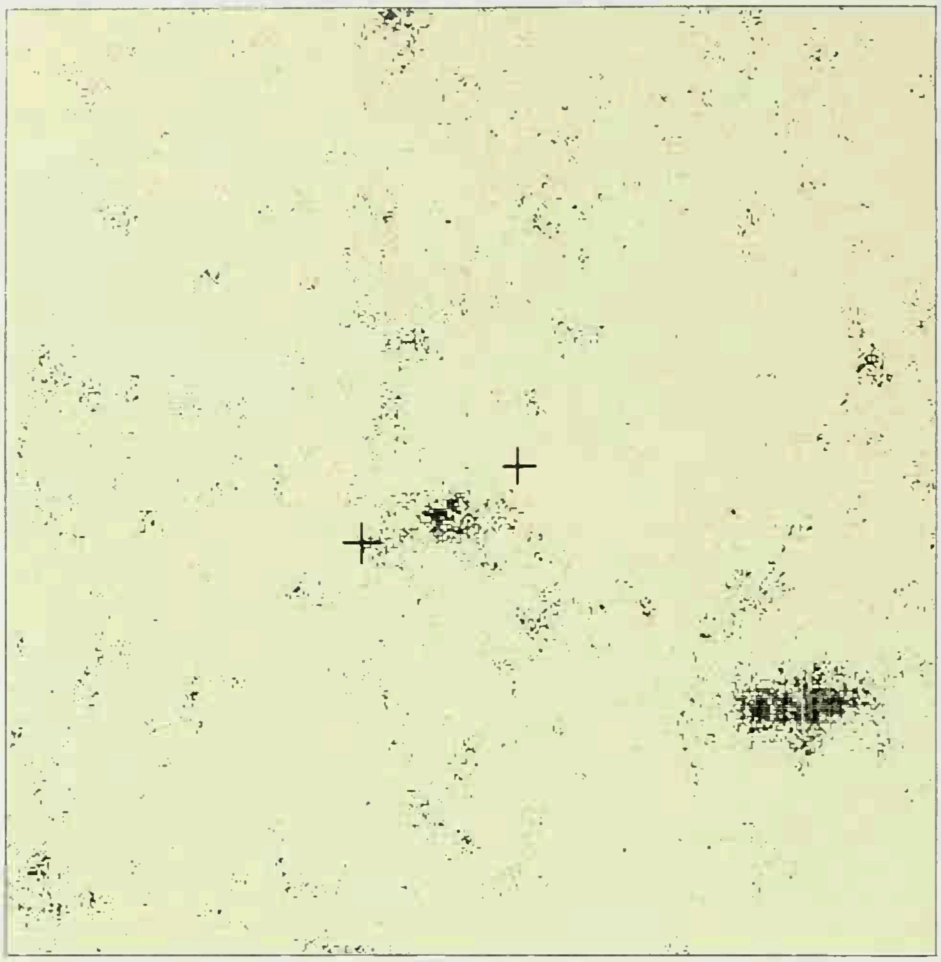

The radio galaxy 3C 184. The small chart (p. 227) shows the observation which detected the galaxy, made with the 5 km aperture synthesis radio telescope at the Mullard Radio Astronomy Observatory at Cambridge University, and published originally in a paper in the Memoirs of the Royal Astronomical Society *by C. J. Jenkins, G. G. Pooley and J. M. Riley. Compare this with the processed image on the facing page.*

forward by the American cosmologist George Gamow, that it was a **hot big bang**. It explains the origin of the microwave background and has, in fact, proved a very fruitful idea; in the light of modern nuclear physics it is possible to work out theoretically what occurred – or perhaps more correctly what could have occurred – in the very early stages of a big-bang universe, the so called **fireball stage**.

Early stages of the big bang

Some theoreticians have been extending their investigations back in time to the unbelievably short period of only 10^{-39} second after the initial explosion, when events may have had a profound influence upon the nature of the whole universe. However, we will begin our account at a much later time – 0·0002 s after the big bang! At 2×10^{-4} s, the universe entered what is called the **lepton era**, with a temperature of 10^{12} K and with many leptons (electrons and MUONS), followed by a reduction in temperature and the presence of protons and neutrons, some of which combine at a temperature of 4×10^{9} K to form the isotopes of hydrogen, deuterium and tritium.

The next stage was the **radiation era**, when the immense pressure of the radiation generated controlled the universe. This occurred some 1 000 s or rather more than 16·5 minutes after the initial explosion, when it was still very hot although the temperature was down to about 5×10^{8} K, and hydrogen began to be converted into helium. This state of affairs continued for some time, the temperature gradually dropping, until something like 3 years after the beginning not only were isotopes of hydrogen and helium formed, but some heavier elements too: the temperature was 10^{6} K. This is a very significant period because we find too much helium in the universe now to be accounted for by supposing it to have been formed inside stars. Its formation during the fireball stage seems the only satisfactory explanation, and the quantity makes it look as though it is more likely that the universe will expand forever, not alternately expand and contract. At all events the radiation era continued for a very long time, until 6×10^{5} years had elapsed and the temperature had dropped to 3 000 K.

Before this, the radiation had heated the hydrogen so that it was ionized, resulting in a vast number of free electrons. Such electrons are efficient scatterers of radiation, so radiation did not stream away; its pressure was a controlling factor and the universe was opaque. When the crucial temperature of 3 000 K was reached the universe became transparent, for the hydrogen was no longer ionized and radiation could pass outwards; its domination ended and we enter the phase we now experience where matter, and hence gravitation, takes over. The changeover point is often referred to as the point at which matter and radiation are 'decoupled'. From then on condensations occur, protogalaxies and then galaxies form, followed by condensation into stars, and so, after $1{\cdot}5 \times 10^{10}$ years we reach the present time. The temperature has dropped until it is no more than 2·76 K, the temperature of the microwave background.

Choosing the correct model universe

The hot big bang theory presents what seems, on present day evidence, to be a very satisfactory description of the early stages of the universe and the presence of the microwave background, and leads to figures for the abundance of hydrogen and helium similar to that found in our own Galaxy. But what of the subsequent expansion? Does it go on eternally – as the helium formation indicates – or will it cease, to be followed by a period of contraction? And if this does occur, will the contraction phase mean the universe ends up as a giant black hole, or will there be a bounce back to another period of expansion? There is the purely physical question of how much matter there is in the universe, and particularly whether there is sufficient to lead to a contraction. In Chapter 7 it was argued that the question is undecided, even though from present evidence it looks as if there is probably too little for this.

How, then, does all this affect our choice of a correct model of the universe? If an analysis is made of the various models other than the steady state, which has no satisfactory explanation for the microwave background, additional points emerge. In its early stages the universe looks rather like the Einstein-de Sitter model, but what of the later periods? Does the Hubble distance-velocity relation for galaxies hold? In fact the big-bang models do give slight differences for velocities at very large distances, and observations tend to favour the Einstein-de Sitter and, more particularly, the Eddington-Lemaître type of model. One can only say 'tend to favour' because the optical observations of very distant galaxies