Observational Cosmology
Final Exam
Fall 2015
100 points possible

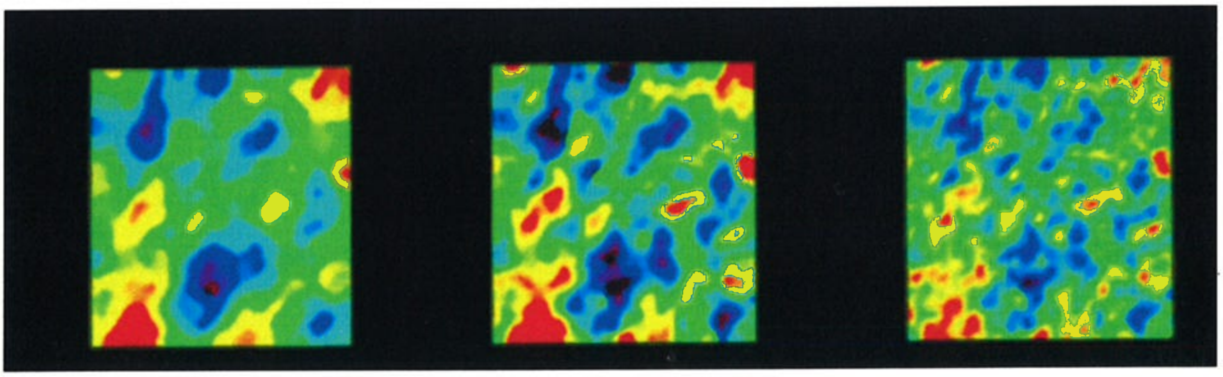
There are 10 problems in this exam. Start with the problems that you feel you can do quickly and then work towards the harder ones. Pay attention to the time.

1. [15 points]
(a) List the four main techniques astronomers use to constrain the properties of dark energy [5 points].

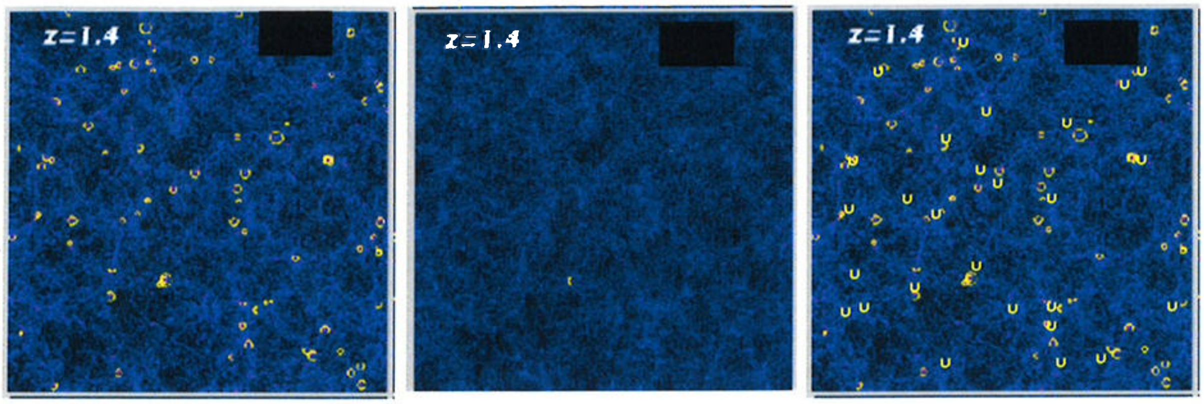
(b) Provide a ~3 sentence explanation of how each technique works. [You will not be penalized for providing a longer answer. – 5 points]

(c) Each technique relies upon the manner in which one or more quantities (e.g. the luminosity distance, growth factor) varies as a function of redshift to constrain the cosmological parameters. List the different (redshift-dependent) quantities each technique utilizes to constrain the cosmological parameters [5 points]. [There may be more than one.]

2. [6 points]
Here are three maps of the cosmic microwave background. Which of these maps correspond to a universe with $\Omega_m = 1$, which correspond to a universe with $\Omega_m = 0.3$, and which corresponds to universe with $\Omega_m = 0.8/\Omega_\Lambda = 0.7$? The angular scale subtended by each panel is the same. Briefly explain your reasoning.



