Astronomy C - Astronomy C 2020 - Camas C-Invite - 12-12-2020

(Credit: Sidney Harris)

Instructions:

- The test has a total of 255 points with **Section A** (Deep-Sky Objects), **Section B** (General Concepts), and **Section C** (Calculations and Advanced Concepts).
- Do not worry about significant figures. If in doubt, use 3 or more in your answers, and make sure to include proper units unless asked not to include units.
- Some question is broken down into several subparts (a, b, c, etc.). If it is fill-in-blank type, make sure your answer to each subpart is in the a-b-c order. Keep your answer short.
- In short-answer/essay questions, you can describe math equations in plain text, and numerical answers may be given in scientific or standard notation. For example, for the follov question:
  - (a) What is Solar radius in kilometers?
  - (b) What is Solar luminosity in ergs/s?
  - (c) How do you calculate luminosity of a main-sequence star when given its solar mass?
- You should type in the answer box
  - (a) 6.96 * 10^5 km
  - (b) 3.83E33 ergs/s
  - (c) L = L_sun * (M/M_sun)^3.5
- All questions will be manually reviewed; However, for Math questions (labeled as **[**** - Math]** in subject), if you feel show of work is easier on paper than describe in the answer box, you can specify your final answer here, then scan or snap pictures of yourwork **AFTER** the competition, and submit a single document with the scanned work to Google form. The link is at https://forms.gle/kz7dHE8u8zXsWyGr6 (https://forms.gle/kz7dHE8u8zXsWyGr6) (https://forms.gle/kz7dHE8u8zXsWyGr6) (Please save this link as needed). Submission has to be within 15 minutes after the end of the time block to be fully scored.
- Ties will be broken by these questions: 28, 24, 26, 27, 19, 22, 17, 12, 7. Plan your time wisely.

Section A: Deep-Sky Objects

Use **the Image Sheet (LINK)** (https://scilympiad.com/Data/turs/10H6/tests/00017N/DSO-Camas-Invite-2020.pdf) to answer the following questions. Points are shown for each question or sub-questions (72 points)

1. (6.00 pts) (a) Which two images show the DSO(s) that was(were) used by scientist to study WHIM? Specify in first box, separated by comma, no space.
(b) What is the signal that indicate the presence of WHIM?
(c) What is the background source in such DSO(s) that allows the quantification of WHIM?

6,15	X-ray absorption of O-ions	SMBH

2. (6.00 pts)

(a) Which DSO is shown in Image 12?
(b) In what wavelength is this DSO first detected? (Optical, Radio, X-ray, Infrared, gravitational wave)?
(c) Many galaxies within the DSO has extra bright radio signal. What effect is most responsible for the ability to observe such radio source located billions of light-year away from us?

MACS J0717.5+3745 | X-ray | Gravitational lensing

3. (4.00 pts) (a) Which is the X-ray image of PSS 0955+5940?
(b) What is the source of X-ray emission?
(c) If we believe the interpretation of the distances of such objects from Chandra study , what is the implication of such results to our understanding of dark energy?

16 | accretion disk around SMBI | Dark energy density increas

4. (6.00 pts) (a) What is the DSO in image 1?
(b) What is the significance of this particular DSO?
(c) The jet extending from the core shows strong relativistic effects. What is the name for such motion?

3C273 | First quasar | Superluminal motions

5. (6.00 pts) (a) Which DSO is depicted in Image 7?
(b) A prominent feature is the plasmas jet originated from the core. What is the name for the magnetic field effect that drives this jet motion?
(c) What is the size of the image in X/Y directions, measured in parsec?

M87 (Virgo cluster) | Blandford-Znajek effect | 30,000

6. (6.00 pts) (a) Which DSO is Image 17?
(b) What does the color contour represents?
(c) What is most significant variation effect that can modify the conclusions shown in this image?

Chandra Isotropic Universe | Hubble velocity | Dust skewing luminosity of

7. (8.00 pts) (a) One of the DSO has a distinguished disk shape structure that indicates it follows similar formation pathway as our Milky Way. Which image is that?
(b) What is the wavelength range the data show in this image is obtained at (Radio, X-ray, Optical, Infrared, Gamma Ray), and which telescope was(were) used?
(c) What is the name for this DSO?
(d) Describe the difference in formation model vs our Milky Way, if this DSO is occurring at high redshift as the name indicates.

