Introdução à Astronomia
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Aula 14 – 02 julho 2007

A Expansão do Universo

referências:

http://www.pnas.org/cgi/content/full/101/1/8

http://www.astro.ucla.edu/~wright/cosmo_01.htm

Frank Shu, The Physical Universe

Sciama, Modern Cosmology

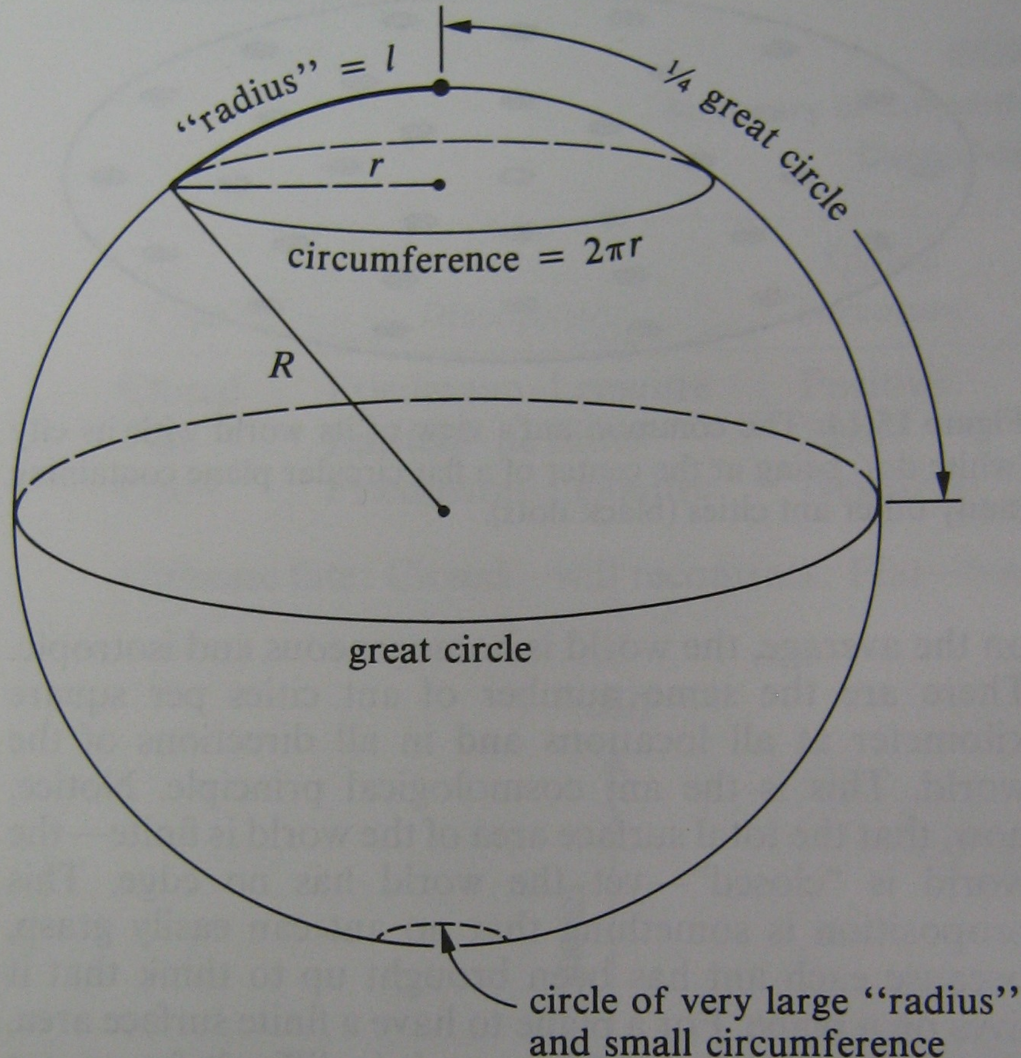


Figure 15.15. The geometric experiments of two bold ant surveyors who discover that the ratio of the circumference $2\pi r$ of a circle to its "radius" l does not equal 2π if the "radius" l is large. Notice that the quantity r is not the line of sight distance l that the ants can measure. Because r and R exist in the third unobservable dimension, ants can never measure r and R directly. They can, however, measure the circumference $2\pi r$, and by measuring the discrepancy between $2\pi r/l$ and 2π, the ants can indirectly calculate the radius of curvature R of their world.

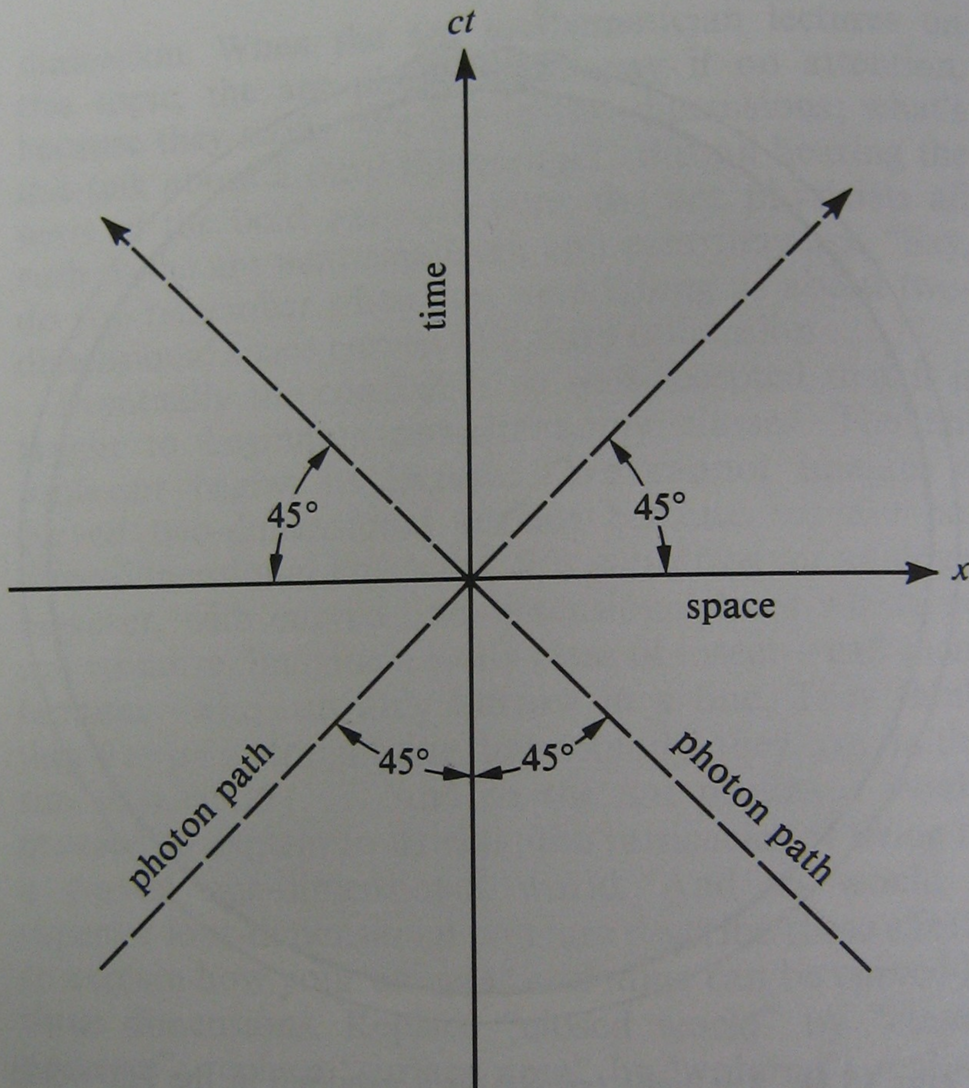


Figure 15.18. The trajectories of photons in flat spacetime are at angles of 45° to the coordinate axes.

