Problem Set on “Surveys” lecture

Intro:
This problem set does not contain any “new” material. Its purpose is to go over two basic concepts taught in the last lecture, so that you can familiarize yourself with them:

1) The galaxy luminosity function and the Schechter formula, and
2) redshift space distortions in galaxy redshift surveys .

Even though this problem set seems very long, most of the words are instructions and help related to each task. Please ask me if you get stuck somewhere, or if you don’t understand a question.

1) Luminosity function + Schechter formula

1a) What is the definition of the *luminosity function* (LF) in words? Can you also write down the definition of the LF in a formula? What are the units of the LF?

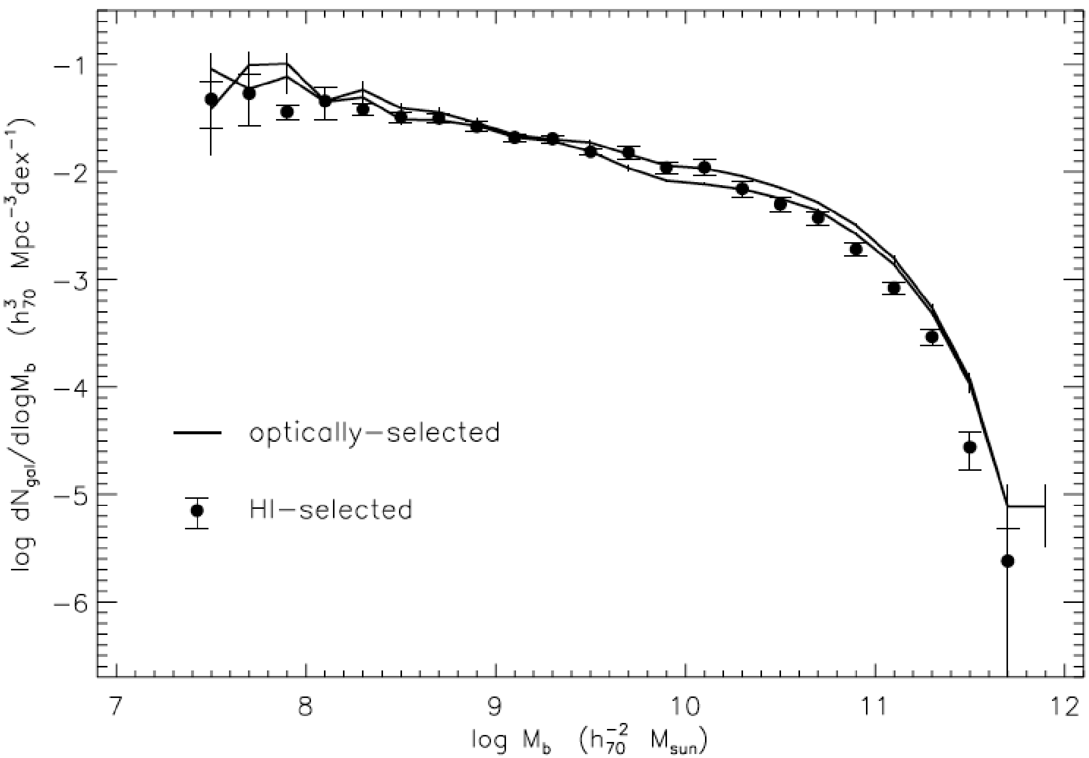
1b) Can you write down the *Schechter function* equation, as presented in the lecture? Can you explain the meaning of each parameter in words? What are each parameter’s units?
(You will have to memorize the formula for the final exam, but once you have understood what it means you can remember it very easily)

1c) On the next page, you see a plot of the *baryonic mass function* (BMF) of galaxies. The measurement shown has been obtained from real data from the Sloan optical survey and the ALFALFA radio survey. (Forget about the two thin black lines, only consider the black datapoints and their errorbars).

The BMF is exactly like the LF, but instead of luminosity we study the *baryonic mass* of each galaxy. In this context, baryonic mass typically refers to the mass that we can observe with our telescopes. In turn, this usually means the mass of stars (which we can infer from the optical luminosity of a galaxy) plus the mass of hydrogen gas (which we can measure from the radio luminosity of a galaxy): $M_b = M_* + M_{gas}$.

Take a look at the axes of the plot… First of all, notice that this is a log-log plot (why?). Moreover, notice that the BMF is not defined in exactly the same way as you saw in class or as you wrote down in question 1a (take a look at the y-axis label). “Massage” the equation you wrote down in question 1a, such that you convert it to the same definition used in this plot. Now, can you write down how the Schechter formula looks like according to this “massaged” definition of the BMF?

(since we are now talking about mass and not about luminosity don't forget to rename some of your variables in the Schechter formula (e.g. L -> M, L* -> M*, etc.))