Expected Answer: (a) 18 ■ (b) Radio (VLA, ALMA) ■ (c) DLA0817g ■ (d) Hot gas need a long time to cool down and for a disk galaxy, so many such galaxy form at $z < 1$. High redshift disk galaxy suggest they form through mergers and filament structures, i.e. "cold" mode. ■

8. (6.00 pts)
(a) Which image(s) is(are) related to MACS 1149+2223?
(b) What directly produces the prominent X-ray signal in the center of this cluster? What is the force that hold such source together, which is also reason for the strong lensing effect?
(c) What is the name of exploding star, i.e. Supernova event, that was observed, which would not be visible without gravitational lensing effect of MACS-1149?

9,13 | Hot gas, dark matter | SN Refsdal

9. (6.00 pts)
(a) Which image shows the SED (Spectral Energy Distribution) measurement of GOODS-S 29323?
(b) What feature in the observation suggests that early-universe black holes could formed in a "direct-collapse" model?
(c) What is the temperature (Kelvin) threshold for such primordial collapse of gas, and what is the type of photons that can prevent gas fragmentation at this temperature at early universe?

8	Steepness or redness of IR	10000 K, Lyman-Werner ph

10. (6.00 pts)
(a) What is(are) the image(s) for 1E0657-56 (Bullet cluster)?
(b) What are the features in the image(s) that represent concentration of dark matter?
(c) A prominent feature of this DSO is the bow-shaped shock that causes local heating of colliding gas. In Radio wavelength (e.g. ALMA), this _____ effect allows direct measurement of electron temperatures. Fill in the blank

5,2	contours	Thermal SZ (Sunyaev-Zeld

11. (6.00 pts)
(a) Which image shows the verification of SN-UDS10Wil as a Type-Ia Supernova at high redshift?
(b) What is the peak luminosity magnitude that would be observed, considering its redshift is at 1.914?
(c) If we observe similar Supernova (same progenitors) near Milky way, it usually takes about 15 days to observe a drop of 1.1 magnitude in luminosity. What is the number of days fo SN-UDS10Wil to show same magnitude drop, if we are able to monitor it continuously?

14	26.2 +/- 0.4	43.7

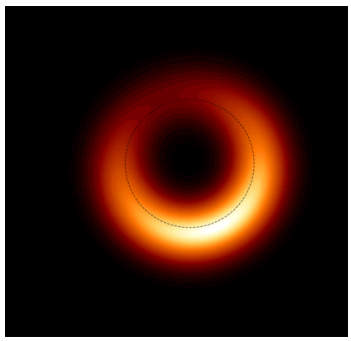
12. (6.00 pts)
(a) Which image corresponds to GW151226?
(b) This gravitational wave signal is produced by the coalescence of two black holes. What is the mass of the combined black hole, in solar mass (no unit)?
(c) Assume the two black holes undergo nearly-circular orbits around each other before merging, what is the minimum number of physical quantities (parameters) required to describ the orbital motion and the observed gravitational wave signal?

4	21	15

Section B: General Concepts

Points are shown for each question or sub-question, for a total of 92 points.

13. (10.00 pts)
[Black hole] Image below shows the famous first image of Black hole at the center of M87 galaxy, taken by the Event Horizon Telescope.

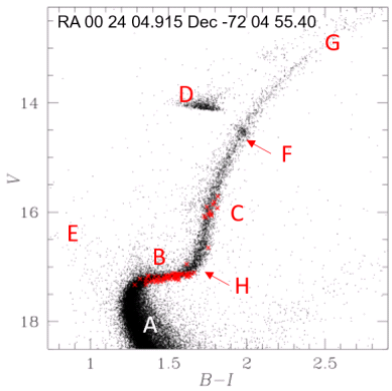


[2 pts] (a) What is the wavelength this image was taken at? What is the advantage of the particular wavelength?
[2 pts] (b) What is the black hole diameter as defined by its Schwarzschild metric in parsecs?
[2 pts] (c) What is the diameter of the shadow (ring) in parsecs? What is the source of the emission?
[2 pts] (d) What physical effects are the observed asymmetry attributed to? And especially what north-south asymmetry indicates?
[2 pts] (e) The blackhole at the center of Milky way, Sag A*, is smaller but much closer. Why were we able to use Event Horizon Telescope to capture M87, but not Sag A*?

