Winter, 2020

Yale University

KEY: Astronomy C

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Questions?
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Directions:
Unless otherwise stated, each sub-question is worth two points.

1 Answer Key: Part A

1. (a) GW151226 (+1), Gravitational Waves (+1)
   (b) GRB 150101B (+1), January 1st, 2015 (+1)
   (c) Bullet Cluster(+1), Infrared (+1)
   (d) Bullet Cluster (+1), anything related to dark matter (+1)
   (e) GOODS-S 29323 (+1), Infrared (+1)
   (f) 3C 273 (+1), OVV (+1)
   (g) NGC 2623 (+1), New General Catalogue (+1)
   (h) MACS J1149.5+2223 (+1), MAssive Cluster Survey (+1)
   (i) PSS 0955+5940 (+1), Quasi stellar radio source (+1)
   (j) M87 (+1), clockwise (+1)
2. (a) The universe is not in nitely old (+1), so light from old stars has not had time to reach us (+1)
   (b) Isotropic and homogenous (+1), it resembles a blackbody with small temperature uctuations (+1)
   (c) Not isotropic AND yes homogenous (+1). There is no preferred location (any bar is the same), but the bars are the preferred direction (+1).
   (d) Frequent collisions (+1) through Thomson scattering (+1)
   (e) Decoupling is caused by plummeting of free electron density (+1) during recombination because CMB photons are too low energy (+1) to hydrogen ionized.
   (f) i. Spherical harmonics (+1) for increasing/various multipoles (+1) of the CMB.
   (g) A correlation function requires 0->180 degrees (+2), spherical harmonics does not
   (h) Polarization of CMB (+2)
   (i) Gravitational waves, in ation
3. (a) 1.70-1.85
   (b) 19
   (c) Older galaxies are more massive
   (d) It suggests the bottom-up model is true. The less massive galaxies merge to form the older, more massive ones.
   (e) 1-3 times 10e3 Mpc
   (f) 1-2 times 10e4 Mpc
   (g) The emission lines (+1) are from hot stellar nurseries / lots of heated gas and dust (+1).
   (h) green (+1), star forming usually happens in disks OR smaller radius means higher density (+1)
   (i) strangulation (+1) and ram-pressure stripping (+1)
4. (a) 2.6-2.8K
   (b) 1090-1110
   (c) yes, (+1) V>c is possible because space is not an object (+1), so it is not bounded by the speed of light.
   (d) Friedmann Equation
   (e) scale factor
   (f) cosmological constant
   (g) 0 OR at

(h) 0.5-3 10e-26 kg/m3

(i) 2-5 x 10e-28 kg/m3

(j) 4.7-5.3 x 10e-19 kg/m3.

(k) 1-3 e 6 M_sun

(l) globular clusters

(m) This suggests that globular clusters likely started forming after recombination (+1); OR This would support a bottom up or hierchical model of galaxy formation (+1); OR Isothermal or adiabatic density uctuations above this mass that survived recombination could have collapsed (+1).

2 Answer Sheet B: Questions 5-8

5. (a) 9.4-9.5 e 15 m
   (b) 3.26-3.27 ly
   (c) 3.8-3.9 e 26 W
   (d) 6.9-7 e 8 m
   (e) 4.74
   (f) -26.74
   (g) 325.25 days
   (h) -19 - -20
   (i) 3000-4000K
   (j) 2000-3000 R
   (k) $v = H_0 d$
   (l) $D_{\rm pc}$ = 1=
6. (a) 40-50 Mpc
   (b) -17.5-18.5
   (c) Faber-Jackson (+1), 75-125 km/s (+1).
   (d) Kormendy relation (+1), 10-15 kpc (+1)
   (e) 7,500-20,000 m/s
   (f) 5
   (g) These galaxies lost their gas early (+1) in their histories and have ceased forming new stars (+1). Hence, they are now primarily composed of ancient stars.
7. (a) 6.0 - 8.0 $\times 10^{16}$ m
   (b) 750 - 800 years
   (c) Neon
   (d) 0.03 - 0.04 seconds
   (e) 1 - 2 $\times 10^{-12}$
   (f) 0.5 - 5 $\times 10^{5} L_{\odot}$
   (g) 4 - 5 $\times 10^{4} L_{\odot}$ (+1) The source is "not accretion" (+1)
   (h) Synchroton
   (i) D
8. (a) 70 - 110 degrees
   (b) 0.6 - 1.3 $\times 10^{-4} L_{\odot}$
   (c) 0.5 - 2 $\times 10^{44}$ J
   (d) 1 - 3 $\times 10^{14}$ yr
   (e) A
   (f) Award one point for mentioning any one of the following, up to a maximum of four points:
      i. The $average\ number\ of\ electrons$ per atom is greater in metal rich stars.
      ii. This causes the $opacity$ of metal rich stars to be greater.
      iii. Stars will then $"puff\ up"$ because it is harder for energy to escape.
      iv. Radius will $increase$, and temperature will $decrease$.
   (g) B
   (h) 0.5 - 0.7