trajectory of a photon is at 45° relative to the axes, be-

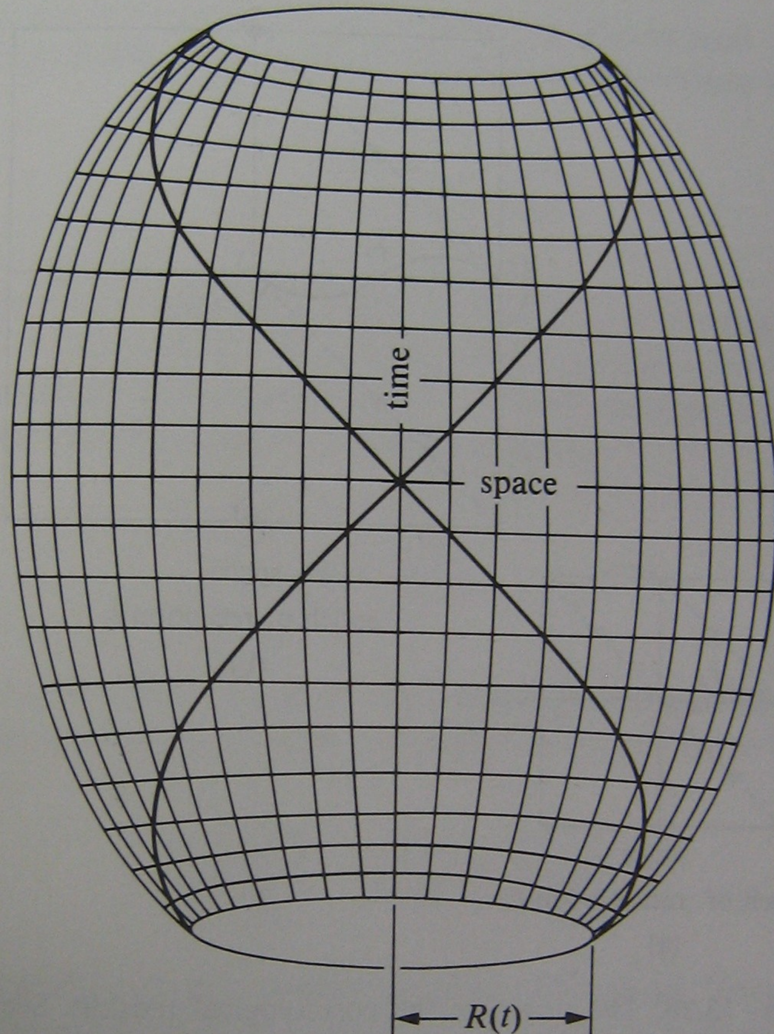


Figure 15.19. Curved spacetime in a closed, matter-dominated universe during the middle half of its existence. Galaxies on average travel upward along the time axis without moving with respect to the spatial grid. Photons travel along trajectories which are at 45° angles to the local spacetime axes ("corner to corner" if we construct little square grid markers). The space axis, at each instant of time t, forms a closed loop with radius $R(t)$ in an artificial "fourth" dimension. During the expansional phase, when $R(t)$ is an increasing function of t, notice that the individual square grids become larger. This is the expansion of spacetime that is the essence of relativistic cosmologies in the present epoch.

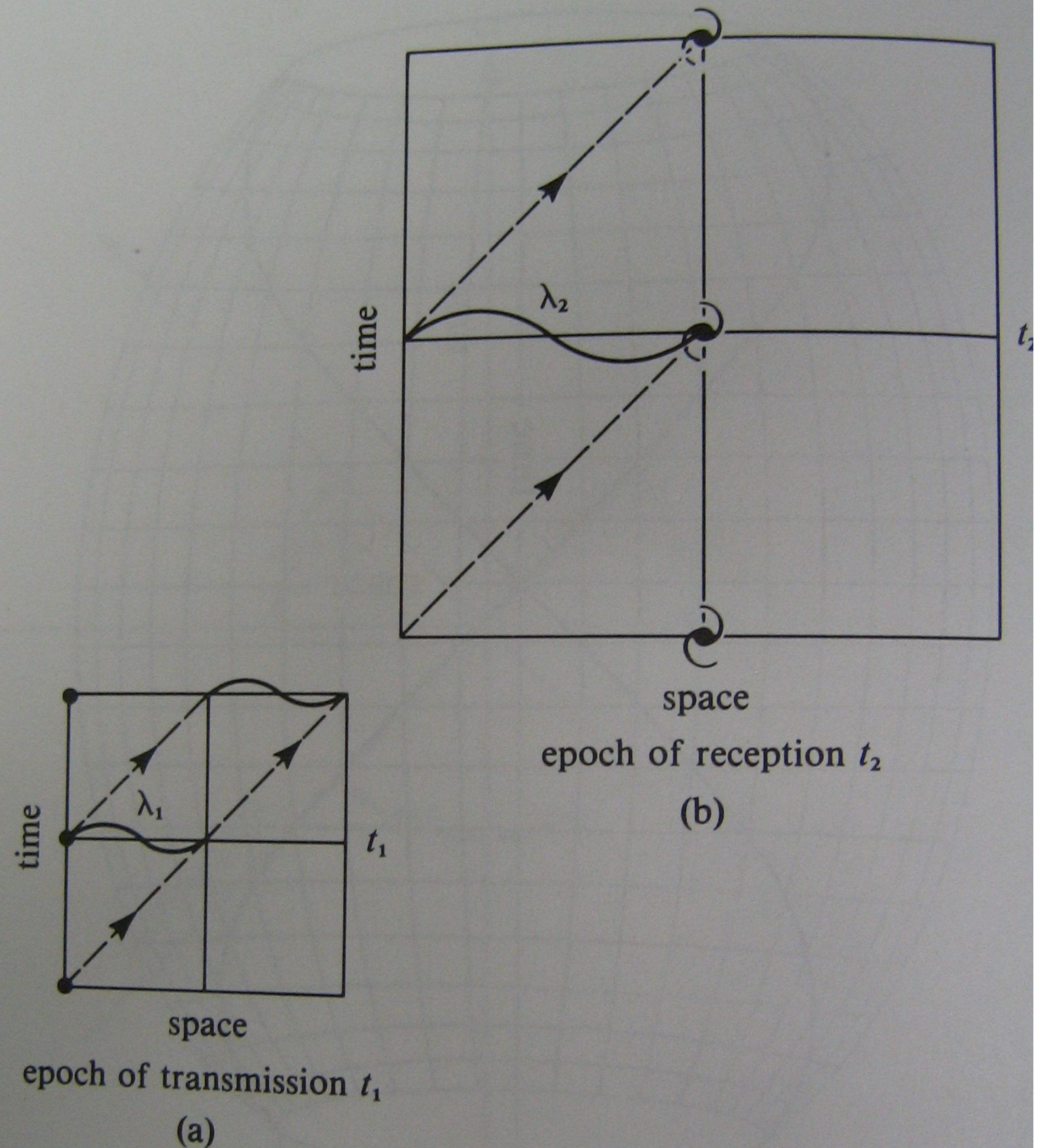


Figure 15.20. The origin of the cosmological redshift. See th text and Figure 15.19 for explanations.

Testes cosmológicos através do diagrama de Hubble

fontes padrão

f = L / 4 pi r^2 * 1/(1+z) * 1/(1+z)

