Introductory Astronomy **NAME:**

Homework 25: Black Holes: Homeworks and solutions are posted on the course web site. Homeworks are **NOT** handed in and **NOT** marked. But many homework problems (~ 50–$70\,\%$) will turn up on exams.

1. Did you complete reading-homework-self-testing for the Introductory Astronomy Lecture (IAL) by the weekly due date?

   a) YYYessss! b) Jawohl! c) Da! d) Sí, sí. e) OMG no!

2. "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)

3. 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

4. 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 including the Earth's surface temperature.
   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.

5. The Schwarzschild and Kerr solutions of general relativity predict a region of infinite density: in the Schwarzschild solution this region is a point and in the Kerr solution it is an infinitely thin ring. This region is called the:

   a) ergoregion. b) X-ray source. c) multiplicity. d) event horizon. e) singularity.

6. Black holes:

   a) certainly do **NOT** exist as all absolutely agree.
   b) probably 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) exist. There are multitudinous massive compact objects that are now conventionally called black holes. So conventional black holes exist by convention. But the theoretical defining characteristic of black holes is the event horizon, the surface through which nothing, including light, can escape. Is there evidence for the event horizon? Yes. Many gravitational wave detections since 2015 are very well accounted for by merging black holes with event horizons. Also, in 2019 the Event Horizon Telescope imaged a supermassive black hole with the image being consistent with event horizon existence. So there is now very strong evidence that black holes (with event horizons) do exist. Ovewhelmingly most astronomers now accept their existence. It is always possible that a counter theory to black holes might come along that accounts for the evidence as well or better than black holes. So people will keep an open mind, but without worrying about counter theories much in the meantime.
   d) do not exist now, but will billions of years in the future.
   e) are redundant.

7. "Let's play *Jeopardy*! For $100, the answer is: The theoretical defining characteristic of a black hole is this surface from which and from below which light cannot escape. From 2015 on, evidence from gravitational waves from the mergers of stellar-mass compact objects and actual imaging of the supermassive compact objects at the centers of galaxies have convinced people beyond almost all doubt

that these objects have this defining characteristic, and so are black holes. In fact, it is hardly worth mentioning any doubt of the existence of black holes at all, except in being absolutely strict.'

What is the ____________, Alex?

a) singularity b) Earth's horizon c) event horizon d) duality e) lost horizon

8. The formula for the Schwarzschild radius is

$$R_{\rm Sch} = \frac{2GM}{c^2} = 2.95318 \left(\frac{M}{M_\odot}\right) \text{ km} ,$$

where $G = 6.67430 \times 10^{-11}$ (in MKS units) is the gravitational constant, M is the mass of an object, c is the speed of light, and $M_\odot = 1.9885 \times 10^{30}$ kg is the mass of the Sun. This formula follows from general relativity for a non-rotating, 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.

9. Compact X-ray sources in binary systems where the source seems to have **MORE** than $2.2\,M_\odot$ are probably:

a) neutron stars. b) black holes. c) white dwarfs. d) main sequence stars. e) red dwarfs.

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

    a) The paradox **CANNOT** 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.

11. Probably because of complex magnetic and electric field effects about rotating black holes with accretion disks, these objects perpendicular to their accretion disks exhibit:

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

12. These black holes 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 this kind of black hole is:

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

13. It is believed that black holes can lose rest mass energy and thus mass by:

a) **HAWKING** radiation. b) the **HAWKINS** method.
c) the **SCHWARZSCHILD** behavior. d) the **KERR** effect. e) the **EINSTEIN** field.