Moderne partikkelfysikk

- Studier av materiens minste byggestener og av kreftene mellom dem
  - Eksperimentelt, ved å se på kollisjoner mellom partikler.
  - Teoretisk, ved å utvikle modeller og regne ut hva som skjer.

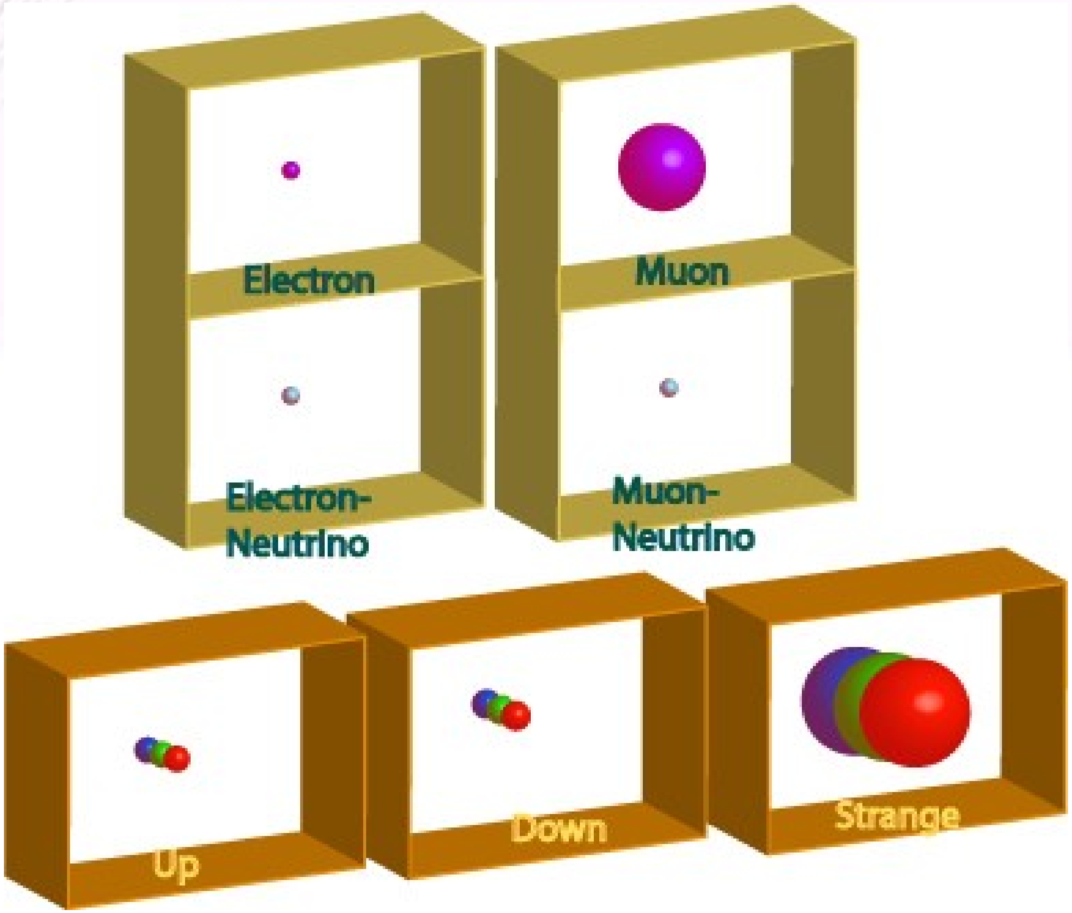
Ingredienser (fra forrige time)

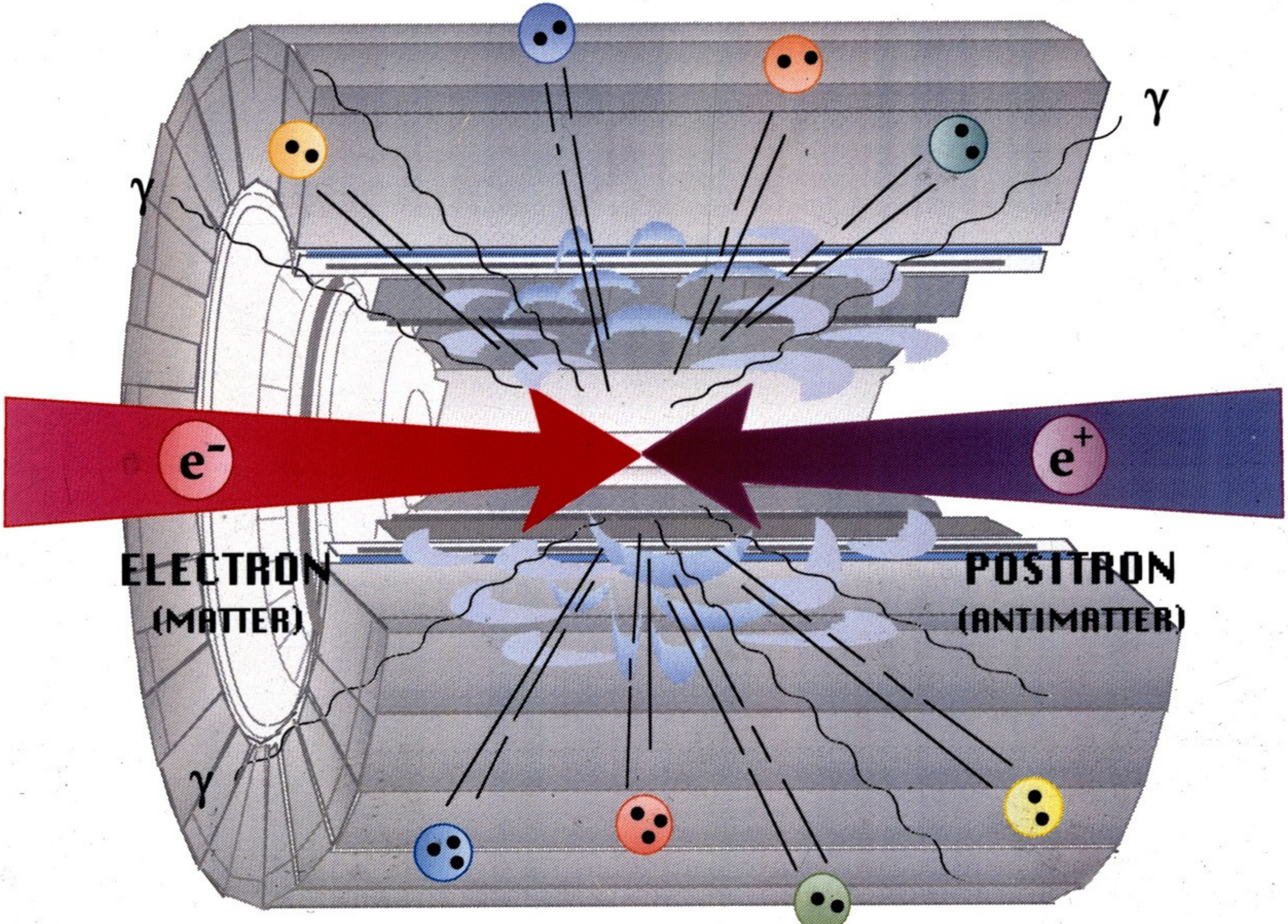
- Kvarker
- Leptoner
- Vekselsvirkningspartikler
- Men hvor mange?

