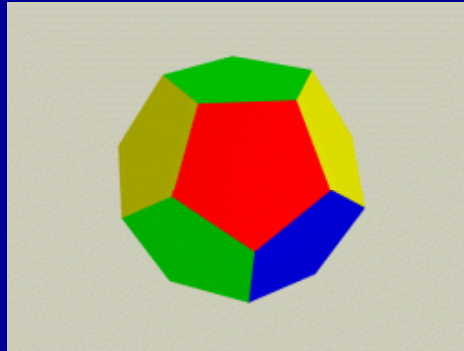


# Ciemna materia i ciemna energia

Największy nierozwiązany problem w fizyce

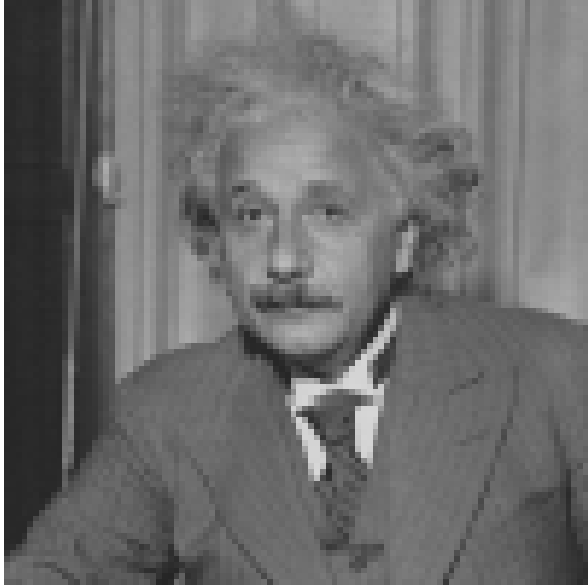


**Stanisław Bajtlik**

Centrum Astronomiczne im. M. Kopernika

Warszawa

**CERN, 17 IV 2007**



Albert Einstein

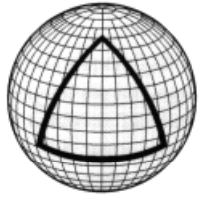
1879 - 1955

General Relativity (1916):

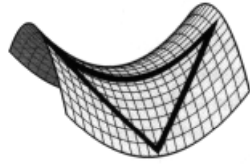
$$G_{\mu\nu} = 8\pi T_{\mu\nu}$$

*geometry*

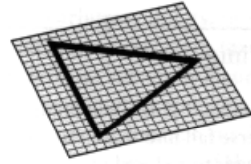
*matter*



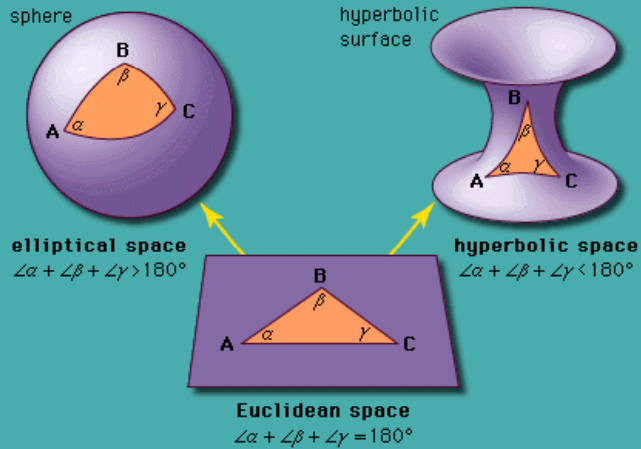
Closed Geometry



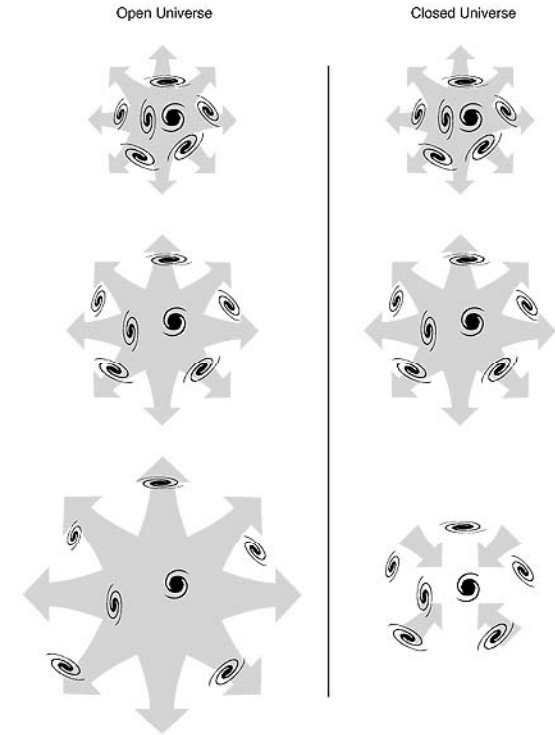
Open Geometry



Flat Geometry



©1997 Encyclopaedia Britannica, Inc.



An open universe expands forever because it does not contain enough mass, and so does not have enough gravity to slow the expansion of space. A closed universe contains enough mass to halt the expansion, and eventually collapses. A universe with a "critical density" of matter in space is exactly balanced between these two alternatives, and expands at an ever-slowing rate.