hc/λ tempo

réguas padrão

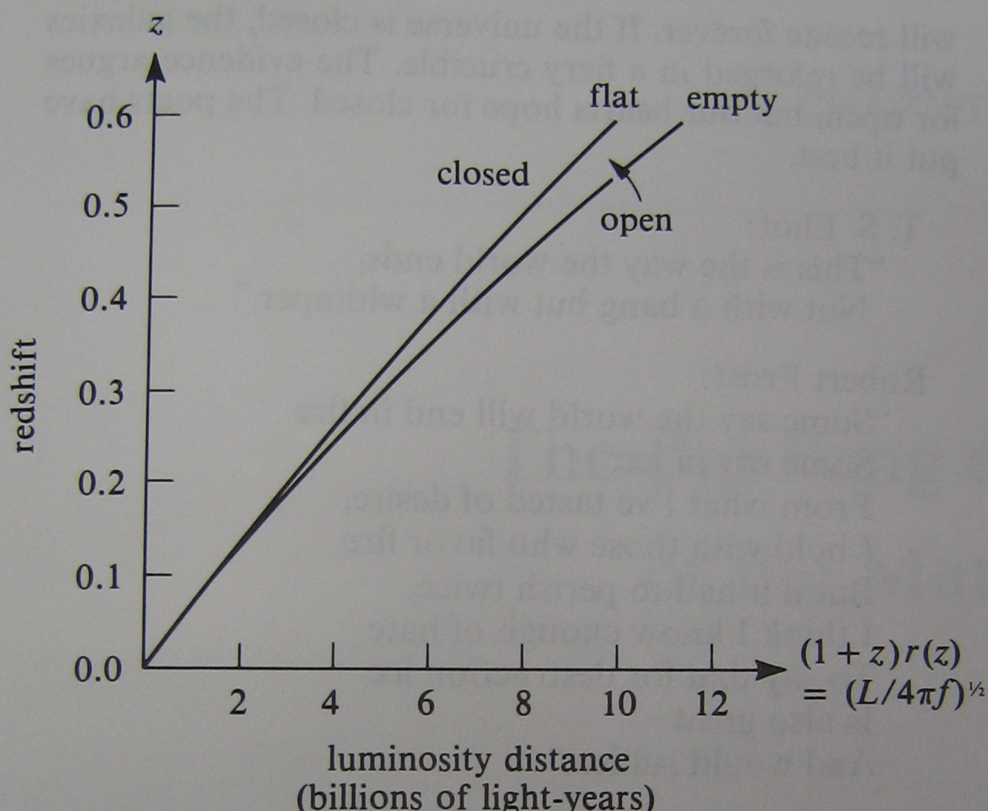
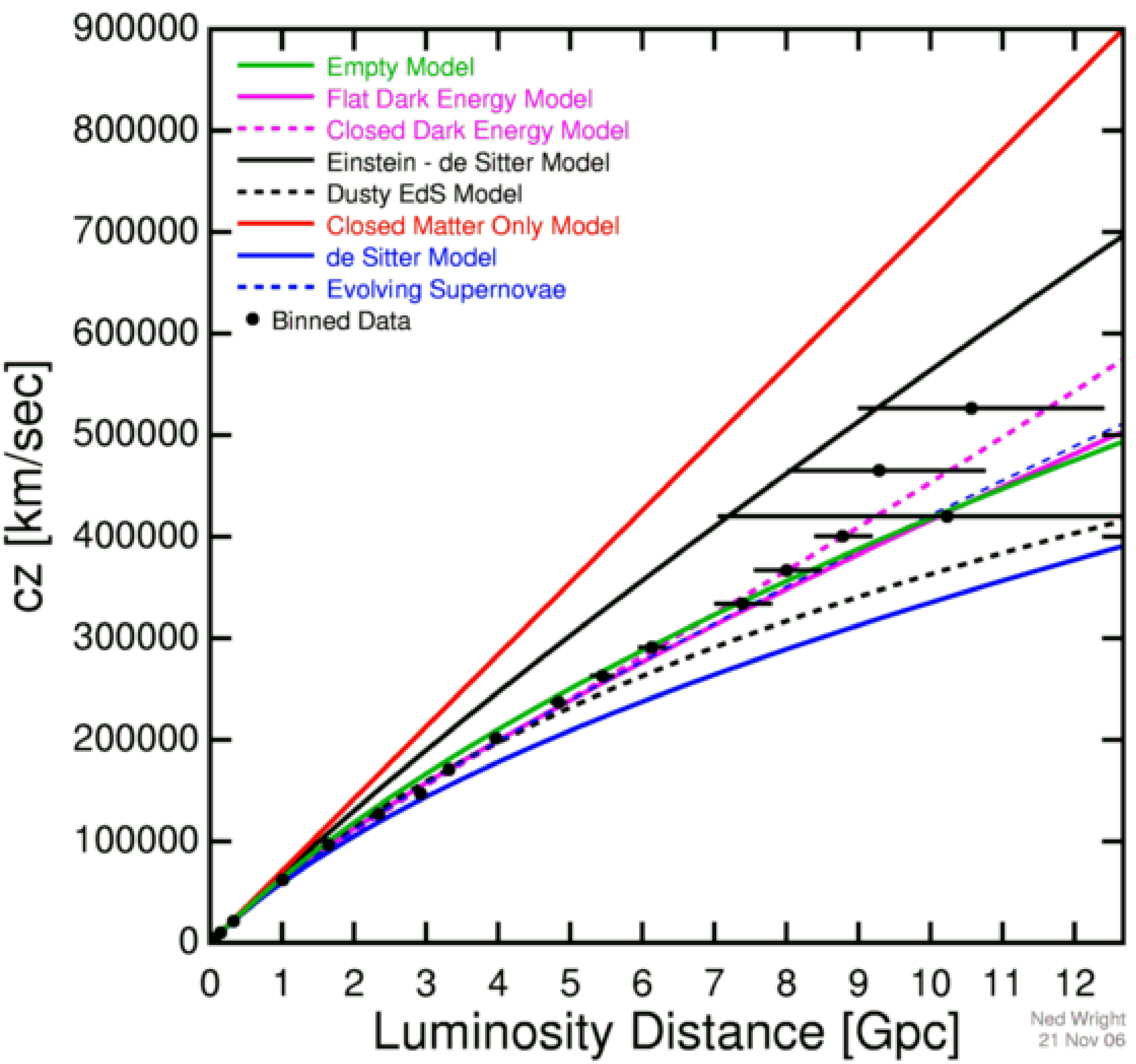


Figure 15.23. Theoretical Hubble diagram in which galaxies of a given luminosity L but of different apparent brightness f and redshift z in an open universe would lie between the curves labelled "flat" and "empty," while galaxies in a closed universe would lie above and to the left of "flat." All conventional cosmological models exhibit a linear relationship between redshift and luminosity distance at low z (Hubble's law), so only observations of the curvature in this relationship at high z can reveal whether the universe is open or closed. Unfortunately, as is discussed in the text, the interpretation of the observational Hubble diagram at high z is complicated by evolutionary and cannibalism effects.

why many astronomers believe that the universe is open. If they are correct, evolution is more important than


Empty Model
Flat Dark Energy Model
Closed Dark Energy Model
Einstein - de Sitter Model
Dusty EdS Model
Closed Matter Only Model
de Sitter Model
Evolving Supernovae
Binned Data
cz [km/sec]
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
0 1 2 3 4 5 6 7 8 9 10 11 12
Luminosity Distance [Gpc]
Ned Wright
21 Nov 06

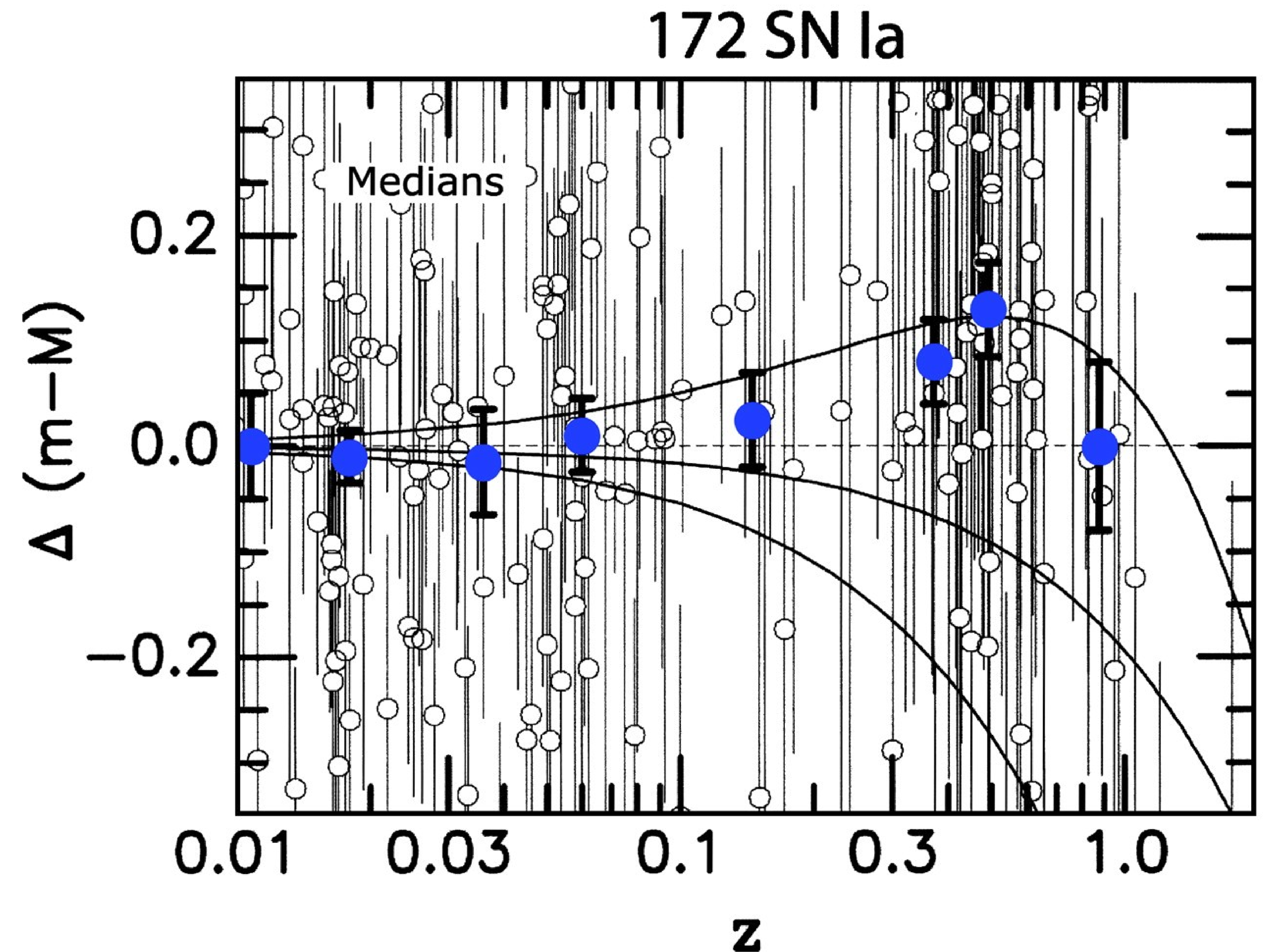

172 SN Ia
Medians
0.2
0.0
−0.2
Δ (m−M)
0.01
0.03
0.1
0.3
1.0
z

Fig. 6. Deviations in the Hubble diagram. Each point in this plot shows the difference at each redshift between the measured apparent brightness and the expected location in the Hubble diagram in a universe that is expanding without any acceleration or deceleration. The blue points correspond to median values in eight redshift bins. The upward bulge at z {approx} 0.5 is the signature of cosmic acceleration. The hint of a turnover in the data at the highest redshifts, near z = 1, suggests that we may be seeing past the era of acceleration driven by dark energy back to the era of deceleration dominated by dark matter. From top to bottom, the plotted lines correspond to the favored solution, with 30% dark matter and 70% dark energy, the observed amount of dark matter (30%) but no dark energy, and a universe with 100% dark matter (from ref. 18).