1973

LEPTONS

QUARKS





Eliane Onursal

Partiklers levetid

Heisenbergs usikkerhetsrelasjon

$$\Gamma\tau = \Delta E \Delta t \geq \hbar$$

Partikkel*vidde*

$$\Gamma = \frac{\hbar}{\tau} = \frac{6.5 \cdot 10^{-22} MeVs}{\tau}$$

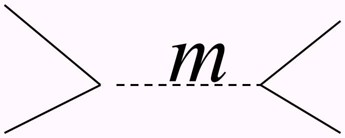
$$\Gamma = \Gamma_1 + \Gamma_2 + \Gamma_3$$

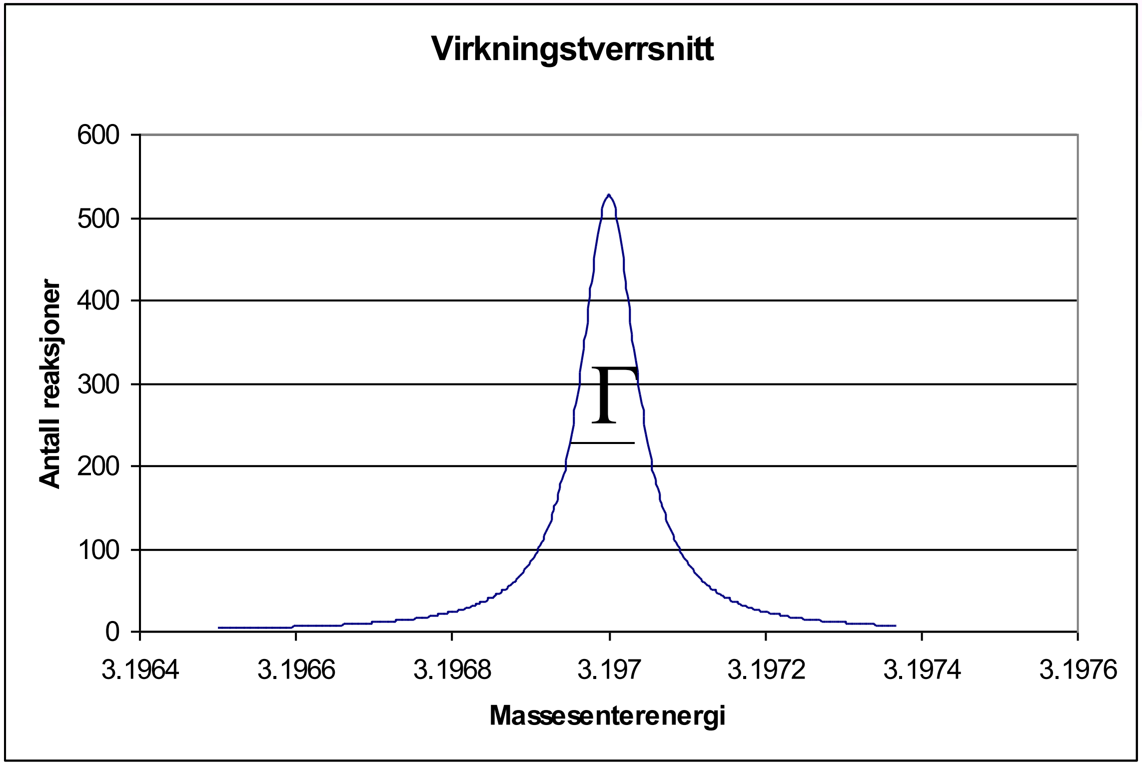
Er en sum av *delvidder* som gir sannsynlighet til henfall til forskjellige slutt-tilstander

$$Br_i = \frac{\Gamma_i}{\Gamma}$$

Resonans

$e^+ e^- \rightarrow$ (kvarker) $\rightarrow$ hadroner





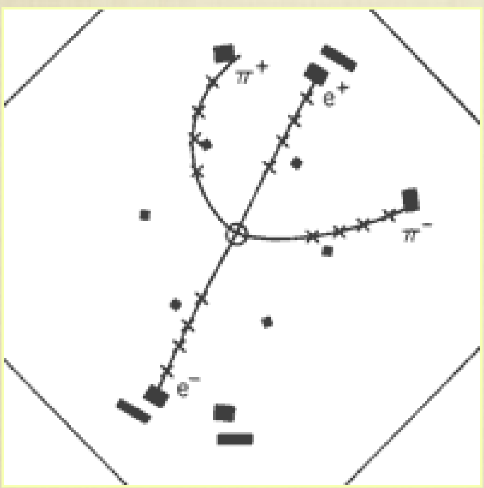
PARTICLE SPECTRUM

1974

And the charm quark was to be discovered soon afterwards :

The NOVEMBER REVOLUTION (11 November 1974)

Two groups discovered ~ simultaneously a new particle, which they called **'Psi'** at SLAC (Burt Richter) and '**J**' at Brookhaven (Sam Ting).



EW LETTERS 2 DECEMBER 1974

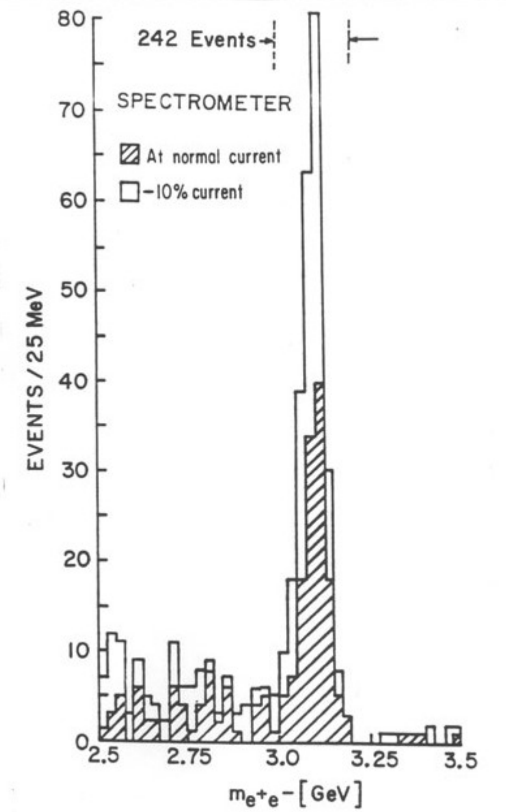


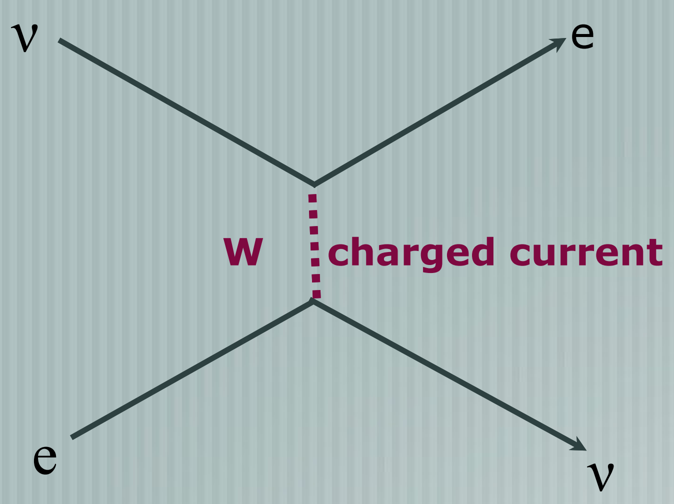
FIG. 2. Mass spectrum showing the existence of J. sults from two spectrometer settings are plotted owing that the peak is independent of spectrometer rrents. The run at reduced current was taken two nths later than the normal run.

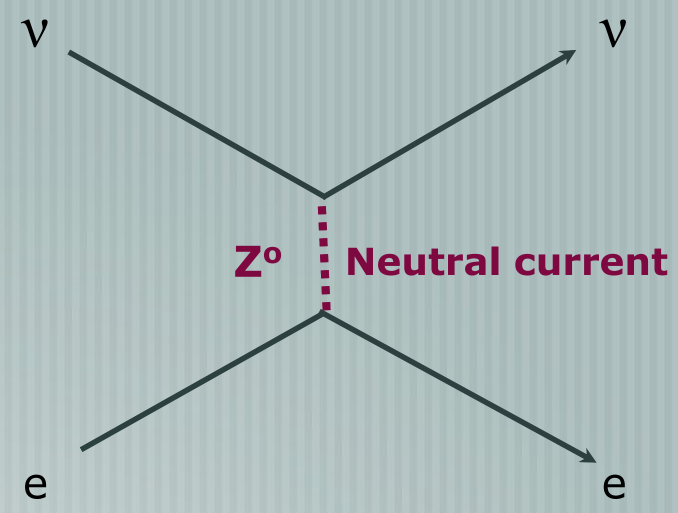
The J/psi resonance was 'long-lived' (~10^{-20} sec). It could only decay by weak interactions, preferably into an s-quark. This explains the narrow peak.

