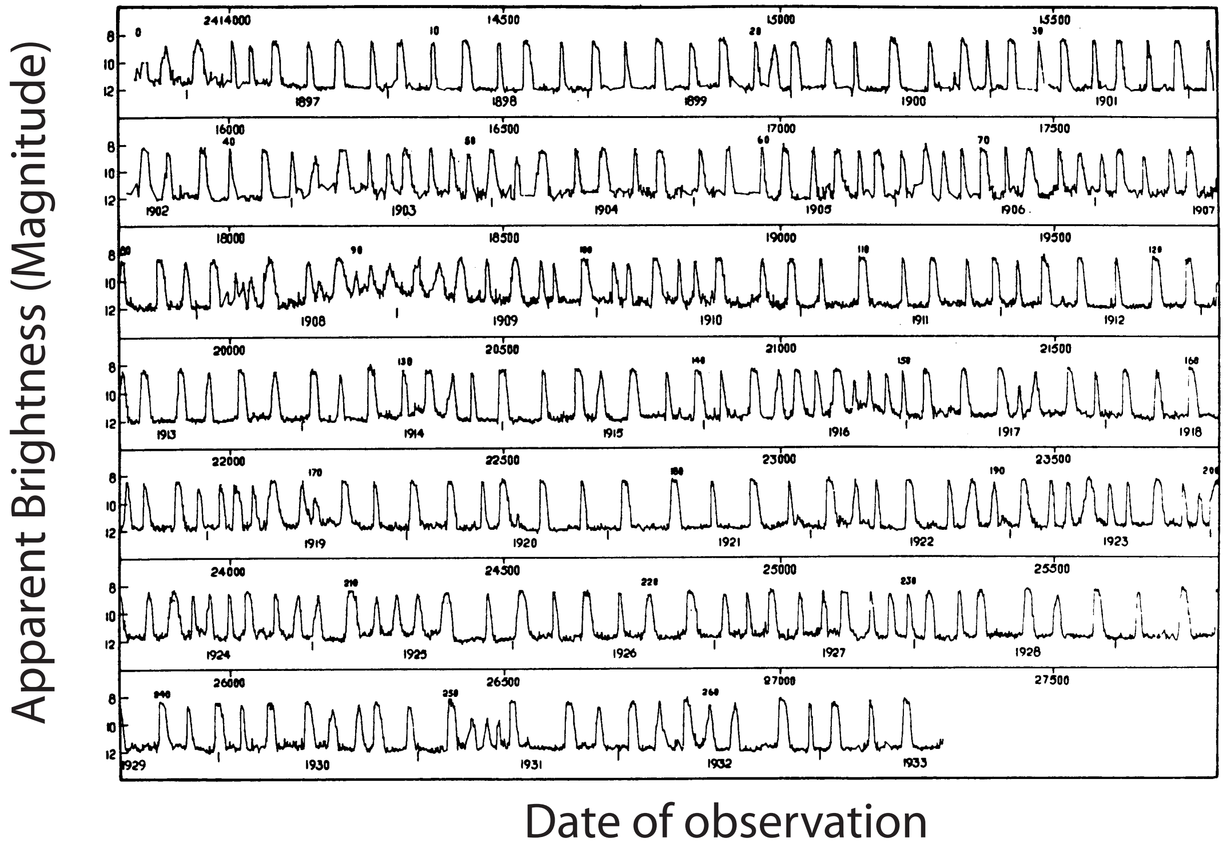
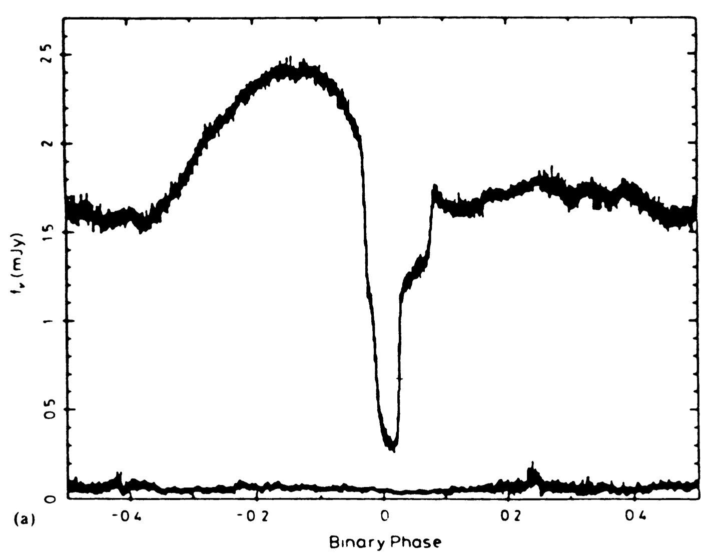
The light curve of a dwarf nova