Hubble diagram at high z is complicated by evolutionary and cannibalism effects.

why many astronomers believe that the universe is open. If they are correct, evolution is more important than cannibalism.

Problem 15.12. Another observational cosmological test involves the use of "standard rulers." Suppose we have a galaxy of fixed length l_0 in its rest frame, and suppose this length is oriented perpendicular to our line of

Define $\alpha_0 = H_0 l_0/c$, and calculate its numerical value for a large galaxy. Convert your answer to seconds of arc. With the functions $r(z)$ given in Problem 15.11, plot $\Delta\theta$ versus z as expected theoretically for a flat and an empty universe. Can you explain why $\Delta\theta$ *increases* with large z for a flat universe? *Hint*: consider whether the universe as a whole can act as a gravitational lens. Construct the two-dimensional analogue of the effect (for a closed universe) by considering rulers on an expanding sphere. (See figures below.)

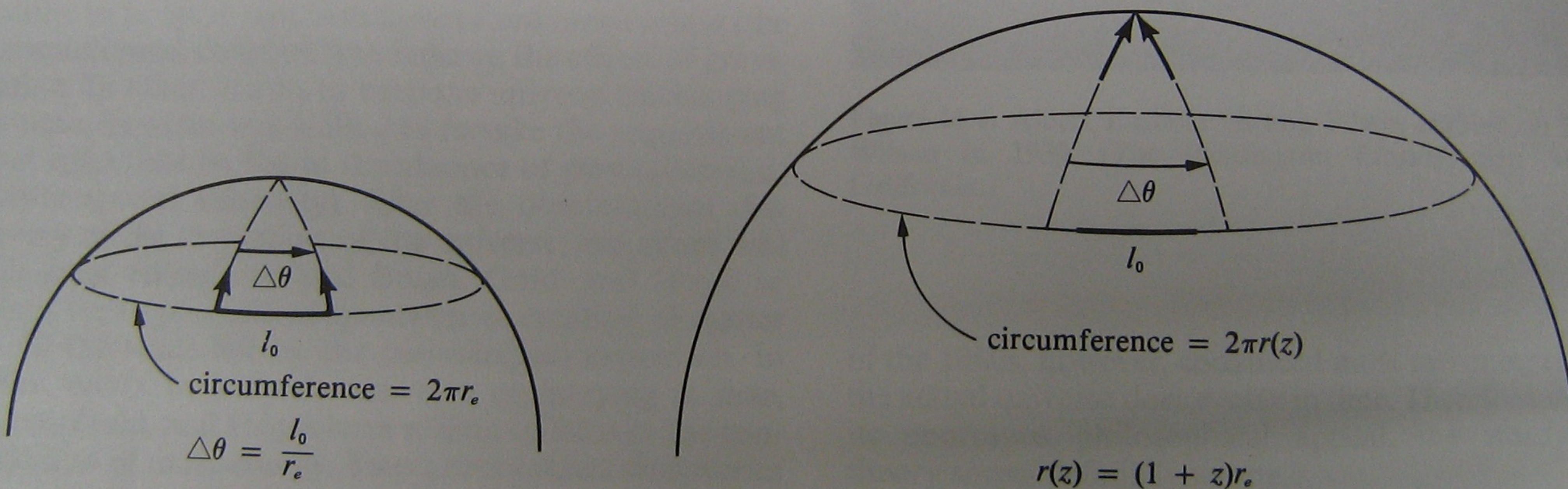


Figure P15.12

O Universo estacionário e o Big-Bang

Os quasares

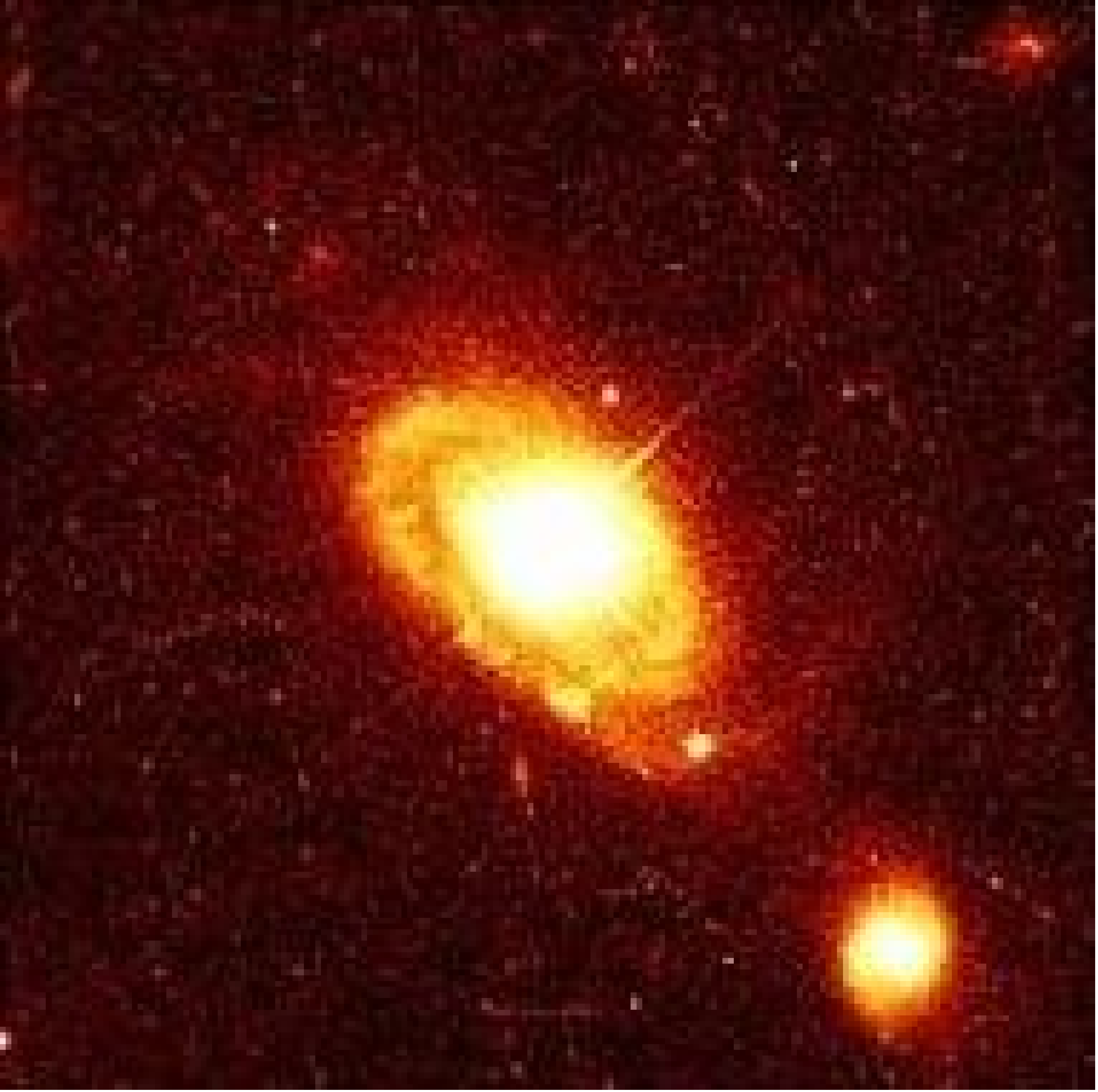
A radiação cósmica de fundo

Os diagramas L x z

o paradoxo de Olbers

a nucleosíntese no Big-Bang

Quasares e rádio galáxias



PG0052+251

este é um dos poucos quasares em que podemos ver traços da galáxia à qual ele pertence.

lembrem que pensamos que quasares são o núcleo de galáxias muito jovens.