Fields

Electroweak Interaction

1968





Glashow, Salam, Weinberg (1968) - Electroweak Force

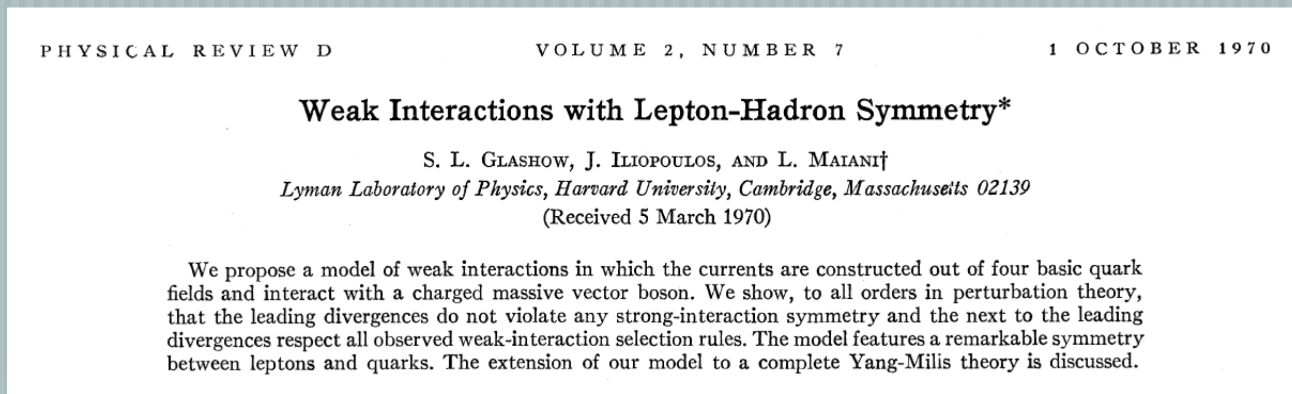
- The electromagnetic and weak interaction are different aspects of the same 'electroweak' force
- All quarks and leptons have a 'weak' charge
- There should be a 'heavy photon' (Z^o) and two charged vector boson ($W^{\pm}$) of mass ~ 50-100 GeV
- They acquire their mass by the interaction with the (new) "Higgs field" H.
- There are only 'left-handed' interactions

Fields

Electro-weak Interaction

1970

Milestone paper (Glashow, Iliopoulos, Maiani)

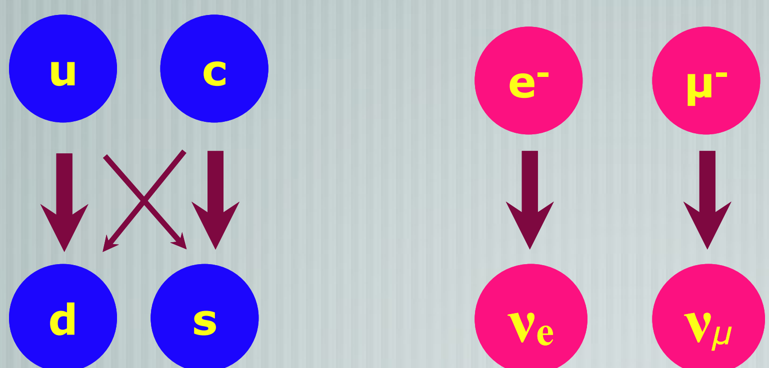

PHYSICAL REVIEW D VOLUME 2, NUMBER 7 1 OCTOBER 1970

Weak Interactions with Lepton-Hadron Symmetry*

S. L. Glashow, J. Iliopoulos, and L. Maiani†
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02139
(Received 5 March 1970)

We propose a model of weak interactions in which the currents are constructed out of four basic quark fields and interact with a charged massive vector boson. We show, to all orders in perturbation theory, that the leading divergences do not violate any strong-interaction symmetry and the next to the leading divergences respect all observed weak-interaction selection rules. The model features a remarkable symmetry between leptons and quarks. The extension of our model to a complete Yang-Milis theory is discussed.

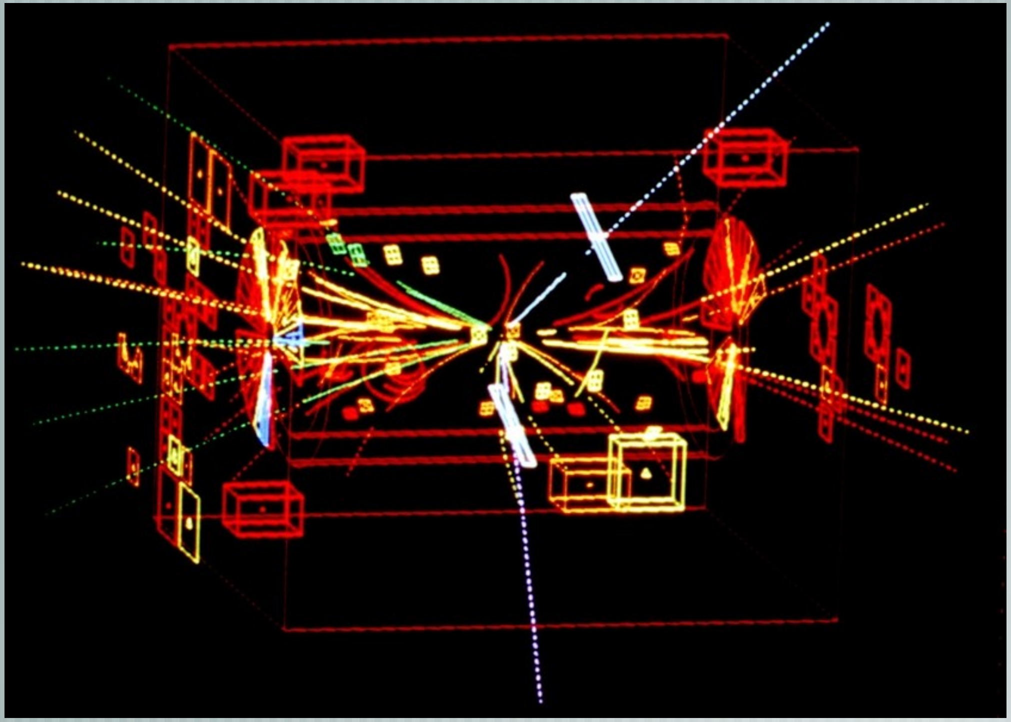
Quarks Leptons

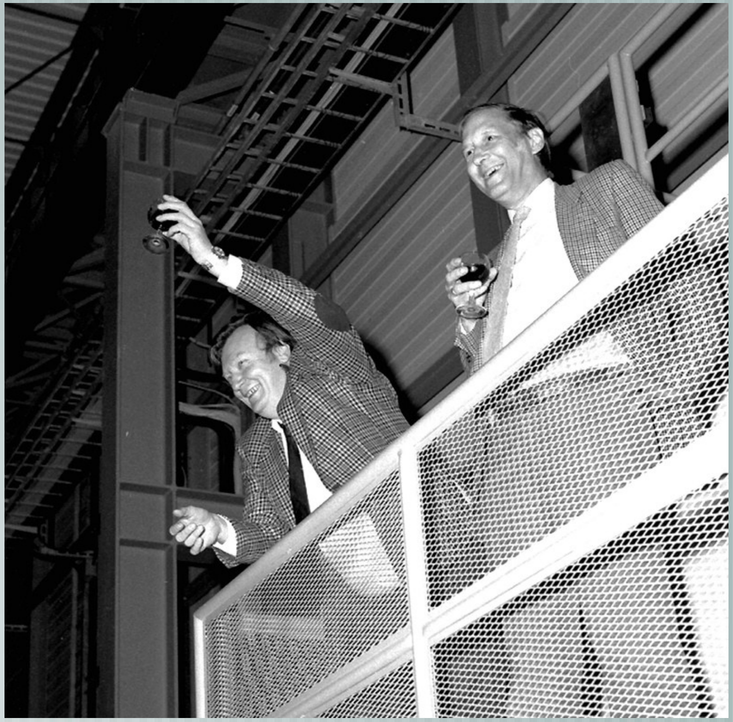


This was now called the 'Standard Model' (with two families)