3. [6 points]
The figure below shows the locations of high-redshift galaxy clusters found in the same comoving volume in three different universes. Which universe corresponds to $\Omega_m = 0.3$, which corresponds to $\Omega_m = 1$, and which corresponds to $\Omega_m = 0.3/\Omega_\Lambda = 0.7$? Assume that the number density of clusters in each of these universes is the same at $z = 0$. [Note that the white dots and U's both represent clusters.]




4. [21 points]
(a) On approximately which scale is there a feature in the matter power spectrum measured by the BAO technique? [2 points]

(b) Excess power in the matter power spectrum can be seen both along the line of sight and in the plane of the sky. Which redshift-dependent quantities relevant to the determination of the cosmological parameters (e.g. see question 1c) does structure in each of these directions constrain? [3 points]

(c) What is the name of the test which compares the ratio of the size of the structure in the plane of the sky vs. along the line of sight? [2 point]

(d) Which quantity is more sensitive to changes in the cosmological parameters (e.g., comparing a $\Omega_m = 1$ universe with a $\Omega_m = 0.3/\Omega_\Lambda = 0.7$ universe)? The angular separation of structure in the plane of the sky or structure along the line of sight? Justify your answer. [4 points]

(e) Assume that there is a separation of $\Delta z = 0.08$ (along the line of sight) between features in the matter power spectrum at $z \sim 1$ and we know that $\Omega_k$(curvature) $= 0$. What is $\Omega_m$ and what is $\Omega_\Lambda$? [5 points]

(f) How would your answer to part (e) change if it was known that $w = -0.7$? [5 points]

5. [8 points]

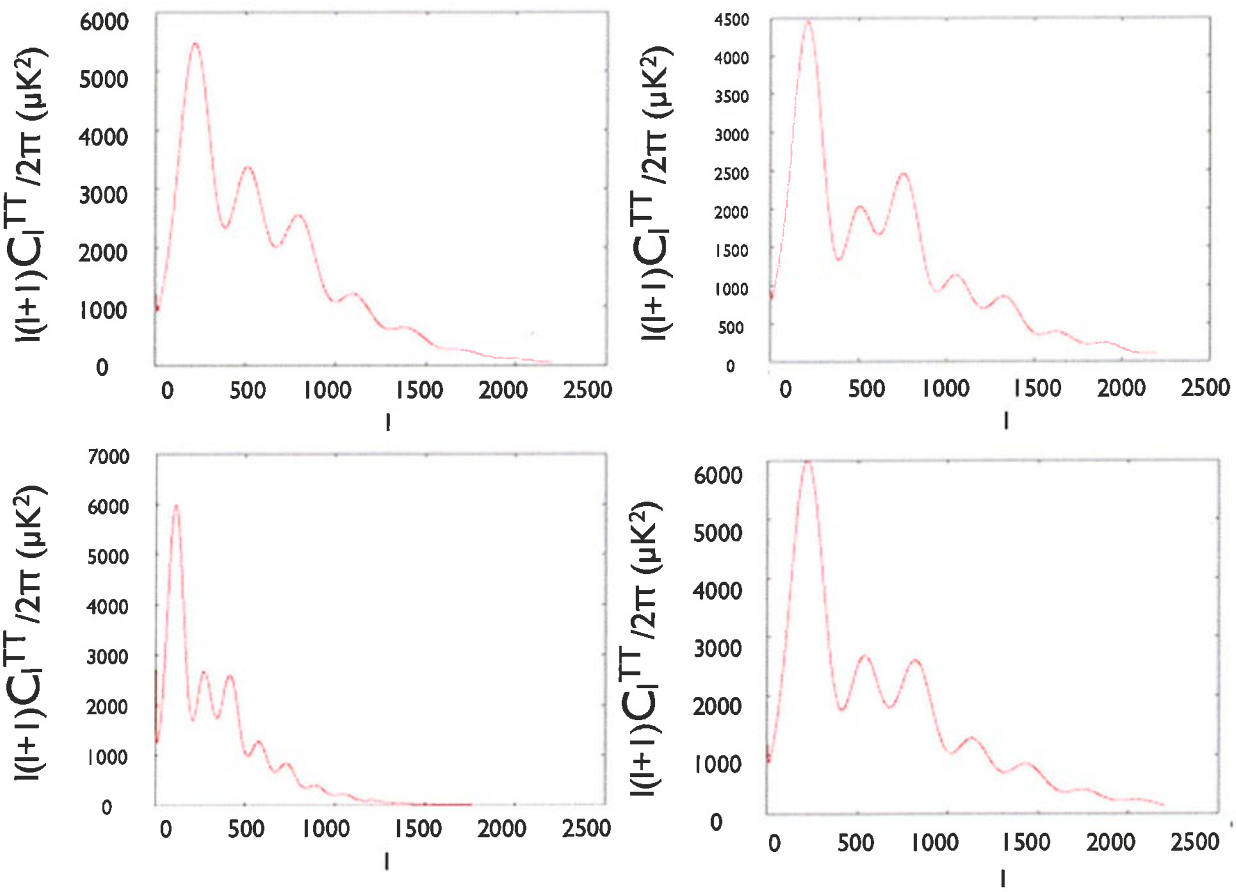
Match the CMB TT power spectrum to the set of cosmological parameters? Justification for your answers is also important for full credit. Pay attention to both the horizontal and vertical axis scales.