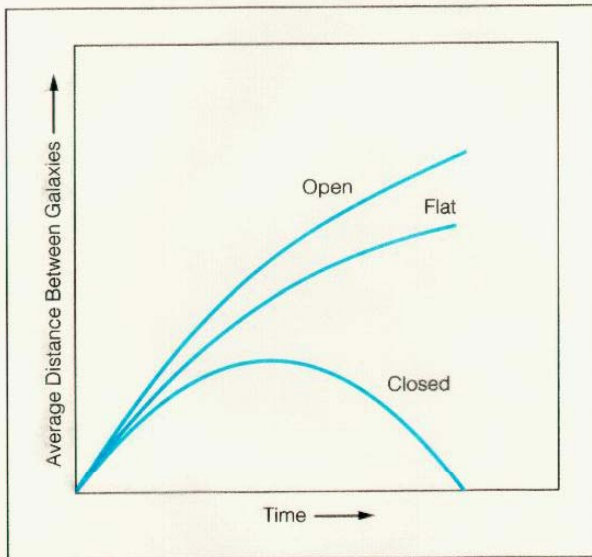
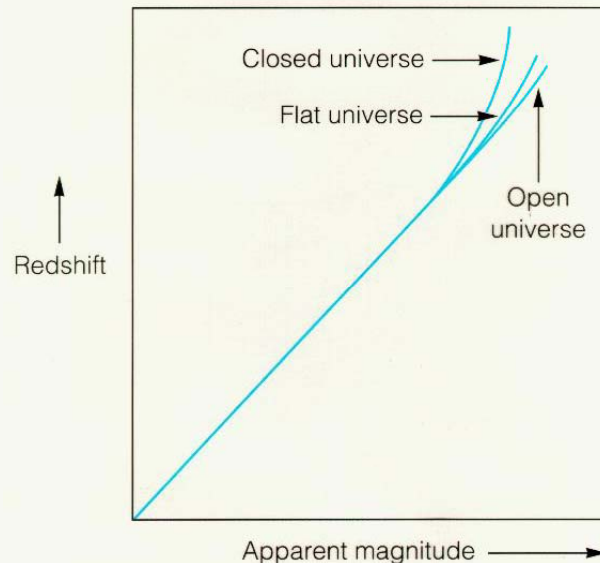
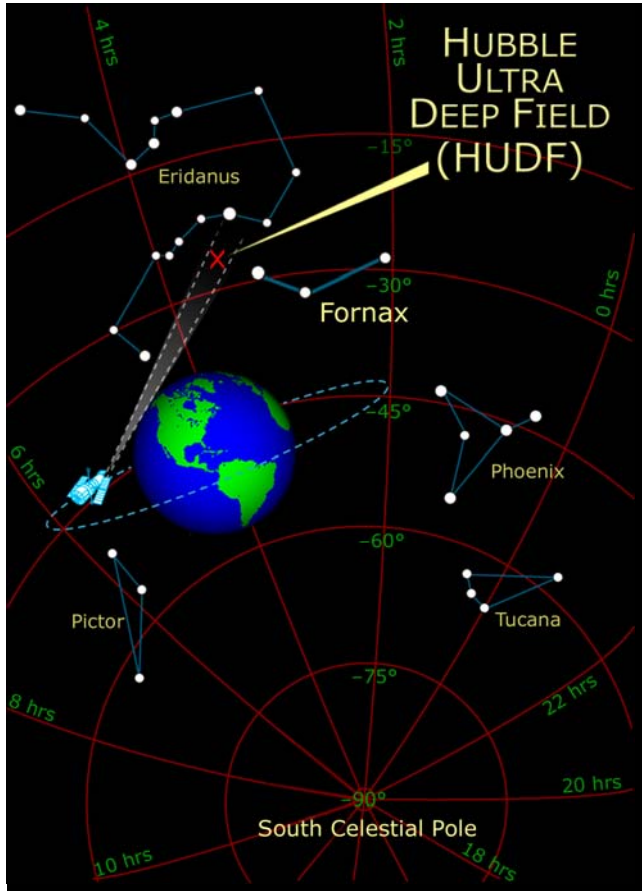


Figure 21.6 The three possible fates of the universe.



$$\Omega = \rho / \rho_{\text{crit}}$$

$\Omega_{lum}$  

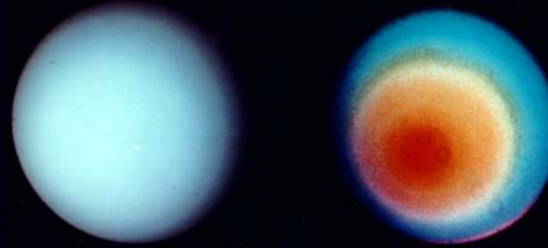


„... Powstaje zasadnicze pytanie: jaki jest znak krzywizny przestrzennej ? ... To zagadnienie jest według mnie najważniejsze. Przy obecnym stanie astronomii nie wydaje się możliwe jego rozstrzygnięcie. Stała Hubble'a jest stosunkowo dobrze znana, tak, że wszystko zależy od możliwie dokładnego określenia wartości  $\Omega$ .

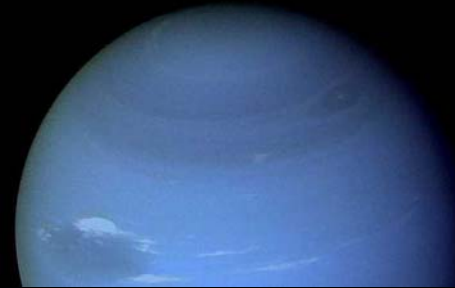
...zawsze można podać kres dolny wielkości  $\Omega$ , a nie można podać górnego. Dzieje się tak ponieważ bardzo trudno zdać sobie sprawę z tego, jaka część  $\Omega$  pochodzi od ciał, których nie można obserwować (bo nie promieniują).”

Albert Einstein, „*Istota teorii względności*”

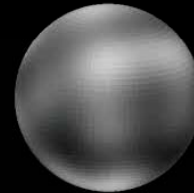
Uranus, 1781, William Herschel



Neptune, 1846, Johan Galle, John Adams, Urbain Leverrier



Pluto, 1930, Clyde, W, Tombaugh

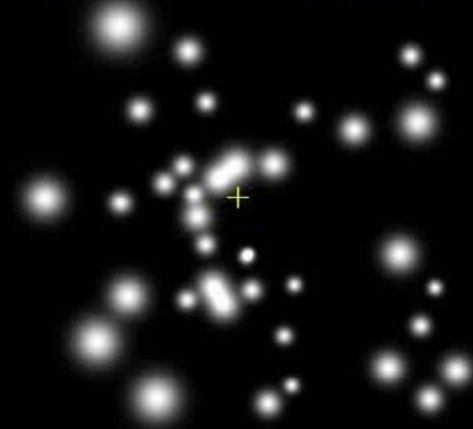


But:

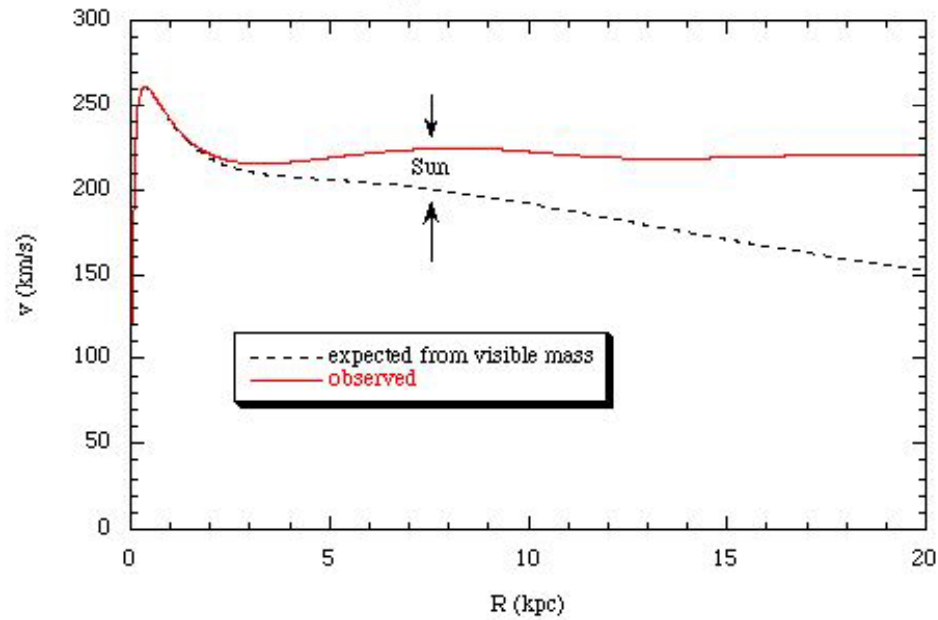
The French mathematician Urbain Le Verrier, co-predictor with J.C. Adams of the position of Neptune before it was seen, in a lecture at 2 Jan 1860 announced that the problem of observed deviations of the motion of Mercury could be solved by assuming an intra-Mercurial planet, or possibly a second asteroid belt inside Mercury's orbit.

1992

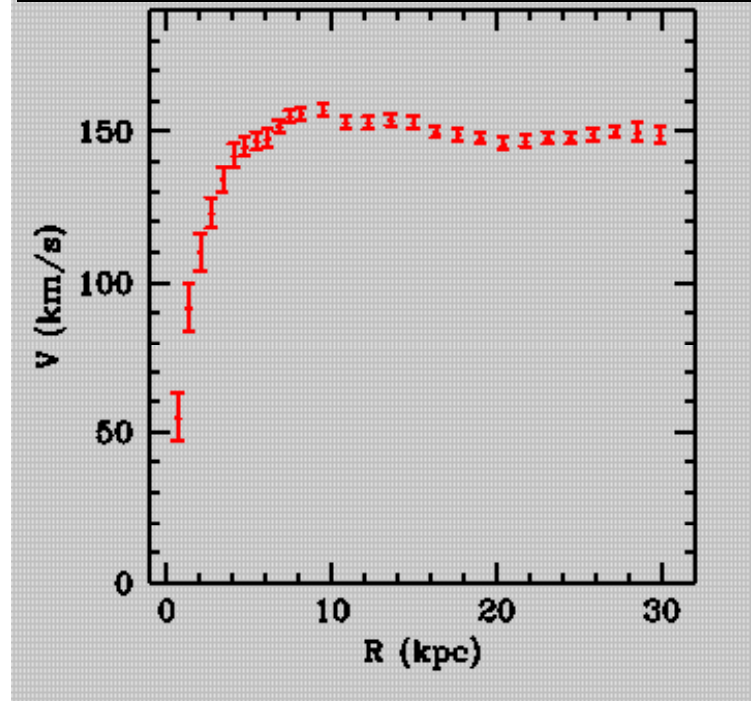
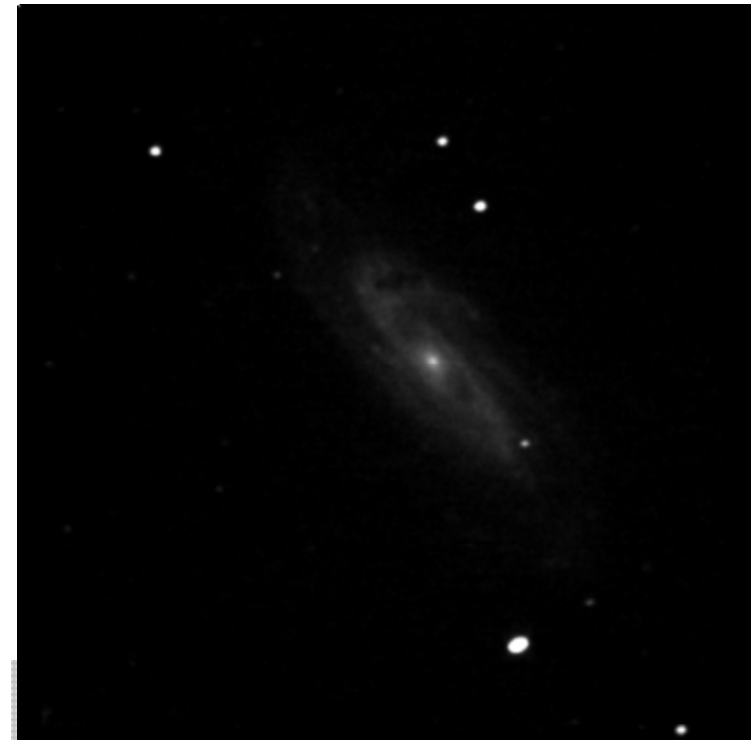
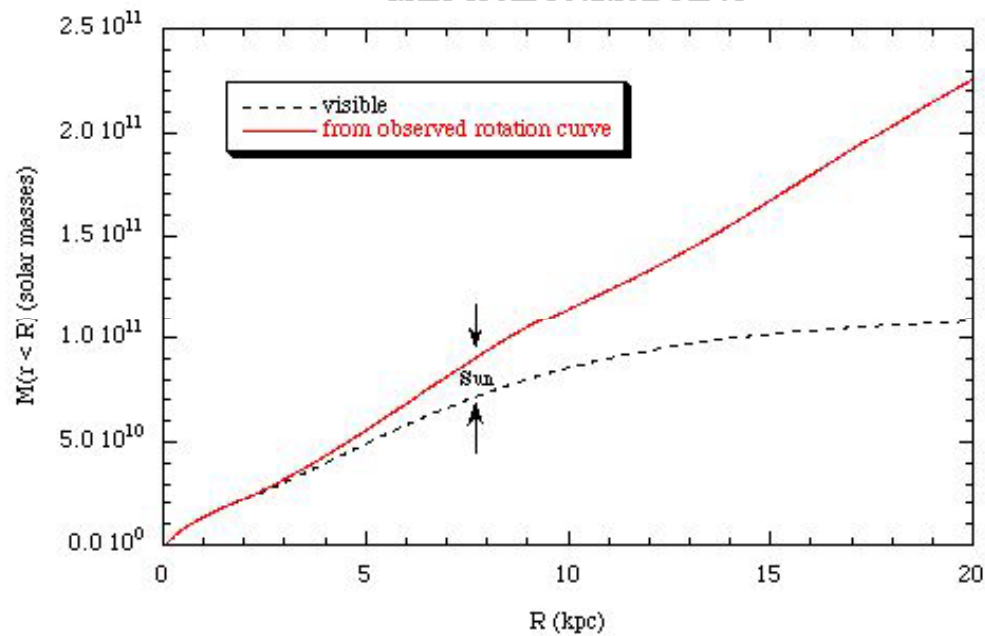
10 light days