Discovery of the W, Z bosons at CERN (1983)

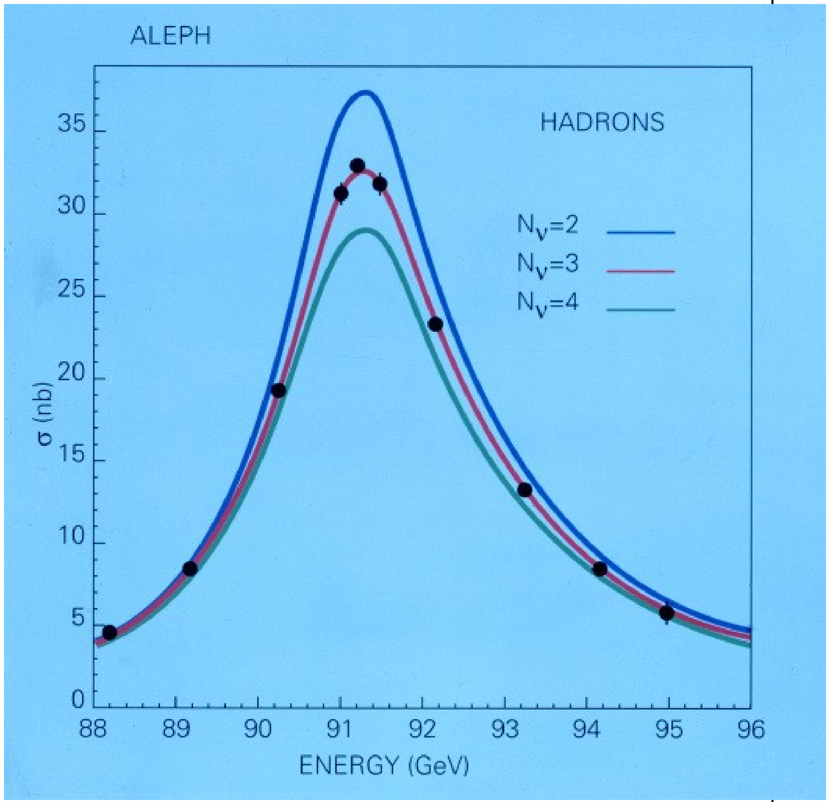
(Carlo Rubbia - leader of UA1 collaboration, and proponent of proton-antiproton collider in SpS)
(Simon van der Meer - inventor of stochastic beam cooling)

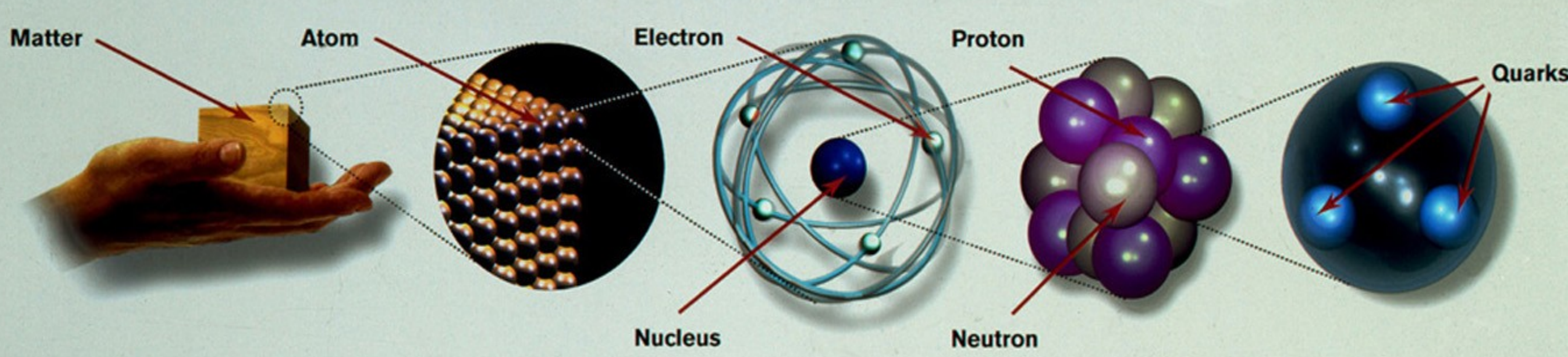




Siden ble en generasjon til funnet!

- Vil vi finne fler?
- Sannsynligvis ikke!





Matter particles

All ordinary particles belong to this group

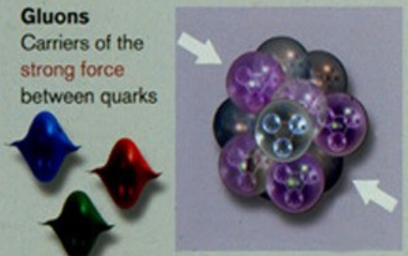
	LEPTONS		QUARKS	
FIRST FAMILY	**Electron** Responsible for electricity and chemical reactions; it has a charge of -1	**Electron neutrino** Particle with no electric charge, and possibly no mass; billions fly through your body every second	**Up** Has an electric charge of plus two-thirds; protons contain two, neutrons contain one	**Down** Has an electric charge of minus one-third; protons contain one, neutrons contain two
SECOND FAMILY	**Muon** A heavier relative of the electron; it lives for two-millionths of a second	**Muon neutrino** Created along with muons when some particles decay	**Charm** A heavier relative of the up; found in 1974	**Strange** A heavier relative of the down; found in 1964
THIRD FAMILY	**Tau** Heavier still; it is extremely unstable. It was discovered in 1975	**Tau neutrino** not yet discovered but believed to exist	**Top** Heavier still	**Bottom** Heavier still; measuring bottom quarks is an important test of electroweak theory

These particles existed just after the Big Bang. Now they are found only in cosmic rays and accelerators

Force particles

These particles transmit the four fundamental forces of nature although gravitons have so far not been discovered

Gluons
Carriers of the strong force between quarks



Felt by: quarks

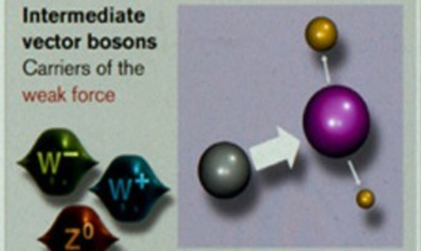
The explosive release of nuclear energy is the result of the strong force

Photons
Particles that make up light; they carry the electromagnetic force

Felt by: quarks and charged leptons

Electricity, magnetism and chemistry are all the results of electro-magnetic force

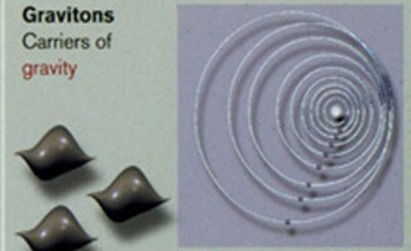
Intermediate vector bosons
Carriers of the weak force



Felt by: quarks and leptons

Some forms of radio-activity are the result of the weak force

Gravitons
Carriers of gravity



Felt by: all particles with mass

All the weight we experience is the result of the gravitational force

Higgsmekanismen

- Mekanisme for å gi alle partikler *masse*
- Forutsier en ny partikkel, higgspartikkelen, men sier ikke mye om dens egen masse.
- Eksperiment viser at den må være tyngre enn ca 114 GeV
- For gitt masse så kan imidlertid produksjons og henfallsannsynligheter beregnes i Standardmodellen
- Derfor kan Standardmodellen etterprøves.