Expected Answer: (a) VLBI wavelength is 1.3mm. Transparent from the interference of plasmas emission around the accretion disk, get close to the black hole shadow, build interferometry ■ (b) $6.1 \pm 0.3 \times 10^{-4}$ parsecs; ■ (c) Ring size is $3.36 \pm 0.36 \times 10^{-3}$ parsec. Hot plasma in quiescent accretion flow (Synchrotron emission) ■ (d) Asymmetric ring is due to strong gravitational lensing and relativistic beaming, and the north-south asymmetry shows its spin direction is away from the Earth. ■ (e) The smaller BH Sag A* has much faster variation in its accreting disk. The slow rotation of M87 allow high-quality interferometry data collection using VLBI. ■

14. (10.00 pts) **[H-R Diagram]** Image below shows V-band magnitude vs. color B-I for a globular cluster. Answer questions below using this diagram.

[5 pts] (a) List the stages labeled on the H-R diagram, A through E.
[2 pts] (b) Why is the luminosity roughly constant at state B?
[3 pts] (c) Why is there a cluster at point F?



Expected Answer: (a) A=Main Sequence; B= Sub Giant; C=RGB/Red Giant Branch; D = Horizontal Branch; E = Blue stragglers. ■ (b) Helium core is below Schonberg-Chandrasekhar limit and in equilibrium; Outer H-shell fusion inflates the envelop and stars cools. ■ (c) Moving up the RGB, shell convection reduces the surface [H] concentration, slowing down the progress. ■

15. (7.00 pts) **[H-R Diagram - Math]** Continue on previous question: Point G in the previous question reaches a limit at the upper-right corner of V=12.5).

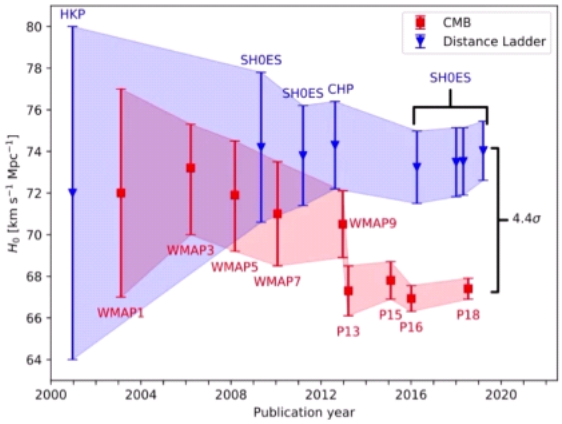
[2 pts] (a) What is the physical mechanism for this limit?
[5 pts] (b) If we know this physical limit always corresponds to -3.0 magnitude, ignoring extinction effect, what is the distance, in kpc, to this cluster?

(This effect is used as standard candle in recent study by U. Chicago group to verify Hubble constant).

Expected Answer: (a) Tip of RGB: helium core reaches fusion temperature, or Helium flush. ■ (b) m-M = -5 +5 log d, , d=$10^{(12.5+3+5)/5}$ = 12590 pc = 12.6 ± 1 kpc. ■

16. (10.00 pts)
[Hubble's tension] CMB verified a great deal about the model of our universe expansion, including Hubble's law, or Hubble constant H_0, which describes the expansion speed of the universe at the present day.

[2 pts] (a) Who first proposed Hubble's law?
[2 pts] (b) Recent CMB data suggest that Hubble's constant H_0 should be close to 67.4 km/s/Mpc, shown in the bottom chart as the red data with reducing σ over the years. What is the reason for the reduced error bar and sudden drop in H_0 estimate by CMB?
[3 pts] (c) Meanwhile, study based on distance ladder continue to show converged estimate of H_0 close to 74 km/s/Mpc, creating so-called "Hubble tension". The distance ladder data are shown below in Blue. List three key steps of the "distance ladder."
[3 pts] (d) Give two possible systematic errors or limitations in the distance ladder approach for Hubble constant.