1d) By eye, make a Schechter function fit to the data in the plot above. From this fit can you approximately deduce the Schechter parameters for this measurement of the BMF? Use your eyes and perhaps a ruler. Sketch on the plot any points or lines that helped you deduce the parameters. Don't forget to write down the parameter values with their units, and also don't forget to check if the values that you obtained make sense based on what you saw in lecture.

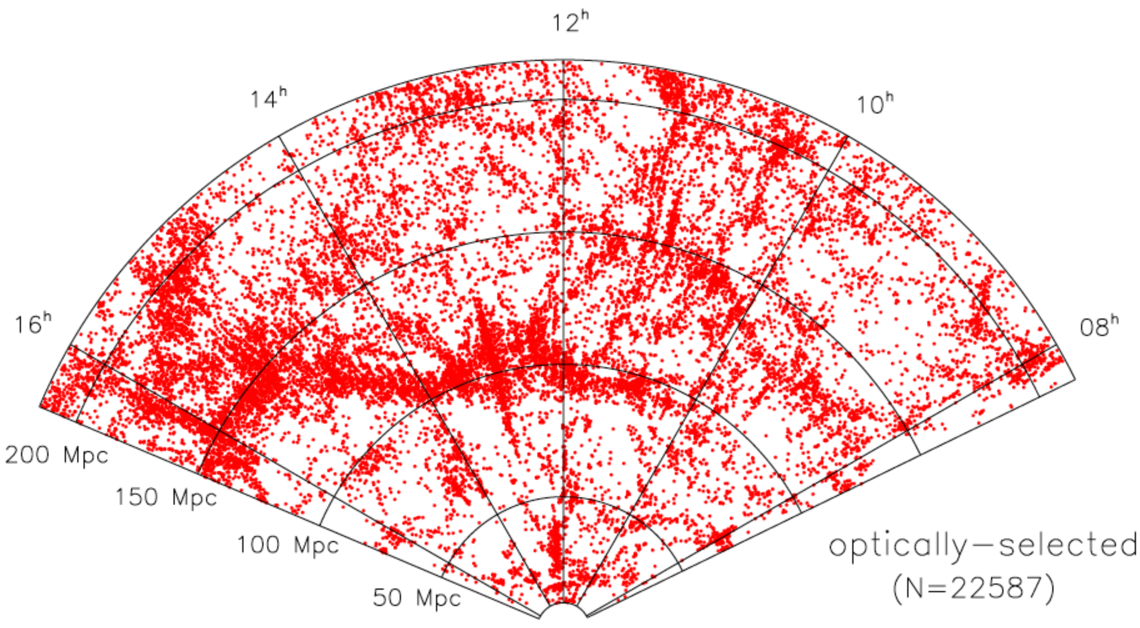
1e) Based on the BMF measurement shown, what baryonic mass bin has the largest number density of galaxies? (consider only the range of baryonic masses probed by the measurement)
How would you characterize these galaxies? (giants? dwarfs? M*? other?)
If you could see all the galaxies within a box of our universe that is 100 Mpc on a side, how many galaxies belonging in this specific bin would you expect to find?

1f) (This is a bonus task for those who have too much free time. It is easy but it takes some time, so do it at home after you have finished the rest of this problem set)
Based on the datapoints of the BMF make a plot of the distribution of baryonic mass in each baryonic mass bin, i.e. M_b * dN / dV dlogM_b . In order to do this you will need

to read out each datapoint of the BMF with a ruler, calculate the equation above, and then replot the result on a set of axes.
Which bin has the highest baryonic mass density? Is it indeed close to “M*” as we argued in lecture?

2) Redshift space distortions

Below you see a *coneplot* of a “small” region of the Sloan Digital Sky Survey (SDSS) redshift survey. The region of the sky plotted here is a “slice” of the sky: it spans about 8h30m in R.A. and 12° in Dec, and it extends out to a maximum redshift of z_{max} = 0,05 . Every galaxy brighter than an apparent optical magnitude of m_{lim} = 17,5 mag is plotted as a red dot. Remember that, in a coneplot, we are viewing the sky slice from “above”. This means that all declinations (i.e. the direction perpendicular to the sky “slice”) are collapsed onto a single plane. Also remember that, since galaxies are included based on an apparent magnitude threshold, this represents a *magnitude-limited* (or *flux-limited*) sample.



2a) Mark with a dot the position of the observer (i.e. earth) on this coneplot. What is the *absolute magnitude* of the least luminous galaxy visible with Sloan at the near edge of the coneplot? How would you characterize this galaxy? (dwarf? giant? L*?)

What about at the far edge of the coneplot?