Typical rotation curves



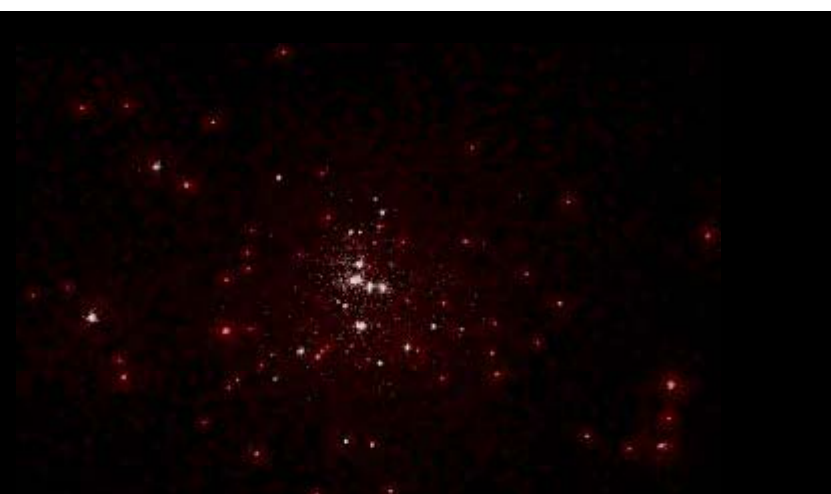
Mass from rotation curve





# Dynamics of galaxy clusters

Fritz Zwicky (1898-1974)



# Dynamics of pairs of galaxies

Roman Juszkiewicz

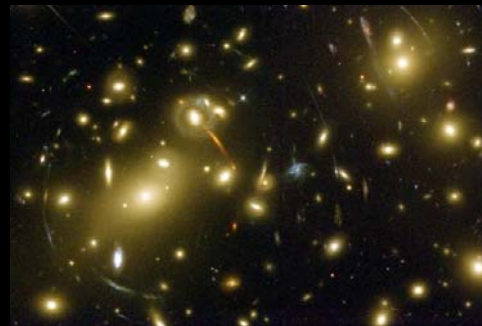


# Gravitational lensing

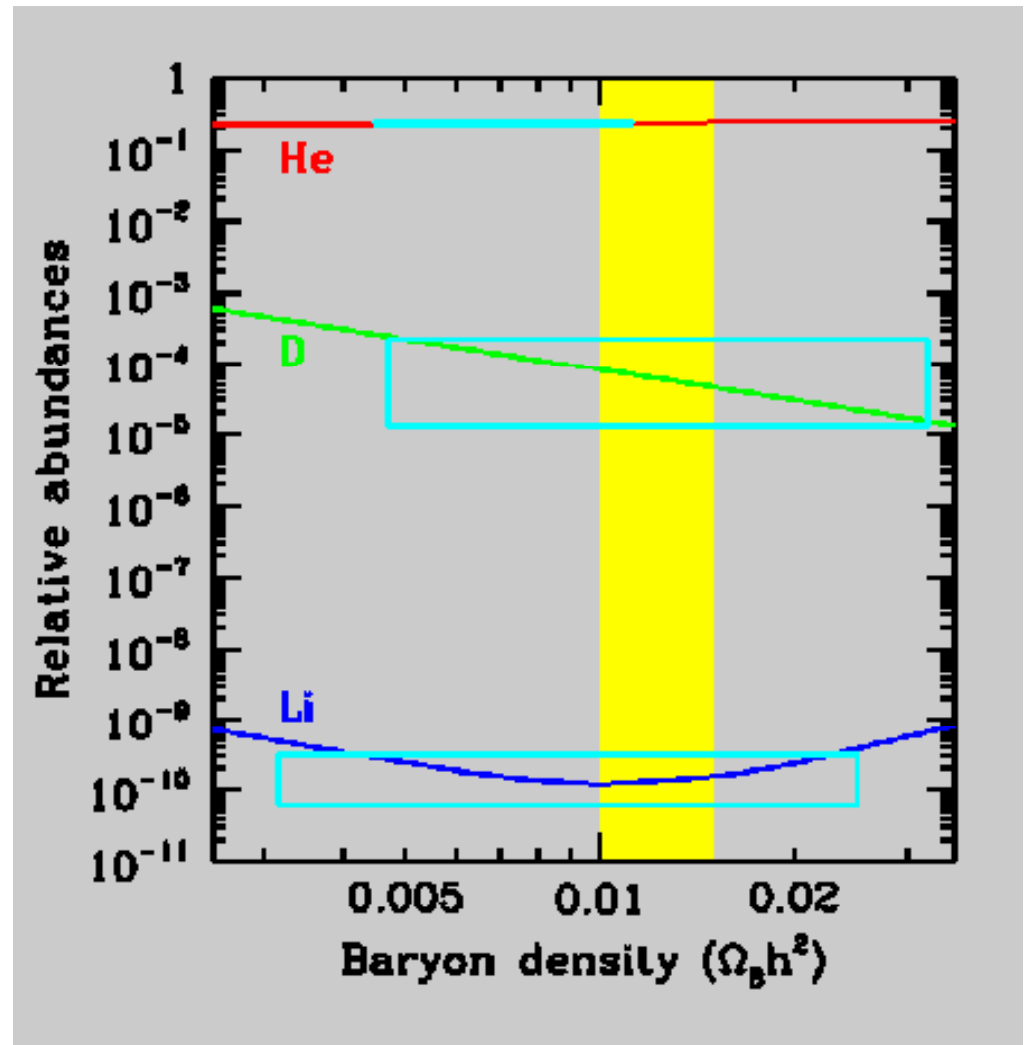
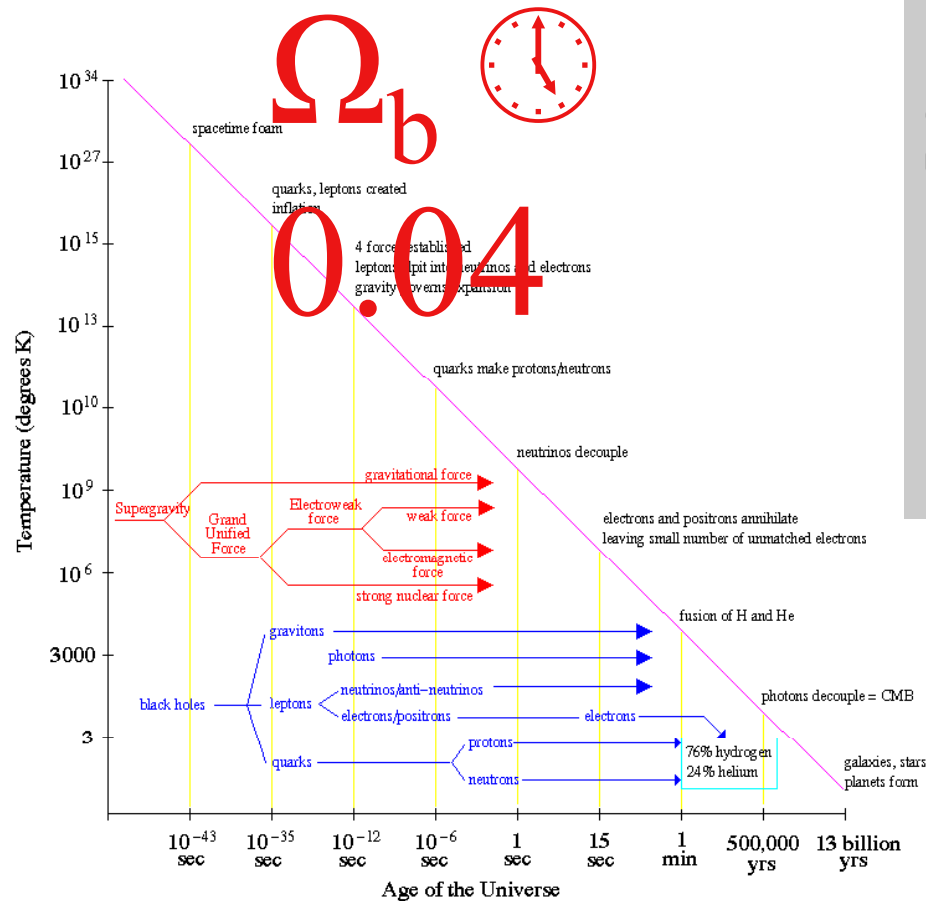
$$\Omega_{\text{dm}} \text{ ⌚ } 0.3$$