NGC7320 – 800 km/s
as outras - 6000 km/s

os “seguidores” do universo estacionário mostram este e outros exemplos como prova que existem muitos objetos (e eles acreditam que isto vale para todos quasares) cujo redshift não é cosmológico.

neste caso, estas pessoas, argumentam que a galáxia NGC7320 está associada às outras quatro, que tem redshift 7.5X maior.

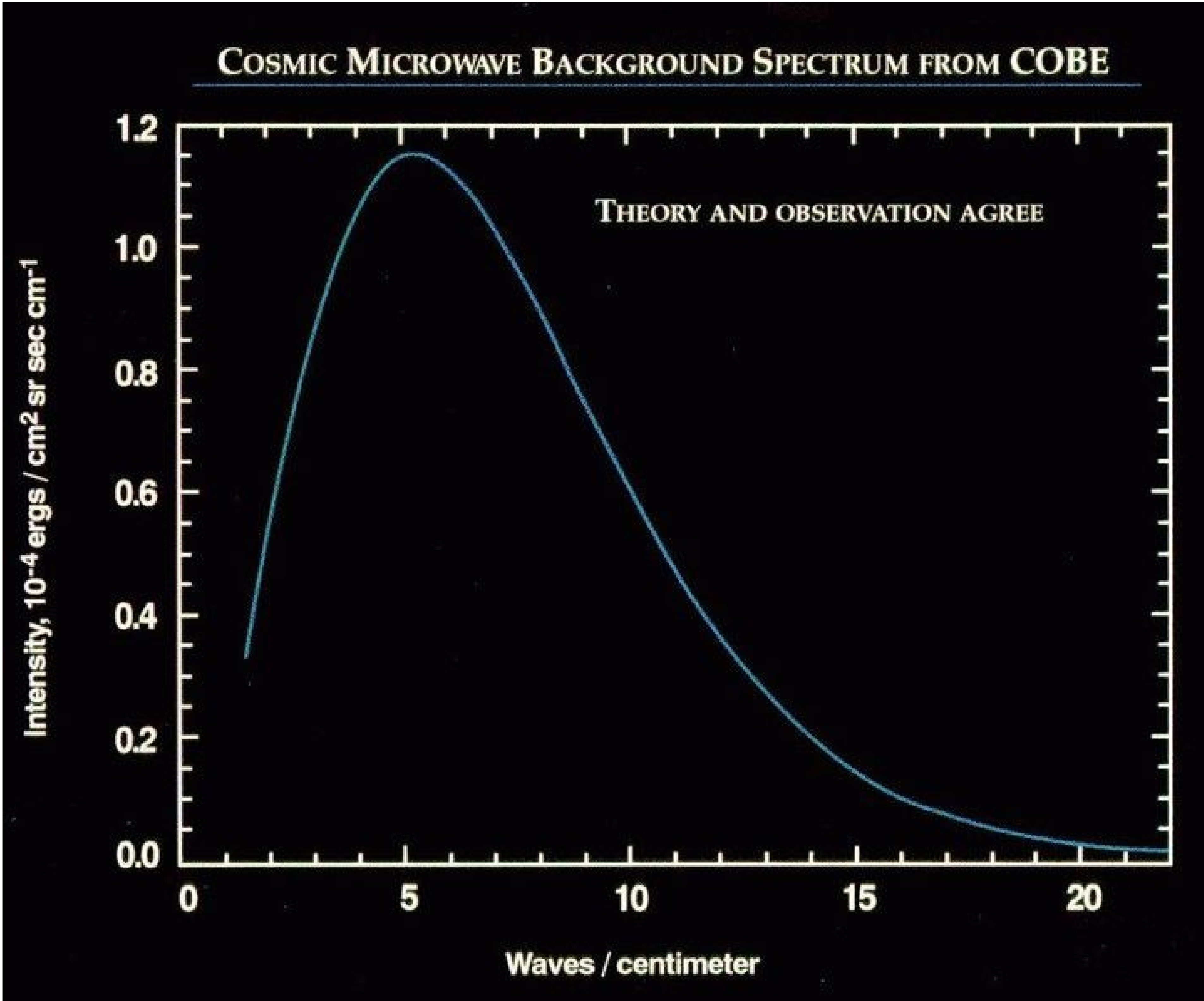
A Radiação cósmica de fundo:

vem de todas direções do céu com a mesma intensidade (é isotrópica)

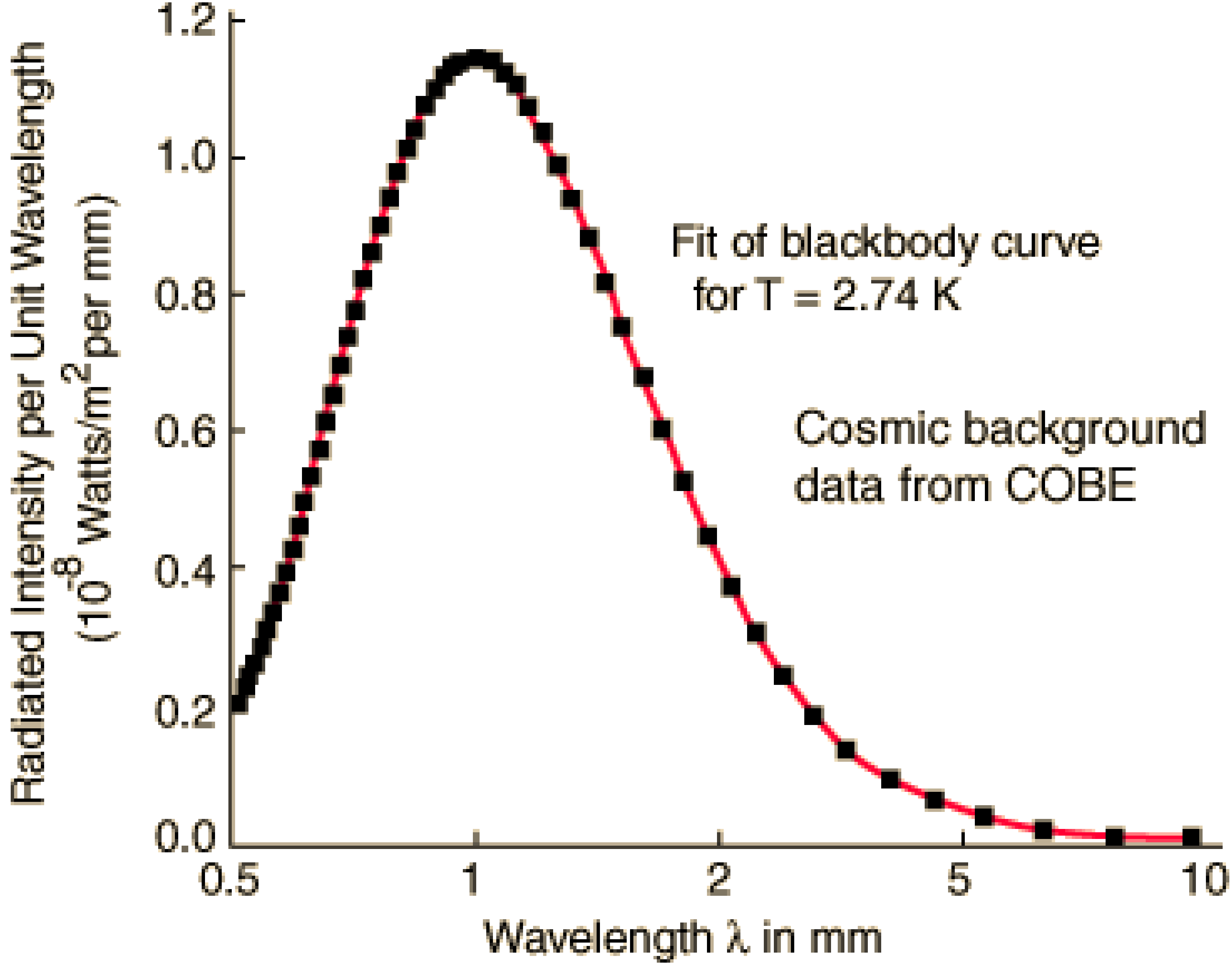
foi descoberta por acaso na década de 1960 por engenheiros que trabalhavam com telecomunicações e tentavam reduzir as fontes de ruído a um mínimo.

