ASTRONOMY 1102 – 1

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ANSWERS to HW7, due April 5, 1999

The following represent comprehensive answers to the questions asked. Only the main idea is required for full credit in a given question.

1) Red dwarfs are red, Main sequence stars of low mass, so their spectral type is MV.

White dwarfs are cooling, dead stars, with no internal nuclear burning, produced as the endpoint of evolution of main sequence stars less massive than $8M_{\odot}$.

Brown dwarfs are stars with less than $0.08M_{\odot}$, that never attain temperatures high enough to fuse H into He.

Black dwarfs are the ultimate endpoint of white dwarfs, when they have cooled to invisibility.

2) Main sequence stars with mass M will die when all nuclear burning has ceased, leaving one of three possible types of dead stars: for $M \leq 8M_{\odot}$ a white dwarf, for $8 < M \leq 50M_{\odot}$ a neutron star, for $M > 50M_{\odot}$ a black hole. So,

$$5M_{\odot} \rightarrow \mathrm{WD} \qquad 25M_{\odot} \rightarrow \mathrm{NS} \qquad 50M_{\odot} \rightarrow \mathrm{BH}$$

3) White dwarfs explode when they have accreted enough matter so that their mass exceeds the Chandrasekhar Mass ($1.4M_{\odot}$). This can happen if the WD accretes matter from a companion star in a binary or when it merges with another star. What follows then, is a C detonation which according to most calculations leaves no neutron star. We see such explosions as Supernovae of type Ia.

4) A type II SN is the result of the collapse of a massive star. The most likely product of this collapse is a neutron star but the most massive stars ($M > 50M_{\odot}$) may produce a black hole. However, we do not know if such explosions would look like ordinary SN II or would produce an even brighter event for which we simply do not have enough data.

5) Pulsars emit along a narrow beam in analogy with a "lighthouse". This beam is directed along the magnetic pole of the NS which may be spinning in general around a different axis. Therefore the beam sweeps a hollow cone in space. Only if we happen to be within this cone (actually in the "wall" of the hollow cone), and if the pulsar is not too far away, would we see it as a pulsar. Eventually, after a million years or so, the neutron star's rotation (spin) will have slowed down so much that it no longer emits pulsed radiation and what is left is an old, slowly spinning neutron star. These must be very numerous in the Galaxy; roughly the result of many generations of pulsars. The Galaxy is 10^{10} yr old, so the total number of old NS may be estimated as (number of pulsars seen)x(age of Galaxy)/(lifetime of typical pulsar) $\sim 10^9$ pulsars.

6) Millisecond pulsars are seen in binaries much older than the lifetime of an ordinary spinning pulsar. They are thought to have been spun up by accretion in a binary. Since close binaries form readily in globular clusters it is not surprising that a large fraction of millisecond pulsars are found in globular clusters.

7)PSR 1913+16 consists of two neutron stars orbiting one another, one of which we do see as a pulsar. The other NS may also be a pulsar but we do not see it. Since its discovery in 1974 it has been seen to evolve exactly according to General Relativity: its orbit is getting smaller and the period is getting shorter at the rate predicted by Einstein's GR; and the axis of the orbit (or the perihelion) advances at a rate of 4 degrees every yr (much faster than in the case of Mercury: 43 arcsec every century!).

8) The gases from a SN explosion expand froming a supernova remnant (SNR). Type Ia SNe do produce a SNR but leave no NS. Type II SNe leave a NS but the SNR expands and fades away in about 10^4 yr so you would expect only about 10 % of pulsars to have any association with a nearby SNR.

9) An orbiting NS binary, in order to produce pulses with the observed pulsar periods of seconds and fractions of second, would decay and merge very rapidly. The orbital period of such a NS binary would rapidly get shorter due to the emission of gravitational waves. In contrast the periods of pulsars do change but the periods get longer and at a much slower rate.

10) Deflection of light (first verified in the total solar eclipse of 1919)

Advance of Mercury's perihelion (GR explains the "extra" 43 arcsec/century of precession which cannot be accounted for using Newtonian mechanics and taking all the perturbations of the planets into account)

Gravitational Redshift (early attempts to measure it in the spectral lines of the sun and nearby white dwarfs failed, but it was confirmed by a famous experiment conducted in 1960 by Pound and Rebka in Harvard)

11) At the photon sphere or photon radius ($1.5R_S$)

12) At the photon sphere the light from a flashlight pointed within 90 degrees from the vertical (defined as the direction of the Zenith, exactly opposite to the center of the black hole) can escape: the exit cone has an opening of 90 degrees. At the event horizon the exit cone vanishes: even a light beam pointed toward the Zenith could not escape.

13) Black hole candidates are X-ray binaries in which the compact accreting star, emitting copious X-rays but little optical radiation (this requires either a WD, a NS or a BH), has a mass of $> 3M_\odot$ so it cannot be a white dwarf or a neutron star. The binary for which the quality of available data is highest so that it constitutes the best case is currently V404 Cygni.

14) Mass, Angular Momentum (rotation), Electric Charge.

15) $R_S = 3(M_{BH}/M_\odot)$ km; so for a 10 $M_\odot$) BH it is 30 km.