Standardmodellen (SM) oppsummert

- Tre *og bare tre* generasjoner kvarker og leptoner.
- Forening av elektromagnetisme og svake kjernekrefter.
- Litt asymmetri mellom materie og antimaterie (CP brudd) på en selvkonsistent måte
- En mekanisme for å gi partiklene masse
- Ingen jordiske observasjoner bryter med SM, Standardmodellen er en stor suksess!

Ubesvarte spørsmål

- Mekanismen for å gi partiklene masse må bekreftes av eksperiment, d.v.s: vi må finne higgspartikkelen.
- S.M. kan ikke forutsi verdier av massene.
- Hvorfor er elektron og protonladningene like?
- Hvorfor ingen antipartikler i universet? (CP-bruddet vi observerer er for lite til å forklare)
- Kan vi få med gravitasjon i en enhetlig teori?

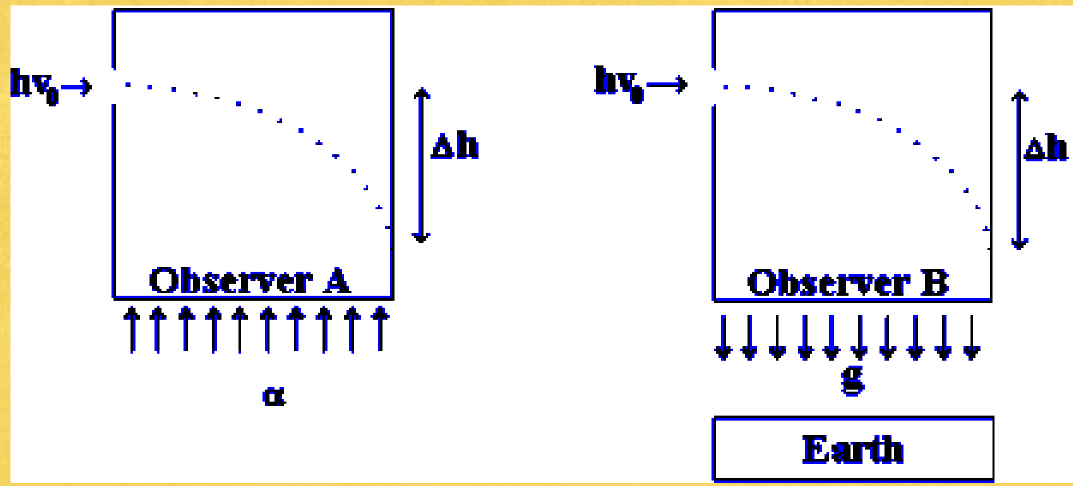
UT I VERDENSROMMET!

- Mørk materie
- Universets ekspansjon
- Mørk energi

Universe

1907

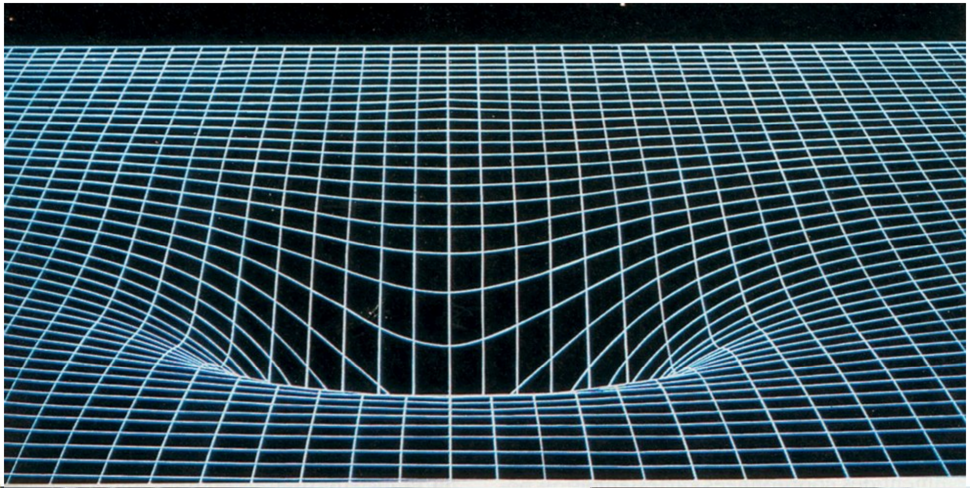
Equivalence Principle

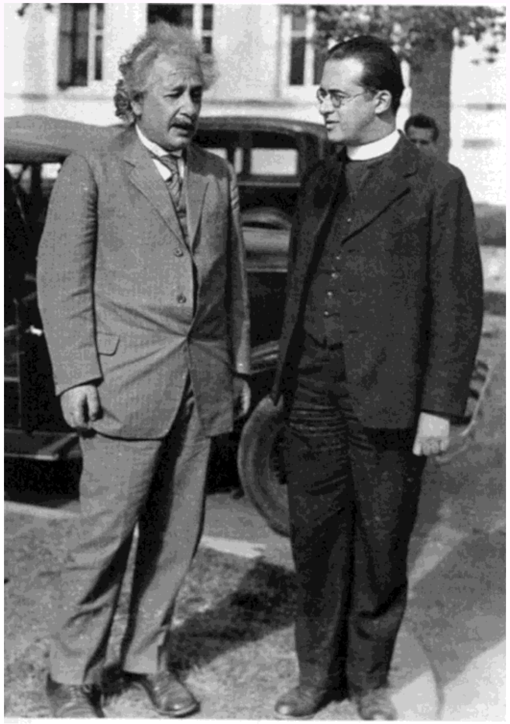


1915

Light rays define the shortest path in space.
Accelerated elevator : light follows follows a parabolic path
Gravitational field : light path must be bent !
Space and time must be curved

Albert Einstein (1912-15) : General Relativity





Mørk materie

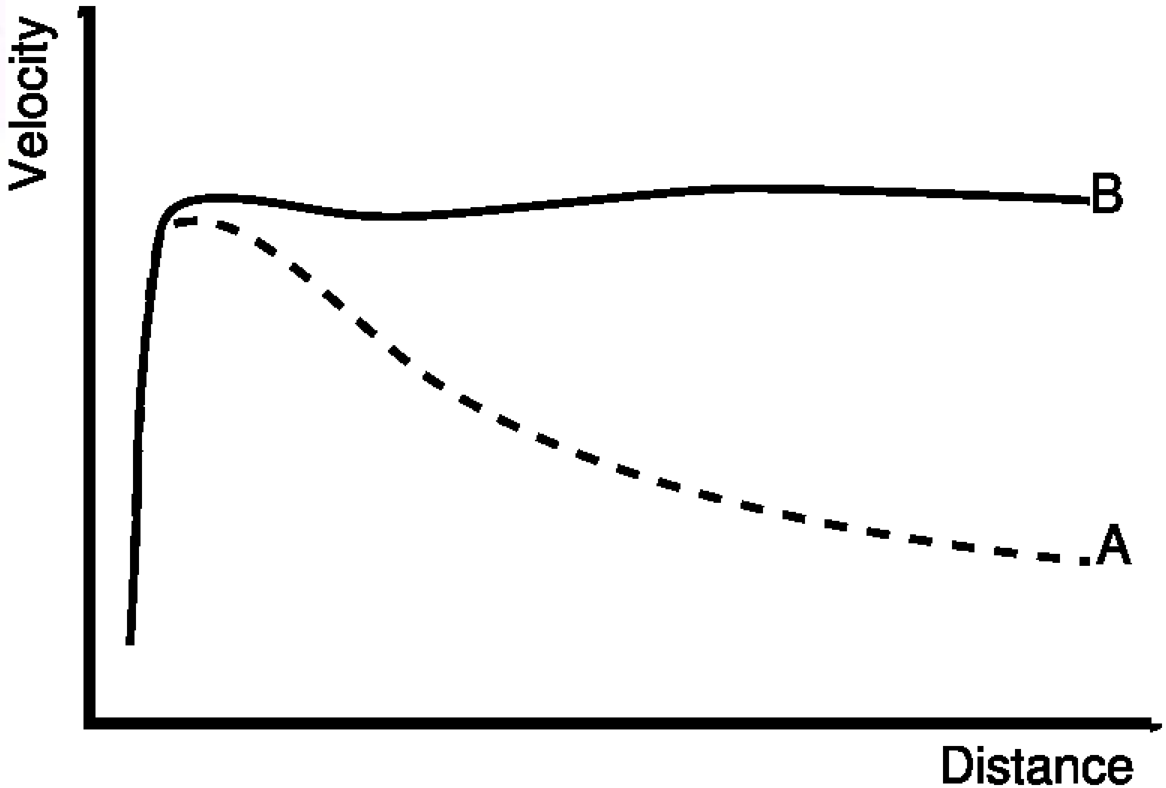
Definisjon: Materie som nesten ? bare føler gravitasjons-kraften. Ingen spor i form av synlig stråling