a radiação corresponde a um corpo negro perfeito, a uma temperatura de 2.74K

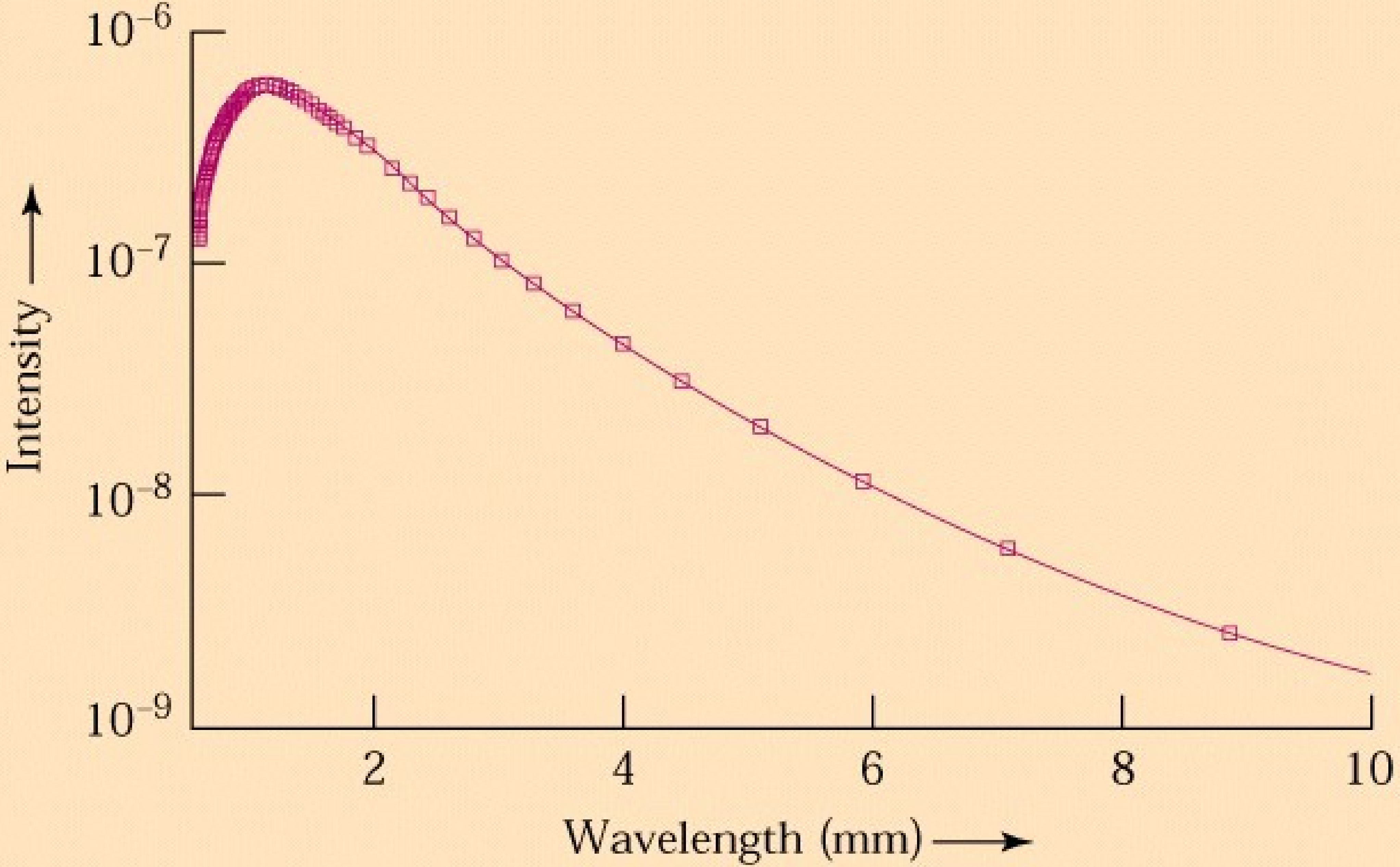
esta radiação deve ter vindo de uma época em que o Universo deixou de ser dominado por radiação e que a matéria ficou transparente à passagem da radiação. Isto corresponde a um z~1000. Isto significa que a temperatura do Universo quando esta radiação foi emitida é da ordem de 3000 K.



COSMIC MICROWAVE BACKGROUND SPECTRUM FROM COBE
THEORY AND OBSERVATION AGREE
Intensity, 10^-4 ergs / cm^2 sr sec cm^-1
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
Waves / centimeter



Radiated Intensity per Unit Wavelength
(10^-8 Watts/m^2 per mm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.5
1
2
5
10
Wavelength λ in mm
Fit of blackbody curve
for T = 2.74 K
Cosmic background
data from COBE

