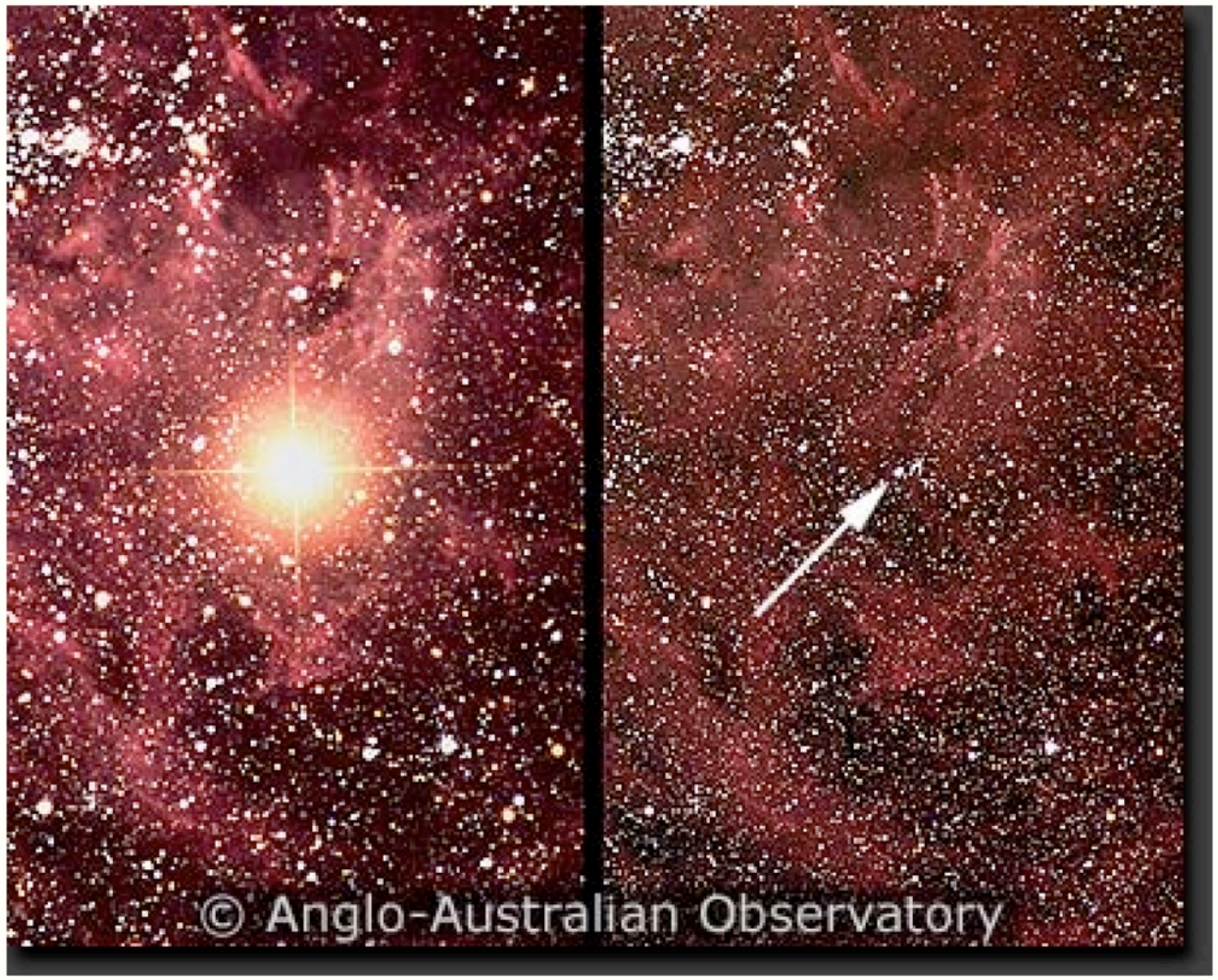
$4p + 2e \rightarrow \alpha + 2\nu + 26{,}7$ MeV

Onze zon zet iedere seconde 570 miljard kilogram waterstof om in helium en verliest alleen daardoor 4,5 miljard kilogram aan massa

(De totale massa van de zon is 1.988×10^{30} kg)