(a) $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, $\Omega_b = 0.04$

(b) $\Omega_m = 0.6$, $\Omega_\Lambda = 0.4$, $\Omega_b = 0.04$

(c) $\Omega_m = 0.3$, $\Omega_\Lambda = 0.4$, $\Omega_b = 0.04$

(d) $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, $\Omega_b = 0.02$



6. [12 points]
(a) Draw a diagram of the matter power spectrum P(k). Why does the matter power spectrum have a turnover at small scales? What is the physical reason? Which observational techniques can we use to constrain its overall shape? Indicate the approximate spatial scales where different techniques are particularly valuable in constraining the overall shape [6 points].

(b) How would you expect the matter power spectrum to change if the cosmic microwave background temperature were higher or lower by 10% (if all other measured parameters $\Omega_m$, $\Omega_\Lambda$, $\Omega_b$, $H_0$, $\sigma_8$ were the same)? What impact would it have (if any) on the comoving length scale of the peak of the power spectrum? [6 points]

7. [8 points]
(a) Estimate how many $z = 1.0$ SNe are necessary to determine the value of $\Omega_m$ to within an uncertainty of 0.03 assuming a flat $\Omega_M + \Omega_\Lambda = 1$ universe and 10% distance errors for the SNe [5 points].

$D_L(\Omega_\Lambda = 0.7, \Omega_m = 0.3; z = 1.0) = 6607$ Mpc
$D_L(\Omega_\Lambda = 0.72, \Omega_m = 0.28; z = 1.0) = 6687$ Mpc
$D_L(\Omega_\Lambda = 0.68, \Omega_m = 0.32; z = 1.0) = 6530$ Mpc

(b) There are a number of potential problems in using high-redshift SNe Ia to constrain the cosmological parameters. Very briefly describe three of these potential problems. [3 points]

8. [10 points]
(a) What is the physical reason we see a damping tail at small angular scales in the CMB power spectrum? [3 points]

(b) Cosmic variance can serve as an important limitation in our attempts to constrain cosmological parameters from CMB experiments. Explain. How does the uncertainty from cosmic variance scale with the l number? [3 points]

(c) Illustrate why with a diagram why a quadrapole in the temperature structure of the CMB leads to polarization in the CMB light [4 points]

9. [5 points]
One method to determine the Hubble constant which allows us to skip the distance ladder uses galaxy clusters and makes use of both the x-ray luminosity and the impact of the Sunyaev-Zeldovich effect on CMB light passing through galaxy clusters. Briefly explain how this method works and indicate how you would use to measure the distance to a given galaxy cluster.

10. [9 points]
(a) Based on observations of sources in the nearby universe (<200 Mpc) and without looking at objects outside this volume, it is possible to constrain $H_0$, $\Omega_m$, $\Omega_b$, and $\sigma_8$ very precisely (using techniques discussed in class). Assume that you do not know the value of any of these parameters at the start, so you will need a strategy to derive them one by one, occasionally breaking degeneracies. However you can assume that the galaxy bias is 1 (i.e., that galaxies are a fair tracer of the underlying mass fluctuations). Explain which

parameters you would derive first (using which techniques?) and how you would use the parameters you derived to derive the other parameters (again using which techniques?) [6 points].

(b) Why are you not able to determine $\Omega_\Lambda$ by observing sources in the local universe? [3 points]