Gravitational Lens in Abell 2218 HST · WFPC2  
PF95-14 · ST ScI OPO · April 5, 1995 · W. Couch (UNSW), NASA



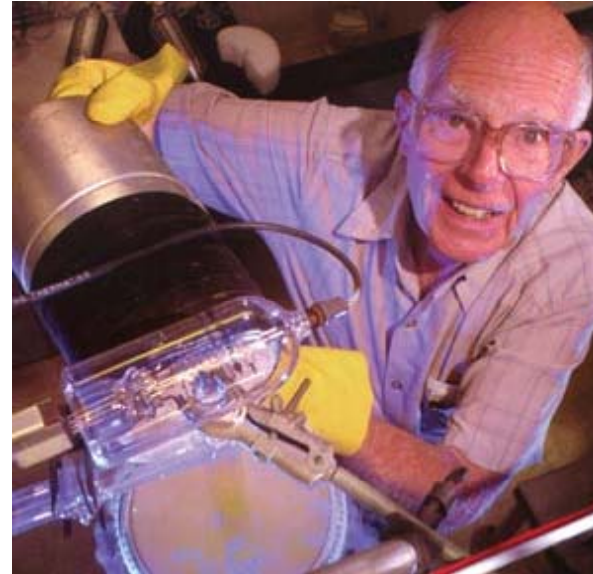
- Helium-4.  $[\text{}^4\text{He}/(\text{H}+\text{He})] = 0.23$
- Deuterium.  $[\text{}^2\text{H}/\text{H}] = 1.5 \times 10^{-5}$
- Helium-3.  $[\text{}^3\text{He}/\text{H}] = (1.2-15) \times 10^{-5}$
- Lithium-7.  $\log[\text{}^7\text{Li}/\text{H}] = -9.8$
- Tritium  ${}^3\text{H}$  is unstable with a half-life of 12.46 years.
- Observational Abundances of Light Elements:  ${}^2\text{H}$ ,  ${}^3\text{H}$ ,  ${}^3\text{He}$ ,  ${}^4\text{He}$ ,  ${}^7\text{Li}$



