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. [10 points]
(a) Two issues that one needs to consider in deriving the correlation function from the apparent three-dimensional spatial distribution of galaxies on the sky is redshift space distortion and biasing. What effect do redshift space distortions have on the spatial position of galaxies in the plane of the sky and along the line and sight? Draw a diagram. Also include the finger-of-God effect if possible on the diagram. Please briefly explain the physical origin of the effects seen on the diagram. [5 points]

(b) What effect does galaxy biasing have on the power spectrum one extracts from galaxy observations (if one does not correct for it)? [5 points]

3. [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 $\Delta z = 0.075$ (along the line of sight) between features in the matter power spectrum at $z \sim 1$ and we know that Ω_k(curvature) $= 0$. What is Ω_m and what is Ω_Λ? [5 points]

(f) How would your answer to part (e) change if it was known that $w = -0.9$? [5 points]

4. [8 points]
(a) What is σ_8? How is it defined? [4 points]

(b) Please describe at least two different techniques discussed in class to constrain this parameter [4 points].

5. [10 points]
(a) Where are the baryons in the present day universe? Approximately what fraction of baryons are in stars, hot gas, and cold gas? [3 points]

(b) How can astronomers use the CMB power spectrum to constrain the matter density in baryons? [3 points]

(c) Another method astronomers use is based on Big Bang Nucleosynthesis. Briefly how do astronomers use this technique to establish the matter density in baryons. Which element provides us with the most sensitive probe of the matter density in baryons? [2 points]

(d) Which would you argue provides a stronger constraint on the matter density in baryons, the CMB or Big Bang Nucleosynthesis considerations? [2 point]

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 Ω_b were higher or lower by 10% (if all other measured parameters Ω_m, Ω_Λ, H_0, σ_8 were the same)? What impact would it have (if any) on the comoving length scale of the peak of the power spectrum? [3 points]

(c) How would you expect the matter power spectrum to change if the Ω_m were higher or lower by 10% (if all other measured parameters Ω_Λ, Ω_b, H_0, σ_8 were the same)? What impact would it have (if any) on the comoving length scale of the peak of the power spectrum? [3 points]

7. [8 points]
(a) Estimate how many $z = 1.0$ SNe are necessary to determine the value of Ω_m to within an uncertainty of 0.05 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) What is the Philips relation? And how is it important in using high-redshift SNe to constrain the cosmological parameters? [2 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) In class we discussed four different distance measures used in observational cosmology: luminosity distance, angular diameter distance, proper motion distance, and comoving distance. For a flat $\Omega = 1$ universe, which of these two distances are equal? Which of these distances is larger than the other three? Which is the smallest? [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 very compelling piece of evidence for the existence of dark matter comes from colliding clusters where we have both deep x-ray data and optical data (to measure the weak lensing). Draw a diagram and explain how such observations of clusters provide compelling evidence for dark matter.

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, Ω_m, Ω_b, and σ_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 Ω_Λ by observing sources in the local universe? [3 points]