Expected Answer: (a) Georges Lemaître ■ (b) WMAP to Planck satellite data which measure much higher resolution spatial nonuniformity in CMB. ■ (c) Parallax -> Cepheid -> Type-Ia SNe ■ (d) Accurate Parallax is difficult (improving with Gaia); Cepheid are rare objects; Type-Ia peak luminosity may be not as absolute (progenitor mechanism, higher redshift bias ...). ■

17. (10.00 pts)
[Hubble's tension- Math]

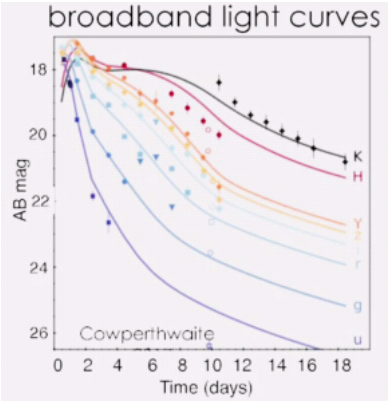
[5 pts] (a) If a galaxy is showing an average redshift of 0.45% in its hydrogen line, at what velocity is the galaxy receding from us in units of km/s? And what is the distance if $H_0 = 7$ km/s/Mpc?
[5 pts] (b) What does does a diverged Hubble's constant tell us about the universe, if the tension between CMB and distance ladder is correct?

Expected Answer: (a) $v = 0.0045c = 1,350$ km/s, $v = H_0 d$, so $d = 18$ Mpc. ■ (b) CMB data represents more early universe expansion, while distance ladder represents late universe. More to learn about dark energy, is not just a Cosmological constant as Λ-CDM assumes. Any reasonable answer demonstrating knowledge or creative thinking would earn full points. Λ-CDM and FLRW models are simple models, and large-scale structures can affect the true distance estimate to CMB ■

18. (10.00 pts)

[GRB] GRB150101B is believed to be similar to GW170817 in mechanism - the latter was more widely monitored including the detailed light curves of kilonova signal shown below. The blue to red shift (in u to k bands) is believed to reflect different opacity and changing jet speeds. Answer following questions briefly (2 pts each)

(a) What is the kilonova powered by?
(b) What is the main elemental content that is responsible for the shift in the peak of spectrum?
(c) What is the highest velocity in the ejecta, in unit of light velocity?
(d) What is the source or location that gives the Blue part of emission?
(e) What does the slower-moving, purple/red part of emission correspond to?



Expected Answer: (a) Radiactive decay of heavy r-process elements ■ (b) Lanthanide ■ (c) 0.3c, 0.1-0.3c accepted ■ (d) From the collision interface of NS-NS merger ■ (e) Accretion disk wind (or ejecta wind) ■

19. (15.00 pts) **[Stellar Evolution]** Answer some questions about the evolution of an 8 solar mass star.

[3 points] a. Give the lifetime of the star on the main sequence in years.

[3 points] b. Calculate the Eddington luminosity of the star in solar luminosities.

[3 points] c. During the resulting supernova, what particle is ejected alongside helium during photodisintegration of Fe-46?

[3 points] d. What element would be exhibited in the spectra of the resulting supernova that Type Ia supernova spectra would not have?

[3 points] e. What would happen to the value of the Eddington luminosity if the opacity of the surrounding gas decreases?

Expected Answer: a. 5.52E7 years b. 256000 solar luminosities c. neutrons d. hydrogen e. it would increase

20. (20.00 pts) **[Stellar Evolution]** Answer some questions about white dwarfs and neutron stars.

[4 points] a. Explain how both white dwarfs and neutron stars keep intact in the absence of fusion.

[4 points] b. What particle takes energy out of a white dwarf from the interior?

[4 points] c. Spectral lines that include atomic or molecular carbon lines would be prevalent in the atmosphere of what type of white dwarf?

[4 points] d. How does a neutron star cool during the first day after being formed from a supernova?