## Nagroda Nobla z dziedziny fizyki, 2002 rok



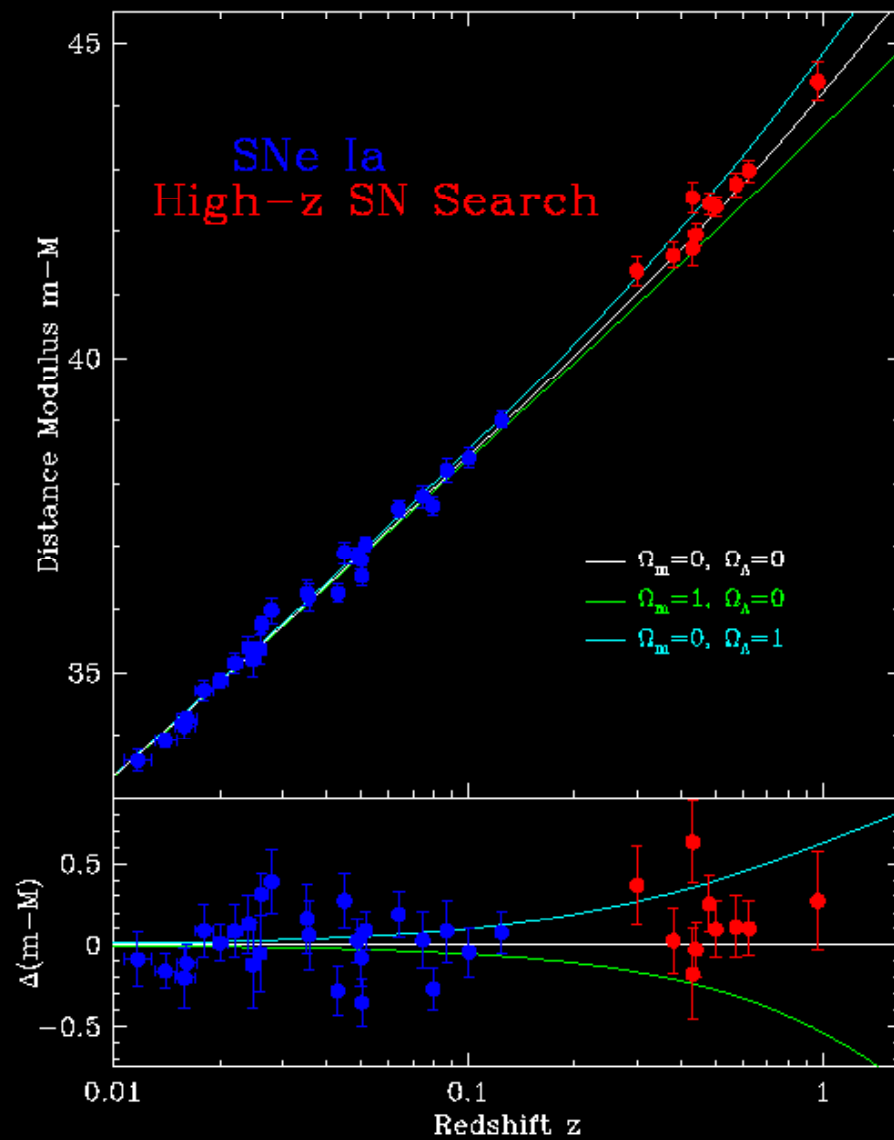
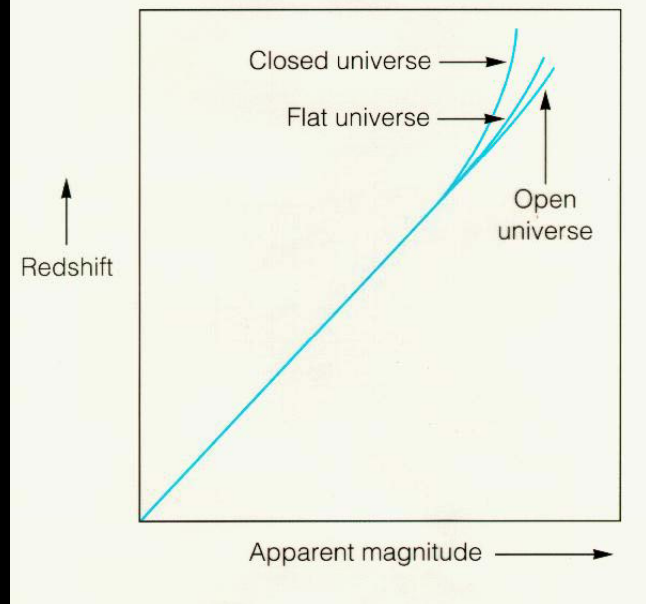
**Masatoshi Koshiwa**, ur. 1926  
International Center for  
Elementary Particle Physics,  
University of Tokyo, Japan



**Raymond Davis Jr**, ur. 1914  
Department of Physics and  
Astronomy, University of  
Pennsylvania, Philadelphia,  
USA

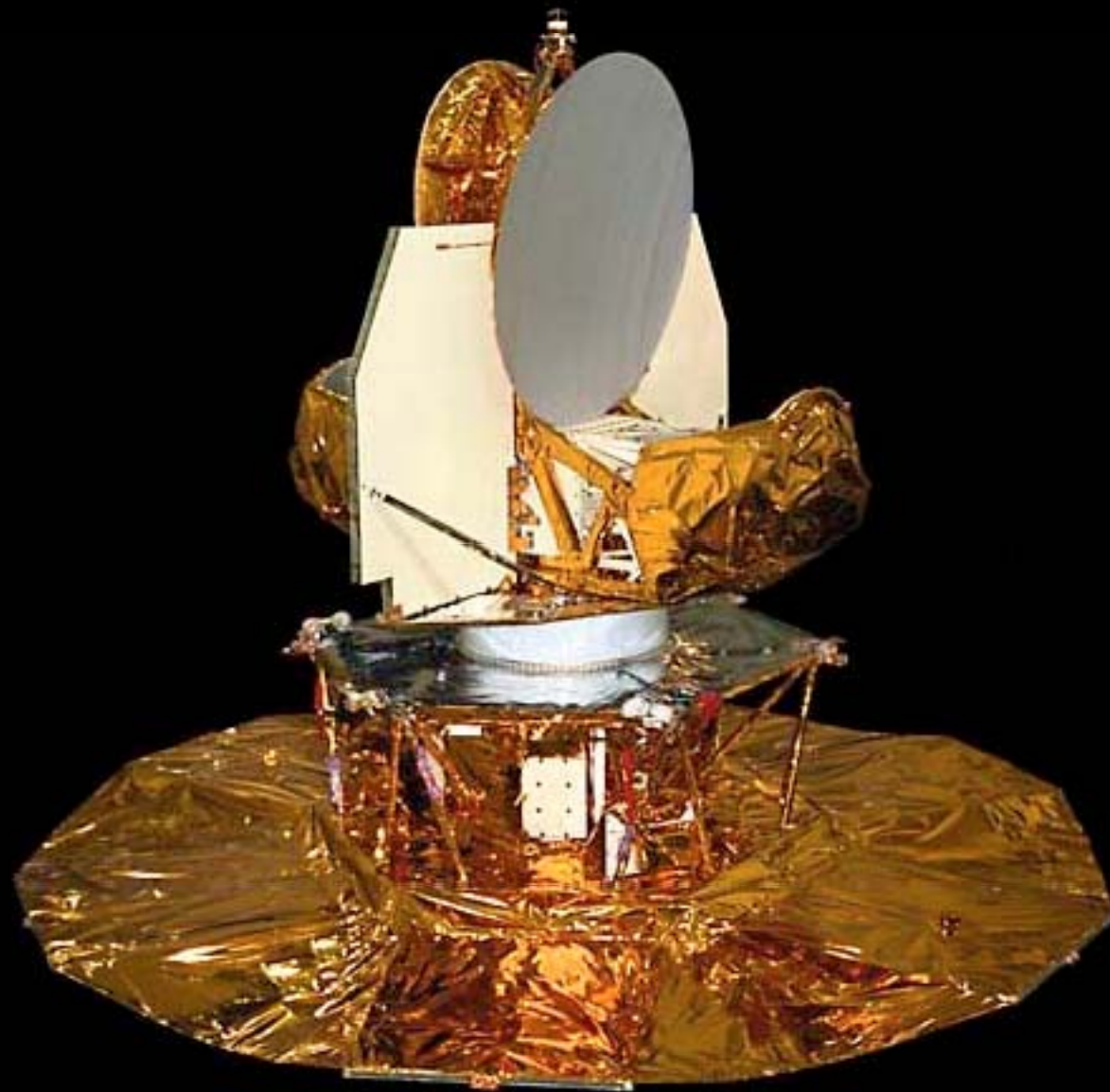
Nagroda Nobla w dziedzinie fizyki za 2002 rok

