Name: ....

ASTRONOMY 1102 – 1
Instructor: Juhan Frank
Third Test – Friday April 9, 1999

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) Some true statements about neutron stars:
  [x] Not all neutron stars are found inside a SN remnant.*SNR expand and fade away*
  [x] A 4 $M_\odot$ NS is impossible.
  [x] A 1.5 $M_\odot$ NS is possible.
  [x] All pulsars are NS.
  [ ] All NS are pulsars. *some no longer pulse*

*2) A WD accreting H–rich material from a normal companion star
  [ ] becomes a type II supernova.
  [x] may produce recurrent nova explosions.
  [x] can under certain conditions become a SN of type Ia.
  [ ] can collapse to a BH.
  [ ] becomes a red dwarf.

3) A white dwarf is
  [ ] the endpoint of the evolution of massive stars (greater than 8 $M_\odot$).
  [ ] supported by thermal pressure, with prominent hydrogen lines.
  [ ] supported by neutron degeneracy pressure.
  [x] formed by the cooling core of a lightweight star.
  [ ] produced only when stars less massive than the sun die.

4) Isolated (single) white dwarfs do not accrete, so they
  [ ] become novae.
  [ ] remain cool and are known as red dwarfs.
  [ ] become supergiants.
  [x] just cool and become black dwarfs.
  [ ] become brown dwarfs.

5) A brown dwarf is
  [ ] a cool white dwarf.
  [ ] an extremely cool main sequence star.
  [x] a star that never reached the main sequence.
  [ ] a H burning dwarf.
  [ ] a star of luminosity class III.

6) What are supernova remnants?
    [ ] neutron stars.
    [ ] black holes.
    [ ] the envelope thrown off during thermal pulses on the AGB.
    [x] the envelope of a massive star ejected by a supernova shock.
    [ ] the central star in a planetary nebula.

7) A WD accreting H-rich material from a companion
    [ ] undergoes recurrent supernova explosions when H fuses to He.
    [ ] explodes when the triple alpha process starts.
    [x] undergoes recurrent nova explosions when H fuses to He.
    [ ] undergoes rapidly recurrent X-ray bursts.
    [ ] produces a core-collapse supernova.

8) A Main sequence star of 0.5 $M_\odot$
    [x] burns hydrogen for a longer time than the sun.
    [ ] dies ejecting a planetary nebula and becoming a neutron star.
    [ ] goes through the He flash at the tip of the AGB.
    [ ] dies in a supernova explosion becoming a neutron star.
    [ ] belongs to luminosity class III.

9*) According to Einstein's General Relativity,
    [x] gravity is equivalent to space–time curvature.
    [ ] gravity has exactly the same effects as in Newtonian theory.
    [x] gravitational waves propagate at the speed of light.
    [x] a mass can bend light rays.
    [ ] neutrinos can move faster than light.

10*) As a massive star successively burns H, He, C, O, Ne, etc
    [x] each new fuel burns hotter and faster than the previous fuel.
    [ ] each new fuel burns cooler and slower and stops when Fe is reached.
    [ ] it remains a red supergiant throughout the evolution.
    [ ] it shifts blueward when a new nuclear fuel is ignited.
    [ ] the star only expands further and further.

11) The chemical elements beyond the iron peak are produced by
    [ ] steady nuclear burning in low mass stars.
    [x] the rapid addition of neutrons (r–process) during SN explosions.
    [ ] Silicon burning.
    [ ] the triple alpha process.
    [ ] a star as it becomes a red giant.

12) One true statement about stellar evolution:
    [ ] all stars, regardless of their mass, become pulsars.
    [ ] all stars when they die produce a WD.
    [x] single WD become black dwarfs as they get older.
    [ ] nothing of interest happens after a WD is formed.
    [ ] only massive stars produce WD.

Part II – Problems (10 pts/problem; total = 40 pts) **NO CALCULATORS!**

Problem 1: Describe briefly the three classical tests of General Relativity. What are these predictions/tests? To what extent have the predictions been confirmed? Do you know of any recent tests?