[4 points] e. The "freezing in" of magnetic field lines allow what quantity to be conserved through the surface as it collapses to form a neutron star?

Expected Answer: a. electron degeneracy pressure b. neutrinos c. DQ d. by emitting neutrinos through the URCA process e. magnetic flux

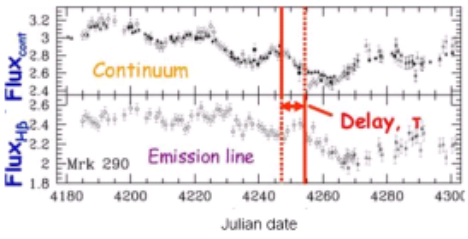
Section C. Calculations and Advanced Concepts

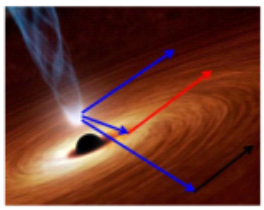
Points are shown for each question or sub-question, for a total of 91 points.

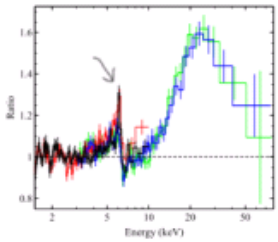
21. (19.00 pts)

[AGN - Math] Accretion disk around Active Galactic Nuclei (AGN) shows Broad-Line Region (BLR) emission lines, e.g. H_β line, which are ionized by UV photons. Observed H_β light curve shows a delay of 25 days compared to the light curve from the continuum part of the spectrum (left image). Shown in the second image, such delay is due to the distance traveled by the reflection (black arrow) vs. original UV emission (red arrow) in the corona (X-ray source) & accretion disk.

[5 pts] (a) If the delay shown is 25 days, what is the radius of the BLR in parsec?
[5 pts] (b) If this AGN is at $z = 0.0302$, what is the maximum extended angle of the BLR disk on the sky in μ-arcsec? Can the disk be resolved by Hubble Telescope?
[5 pts] (c) From the width of the H_β line, we extract a velocity dispersion of 450 km/s. What is the black-hole mass in unit of M_{sun}?
[4 pts] (d) The right-most image shows the X-ray spectrum collected on a galaxy with a significantly asymmetric Fe-line near 6 keV (marked by the arrow). Explain the source of asymmetry?




Center of AGN

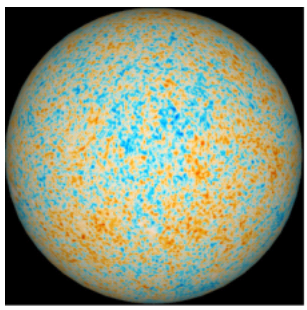


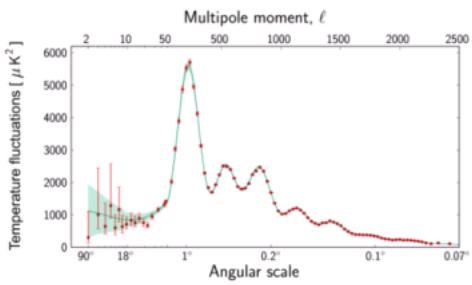
Expected Answer: (a) 0.021 parsec ■ (b) Distance based on redshift ($d = z \times c/H_0 = 129$ Mpc) [1 pt], $33.6 \pm 10\mu$-arcsec. Too small for Hubble resolution of 0.04 arcsec [1pt] ■ (c) Using $M = V^2R/G$ and velocity dispersion of 450 km/s, R of 0.021 pc. Answer: $0.97 \pm 0.1 \times 10^6 \mathrm{M}_{sun}$ ■ (d) Doppler shift (1pt), gravitational redshift (1pt), relativistic beaming (1pt), frame dragging or blackhole spin (1pt) ■

22. (10.00 pts)

[CMB] Cosmic Microwave Background (image on the left) is a "photo" of the Big Bang, and its spatial correlation at different angular scales (plot on the right) ("moments" l is similar t the concept of spatial wavelength).