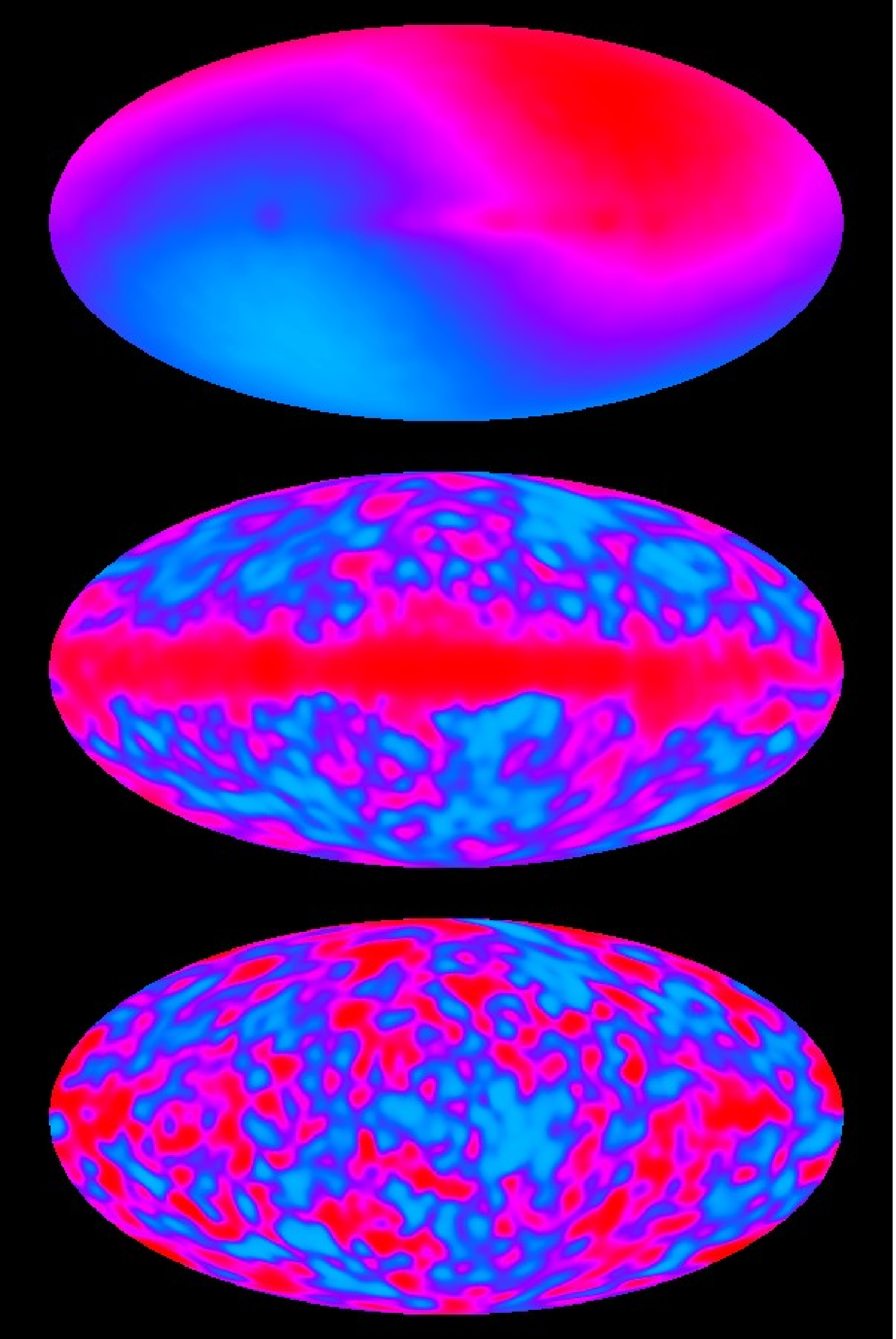


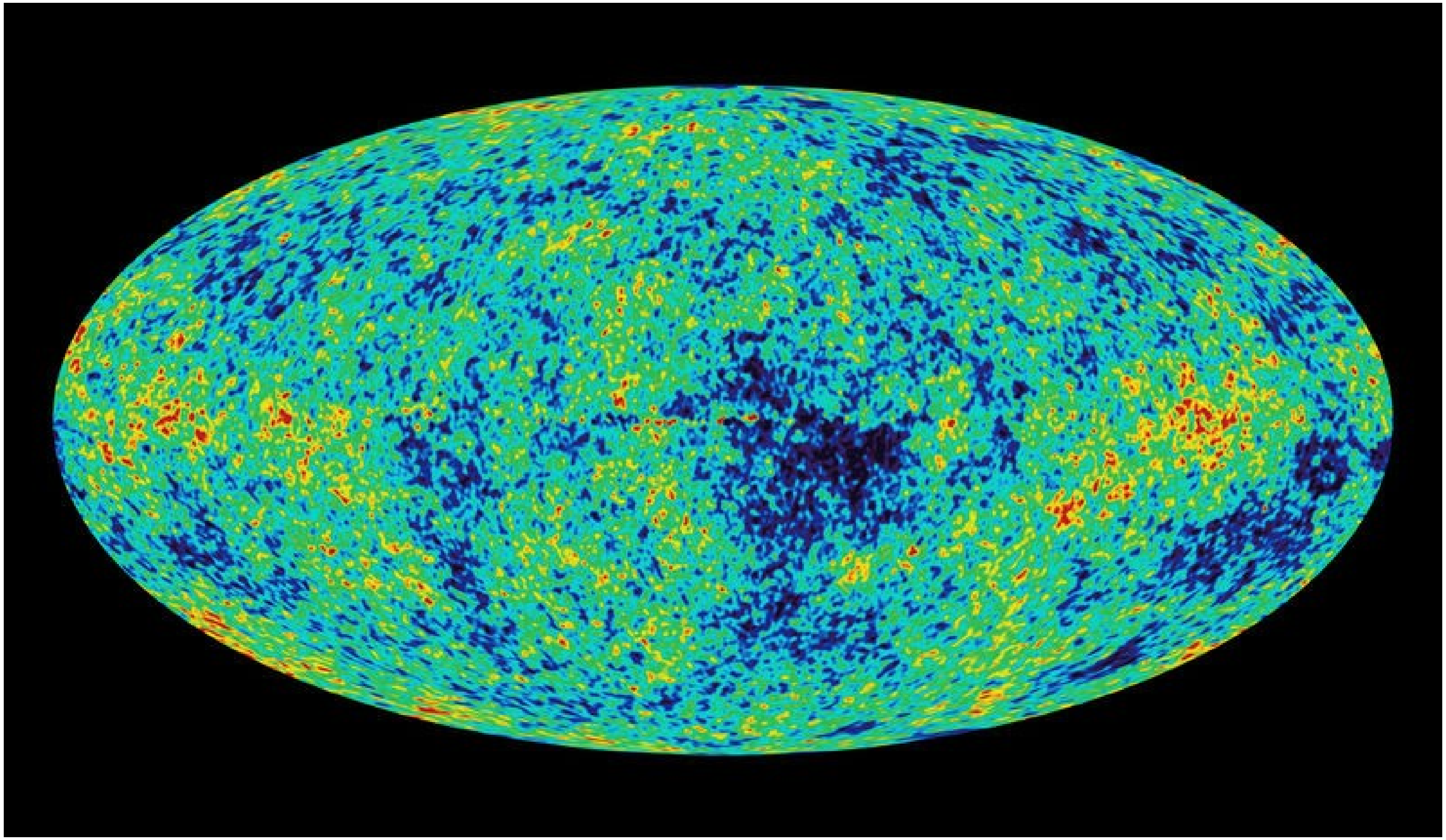
10^{-6}
10^{-7}
10^{-8}
10^{-9}
Intensity
2
4
6
8
10
Wavelength (mm)

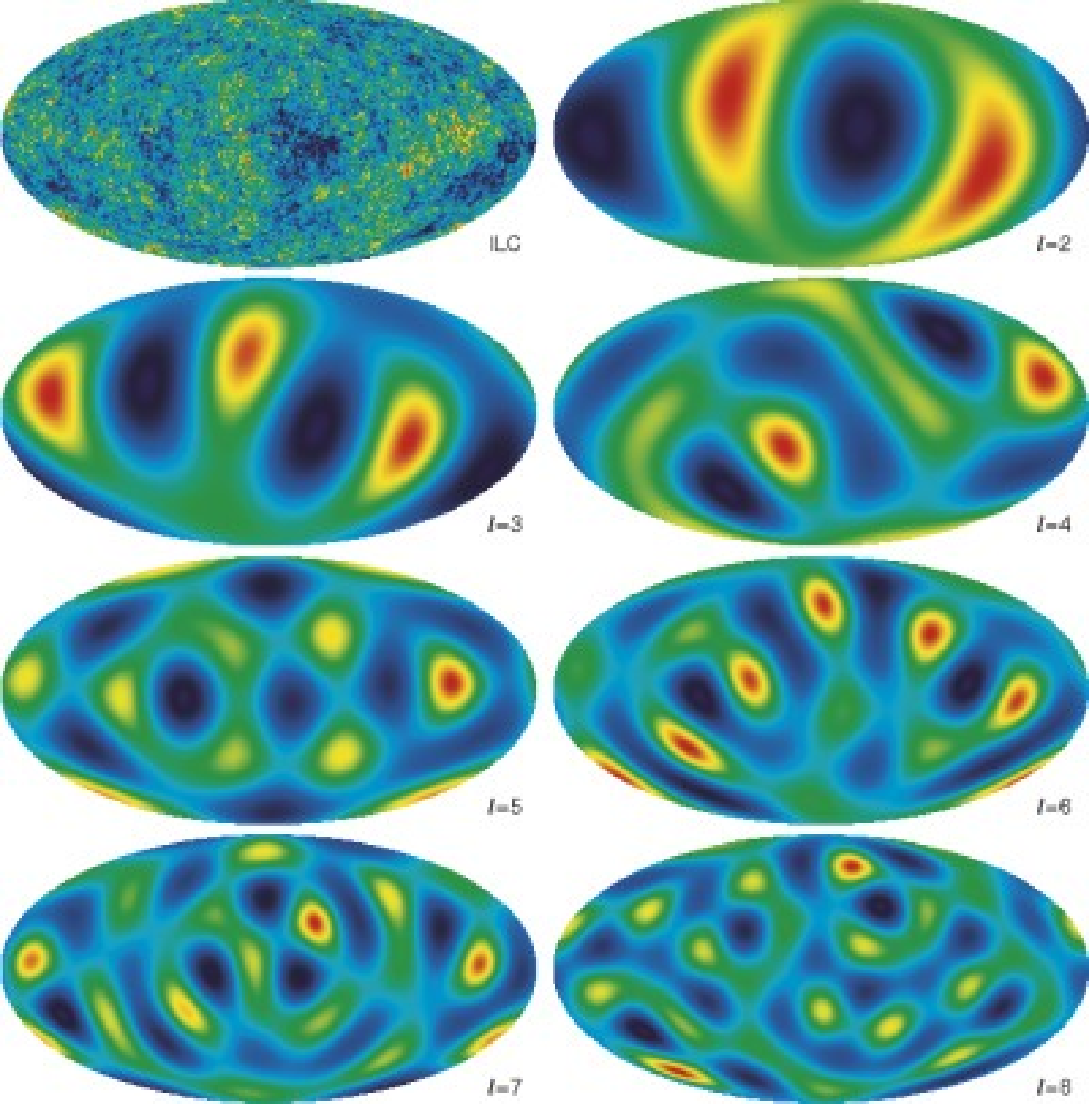
Os mapas do CMB

COBE e WMAP

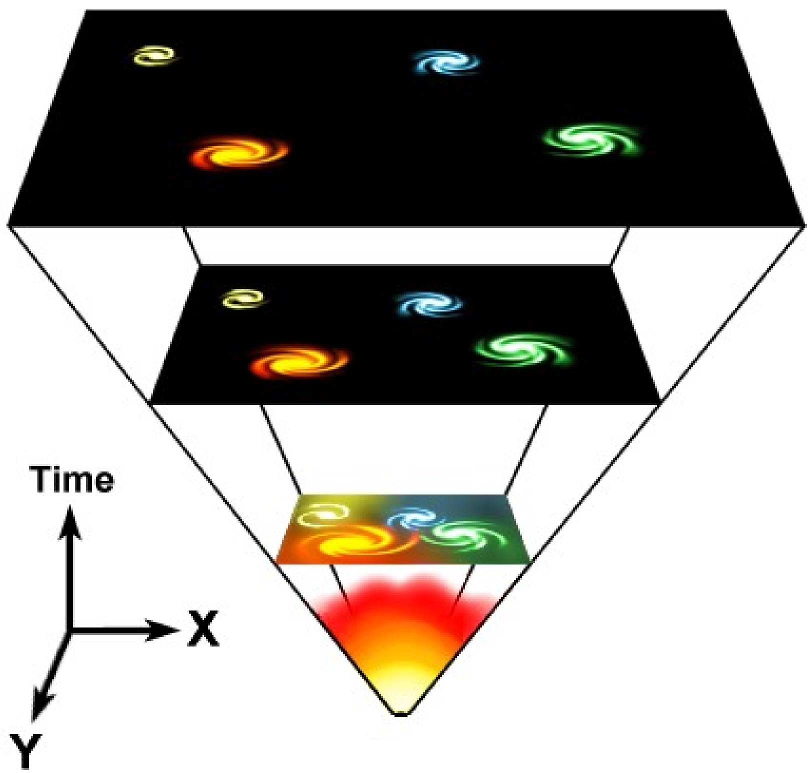
A detecção, pela primeira vez, de anisotropias em pequenas escalas angulares