1) Bending of light rays: light follows the shortest path. In a curved space this is generally curved. The effect is as if gravity can attract photons. The starlight from distant stars will be bent by the sun and will appear to come from further out. This effect was confirmed in the total solar eclipse of 1919.

2) Advance of Mercury's perihelion: Mercury follows an elliptical orbit whose axis turns slowly forward. the result is not an ellipse but a tightly wound rosetta curve. Most of the advance was known to be due to the perturbations (gravitational attractions) of the other planets but there was a discrepancy; an excess of 43 arcsec/century which was explained by General Relativity.

3) The gravitational redshift: light (or any electromagnetic radiation (or even clocks) emitted in the vicinity of a mass is redshifted (appears to run slower) when observed from far away. This was confirmed in experiments in the 60s by Pound and Rebka in Harvard.

More recent tests include: gravitational lenses, the gravitational waves emitted by the binary pulsar PSR 1913+16, the precession of the perihelion of PSR 1913+16, which amounts to 4 degress/yr, and the Shapiro delay.

Problem 2: Answer the following questions about **black holes:**

a) They are fully described by three parameters only, namely *Mass, Angular Momentum or Rotation, and Electric Charge.*

b) Their mass is all concentrated at the *central singularity.*

c) As one approaches a BH, the point of no return is at the *event horizon.*

d) Is there a maximum mass a BH can have? *No: supermassive BH are known to exist.*

e) How big is the photon sphere compared to the Schwarzschild radius?

It is 1.5 times the Schwarzschild radius, the photon sphere is 0.5 outside the event horizon.

$R_S = 3(M_{BH}/M_\odot)$ km, $1.585^2 = 2.512$ $1.585^3 = 4.$ $1.585^4 = 6.3$

$\lambda = cT$ $\lambda f = c$ $\frac{\Delta\lambda}{\lambda_{\text{emi}}} = \frac{\lambda_{\text{obs}} - \lambda_{\text{emi}}}{\lambda_{\text{emi}}} = \frac{v}{c}$ $\lambda_{\text{obs}} = \lambda_{\text{emi}} + \Delta\lambda$

1 pc = 3.26 LY $d(\text{pc}) = 1/p(\text{arcsec})$ $\lambda_{\text{max}} \propto 1/T$ $E \propto T^4$ $Flux \propto 1/d^2$

$L \propto R^2 T^4$ $\sqrt[5]{10} = 1.585$ $\sqrt[5]{100} = 2.512$ On the MS: $L \propto M^3$, $R \propto M$

Problem 3: Suppose that you are in a powerful rocket that allows you to go close to a black hole and remain there stationary without falling in. Let's suppose that your feet point in the direction toward the center of the BH ("below") so that "above" means overhead. You look at the black hole and you look at the starry sky. Where are you with respect to the event horizon and the photon radius if

a) the exit cone is 30 degrees.

This means that you must be somewhere in between the event horizon and the photon sphere.

b) the light from a flashlight pointed in *most* directions can escape the pull of the black hole except if you point it within (say) 30 degrees of the center of the BH.

This means that all directions outside of a relatively small cone pointed toward the BH lead to escape. In other words we have an exit cone of 150 degrees so we must be well outside the photon radius.

Problem 4: A SN of type Ia is seen in a distant galaxy at a peak magnitude of 20. Knowing that the absolute magnitude of this kind of SN peaks at $M = -19$, estimate the distance to the galaxy in Mpc.

The distance modulus is $m - M = 20 - (-19) = 20 + 19 = 39$. Since $39 = 35 + 4$, the distance must be

$$d = (1.585)^4 \times 10^{(35/5)} \times 10pc \approx 6.3 \times 10^8 pc.$$

Expressing d in Mpc,

$$d \approx 630 Mpc.$$

$_1H^1$ $_2He^4$

$_3Li^7$ $_4Be^9$ $_5B^{11}$ $_6C^{12}$ $_7N^{14}$ $_8O^{16}$ $_9F^{19}$ $_{10}Ne^{20}$

$_{11}Na^{23}$ $_{12}Mg^{24}$ $_{13}Al^{26}$ $_{14}Si^{28}$ $_{15}P^{31}$ $_{16}S^{32}$ $_{17}Cl^{35}$ $_{18}Ar^{40}$