Galactic Astronomy

1. Multi-messenger astronomy has been started. [30 points]

   ① Please describe four of messengers [2 points × 4; 8 points]

   ② One of the significant observations was made by LIGO and Virgo. Please describe the key results on GW170817 made by multi-messenger observations. [6 points]

   ③ In the same year, Ice-Cube also made the epoch-making observation on the multi-messenger astronomy (Science selected this result as one of the Top10 discoveries in 2018). Please describe IceCube-170922A and related multi-messenger approaches. [6points]

   ④ Associated with the GW170817, superluminal motion was observed. Please explain what is the superluminal motion with drawing figure and equation [5points]. Please also prove the apparent velocity will become larger than light speed [5 points].

2. There are "stellar black holes" (~10 solar mass) and 'super-massive black holes" ($>10^6$ solar mass) in the center of galaxies. [20 points]

   ① Please derive the Schwarzschild radius using light speed c, blackhole mass of M, and gravitational constant G. [4points]

   ② Please derive the light-crossing time of Schwarzschild radius for "stellar blackholes" and "super-massive blackholes". [2 x 2 points; 4 points]

   ③ To observe time variability around black holes, what kinds of observations and/or instruments are required? [3 points]

   ④ Assuming the distance to a black hole "d" and the mass of the black hole M, please derive the apparent size of the black hole (Schwarzschild radius). [3points]

   ⑤ For the black hole in Sgr A*, d=8kpc and M=$3.7x10^6$ solar mass, please calculate the light-crossing time and the apparent size. [2 x 2 points; 4 points]

   ⑥ Currently, sub-mm VLBI offers the best spatial resolution in observational astronomy. Assuming observing wavelength 1mm and the distance between Mauna Kea in Hawaii and ALMA in Chile as 10000 km, please answer whether direct imaging of the black hole is possible or not. [2 points]

3. In spiral galaxies, the observed rotation velocities show a at rotation curve. The velocity is approximately constant at the outer part of the Milky Way. It is usually assumed that the flat rotational curve is caused by dark matter.

   A. If the flat rotational curves are caused by a spherical dark matter halo, what is the radius dependence of the dark matter density? (10 points)

   B. If the dark matter has disk-like distribution as the spiral galaxy disk, what is the radius dependence of the surface density of the dark matter? (10 points).

4. If you used a single-dish radio telescope to observed the neutral hydrogen in several spiral galaxies.

   A. What is the wavelength that you are going to observed (5 points)

   B. What is the mechanism that produced this line? (5 points)

   C. Draw the likely line profiles that you expected to observe. (5 points)

   D. If you compared the line widths of your observations with the optical luminosity of your sources, what kind of relation you expect to see? (5 points)

   E. How do you explain the relation of d)? (10 points)