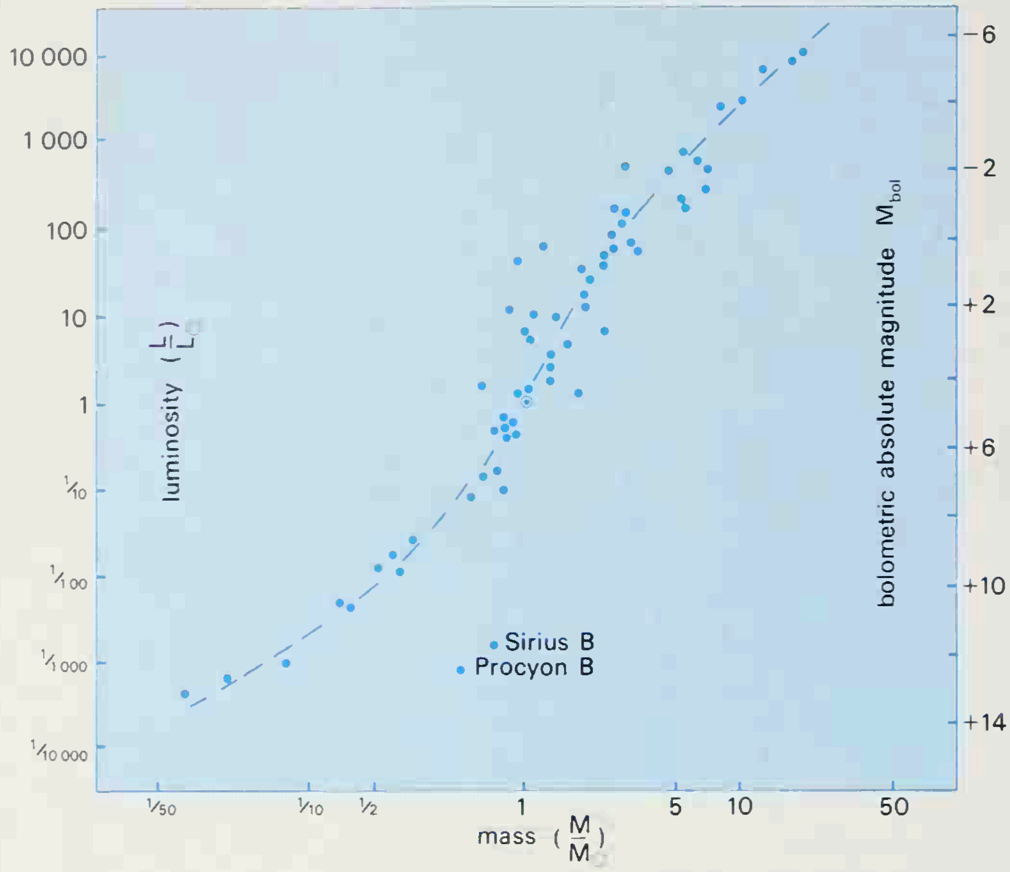

Fig. 3·9
The observed relationship between luminosity, L, and mass, M, expressed in solar units, obtained from observations of stars in binary systems. (For main sequence stars the approximation log L = 4 $\log_{10}$ M may be applied).

be found. Only a few white dwarfs have been studied by this means. Fortuitously, a few others happen to be members of nearby binary systems (for example, Sirius B and Procyon B) and so masses have also been determined by the binary orbit method.

When the range of masses is studied a surprising fact emerges. Although only about 200 stellar masses have been obtained using the above techniques, these range from white dwarfs to giants and so cover the entire range of stellar types. However, we find the masses exist in a narrow range, roughly between 0·05 to 50 times the mass of the Sun ($M_\odot$). When dealing with masses for stellar or galactic bodies it is usual to refer to the mass of the Sun as a standard comparison.

Figure 3·9 shows a plot of luminosity against mass for masses deduced from the binary star technique. This reveals the all-important **mass-luminosity relationship** so vital to the understanding of stellar evolution. It is apparent that the luminosity, L, has a definite dependence on the mass, M, of a star. Roughly speaking, L depends on the fourth power of the mass, (that is $L \propto M^4$), for stars whose mass lies in the range 0·3–20$M_\odot$. This rule is found to be applicable to the vast majority of class V stars but not white dwarfs. These appear too faint for their masses, thus betraying their intrinsically different physical forms.

Densities

We have now pieced together information which has allowed us to obtain temperatures, luminosities, masses and sizes of stars. From the last two we can calculate their mean densities. This calculation will be rather crude because it is known that stars do not have anything like a constant density from their centres to the extremes of their outer envelopes. We shall see later that the density rapidly decreases as we move outwards from the centre. However, to get a feel for overall densities look at Table 3·4.

Table 3·4 **Typical properties of certain stellar types**

star type	mass (M)	radius (R)	density (ρ) kg per m³
Sun (G2 V)	2×10^{30} kg	7×10^5 km	$1{\cdot}4 \times 10^3$
red giant (M0 I)	16 $M_\odot$	500$R_\odot$	2×10^{-4}
white dwarf (A2 VII)	1 $M_\odot$	0·015$R_\odot$	5×10^8

To demonstrate the extreme density of a white dwarf, a matchbox full of white dwarf material would weigh about 10 000 kg (equivalent to a double decker bus). Such condensed bodies have amazing properties, as we shall see later.

Chemical composition

From the absorption line spectra astronomers are also able to deduce the relative proportions (**abundances**), of the differing chemical elements observed in stellar atmospheres. These abundances reveal the chemical composition of only a strictly limited portion of the stellar atmosphere, that in which the absorption lines were formed, and provide no information about the chemical composition of the star's interior. Physical conditions in the stellar atmosphere can also be such that although certain elements may indeed be present we cannot observe their lines with Earthbound telescopes. The determination of abundances from stellar spectra is a complicated process and one must first calculate the physical conditions of temperature and pressure in the atmospheric region where the lines are being formed. Only then can the strength of the lines be used to indicate the abundance of each chemical element. The composition of the atmospheres of most normal stars turns out to be more or less the same as that of the Sun's. A compilation is shown in Table 3·5.

Table 3·5 Abundances of the most numerous elements in the universe

element	atomic number (Z)	mass number (A)	abundance by number	per cent by mass
hydrogen	1	1	92·06	73·4
helium	2	4	7·83	25·0
carbon	6	12		
nitrogen	7	14	0·1	1·13
oxygen	8	16		
neon	10	20		
magnesium	12	24	0·01	0·28
silicon	14	28		
sulphur	16	32		
iron	26	56	0·004	0·16
The remainder to Z = 103, A = 256			—	0·004

To a first approximation, it is true to say that all stars are vast globes of a mixture of hydrogen and helium. Yet subtle differences do occur and it is these which enable astronomers to pursue the questions relating to stellar evolution. In Chapter 6 we shall see that stars may be broadly grouped into what are