[2 pts] (a) What is the temperature of CMB in Kelvin as measured today? What does it verify about the cosmological principle?
[2 pts] (b) The left picture is the fluctuations of temperature on top of a uniform background. What is the magnitude of fluctuation in milli-Kelvin? Which Satellite does this data come from?
[2 pts] (c) What is the source of the first peak that sit at $l \approx 200$ in the angular scale correlation? What does this say about our universe?
[2 pts] (d) What does the second and third peaks each say about the early universe?
[2 pts] (e) The data match a particular theory of the universe very well (solid line in the 2nd graph). What is the name of this theory?





Expected Answer: (a) 2.73K, the universe is spatially homogeneous and isotropic on the largest scale. ■ (b) ~.075 mK (+/- 10); Planck. ■ (c) This is from the acoustic wave that undergoes compression before the photon-baryon decoupling (sound horizon). This is evidence that the universe is very close to flat. ■ (d) 2nd peak = baryonic density; 3rd peak = dark matter density; ■ (e) Lambda-CDM ■

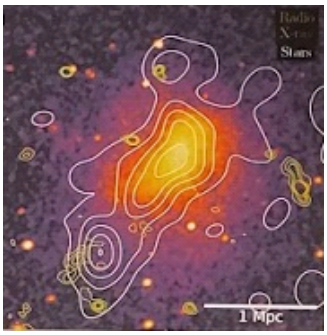
23. (5.00 pts)
[CMB - Math] If the energy density of the universe is 10^{-29} gram/cm^3 today, what is the estimate of matter+energy density at the time when these CMB peaks are formed?

Expected Answer: If use recombination redshift of 1100, one get $(1+z)^3 = 1.3 \times 10^9$ factor at z=1100. So the density is about 1.3×10^{-20} gram/cm^3 at recombination. ■

24. (10.00 pts)
[Galaxy Cluster - Math] MACS J11459.5+2223 is a cluster at redshift of 0.544 with a rich merger history, as shown in the overlay of mass density (white contour) and the X-ray image below. Several radio relics were studied to reveal the dynamics of subclusters. One particular relic is shown to the right of the image as yellow contour, about 1 Mpc away from the center of X-ray luminosity. It is observed to have a Line-of-sight velocity of 300 km/s. This indicates MACS J1149 is merged from two sub main clusters with $16 \times 10^{14} M_{sun}$, and $10 \times 10^{14} M_{sun}$, respectively, and is now at the apo-center. This merger scenario is also consistent with the elongated X-ray luminosity shape stretching from southwest to northeast.

[5 pts] (a) What is the free-fall velocity if the two clusters were on a collision course based on scale shown in the image? Does it justify the hypothesis that the two cluster is at apo center?
[5 pts] (b) If we assume this is the first pass of the collision, how many million years ago did they collide?

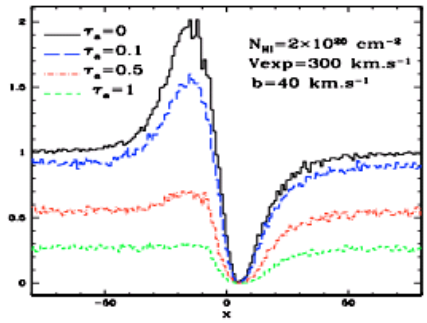
Show work to to get full points on both questions.



Expected Answer: Work should include reference to Kepler's third law, concept of velocity vs orbital radius, and apocenter vs. pericenter. Known information is distance, and current velocity is low (apo-center). (a) Yes, 300 km/s is low vs. 3400 km/s based on Kepler's 3rd law, assuming semi-major axis is about 1 Mpc, and an eccentricity of $e = 1$. (accept any velocity estimate within 2500-4000 km/s range) ■ (b) Collision can be approximated as the pericenter, we can use free fall time to estimate (1/2 orbital period).
$T = \pi \sqrt{1\text{Mpc}^3/(G(M_1+M_2))} = 918$ Myrs. ■

25. (10.00 pts)

[Lyman-Alpha] One of the scientific goals for CANDELS and other recent surveys is to use near-IR to probe the galaxy formation at redshift of z=5-7.
[3 pts] (a) At what minimum redshift will a galaxy has to be for its Lyα emission be observable today with a near-IR filter at 8000 A+?
[3 pts] (b) If we observe more DLA and Lyα emitter galaxies at redshift of 7, what does it tell us about early universe?
[4 pts] (c) For some DLA galaxy systems, we observe a spectrum profile around Lyα peak as below, with $x < 0$ representing redshift (longer wavelength). Take the example of the black curve, what is the reason that the redshifted wing (left side) was enhanced, and the blueshifted wing damped?