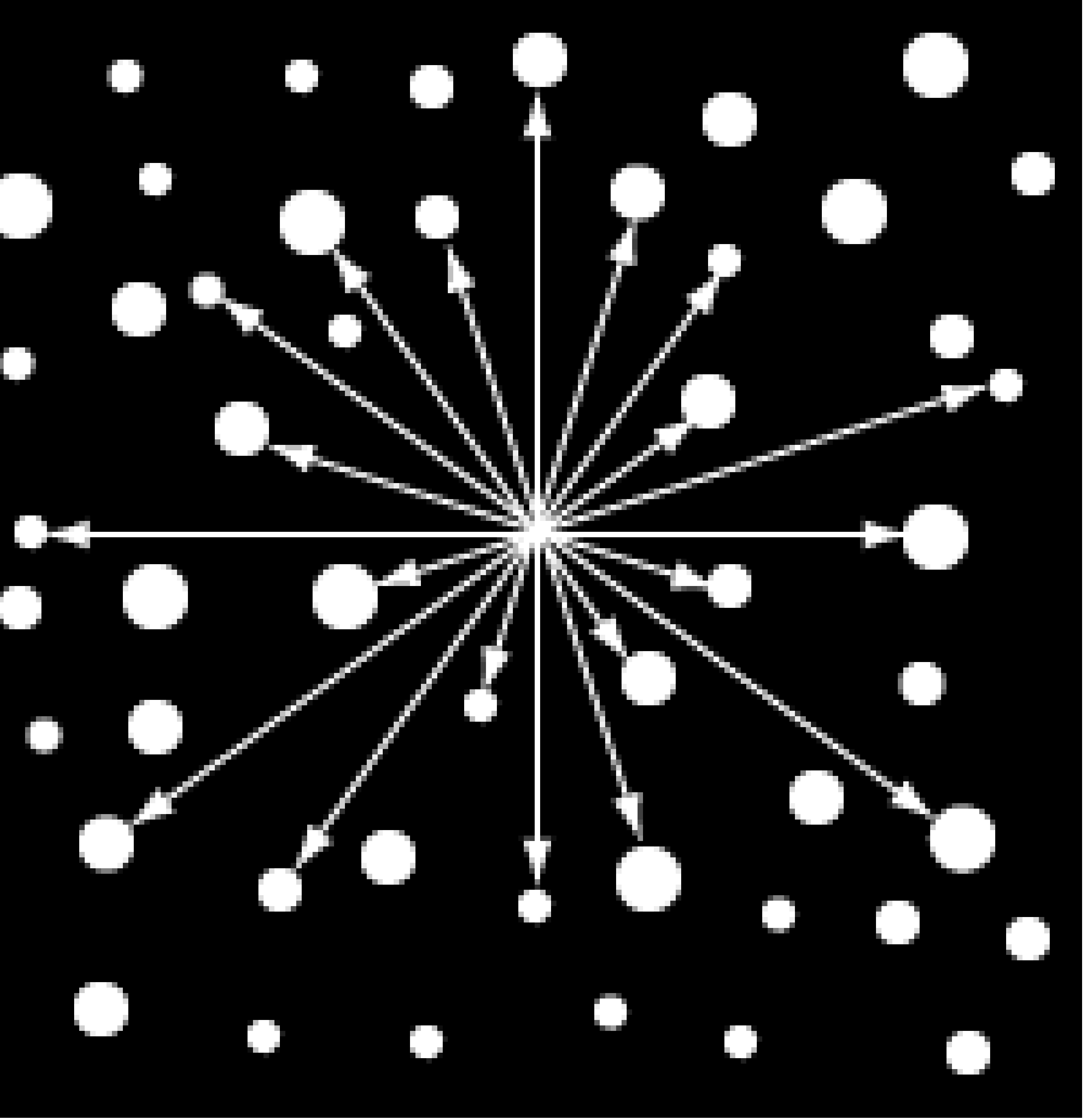


ILC
l=2
l=3
l=4
l=5
l=6
l=7
l=8

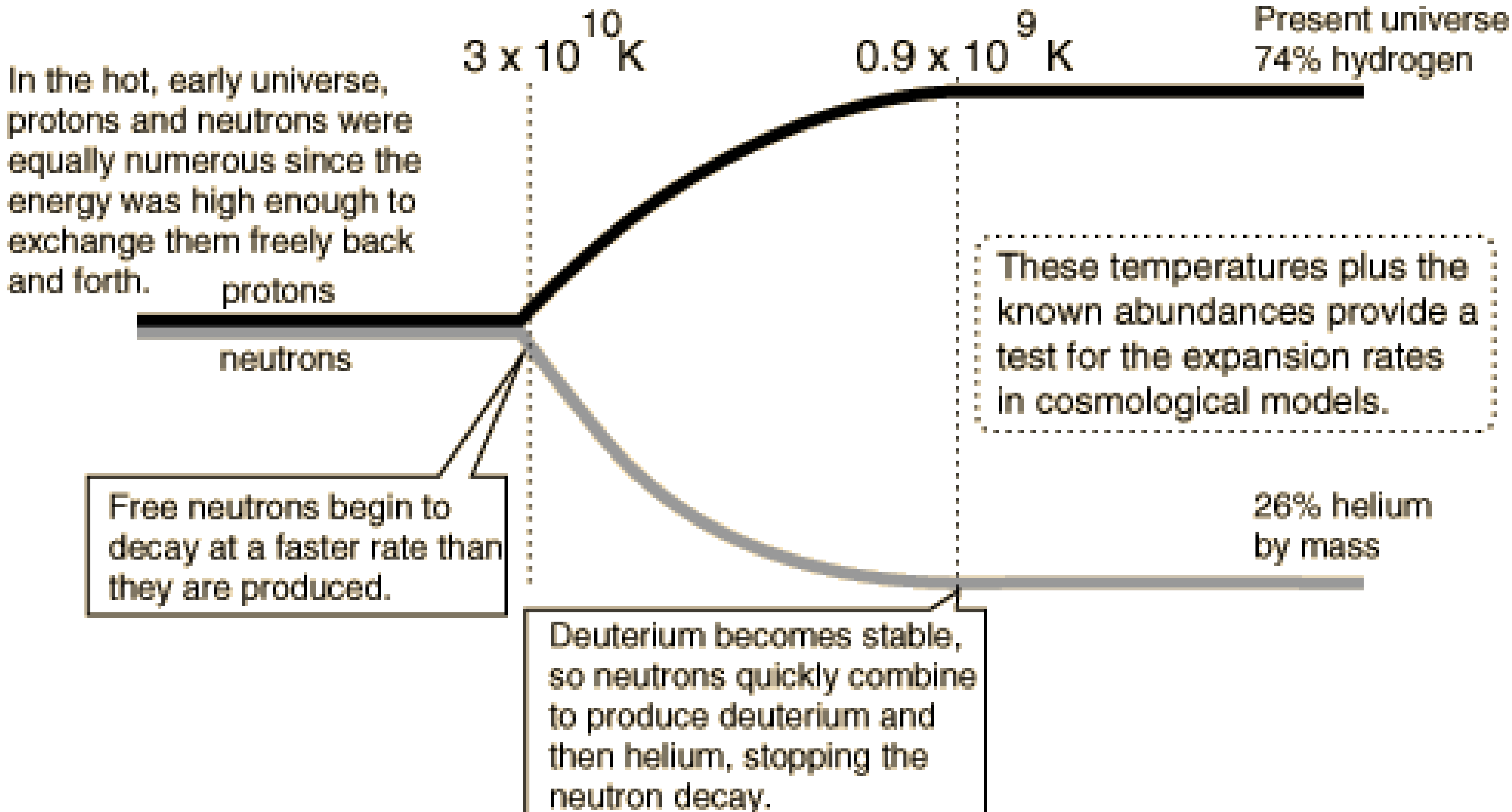

Time
X
Y

O paradoxo de Olbers:

por que o céu é escuro de noite?



Nucleosíntese no bib-bang



os primeiros três minutos:

http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

rho_rad = a Trad^4 / c^2

hoje, rho_rad = 6.5 x 10^{-34} g / cm^3

mas T_{rad} \prop D^{-1} --> rho_{rad} \prop D^{-4}

e na matéria: rho_m \prop D^{-3}

assim:

rho_{rad} / rho_{m} \ prop D^{-1}