2b) The plot above is *isotropic*. This means that the *x* and *y* axes have the same units and the same spacing between the axes' tickmarks (you can't see the *x*- and *y*- axes of course, because they are not plotted ☺). If you could see the axes, what units would they have?
What is strange about this whole story is that if you pick any two galaxies on the coneplot you can read out with a ruler their physical distance in Mpc (try it!). However remember that, when we conduct a survey, distances are not measureable! For each detected galaxy we can only measure its position on the sky (in terms of angles, i.e. R.A. and Dec.) and its redshift *z*.

Make the rough assumption that all galaxies in the coneplot have the same Dec. Now suppose that you have measured some galaxy to have an R.A. on the sky of α_1 and a redshift z_1 and another galaxy to have a R.A. α_2 and redshift z_2. Can you write down the equations that you need to compute from these observational data the distance between the two galaxies in Mpc, as you would measure on the coneplot?

2c) In class we saw that clusters show up in a redshift survey with a characteristic "finger of god" shape. Why is this shape called the "finger of god"? (i.e. why "finger"? and why "of god"?)

Now try to identify on the coneplot all the clusters that you can see (it doesn't matter if you miss some, no one is perfect ☺).
Now rank them from the most massive to the least massive. For the five most massive, can you infer from the coneplot the velocity dispersion of each cluster? The velocity dispersion of Virgo is ~1000 km/s. How do the five clusters above compare in mass with Virgo?

3) Correlation Functions

3a)
i) What is the real space correlation function, $\xi(r)$? Write down the definition in words, and also through a formula. Don't forget to define the quantities in the formula and write down their units.
ii) What is the angular correlation function, $w(\theta)$? As above, write down the definition in words, and also through a formula.
iii) In practice, the physical separation between two galaxies, r, is not measurable. The only separation between galaxies that can be measured in a survey is the angular separation on the sky ($\Delta\theta$) and the redshift separation (Δz). Can you write down a formula that turns $\Delta\theta$ and Δz into an "observational" version of the physical separation (in units of Mpc)?

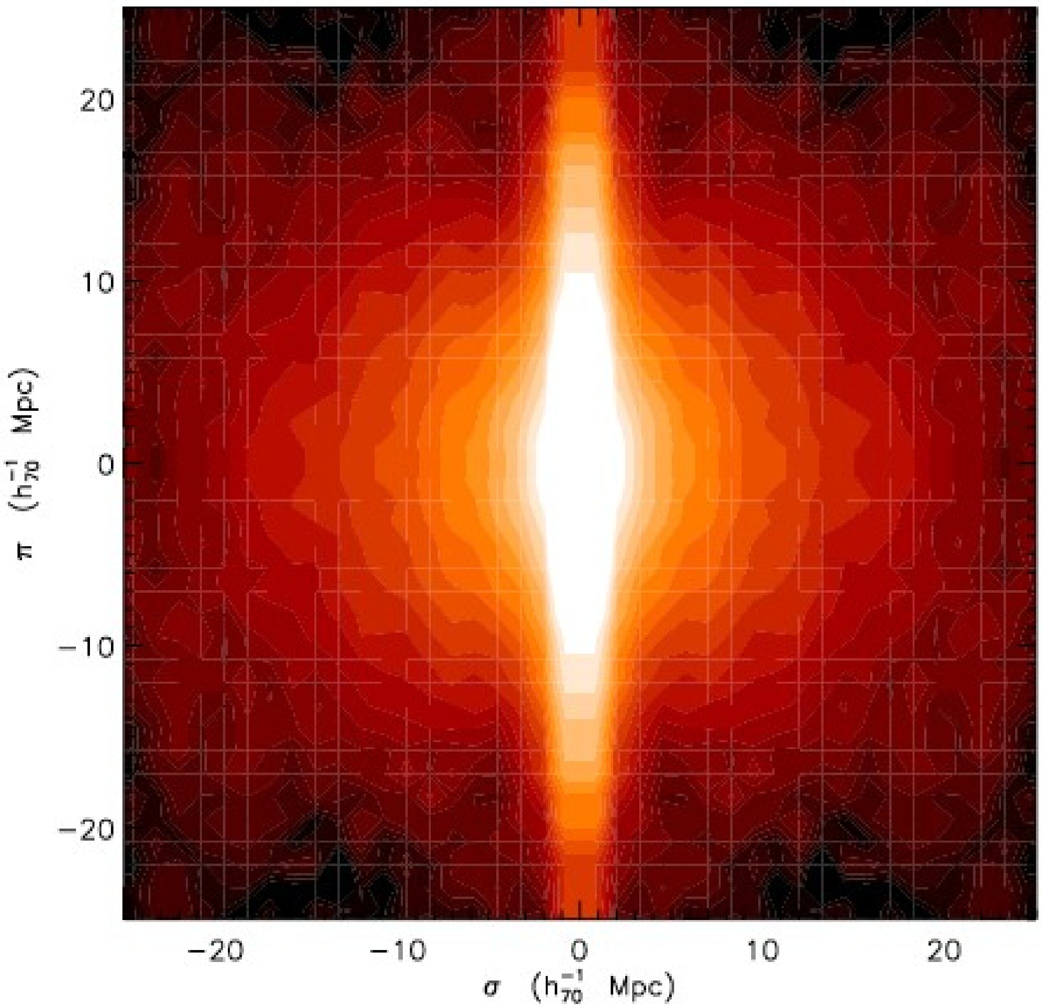
3b)
We saw in class that the angular CF of galaxies detected by a survey scales as