Galaktiske rotasjonskurver viser at

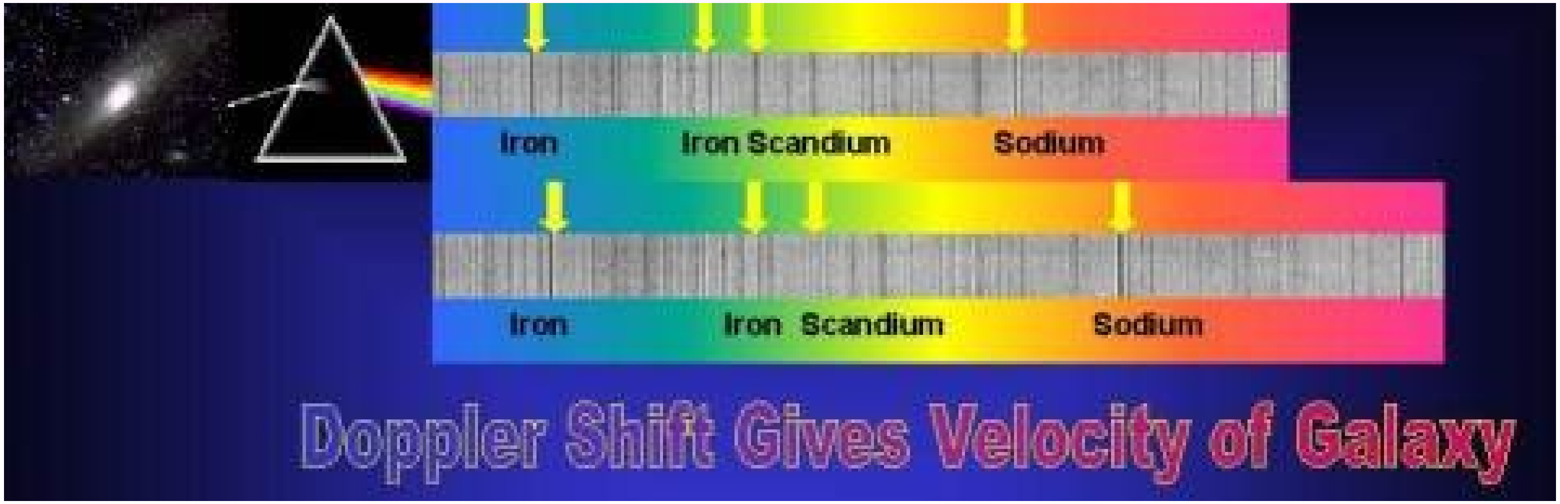
$$\frac{mv^2}{r} \neq G\frac{mM}{r^2}$$

Må enten modifisere Netowns gravitasjon eller innføre mørk materie i galaksenes ytterområder

Rotasjonshastighet som funksjon av avstand til galaksens sentrum.
A:uten mørk materie
B:Observasjon



Dopplereffekt (rød/blå-forskyvning)



$$z = \frac{\lambda_{mottatt} - \lambda_{utsendt}}{\lambda_{utsendt}} \approx \frac{v}{c}$$ (for "små" hastigheter)

Hubbles lov: $v=H_0d$

Objektene i universet fjerner seg fra oss med en hastighet som er proposjonal med avstanden.

Proposjonalitets"konstant":

$H_0=(71\pm3)$ km/s/Mpc

(1 pc = 3,26 lysår)

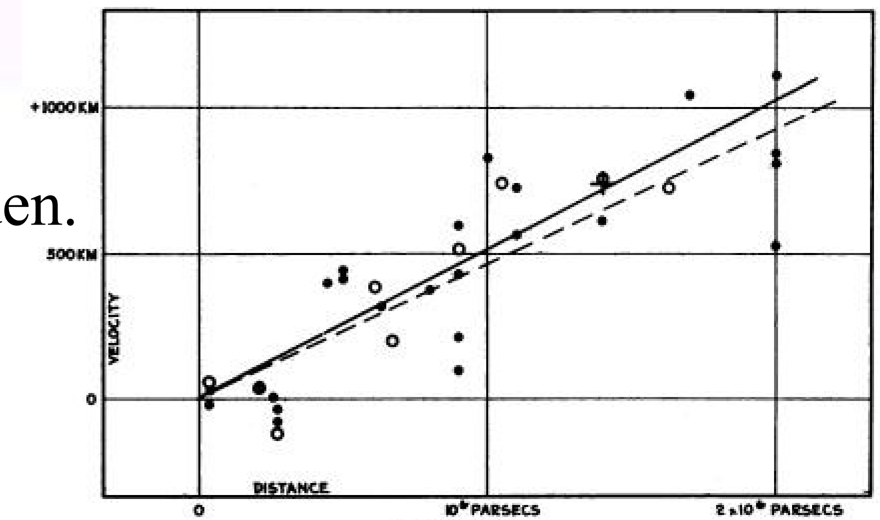


FIGURE 1

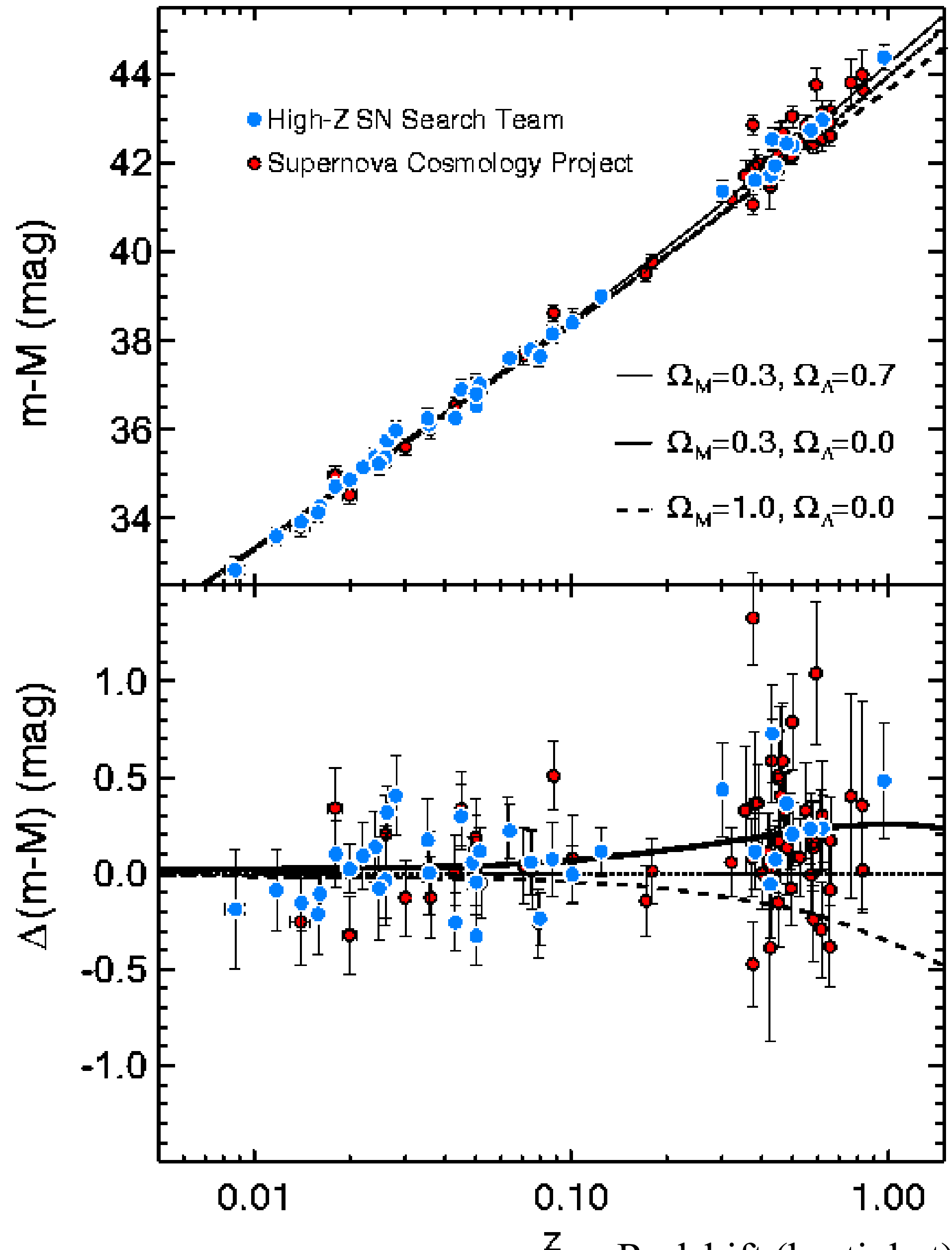
Velocity-Distance Relation among Extra-Galactic Nebulae.

