Introductory Astronomy

Homework 25: Black Holes Not to be handed in. Homework solutions are posted already.

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043 qmult 01200 2 4 2 moderate deducto-memory: Oppenheimer-Volkov limit
Extra keywords: CK-347-10

1. "Let's play *Jeopardy*! For $100, the answer is: This mass which is theoretically known to be about 3 $M_\odot$ is the upper limit on neutron star mass."

   What is the _____ limit, Alex?

   a) Chandrasekhar b) Oppenheimer-Volkov c) Gamow d) neutron star e)'white dwarf

   SUGGESTED ANSWER: (b)

   Wrong answers:
   a) This is the mass limit for white dwarfs.

   Redaction: Jeffery, 2001jan01

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055 qmult 00200 2 5 4 moderate thinking: special relativity

2. A postulate of special relativity is that the speed of light is:

   a) the same for all accelerated observers.
   b) different in different inertial frames.
   c) independent of the gravitational field.
   d) a constant and the same for all inertial-frame observers regardless of their motions.
   e) a constant and dependent on the phase of the Moon.

   SUGGESTED ANSWER: (d) The best answer may be easy to find, but it is hard to figure out whether it's really right.

   Wrong answers:
   c) Does light speed depend on gravitational field? Well even if it does this answer is not a postulate of special relativity.

   Redaction: Jeffery, 2001jan01

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055 qmult 01000 1 1 1 easy memory: general relativity
Extra keywords: CK-362

3. Einstein's general relativity (GR) is primarily a theory of:

   a) gravity, mass-energy, and spacetime. b) electromagnetism. c) light. d) Newtonian forces. e) atoms and nuclei.

   SUGGESTED ANSWER: (a)

   Wrong answers:
   e) Pure general relativity makes no reference to atomic and subatomic particles as far as I know.

   Redaction: Jeffery, 2001jan01

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055 qmult 01100 1 1 3 easy memory: gravitational redshift
Extra keywords: CK-362

4. Electromagnetic radiation that emerges from any gravity well experiences a:

   a) gravitational blueshift. b) gravitational greenshift. c) gravitational redshift. d) transcendental moment. e) senior moment.

SUGGESTED ANSWER: (c)

Wrong answers:

e) All too soon, the author of this question will be experiencing these.

Redaction: Jeffery, 2001jan01

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043 qmult 02100 1 5 3 easy thinking: black holes exist?

5. Black holes:

   a) certainly exist as all agree.
   b) do not exist, but they have caught the popular imagination and astronomers knowing a good thing when they have one keep writing about them.
   c) may exist: there is significant evidence for them, but in the opinion of some at least it is not conclusive.
   d) do not exist now, but will billions of years in the future.
   e) are redundant.

SUGGESTED ANSWER: (c)

Wrong answers:

e) A nonsense answer.

Redaction: Jeffery, 2001jan01

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043 qmult 02300 1 4 2 easy deducto-memory: Schwarzschild and his solution

6. "Let's play *Jeopardy*! For $100, the answer is: He/she is the discoverer of the analytically exact solution for the general relativity in massless-space outside of a non-rotating, chargeless spherically symmetric mass distribution."

   Who is _____, Alex?

   a) Henrietta Swan Leavitt (1868–1921) b) Karl Schwarzschild (1873–1916) c) Albert Einstein (1879–1955) d) Edwin Hubble (1889–1953) e) Georges Lemaître (1894–1966)

SUGGESTED ANSWER: (b)

Wrong answers:

a) She was the discoverer of the period-luminosity relation for Cepheid variable stars (No-488) while working at Harvard College Observatory. Distance determinations by Hubble using this relation established the extragalactic nature of the galaxies.
d) He observationally discovered the expansion of the universe and Hubble's law.
e) Lemaître had theoretically deduced Hubble's law prior to the observational discovery (No-524). He may not even have been the first to notice that such a law must hold in simple general relativity cosmology.

Redaction: Jeffery, 2001jan01

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043 qmult 02320 1 1 4 easy memory: Schwarzschild radius defined

Extra keywords: CK-362

7. The radius of the event horizon of a Schwarschild black hole is the _____ radius.

a) Kerr-Schwarzschild b) ergoregion c) singularity d) Schwarzschild e) right

SUGGESTED ANSWER: (d)

Wrong answers:
e) As Lurch would say: "Aaaarh."

Redaction: Jeffery, 2001jan01

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043 qmult 02420 1 1 2 easy memory: Schwarzschild and Kerr black holes
Extra keywords: CK-362

8. A black hole that is not rotating with respect to an inertial frame is a _____ black hole and one that is so rotating is a _____ black hole.

a) Kerr; Schwarzschild b) Schwarzschild; Kerr c) Einstein; Wheeler d) Wheeler; Einstein e) Tegmark; Wheeler

SUGGESTED ANSWER: (b)

Wrong answers:
e) Mark Tegmark is a high flyer who've I've even met.