$$w(\theta,D) = (1/D)\, w(\theta D)\,, \qquad (1)$$

where D is the survey depth.

i) What is the survey depth, D? Give a definition in words. You may also want to sketch a helpful figure.
ii) Can you give a description of the effects that the formula above represents (which part of the formula represents what effect?). Can you give an intuitive explanation for the effects captured by this formula in words?
iii) What key cosmological principle underlies the derivation of this formula? Describe how you could use the data in a photometric survey (this means no redshift information) to test this cosmological principle based on Eqn. 1.

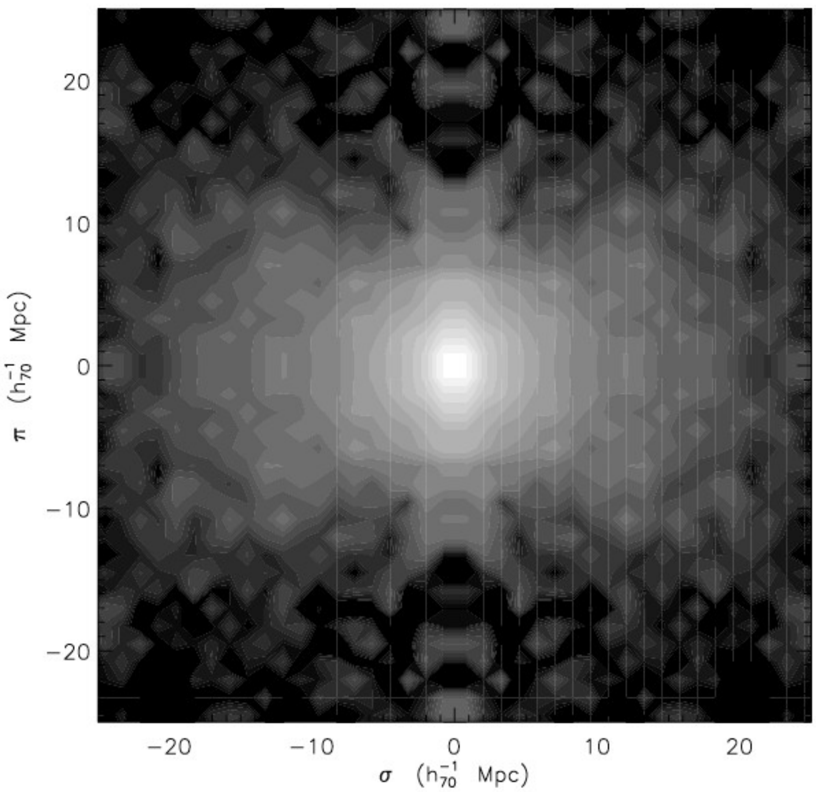
3c)
Below you can see the 2D correlation function of galaxies with red colors, as measured by the Sloan Digital Sky Survey (SDSS).



The *x* and *y* axes are separations between galaxy pairs along the line-of-sight direction and along the projected-on-the-sky direction, respectively. The contours represent the value of the correlation function, ξ(σ,π). Lighter shades represent higher values of the CF, with the darkest contour set at a value of 0,05 and the lightest at a value of 6,3.

i) What measurable survey quantities are used to derive σ and π? Through which formulas?
ii) What is the bright feature close to σ=0 that is elongated in the π direction? Mention the nickname of the effect producing this feature, and what two observational effects are alluded to by this seemingly "peculiar" nickname.

Below you can see a similar measurement of the 2D correlation function, but this time for galaxies detected by the ALFALFA radio survey.



The axes and contours are exactly as defined for the SDSS correlation function shown above.

iii) What is the most striking difference between the SDSS and ALFALFA 2D correlation functions? Given that the SDSS measurement refers to galaxies with red optical colors while the ALFALFA measurement refers to galaxies that are rich in hydrogen gas, what scientifically interesting result can you deduce regarding the properties of gas-rich galaxies?

iv) Why does the ALFALFA 2D correlation function look "squashed" along the π axis at scales of 10-20 Mpc? Can you explain what cosmological information is encoded in the amount of squashing observed? You may try to do this in words, but the addition of a relevant formula would gain you extra points.