Radial velocities, corrected for solar motion, are plotted against distances estimated from involved stars and mean luminosities of nebulae in a cluster. The black discs and full line represent the solution for solar motion using the nebulae individually; the circles and broken line represent the solution combining the nebulae into groups; the cross represents the mean velocity corresponding to the mean distance of 22 nebulae whose distances could not be estimated individually.

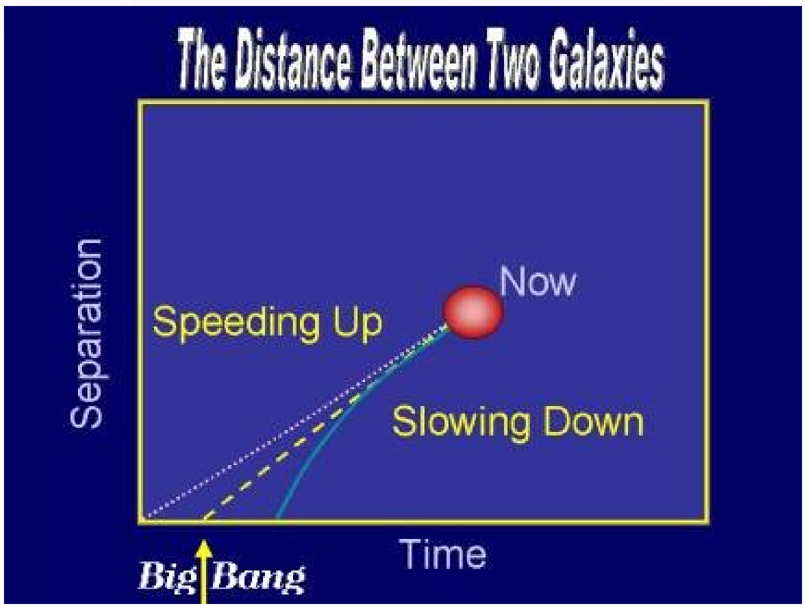
Supernovaer og avstand

- Supernova-eksplosjoner er en godt kjent del av en stjernes livssyklus → godt kjent *og høy* lys-intensitet, L.
  - Kan se fjerne supernovaer p.g.a. intensiteten
- Avstand, r, gitt fra $l = kL/r^2$

m = størrelsesklasse
Høy m betyr svakt lys
(som betyr stor avstand)



Rødskift (hastighet)



Det fins nå noen observasjoner med z godt over 1 (v.h.a. Hubble space telescope)

Men Hubble's konstant var slett ikke konstant gjennom universets historie. For rødskift som nærmer seg 1 skal man se avvik fra dagens verdi

$$\frac{H^2(z)}{H_0^2} = \Omega_M (1+z)^3 + \Omega_\Lambda (1+z)^{3(1+w)}$$

Ω-ene beskriver massen og energien i universet (summerer seg til ca. 1)

Observasjoner passer med

$\Omega_M = \Omega_{synlig} + \Omega_{mørkmaterie} = 0,05 + 0,25$

$\Omega_\Lambda = 0,7$ (mørk, frastøtende energi!)

100 år med sort stråling

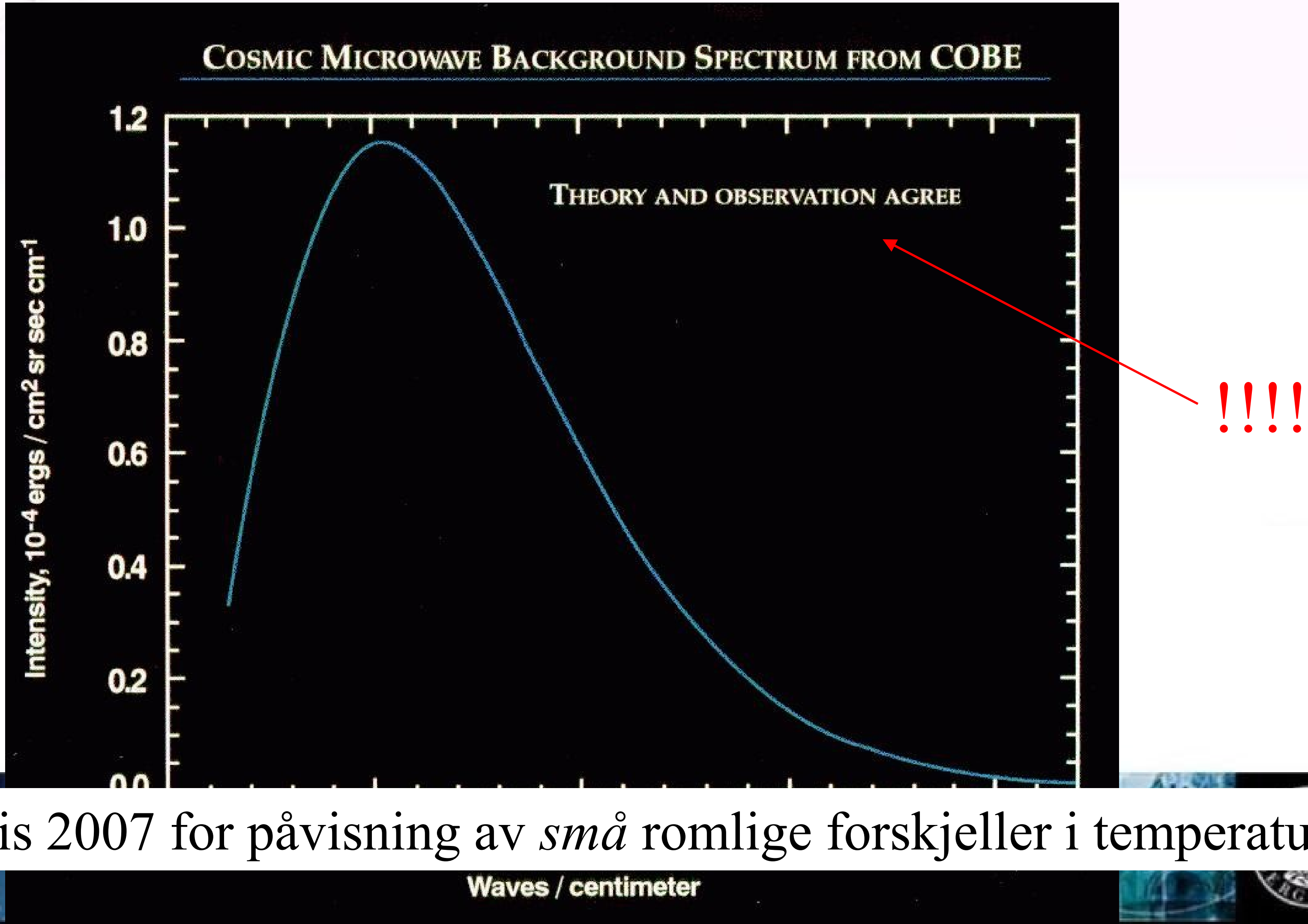
- Alle legemer avgir et strålespekter som bare avhenger av temperatur
- Plancks strålingslov:

$$I(\nu, T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

Plancks strålingslov

- Utledet for 100 år siden ved å anta diskrete energitilstander for fotonene
  - Viktig brikke under utviklingen av kvantemekanikken
- Nå: Viktig som bevis for å underbygge teorien om Big Bang

