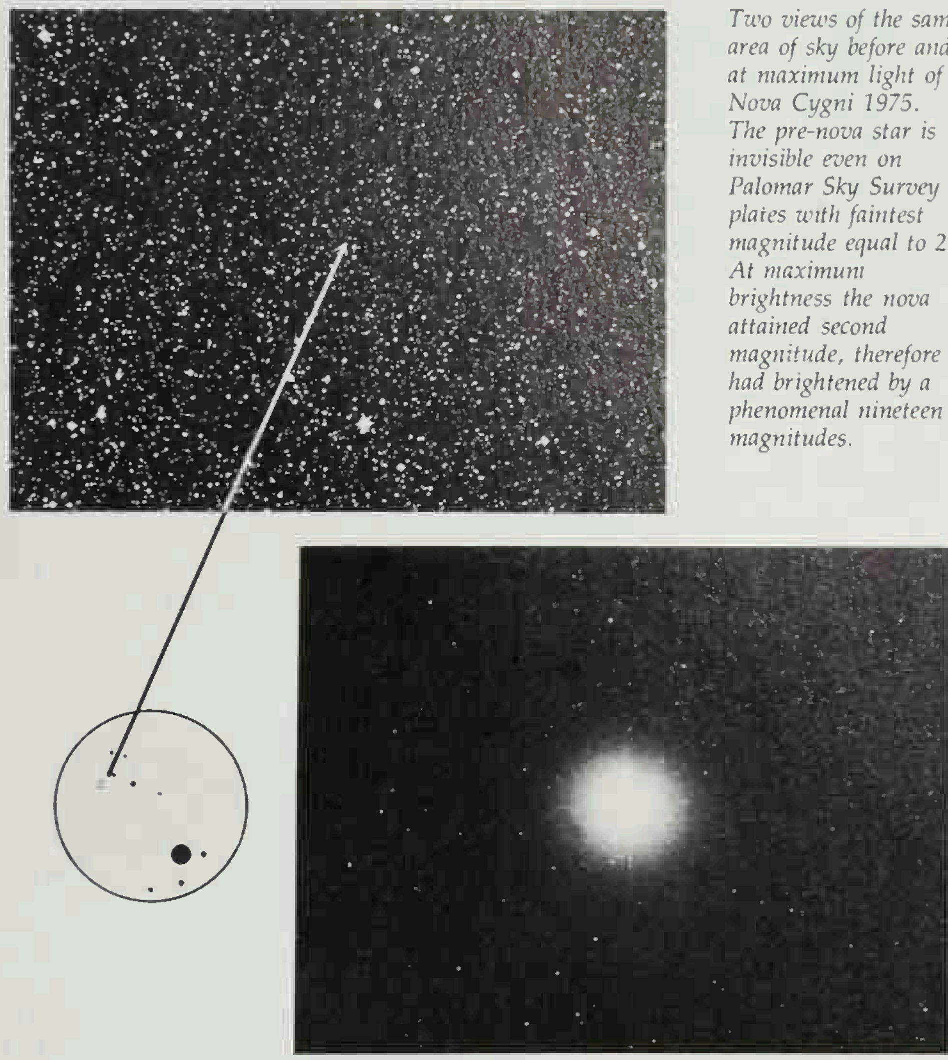
obviously malfunctioned and is only reinstated when the temperature is sufficiently high for the gas to revert from a degenerate to a normal state. Core contraction then ceases. This extremely rapid runaway nuclear burn is termed the **helium-flash**, and takes only seconds to occur. The red giant star then readjusts on a thermal time scale of a few thousand years and the star rapidly crosses the H–R diagram to the horizontal branch. Precise evolutionary tracks beyond this stage are extremely complex and can not be plotted accurately.

In 1939, Subrahmanyan Chandrasekhar calculated that the maximum mass attainable by a white dwarf was $1{\cdot}4\ M_{\odot}$, yet the masses of the stars we are discussing exceed this by factors of two to four. How can these become white dwarfs? From observations we know that stars lose mass during their lives, either by a continuous solar wind type of process (like P-Cygni stars), or by spasmodic mass loss following pulsations (like Mira-type variables). We also observe phenomena termed **planetary nebulae**, which are very hot stars (temperature about 10^5 K) surrounded by a cool expanding shell of gas. We believe these result from a major instability in which a shell containing a large amount of mass is ejected, thereby exposing the deeper, hotter regions of a star. These processes of mass loss can, it is thought, reduce the star below the critical mass limit, and when the nuclear fuels have been exhausted, the star slowly cools, radiating away its stored internal energy to become a white dwarf (see page 70).



Two views of the same area of sky before and at maximum light of Nova Cygni 1975. The pre-nova star is invisible even on Palomar Sky Survey plates with faintest magnitude equal to 21. At maximum brightness the nova attained second magnitude, therefore it had brightened by a phenomenal nineteen magnitudes.

Variable stars

The depopulated zones of the H–R diagram between the main sequence and giant branch are the domains of the intrinsic variables. These are stars whose luminosity varies due to particular internal changes. Their study is important for the clues they reveal for stellar evolution. Variables come in several categories, but two distinct groups are the explosive variables and the regular variables. Thousands of such stars have now been catalogued and some, such as Polaris (α UMi), are visible to the naked eye. The modern detection technique is to photograph a star field and then compare this, usually electronically, with a photograph of the same star field taken at a different time. Stars which have changed in brightness may then readily be picked out.

We have already met two examples of explosive variables in supernovae and planetary nebulae. **Novae** are another. They are believed to be close binary stars in which mass is being transferred from one component to a small secondary star orbiting so close that the pair are nearly in contact. The secondary is thought to be a condensed star, probably a white dwarf or neutron star (see page 70), and the inflowing mass forms a disc around it. This disc sometimes becomes unstable and large flows of material are then pulled by gravitation on to the superdense body. When this happens the material is dramatically heated and may become explosive, resulting in an outburst or flaring which we refer to as a nova (Fig. 3·19). Spectroscopic study of the sudden increase in luminosity reveals the abundances and temperatures of the chemical elements involved, and Doppler shifts of the spectral lines give the velocity of the exploding material. It is now thought that nova outbursts may recur in the same systems after an interval of some thousands of years. Less violent but more frequent flares occur in the **recurrent novae** with intervals of a few decades. The class of stars known as the U Geminorum stars show even more frequent outbursts of still less intensity, their time-scales being of the order of a few tens to hundreds of days.

Novae are not well understood, but the general idea of close-contact binaries is intriguing because of the strong tidal forces they exert on one another, and, if initially formed with quite distinct masses, they will evolve on differing time scales. Study of the evolution of such objects has become very topical within the past few years with the discovery of many

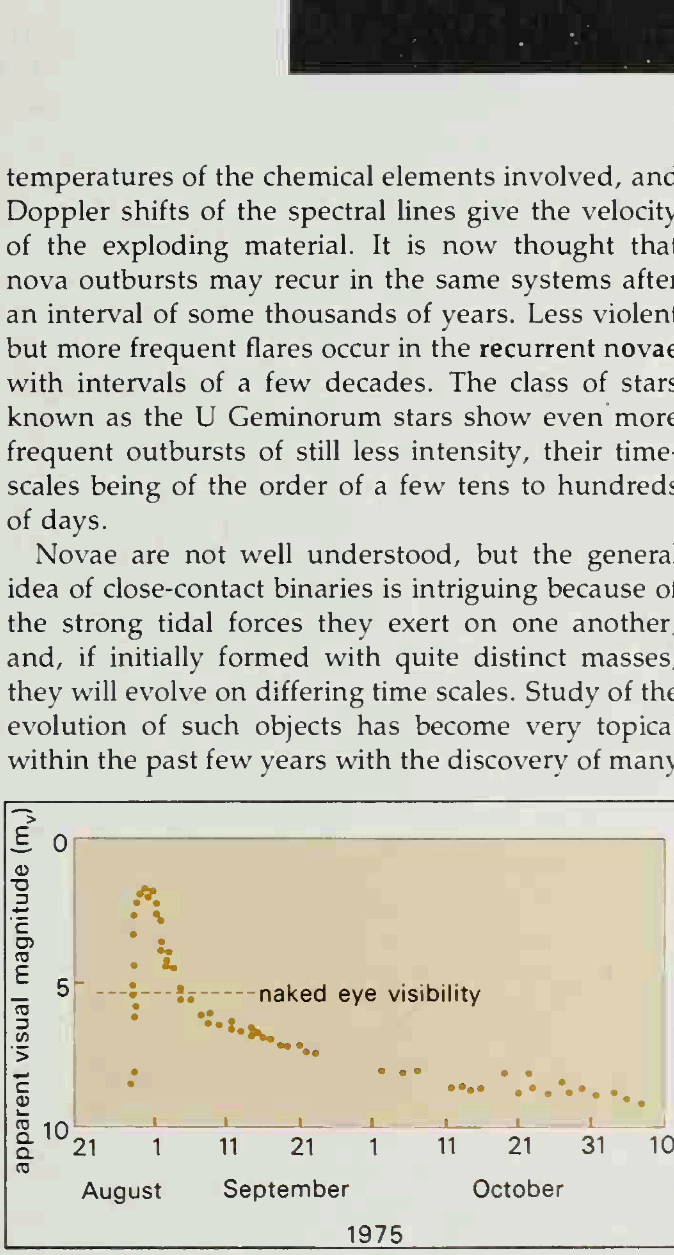


Fig. 3·19
A record of the light curve of Nova Cygni 1975 showing the very steep rise to maximum and subsequent fall before a gradual fading proceeded. Nova Cygni was observable with the naked eye for about a week.