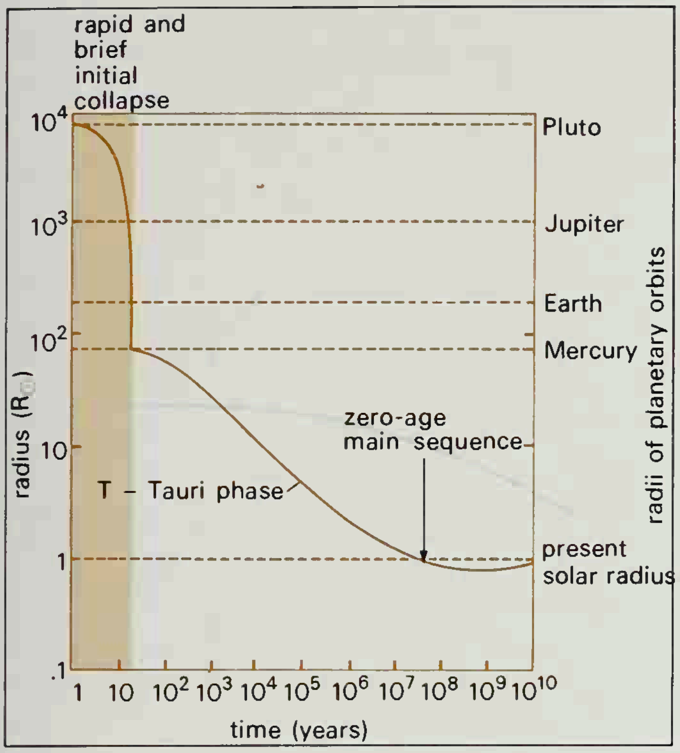
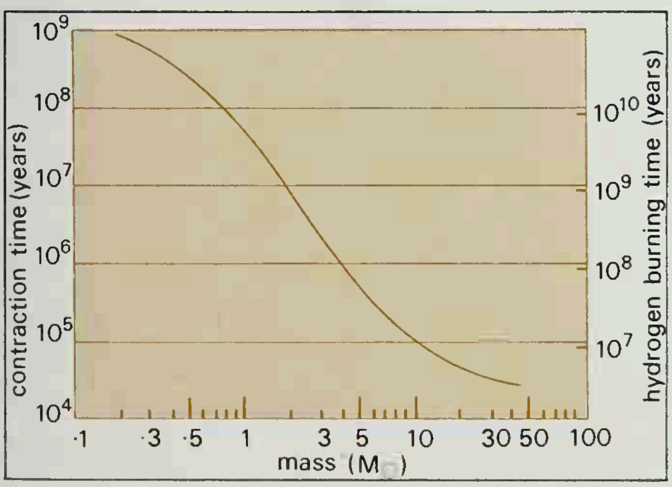


Fig. 3·13 far left: The radius of the Sun during various stages of its history. Notice the very brief initial collapse, lasting a mere twenty years, followed by the slow contraction of T-Tauri stage until arrival on the zero-age-main-sequence with the onset of equilibrium hydrogen core burning.

Evolution

When the protostar arrives on the main sequence and hydrogen burning is supplying the radiating energy of the star, it is then said to be on the zero-age main sequence, ZAMS (Fig. 3·14). A star will stay on the main sequence band of the H–R diagram as long as it is converting hydrogen to helium in its core. This represents a long nuclear time scale. As evolution progresses, hydrogen is converted into the heavier element, helium, which sinks to the core. Eventually the core becomes depleted in hydrogen fuel but enriched with helium 'ash'. For massive stars convection brings in fresh supplies of fuel to the core and burning continues, but in moderate and small mass stars hydrogen is burnt in a thin shell surrounding the helium-rich core. In due course all stars, massive, moderate and small, suffer from fuel depletion and, as a consequence, the energy supply is reduced, pressure falls and the core contracts. This causes a rise in temperature, a subsequent rise in the reaction burning rate and, thus, an increase in pressure: the core contraction is halted. During this readjustment phase, the entire star contracts and is said to be evolving off the main sequence. Such contraction releases gravitational potential energy, half of which is available for internal heating while the other half is radiated away.



At this stage the contraction of the envelope is halted by the new energy supply and it now expands, while the core continues to slowly contract, becoming hotter in the process. As hydrogen is burnt in successive shells moving outwards from the centre of the star, the helium core continues to increase until a stage is reached when it is so large that it collapses due to the pressure of the overlying layers. This instability occurs on a thermal time scale (page 60) and is accompanied by a rapid expansion of the stellar envelope. The star then moves quickly to the right of the H–R diagram (and as expected few stars are seen in this zone of avoidance known as the Hertzsprung Gap), eventually to become a red giant.