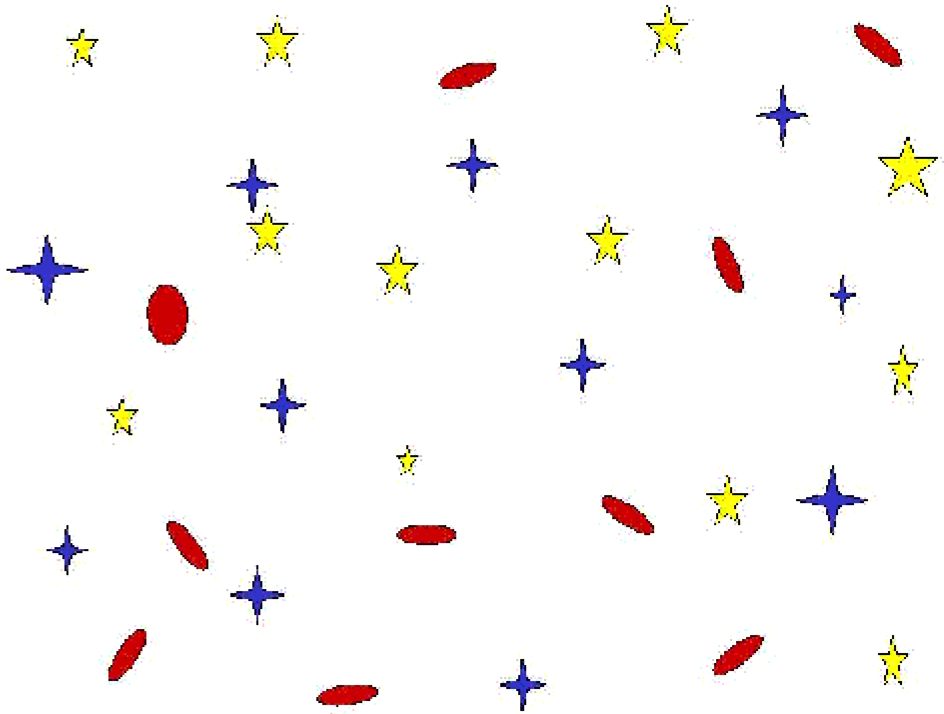
Universets temperatur er (2,725 ±0,002)K



Nobelpris 2007 for påvisning av *små* romlige forskjeller i temperaturer

Hva betyr det at universet ekspanderer?

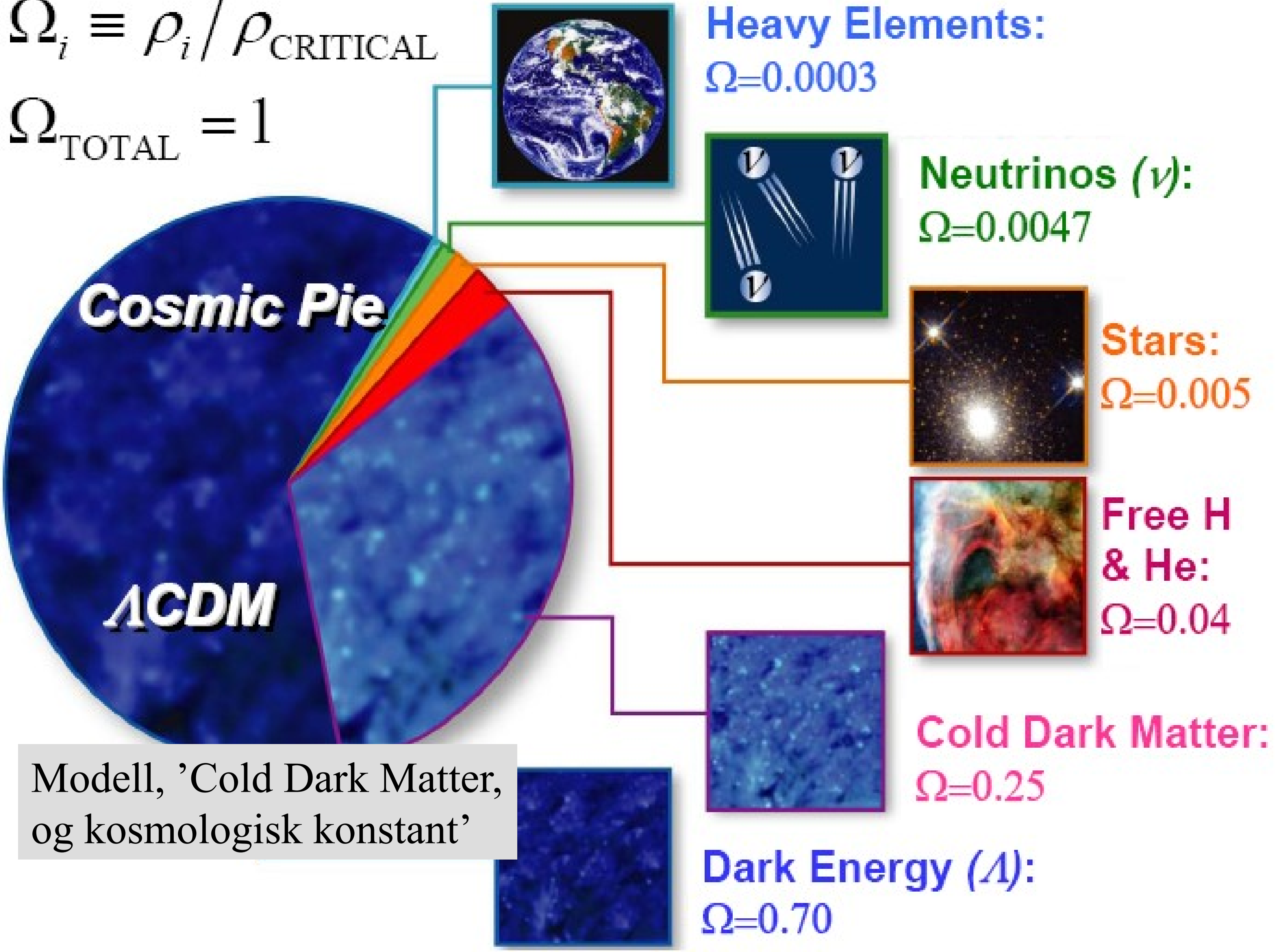
- En **geometrisk** effekt i Einsteins generelle relativitetsteori, der selve skalaen ekspanderer i alle punkter
- Galakser etc.er rosiner i en bolledeig under hevning!
- Tilstedeværelse og temperatur fra kosmisk mikrobølgespekter underbygger Big Bang teori



A Toy Universe

$$\Omega_i \equiv \rho_i / \rho_{\mathrm{CRITICAL}}$$

$$\Omega_{\mathrm{TOTAL}} = 1$$



Modell, 'Cold Dark Matter, og kosmologisk konstant'

Hvorfor har universet bare materie?

- Sakharovs tre betingelser:
  - Brudd på bevaring av baryontall
  - Brudd på partikkel-antipartikkelsymmetri
  - Faseoverganger (system ute av termisk likevekt)
- Partikkelfysikk kan bidra til å belyse de to første betingelser

The Big Bang and its particles

Kosmologi

Astropartikkelfysikk

Partikkelfysikk

Hvilke partikler? →

Big Bang →

13.7 milliarder å

1 ps

10^{-34} s