ASTRONOMY 1102 – 1

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Study Guide for Third Test – Friday April 9, 1998

This test will be based on material we have covered in class, supported by the material in chapters 27, 28, 29 anmd 30 of *Astronomy: from the Earth to the Universe*. The test will consist as usual of two parts: multiple choice questions and problems. I give below an example of what the test will look like and a couple of examples of questions and problems.

Review class notes: do not memorize first, understand first, and then commit to memory only a few basic definitions and laws. Review homework. The basic properties of stars and the H–R diagram **ARE NECESSARY BACKGROUND** for the understanding of both pre–Main–Sequence and post–Main–Sequence evolution of stars: therefore an understanding of the concepts introduced in previous chapters is required. Specifically: meaning of spectral classes and luminosity classes; on the Main Sequence (MS) the surface temperature (or color), luminosity (or absolute brightness or magnitude), stellar radius (size) and mass are all correlated ($L \propto M^3$, $R \propto M$, and T decreases as the mass decreases but no simple mathematical formula can be given. Open and globular clusters and their H–R diagrams are required for observational tests of the theory of stellar evolution. Distance determinations from the distance modulus of standard candles such as Cepheids and Supernovae of Type Ia. Review HW 6 and 7.

Chapter 27: The death of stars like the sun

Although most of this was already in the second test, it is necessary background for understanding the post main sequence evolution of more massive stars. Lightweight stars die as White Dwarfs (WD): degenerate electron pressure supports them aginst their own gravity but there is a maximum mass of 1.4 $M_\odot$ that can be supported. This is the Chandrasekhar Mass. Accreting white dwarfs and nova explosions (novae). Check §27.4 and §27.5. Isolated WDs become black dwarfs but a WD in a binary may receive H-rich matter from the envelope of a companion star (because either the binary orbit has shrunk or the companion evolves to become a red giant). H-rich material accumulates on the WD surface and eventually a *nova explosion* follows. A nova is the result of explosive fusion of H into He on a WD surface. Some have been seen to repeat many times and are known as "recurrent novae".

Chapter 28: Supernovae

The death of a massive star. Red Supergiants. Importance of massive stars for the synthesis of the elements on the periodic table. Accelerating stages of Fusion beyond Carbon and Oxygen. Formation of the layered "onion" structure discussed in class and in HW 6. Collapse of the iron core: photodisintegration, neutronization and the bounce. Neutron degeneracy pressure, compare with electron degeneracy pressure. The bounce leads to 1) the formation of a *neutron star* at the centre of the massive star and 2) the ejection of the envelope in a Supernova (SN) explosion. The two types of SN: Type Ia (White dwarf in binary) and Type II (massive star core collapse). Different light curves and spectral properties. Which has H lines and which doesn't, and why? Type II SN or

Core collapse SN: the death of a massive star; Carbon–detonation SN or Type Ia SN: the collapse of a WD pushed over the brink (maximum mass is Chandrasekhar Mass = 1.4 $M_\odot$). This can happen because of accretion or a merger of two WD. The ejected envelope is seen for 10^4 years as a SN remnant. The formation of the elements in a pre–SN massive star: first the alpha process adds successively more and more ${}_2He^4$ nuclei or α–particles to C^{12}, yielding O^{16}, Ne^{20}, Mg^{24}, and Si^{28}. Then Si–Si fusion leads to Ni^{56} which decays first to Co^{56}, and then to Fe^{56}. Nucleosynthesis beyond iron during the explosion: the r-process (rapid neutron addition). SN 1987A in the LMC: the most extensively studied SN. The last SN detected in the Galaxy happened about 300 yrs ago. What powers the characteristic decays seen in Fig 28-15? Neutrinos from SNe: why do we expect to see them before the optical outburst? If neutrinos have mass they should travel slower than light, right? Is there a contradiction here?