The regular outbursts are very persistent in many of the dwarf novae as is seen in this example where regular monitoring was carried out for many years. Note also that there are periods of slightly smaller outburst which come more frequently.

Within the period of outburst, the orbital light curve shows the effects of eclipses and the hot spot where the mass transfer stream hits the disk. This is shown in the light curve of Z Cha:



Binary System Transformations

- Mass transfer to a normal star.
  - This can produce a reversal of the mass ratio.
  - This can produce a common envelope binary where the two stars retain their centers of mass condensation by joint under a common atmosphere and envelope.
- Mass transfer through a disk to a white dwarf.
  - This can produce a Dwarf Nova for higher rates of mass exchange.
  - This can produce a Classical Nova for lower rates of mass exchange.
  - This can produce a Type Ia Supernova for low rates of mass exchange and for white dwarfs very near their limiting mass.
- Mass transfer through a disk to a neutron star.
  - This can be a binary pulsar.
  - This can be an X-ray source.
- Mass transfer through a disk to a black hole.
  - This can be an X-ray source.
  - The X-rays often flicker rapidly and irregularly for this combination.
- Mass loss by the normal star.
  - This process is often associated with the X-ray binaries.
- Gravitational radiation can draw two neutron stars closer together.
  - This produces a systematic change in binary orbital period which has confirmed the general theory of relativity.
  - If the two neutron stars or two black holes are drawn close enough, they will undergo a rapid merger which produces a very strong gravity wave pulse.

Outbursts and their causes

- Dwarf Novae
  - Instability in disk viscosity.
  - Mass builds up from mass exchange.
  - Viscosity increases.
  - Light output increases.
  - Mass is dumped onto the white dwarf.
- Classical Novae
  - New hydrogen is added to the surface of the white dwarf.
  - At a critical mass and pressure, the hydrogen ignites in a region supported by quantum pressure.
  - The temperature runs away to 200 million degrees.
  - The energy production increases but is limited by the decay of unstable nucleii.
  - The hydrogen rich layer is ejected.
- Type Ia Supernovae
  - Mass is slowly transferred to a white dwarf near the limiting mass.
  - Eventually the white dwarf goes over the limit and collapses to a neutron star while ejecting its outer layers.

Novae Light Curves

The nova outburst occurs when the mass transfer stream through a disk and onto a white dwarf adds hydrogen to the star which is supported by quantum pressure. During a previous phase of evolution, the white dwarf ejected all its hydrogen containing matter and settled into a configuration where the temperature and density are high enough to burn hydrogen but where there was no hydrogen to burn. The mass transfer process changes this and builds up a layer of hydrogen containing matter on the white dwarf surface. As more matter is added, the previously added hydrogen is pushed deeper and deeper into the white dwarf. Eventually it reaches a temperature and density where it can ignite. Under these conditions, the quantum pressure prevents the thermostatic regulation of temperature and the temperature spikes very quickly. The thermonuclear runaway is prevented from reaching very high rates of energy production due to the need for some nuclei to undergo a decay regulated by the weak force. Nonetheless, enough energy is released very quickly so that the outer layer can be blown off as a nova. The light curves for two novae are shown below:

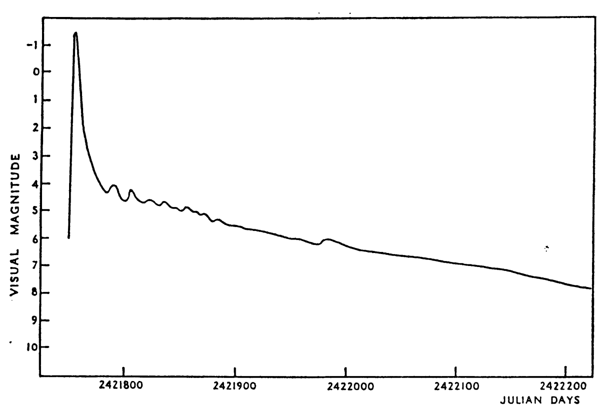


Fig 53

Fig. 53 – Light curve of Nova Aquilae (1918) (*Courtesy of the British Astronomical Association*).

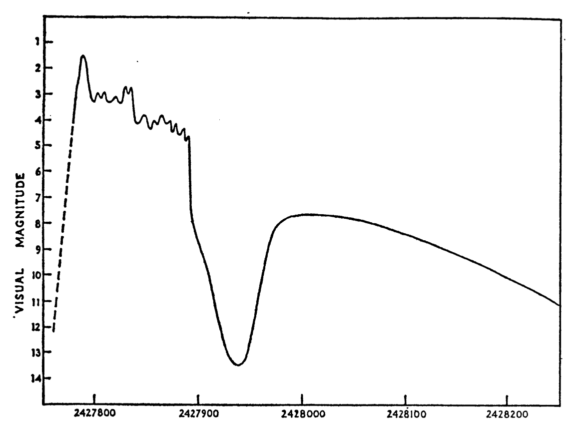


Fig 55

Fig. 55 – Light curve of Nova Herculis (1934) (*Courtesy of the British Astronomical Association*).

The dates for these two novae are given in Julian days. This is a system of day counting which has as its zero point a time well before the zero point of our calendar. The astronomical magnitude scale is logarithmic and a change of 5 magnitudes corresponds to a brightness change of 100. Since these novae show a change of 10 to 13 magnitudes, they undergo a brightness increase of 10,000 to 30,000.

Evolutionary sequences leading to Supernovae and black hole formation

The supernova outburst comes when:

- The mass of the quantum pressure supported star exceeds the mass limit of 1.5 times the mass of the sun.

- The central parts of the star undergo a sequence of nuclear transformations leading to iron.

- The iron disintegrates:
  - due to high temperature in which case it absorbs much thermal energy and leads to a Type II Supernova in a massive star.
  - due to the forcing of electrons into the protons producing neutrons. This leads to a reduction of the quantum pressure and causes the core to collapse in a low mass star and the formation of a Type I Supernova.

- Either collapse must be turned around. A collapse without a turnaround could lead to the quiet disappearance of a star.

- The core bounce sends a shock wave out through the star and blows off the outer layers.

- The shock wave is so strong that the matter processed through the inner part of it is transformed to unstable nuclei.

- The late time light curve of the supernova is supplied by energy due to the nuclear decay of the unstable nuclei.

Black Holes in binary systems.

- We can determine the mass of both components in some binary systems and in a few cases they are too large to be a neutron star.
- These systems are bright in X-ray emissions from the inner parts of their accretion disks.
- The X-rays flicker quickly. Light travel time gives an estimate of the size of the flickering region and leads to the conclusion that the region is very small.

The formation of the black hole can be problematic.

- When the mass is added gradually to a white dwarf, it can lead to the supernova outburst. This produces the Supernova of Type 1a and leaves a neutron star.
- When rapid mass transfer occurs from a red giant to a white dwarf, the mass gaining is so rapid there is no place for the matter to go. A common envelope binary is formed: