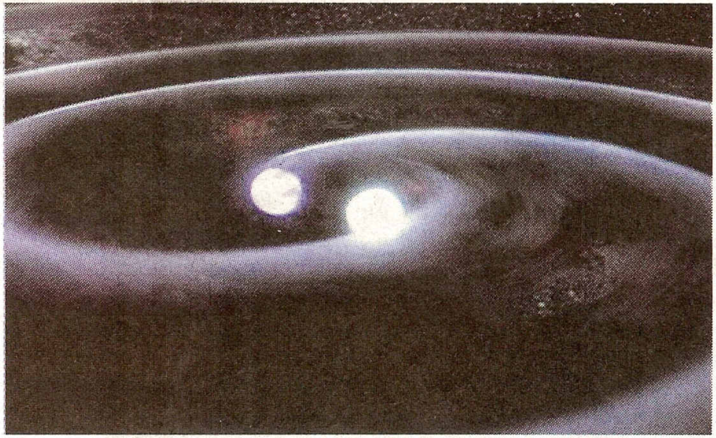
STAR SYSTEM Left: CH Cyg, a 'symbiotic' star system in which a white dwarf feeds from the wind of a companion red giant star. PHOTO: NASA/TOD STROHMAYER (GSFC)/DANA BERRY/CHANDRA X-RAY OBSERVATORY) Right: Two dense white dwarf stars orbit each other every 321 seconds. PHOTO: NASA



BRAINSTORMING From left to right: Astronomers Fred Whipple, Chandra, Gerard Kuiper, Gerald Mulders PHOTO: NASA/CXC/SAO.

The sky was his limit!

IN REMEMBRANCE October 18 was the birth centenary of the Physics Nobel Prize winner for 1983 S Chandrasekhar. The astrophysicist has come to be known for the Chandrasekhar limit, which concerns a class of stars called white dwarfs. The X-ray observatory launched by NASA in 1999 was also named after the great man, writes **C Sivaram**

October 18 marked the birth centenary of S Chandrasekhar, a renowned astrophysicist, immortalised by the Chandrasekhar limit discovered by him in 1930, when he was barely twenty. His contributions span topics such as dynamics of stars, their evolution and stability, radiation transfer processes in their interiors and atmospheres, magnetic fields and rotation, black hole dynamics, to name a few! The Chandra X-ray observatory launched by NASA in 1999, in an elongated orbit has proven to be as prolific and successful as the person after whom it has been named thanks to the path-breaking discoveries in X-ray and high energy astronomy.

The Chandrasekhar limit concerns a class of stars called white dwarfs representing the final stage of 'average' stars like the sun, intermediate in mass.

The story begins with the finding around 1860, that the bright star Sirius has a companion star (dubbed Sirius B) orbiting it but several thousand times fainter and invisible to the naked eye.

However, it had a high surface temperature which implied a radius comparable to the Earth. This in turn implied (as Sirius B was inferred to have a mass about that of the Sun, i.e. three lakhs times more than the Earth), an absurdly high density of a few tons per cubic centimeter. Other white dwarfs were also found, the name actually denoting their high temperature (and hence bluish white light) and small size.

Astronomer Arthur Eddington in his 1926 magnum opus, 'The Internal Constitution of Stars' listed out the attributes of most types of stars, but noted that the extremely high density of white dwarfs appeared contrary to the then known laws of physics.

The advent of quantum mechanics with the implications of the uncertainty principle and new statistical mechanics, solved this puzzle as shown by R Fowler.

White dwarfs, marking the end point of stellar evolution represent collapsed configurations in equilibrium; the gravitational force tending to compress them being balanced by the quantum degeneracy pressure caused by the dense packing of electrons and ions. (The pressure occurs even when there are no thermal motions.)

The estimated radius depends only on the mass and (for a solar mass) agreed with the observed value for Sirius B. In this theory, a star of any mass can end up as a white dwarf.

Chandrasekhar, however, realised around 1930, that at higher densities, the electron velocities would be relativistic, so the formula for the relativistic degeneracy pressure must be used to counteract the gravitational force.

But he discovered that the use of this formula implied an upper limit to the mass of the white dwarf which can be supported against its self-gravity.

This worked out to be about 1.5 solar mass. Any white dwarf more massive than that would collapse under its gravity. He supported this conclusion in the next few years with intensive numerical calculations. Stalwarts like Eddington were unhappy with this result partly because many stars were known even then to be several times more massive than the sun. Very little was known at that time about even how stars generate their energy or how they evolve. Now we know that a massive star loses a considerable amount of mass as it evolves through a giant phase through stellar winds, etc.

Fallout with Eddington

The public confrontation with Eddington upset Chandrasekhar, who soon left England to work in the US for the rest of his life. Within a decade, he became a distinguished professor at the University of Chicago and a fellow of the Royal Society. A few years later, he became editor of the Astrophysical Journal.

During his nearly two-decade tenure he raised its status to the world's leading journal in astrophysics.

A few years after he left England, he summarised the status of stellar structure, including his own research in a classic monograph 'Introduction to the study of stellar structure', University of Chicago Press, 1939.

He elaborated on a new effect called 'dynamical friction', a force arising because of the gravitational effect of a star cluster or a dwarf galaxy as it travels through an extended distribution of stars which cause an enhancement of density of stars behind it. Consequently an increased gravitational force would slow down its motion. It is called dynamical friction and is important in various astrophysical situations like decay of orbits of globular clusters, merging of galaxies, motion of black holes in a distribution of stars etc.

> “ THE CHANDRASEKHAR LIMIT AND ITS IMPORTANCE WAS REALISED AS OBSERVATIONAL EVIDENCE ACCUMULATED FOR NEUTRON STARS (ESPECIALLY PULSARS) AND BLACK HOLES. MOST OF THE HIGH ENERGY PHENOMENA IN ASTROPHYSICS ARE ASSOCIATED WITH THESE SO-CALLED COMPACT OBJECTS.

After several key papers on the radiation equilibrium of stellar atmospheres (over 25), he wrote the classic monograph 'Principles of radiative transfer' in 1950. This is also used by people working in diverse fields like reactor neutron transport, pyrometry and spacecraft shields etc. His work on radiative transfer had overlapped with well known Russian astrophysicist Ambartsumiyan.

The Chandrasekhar number

A new dimensionless parameter, the Chandrasekhar number, is named after him. His work with Brazilian Mario Schonberg, led to the Chandrasekhar-Schonberg limit, which gives the mass limit for the burnt out hydrogen core of a star before it again collapses to trigger helium burning, causing the outer layer to expand.

In the 1960s, Chandrasekhar became interested in the role of Einstein's general relativity in astrophysics. He investigated the classic problem of the stability of rapidly rotating celestial objects, which assume various shapes.

These objects are also important in nuclear physics. The role of gravitational radiation in the stability of these objects led to the Friedmann-Schultz-Chandrasekhar instability among other things. It led to another monograph on 'Ellipsoidal figures of equilibrium' in 1969.

His study on scattering of various types of radiation by (especially) rotating black holes led to the treatise 'Mathematical theory of black holes' in 1983, the year he also received the Nobel Prize in physics shared with nuclear astrophysicist William Fowler.

The importance of the Chandrasekhar limit was realised as observational evidence accumulated for neutron stars (especially pulsars) and black holes.

So heavier stars end up as neutron stars or black holes after exploding as supernovae and producing the heavier elements! Most of the high-energy phenomena in astrophysics are associated with these so called compact objects (white dwarfs, neutron stars and black holes).

Deccan Herald, Spectrum Science, Tuesday, Oct 19, 2010, pp.3