Chapter 29: Pulsars and Neutron Stars

Origin and properties of a NS. Typical size, mass and density compared to other well-known standards: thimbleful weighs a mountain, a tsp of NS matter weighs 1 billion tons! Fast spin and strong magnetic field: trillion times stronger than Earth's field. Pulsars: history of discovery: Jocelyn Bell and Anthony Hewish. Pulsars are Galactic as demonstrated by Fig. 29-5. The lighthouse model (Fig 29-7). Why are other pulsar models ruled out (Check table 29-1). Pulsar spin-down (§29.5). NS binaries: X-ray sources or X-ray binaries, X-ray pulsars (not in text): accretion onto a magnetic pole. Millisecond pulsars. Pulsars in globular clusters: fast pulsars should be young but are actually old. Paradox resolved: Accretion spin-up. Maximum mass for neutron stars is somewhere around 3 $M_\odot$: collapse to black hole. Compare with Chandrasekhar Mass and Type Ia SN. "The" Binary Pulsar PSR 1913+16: Hulse & Taylor 1974, Nobel winners in 1993. Gravitational Wave emission and orbital decay: the orbital period gets shorter exactly as predicted by Einstein's General Relativity. Final inspiral and detection by LIGO (Hanford, WA & Livingston, LA).

Chapter 29: Black Holes

Einstein's General Relativity (GR): gravity = space-time curvature. The three classical predictions/tests of GR: deflection of light, advance of Mercury's perihelion, and gravitational redshift. The verification: the total solar eclipse of 1919, the *additional* drift of the axis of Mercury's orbit by 43 arcsec per century, and the redshift experiments of around 1960. Modern tests that further confirm Einstein's GR: gravitational lenses, gravitational wave emission from PSR 1913+16 and the faster advance of its periastron (4 degrees/yr!), and the Shapiro delay (delay of interplanetary signals from probes as they pass the sun). The formation of stellar black holes (BH). How much does light bend and what fraction escapes from various distances from the BH. The photon radius. The event horizon. The Schwarzschild radius $R_S = 3(M_{BH}/M_\odot)$ km. Several myths debunked: What would happen if the sun were replaced with a BH of 1 $M_\odot$? Rotating BH, briefly. Other types of BH: mini BH and Supermassive BH.

SAMPLES:

Part I – Multiple Choice questions (5 pts/question; total = 60 pts)
Identify the correct answers by placing a check between the brackets [ ]. Check **ALL** correct answers in the questions identified by a *.

*1) Why are SN of type Ia good standard candles? Because they
- [ ] have the same apparent magnitude.
- [ ] have the same absolute magnitude.
- [ ] have the same luminosity.
- [ ] obey the Period–Luminosity relation for Cepheid Variables.
- [ ] result from the collapse and detonation of the same mass.

5) What do astronomers mean by the expression "black hole candidates"?
- [ ] Massive stars destined to become black holes.
- [ ] Black holes in active galactic nuclei.
- [ ] Low–mass mini black holes.
- [ ] X–ray binaries where the accreting compact object has more than 3 $M_\odot$.
- [ ] None of the above.

Part II – Problems (10 pts/problem; total = 40 pts)
Problem 1: A SN type Ia is detected in a distant galaxy reaching a peak magnitude in the V band of $m_V = 18$ before fading away in the following months. Knowing that the peak V band luminosity corresponds to $M_V = -19$, estimate the distance to the galaxy.

Problem 2: A SN type Ia reaches a peak V band luminosity corresponding to $M_V = -19$. The fastest and brightest novae reach a peak luminosity of $M_V = -9$. How much brighter (by what *factor*) is a *Super*nova than a nova?

Problem 3: Both the theories and the available observations of neutron stars of different masses strongly suggest that all neutron stars, regardless of their mass, have a radius of about 10 km. Knowing that the Schwarzschild radius of a black hole varies as $R_S = 3(M_{BH}/M_\odot)$ km, what would be the maximum neutron star mass that would avoid collapse to a black hole? (The analog of the Chandrasekhar Mass)