Institute of Astronomy, National Central University

PHD QUALIFYING EXAMINATION 2018: GALACTIC AND EXTRAGALACTIC ASTROPHYSICS

1. In recent years, multi-messenger astronomy has been established. (In total 28 points + bonus 5 points)
   - (1.1) Please describe the four of messengers (2 points × 4; 8 points)
   - (1.2) Please describe the major messenger sources (2 points × 5; 10 points)
   - (1.3) Please list up key science projects for this forefront science fields with proper scientific and instrumental reasons (at least 5 projects; 2 points × 5; if more than 5 projects, additional 5 points; 10 + 5)

2. Composition of our Universe is estimated as 76% of dark energy, 20% of dark matter, and 4% of baryon. (In total 22 points)
   - (2.1) Please describe three observational efforts to estimate this fraction. (2 points × 3; 6 points)
   - (2.2) To map the dark matter distribution and investigate dark energy, dark energy survey (DES) and Subaru/Hyper-Suprime-Cam surveys (both in optical) have been ongoing. What is the physical background of these surveys? Please use cosmic shear and gravitational lensing for this explanation. (8 points)
   - (2.3) For further observational efforts, the launch of eROSITA (X-ray) mission is scheduled in 2018-2019. What is the importance of this entire sky survey in X-ray? Please describe by mentioning cluster of galaxies, dark matter, dark energy, and large-scale structure. (8 points)

3. Here we use a simple argument to show the relation between luminosity distance and angular distance used in cosmology. (In total 15 points)
   - (3.1) First of all, $r(t) = a(t)r_0$ represents the separation of two points as universe expands with rate $a(t)$. Given that the CMB temperature changes as $T(t) \propto a(t)^{-1}$, show that $T_{\text{emit}} = (1+z)T_{\text{observe}}$. (3 points)
   - (3.2) Given that CMB behaves like black-body, then its luminosity for a patch of CMB with size R and temperature T follows the Stefan-Boltzman law. If this patch of CMB is emitting with temperature T_{emit}, then what is the expression of flux that received at distance D_L (the luminosity distance) away? (4 points)
   - (3.3) From observer's point of view (at present time t_0), the observer sees this patch of CMB subtended an angular size of $\theta = R/D_A$, where D_A is the angular distance. Then what is the expression of the flux received by the observer? (4 points)
   - (3.4) Combine the results in (3.1), (3.2) and (3.3) and show that

     $$D_L \;=\; D_A(1+z)^2$$

     This is the relation between luminosity distance and angular distance. (2 points)
   - (3.5) Give one example of astrophysical object to measure luminosity distance and angular distance. (1 point × 2; 2 points)

4. The space within a galaxy cluster can fill with inter-cluster medium with temperature of $\sim 10^8 K$. Assume this gas is fully ionized hydrogen, show or calculate the following: (In total 15 points)

   (4.1) Using equation of hydrostatic equilibrium, show that the pressure can be expressed as

   $$P = \frac{GM\rho}{r}$$

   What assumption(s) you have to make? (7 points)

   (4.2) Express the classical ideal gas law for the fully ionized hydrogen gas as $P = P(\rho, T)$. What is the mean molecular mass μ in this case? (4 points)

   (4.3) Using result in (4.1) and (4.2) and estimate the mass (in $M_\odot$) of the hot inter-cluster medium gas, assuming $r \sim 1$ Mpc as the typical size of a galaxy cluster. (4 points)

   Constants in cgs-unit: $G = 6.7 \times 10^{-8}$erg cm g^{-2}, $k = 1.4 \times 10^{-16}$erg K^{-1}, $m_p = 1.7 \times 10^{-24}$g, 1pc $= 3.1 \times 10^{18}$cm, $M_\odot = 2 \times 10^{33}$g

5. Distance scale and Hubble constant. (In total 20 points)

   (5.1) For simplicity, let's a point source with mass m is orbiting at distance r from the center of a spherical galaxy with mass M, show that $M = \frac{v^2 r}{G}$, where v is the velocity of the point source. (3 points)

   (5.2) Given the surface brightness $I = \frac{L}{4\pi r^2}$, show that $M \propto v^2 (L/I)^{1/2}$. (3 points)

   (5.3) Assume that the mass to luminosity ratio is a constant for the galaxy, and $v = v_{\rm max}$ at r due to flat rotation curve of the galaxy, show that $L \propto v_{\rm max}^4$ – this is the famous Tully-Fisher relation. (6 points)

   (5.4) The Tully-Fisher relation can be used to derive the Hubble constant, explain how this can be done. (4 points)

   (5.5) Besides Tully-Fisher relation, Type Ia supernovae can also be used to derive Hubble constant. Explain why Type Ia supernova is a good standard candle. (3 points)

   (5.6) Give one reason why we need accurate measurement of Hubble constant. (1 points)