Expected Answer: (a) Lyα is 1216 A, so (8000/1216-1) = 5.58 z ■ (b) Reionization starts at around z=7; Star formation is very active; Lots of neutral hydrogens; (any answers alone these lines will work) ■ (d) Lyα emission from central region of galaxy towards us is absorbed by the galactic wind or shell of hydrogen, and scattered/infalling materials enhanced the red emission ■

26. (5.00 pts) **[Lyman-Alpha - Math]** What is the age difference between a galaxy at $z = 6$ and one at $z = 7$, in Million-years?

Describe your calculation and model approach to get full points. Assume $H_0 = 70$ km/s/Mpc, and Λ-CDM model with Ω_m=0.3, Ω_Λ)=0.7.

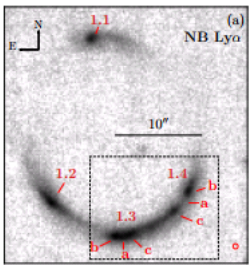
Expected Answer: $t(z) = 2/(3H(z))$ is a good approximation at early universe, and $H^2(z) = H_0^2(\Omega_m(1+z)^3 + \Omega_\Lambda)$. This gives a $\Delta t = 0.0119/H_0$, or ~ 165 Myrs. Accept answer within ± 20 Myrs. ■

27. (12.00 pts)
[Lensing - Math] Strong gravitational lensing allows such galaxy at early universe to be magnified - Below is the a galaxy ~ 7.6 billion parsec away that is captured behind a massive cluster at redshift of z=0.335.

[2 pts] (a) What is the name for the ring formed in picture below?
[10 pts] (b) What is your estimate of the cluster mass in solar mass, to within 30% error?

Instead of Google search, we can get a quick estimate of the mass of the lensing cluster (M) based on the ring angular radius (θ) as follows: $\theta = \sqrt{\frac{4GM}{c^2 d}\frac{1-x}{x}}$

Here the distance to source of the light is d, c is the light velocity, G is the gravitational constant, and x is the ratio of the distance to the lens vs distance to the source (d).



Describe the assumption and solution procedures to get full points.

Expected Answer: (a) Einstein ring ■ (b) First, we can estimate distance to the lens from Hubble's law, $z = 0.335$, we get $d \times x = 1435$ Mpc. Using the formula for angle with conversion of 10 arcsec to radian, we can estimate a mass of $2.08 \times 10^{13} \mathrm{M}_{sun}$. The actual estimate is about $1.7 \times 10^{13} \mathrm{M}_{sun}$ (MACS0940+0744). Accept answer of $1.5 - 2.5 \times 10^{13} \mathrm{M}_{sun}$. ■

28. (20.00 pts) **[Galaxy]** Answer some questions about the structure and evolution of a spiral galaxy.

[4 points] a. What quantity must be added onto the apparent magnitude of a galaxy to account for redshift?

[4 points] b. In the bulge region, the surface brightness distribution changes in proportion to the radius taken to what number power?

[4 points] c. Give the main difference between galaxies in the early universe and galaxies today according to the Butcher-Oemler effect.

[4 points] d. How does the thick disk form in the galaxy?

[4 points] e. How does the thin disk form in the galaxy?

Expected Answer: a. K-correction b. 1/4 c. galaxies in the early universe are bluer than galaxies today d. through mergers with other galaxy fragments e. matter slowly congregating around the midplane of the galaxy

Congratulations! Enjoy the rest of the competition. Again, if you need to submit work document, you have 15 minutes to do so at this form: https://forms.gle/kz7dHE8u8zXsWyGr6 (https://forms.gle/kz7dHE8u8zXsWyGr6)

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