*“for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos”*

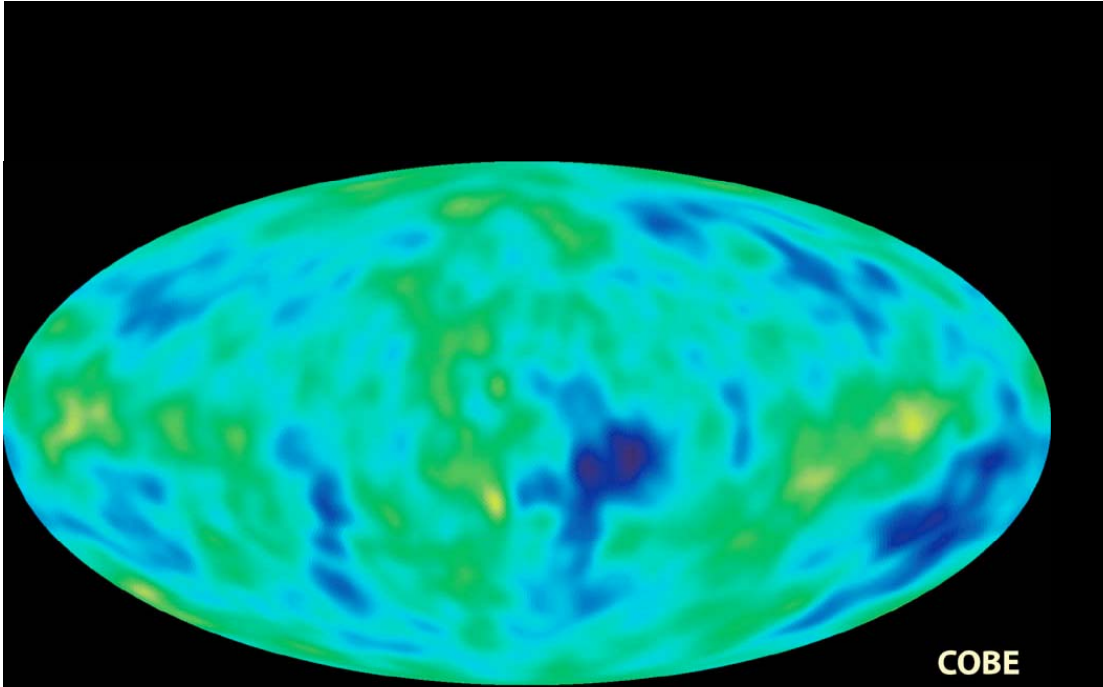


$$\Omega_\Lambda \text{ (clock icon)} 0.7$$

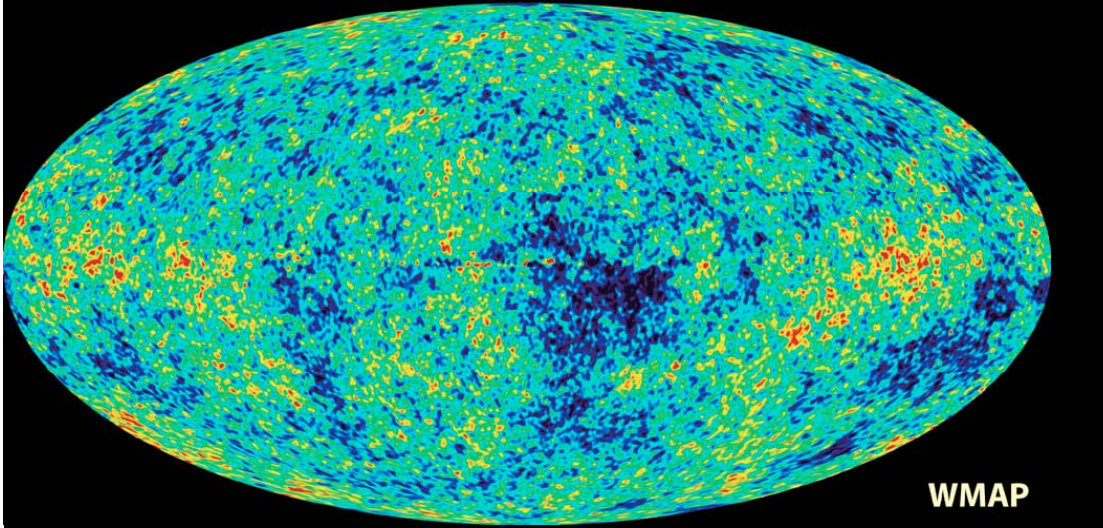
$$\Omega_{\text{tot}} \text{ (clock icon)} 1$$