Redaction: Jeffery, 2001jan01

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043 qmult 02500 2 4 4 moderate deducto-memory: making black holes

9. The formula for the Schwarzschild radius is

$$R_{\rm Sch} = \frac{2GM}{c^2} = 2.9542 \left(\frac{M}{M_\odot}\right) \text{ km} ,$$

where $G = 6.6742 \times 10^{-11}$ (in MKS units) is the gravitational constant, M is the mass of an object, c is the speed of light, and $M_\odot = 1.9891 \times 10^{30}$ kg is the mass of the Sun. This formula follows from general relativity for a spherically symmetric mass distribution, but it also accidently can be obtained by setting the escape velocity equal to the speed of light in the Newtonian formula for the escape velocity from a spherically symmetric mass distribution. According to general relativity if any object is compressed within its Schwarzschild radius it:

a) will become Karl Schwarzschild. b) may, but not necessarily will, become a black hole. c) must cease to exist. d) must become a black hole. e) will become a Schwarzschild.

SUGGESTED ANSWER: (d)

Wrong answers:
a) As Lurch would say: "Aaaarh."

Redaction: Jeffery, 2001jan01

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043 qmult 02720 2 4 1 moderate deducto-memory: X-ray source neutron stars
Extra keywords: CK-355,362

10. Compact, short-wavelength X-ray sources in binary systems where the source seems to have **LESS** than $3\,M_\odot$ but more than $1.4\,M_\odot$ are:

a) possibly neutron stars. b) certainly black hole candidates. c) white dwarfs. d) main sequence stars. e) presidential candidates.

SUGGESTED ANSWER: (a) There is no lower limit on black hole mass. Compress any mass to within its Schwarzschild radius and according to GR it must become a black hole. But this

compression may not happen if self-gravity can't do it and for self-gravity do it the compact object may have to be greater than 3 $M_\odot$.

Wrong answers:
c) Certainly not.
e) This is the election year answer.

Redaction: Jeffery, 2001jan01

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043 qmult 02900 2 1 2 moderate memory: black hole jets

11. Probably because of complex magnetic and electric field effects about rotating black hole candidates, these candidates exhibit:

a) planes of glowing gas. b) jets of glowing gas. c) jets of ice water. d) stirrups of ice water. e) dendritic patterns.

SUGGESTED ANSWER: (b)

Wrong answers:
c) Liquid water can't exist for long in the low pressure conditions of space.
d) A nonsense answer.
e) Dendritic means branching. This answers appears to belong to a question about lightning.

Redaction: Jeffery, 2001jan01

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043 qmult 03010 1 1 1 easy memory: supermassive black holes
Extra keywords: CK-357

12. These black hole candidates are found in the centers of large galaxies. They have masses of order 10^6 $M_\odot$ to 10^9 $M_\odot$. The name given to the kind of black hole these objects may be is:

a) supermassive black hole. b) primordial black hole. c) Schwarzschild black hole. d) singularity black hole. e) worst-case black hole.

SUGGESTED ANSWER: (a)

Wrong answers:
e) As Lurch would say: "Aaaarh."

Redaction: Jeffery, 2001jan01

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043 qmult 04000 2 5 5 moderate thinking: Sun black hole
Extra keywords: CK-363-3

13. If the Sun instantaneously and without any other catastrophic effects collapsed to being a black hole, what would happen to the Earth?

a) Nothing: everything would be just as before.
b) The Earth would plunge into the solar black hole drawn by its sudden super-gravity.
c) The Earth would suddenly have escape velocity from the solar system and would fly off into space.
d) Because of strange quantum mechanical effects every possible event would happen to the Earth in infinitely many different parallel universes.
e) The Earth's orbit would be unaffected, but the Earth's surface temperature would soon fall too low to sustain life.

SUGGESTED ANSWER: (e)

Wrong answers:

b) The gravity field outside of the Sun's current radius would be unaffected by the instantaneous collapse.
d) In the many world hypothesis something like this happens all the time: it doesn't take a collapse of the Sun to being a black hole.

Redaction: Jeffery, 2001jan01

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043 qmult 04100 2 5 2 moderate thinking: black hole binary masses
Extra keywords: CK-363-9

14. The more massive the star is, the faster it evolves in general. But black hole candidates in binary systems (which are presumably the compact remnants of ordinary stars) are sometimes less massive than their ordinary star companions. Resolve this paradox.

a) The paradox can **NOT** be resolved: such systems are a complete mystery.
b) The black hole candidate progenitor was more massive than the companion, but lost significant mass in late stellar evolution and even more mass in the supernova explosion that is believed to have preceded the formation of the candidate.
c) Some mass always just disappears completely from the universe during black hole formation. This non-conservation of energy is a consequence of general relativity.
d) Companion stars always form much later than the candidate progenitors and are gravitationally captured by the candidate's super gravity field.
e) If you have just the right amount of inertial frame and a nearby quasar and add a couple of ad hoc hypotheses, then the masses work out right.

SUGGESTED ANSWER: (b)

Wrong answers:
d) Stellar mass black hole candidates do not have super gravity, except very close to. Although captures of stars are possible by other stars, such events are exceedingly rare. Almost all binary systems were formed as binaries.
e) As Lurch would say: "Aaaarh."

Redaction: Jeffery, 2001jan01