The envelope has now cooled and become convective, the radiative energy is supplied by hydrogen shell burning and the helium core is still contracting and heating. What happens next depends on the mass of the star (Fig. 3·15). For large and moderate

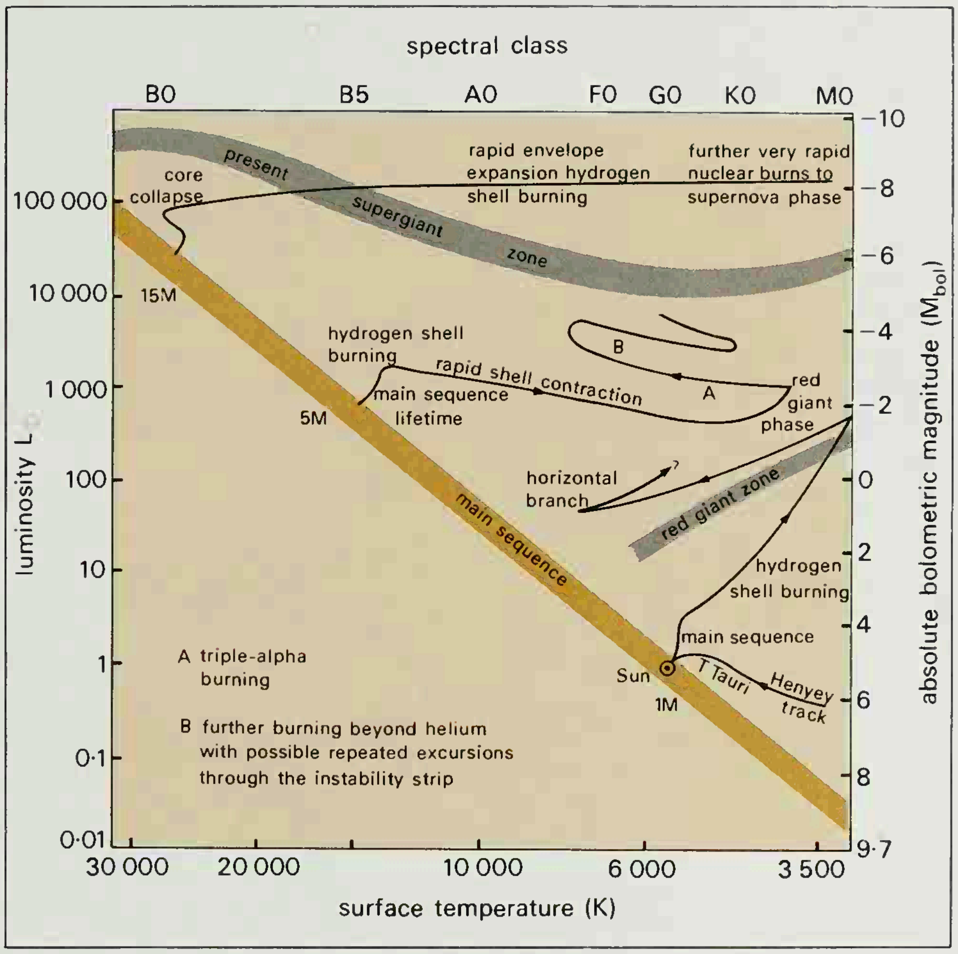


Fig. 3·15 above: H–R diagram showing possible evolutionary tracks of stars of varying mass. Many theoretical models are constructed to attempt to describe the ways in which stars evolve, all are sensitive to the mass and initial chemical composition of the stars, and for late stages of evolution they become very complex in nature. The models attempt to reproduce observations of the H–R diagram of stellar clusters.

mass stars the core temperature increases until it is about 10^7 K when helium can fuse to carbon by the triple-alpha process. This supplies energy which halts the contraction and the star settles down to another stable period, although lasting much shorter than the main sequence lifetime. Eventually helium in the core runs out as the core becomes carbon rich and begins to contract. Further evolution proceeds and may entail higher orders of nuclear burning, involving oxygen and silicon, for example, but the duration of these phases is extremely short. Sector diagrams of a main sequence star and of the envelope and core of a red giant are shown in Figs. 3·16–3·18.

Death

It is during these burnings that the very heavy elements in the universe are synthesized, probably