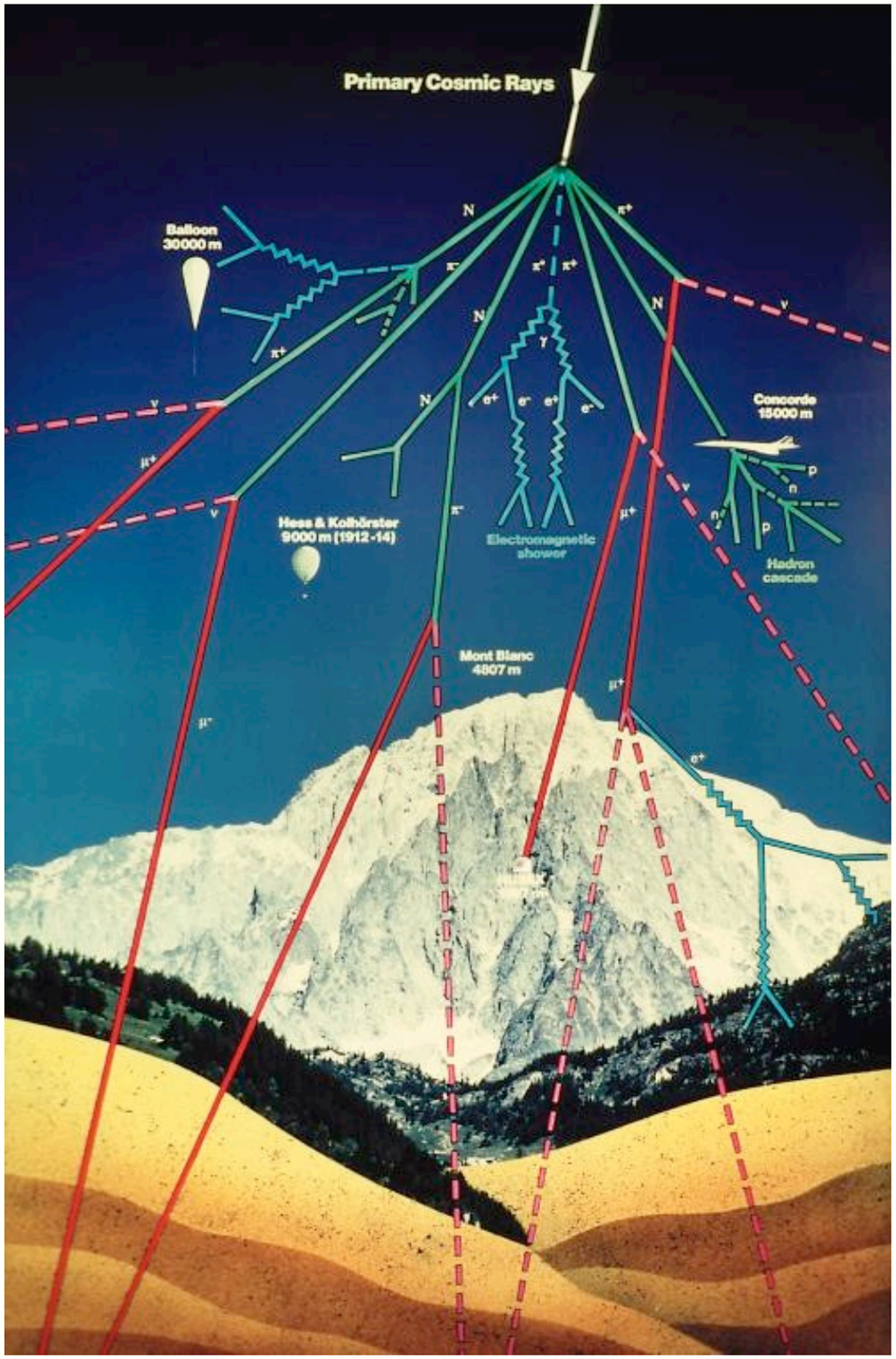
Kernfusie in zware sterren



Supernova 1987a

Krabnevel
(1054)

Natuurlijke bronnen van hoog-energetische deeltjes



Kosmische straling:

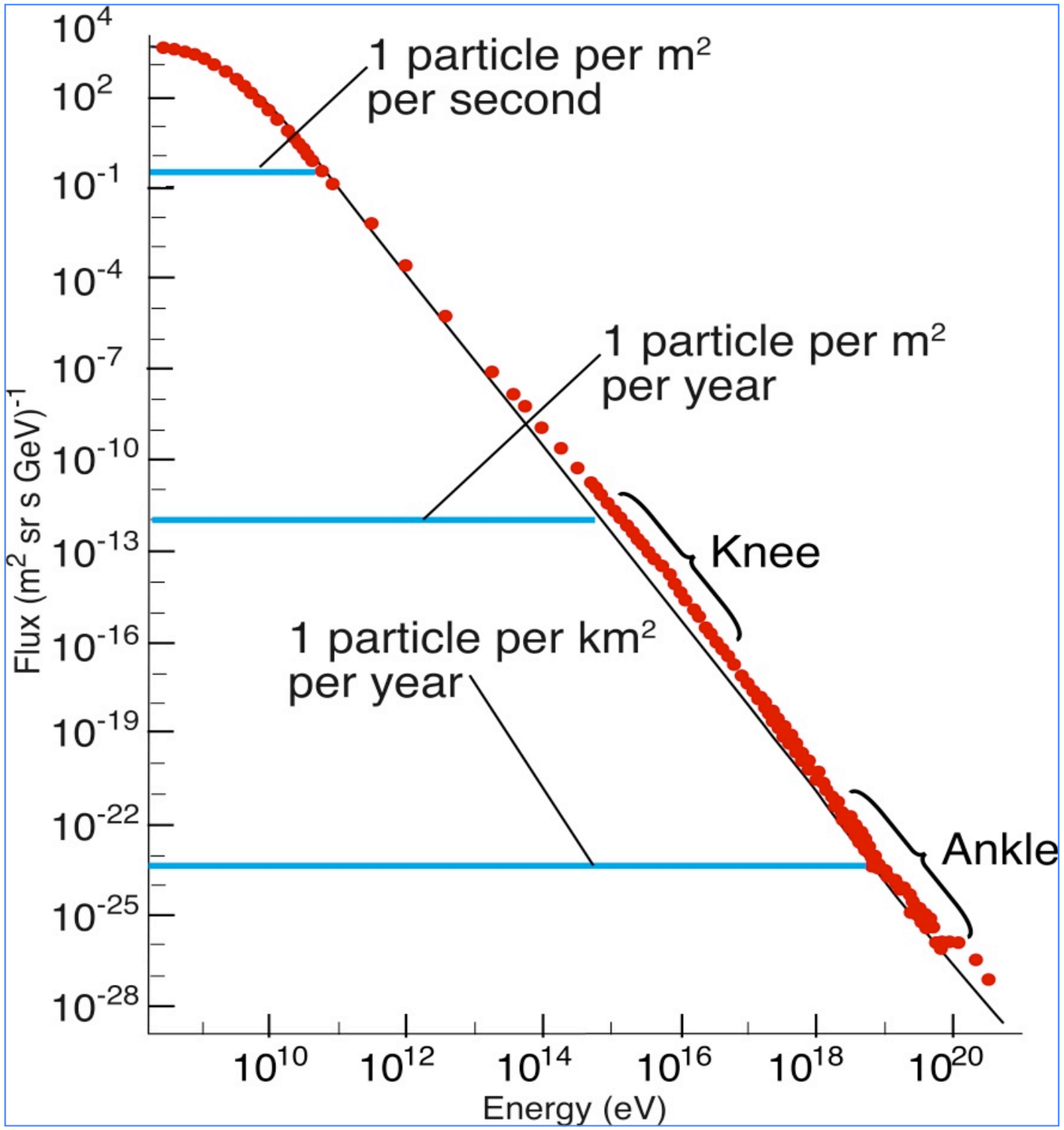
ioniserende straling van buiten de atmosfeer

- secondaire μ-deeltjes:

  $c\,\tau = 660$ m

- produkt van botsingen tussen kerndeeltjes

V. Hess



Energiespectrum
van de primaire
kosmische straling:

aantal deeltjes
per vierkante meter
per seconde
met energie tussen
10^8 en 10^{20} eV
dat de atmosfeer
binnendringt