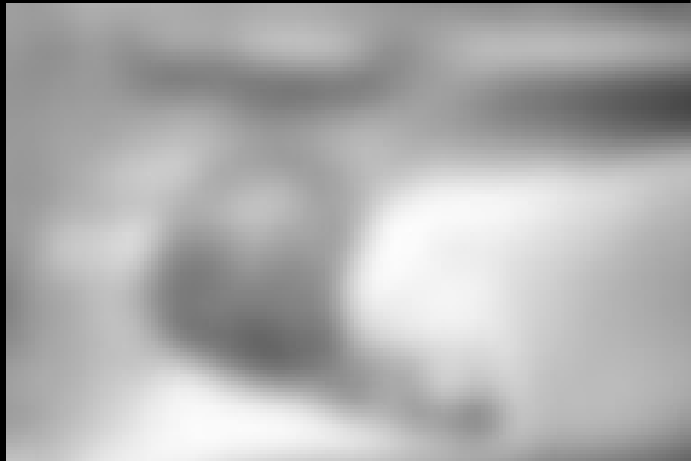
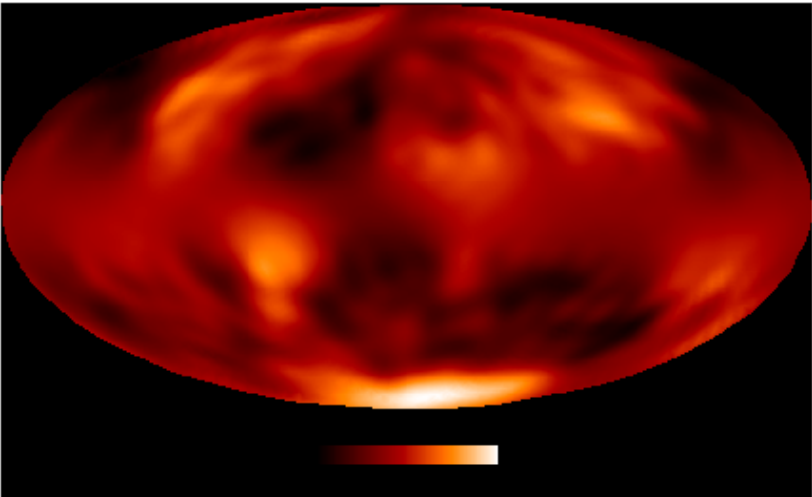
MAP990389

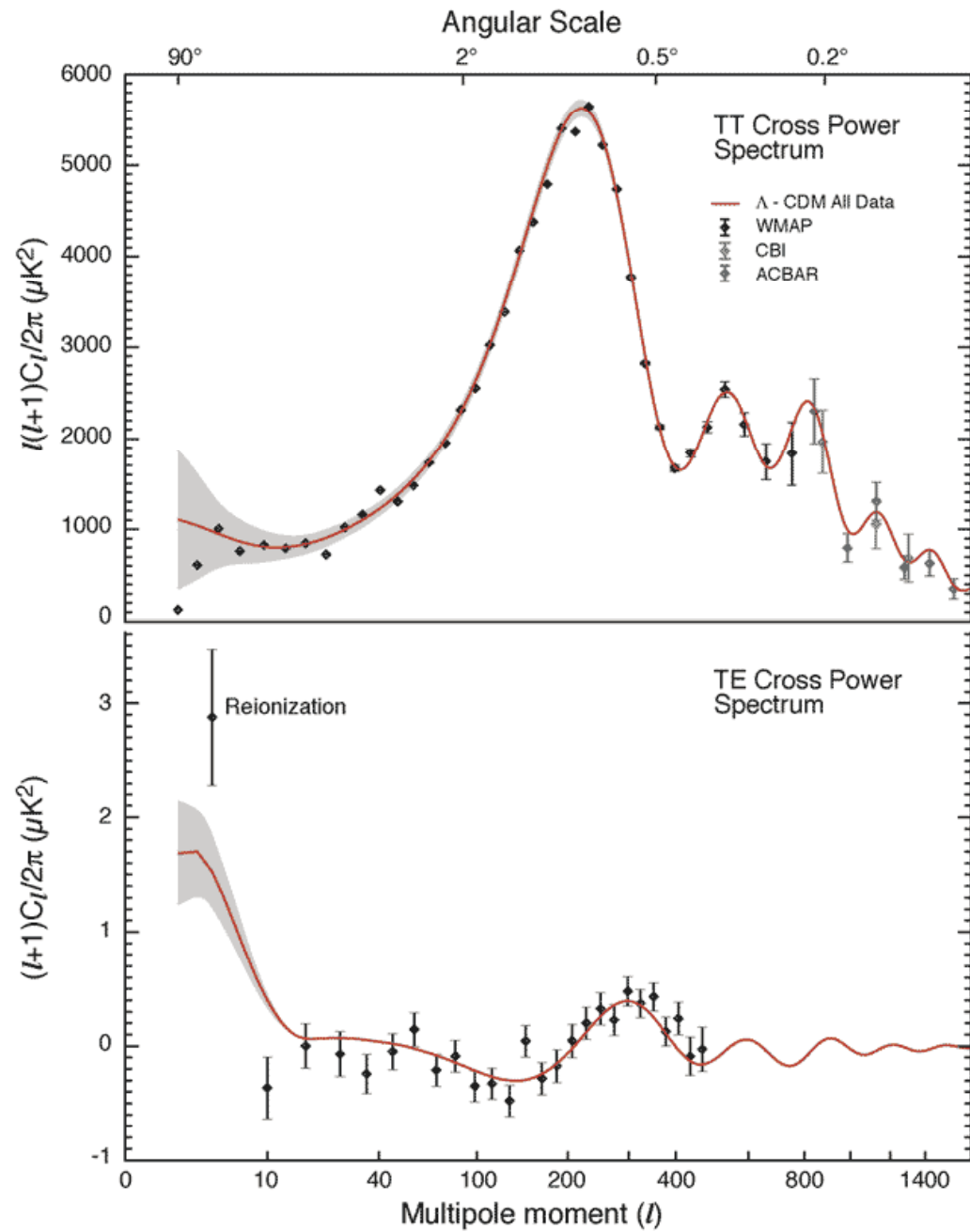


COBE



WMAP





*Ile materii jest we Wszechświecie ?*

$\Omega < 1$  Wszechświat otwarty (ujemna krzywizna)

$\Omega = 1$  Wszechświat płaski (euklidesowy)

$\Omega > 1$  Wszechświat zamknięty (dodatnia krzywizna)

*Obserwacje:*

$\Omega_{\text{mat. świecąca}} \approx 0.005$

$\Omega_{\text{mat. barionowa z nukleosyntezy}} \approx 0.03$

$\Omega_{\text{dynamika galaktyk i gromad, soczewkowanie graw}} \approx 0.3$

$\Omega_{\Lambda \text{ standard ruler, supernowe}} \approx 0.7$

$\Omega_{\text{inflacja, MBR}} = 1.0$

