DOWNLOAD PDF LARGE SCALE STRUCTURE

Chapter 1 : Galaxy Clusters

A cold, dark matter simulation of the large-scale structure in the nearby Universe. This image is ~ million light years square. Red regions show high concentrations of galaxies, including galaxy superclusters and filaments, while blue areas show low galaxy concentrations in the voids.

As we look out into the universe we see structure on a wide range of physical scales. The most obvious example is that stars cluster in groups and galaxies. Early redshift surveys of the s showed that these galaxies are also not distributed randomly throughout the Universe. They are found to lie in clusters , filaments, bubbles and sheet like structures. There exist large regions of the Universe which contain almost no galaxies. The nearby universe then shows a large amount of structure on the very largest scales. The positions of galaxies in the Center for Astrophysics CfA redshift survey. The plot shows a thin slice through the universe the pie shapes containing nearly 10, galaxies. The observer is situated at the narrow end of the slice. Distances radially outward indicate the observed redshift of a galaxy. Recent very large scale galaxy surveys have now reached far enough out into our local volume to begin to see the end of greatness. That is they sample a large enough volume of space that the largest structures in the survey about Mpc in size are no longer of the same size of the survey itself. Galaxy surveys with well defined selection criteria enable us to extract information about the clustering pattern. Such surveys are driven in part by the map-makers instinct: They are also driven by a more theoretical desire: To characterize the distribution of galaxies a number of statistical tools have been developed. The most widely used approach to quantifying the degree of clustering observed is to measure the correlation functions. For example the two-point correlation function is the probability, in excess of random, of finding a galaxy at a fixed distance from a random neighbor. Its Fourier transform is the power spectrum which is now more widely used. Beyond this one investigates higher order correlation functions, for example the distribution of counts-in-cells: For further information go here. Return to my research interests page for a bibliography.

Chapter 2 : Structure - Large Scale Scrum (LeSS)

This disambiguation page lists articles associated with the title Large-scale structure. If an internal link led you here, you may wish to change the link to point directly to the intended article.

A postscript version of this paper can be found here: The basic properties of the XSC, including photometric sensitivity, source counts, and spatial distribution are presented here. Finally, we employ a photometric redshift technique to add depth to the spatial maps, reconstructing the cosmic web of superclusters spanning the sky. Panoramic view of the entire near-infrared sky reveals the distribution of galaxies beyond the Milky Way. The map is projected with an equal area Aitoff in the Galactic system Milky Way at center. A locator key is provided in Figure 2 ; a more detailed chart is given here. An animation that shows the cosmic web separated by sliced redshift is given here-animation beware: The focus has shifted to the distribution and nature of dark matter and dark energy that drive the dynamics of the expanding cosmos. The study of the local Universe, including its peculiar motions and its clustering on scales exceeding Mpc, is an essential ingredient in the connection between the origin of structure in the early Universe and the subsequent formation of galaxies and their evolution to the state we observe today. Key issues include the location and velocity distribution of galaxies, leading to the mass-to-light relationship between what is observed and what is influencing the mass density field. Galaxy clusters and large scale structures are labeled. The CMB dipole Lineweaver et al is located to the right of the Shapley Concentration item "F" in figure , while the galaxy clustering dipole Maller et al b is located 16 degrees northward of the CMB dipole, adjacent to the Virgo and Shapley superclusters. A more detailed chart is given here. Spurred on by the enormous success of the redshifts surveys cf. Many years of observations and hard work to detect and extract sources has produced a gap-free image atlas of entire sky, and catalogues containing stars and galaxies. The literature is now populated with many influential papers that used 2MASS to address fundamental extragalactic issues, including luminosity functions cf. Cole et al ; Kochanek et al ; Bell et al , galaxy morphology cf. Jarrett et al , distance indicators cf. Karachentsev et al , angular correlation functions cf. Maller et al a , and the dipole of the local Universe cf. Maller et al b. The 2MASS view of the "cosmic web"--the space distribution of galaxies in the local Universe--is the focus of this paper. Figure 1 is an attempt to encapsulate our present understanding of the large scale structure that embodies the local Universe. Figure 2 provides a locator key to the extragalactic sky. A more detailed sky chart is given here. The final source catalogs and image Atlas was released to the public in the fall of Cutri et al The images were acquired using an efficient drift scan and freeze-frame technique, painting the sky with 8. The typical 1-sigma background noise is This paper will focus on these resolved galaxies. The differential source counts, Figure 3 , illustrate the depth and areal coverage of the 2MASS galaxy catalog for unobscured regions of the sky. Morphology -- As a function of Hubble or morphological type, 2MASS is most sensitive to early-type spirals and ellipticals whose light is dominated by the older population of stars emitting in the near-infrared , and less sensitive to late-type spirals whose light is dominated by the younger, hotter disk population , dwarfs low surface brightness and compact objects resolution limitations of 2MASS ; see Jarrett , Bell et al , and Jarrett et al The Galactic "zone of avoidance" ZoA is still, however, a formidable barrier due to the sheer number of stars that produce a foreground confusion "noise". Spatial over-densities from galaxy clusters trace the large scale structure; see for example the beautiful maps of Courtois et al who reconstructed the extragalactic sky using galaxies archived in LEDA. Tully ; Tonry et al and the more distant "cosmic web" structures; see Figure 5. This technique mitigates the biasing effects of non-uniform incompleteness due to surface brightness differences and galaxy morphology see above. The figure illustrates how 2MASS creates a uniform view of the local Universe, except for the extreme Galactic Center, bridging the two hemispheres above and below the plane of the Milky Way center region of figure. A further enhancement to the all sky maps is to color-code the galaxies according to their total integrated flux. Since the integrated flux is strongly correlated with the distance to the object assuming 2MASS galaxies have roughly the same luminosity; see the next section , the color-coding effectively adds depth to the surface density maps. In this way a qualitative view of the 3-D galaxy distribution is created, illustrated in Figure 6 using a Supergalactic projection. This simple and effective method delineates real large scale structure in the local Supercluster and beyond Figure 6. We can marginally improve upon the "photometric redshift" by correcting the luminosity estimate using the K-correction deduced from the near-infrared colors, described in the next section. The J, H and Ks source counts are represented with blue, green and red lines, respectively. For comparison, the narrow but deep K-band galaxy counts of Glazebrook et al and Gardner et al are shown in black. Three Ks-band flux limits are shown: All longitudes are used to draw the galaxy sample. The grey-scale represents the total integrated flux along the line of sight -- the nearest and therefore brightest galaxies produce a vivid contrast between the Local Supercluster center-left and the more distant cosmic web. The dark band of the Milky Way clearly demonstrates where the galaxy catalog becomes incomplete due to source confusion. Some well known large-scale structures are indicated: The Galactic "anti-center" is front and center, with the Orion and Taurus Giant Molecular Clouds forming the dark circular band near the center. The Local Universe The current generation of large and uniform redshift surveys e. Velocity measurements will always be in the position of catching up with broad-band imaging. A three-dimensional reconstruction of the local universe is therefore possible and within our reach using broad-band photometry from large-scale surveys. Here we use only the 2MASS galaxy catalog to create a first-look version of the local universe. With the coming of optical and mid-infrared broad-band and spectroscopy surveys, this view will sharpen and reach greater depths. Photometric Redshifts -- The 3-band near-infrared photometry of 2MASS is used to estimate luminosity distances to galaxies. Although this technique is crude in terms of accuracy, it does provide a means to generate qualitative maps of the spatial distribution of galaxies and thereby construct an all sky "big picture" view of the local Universe. Here we adopt the technique devised by Kochanek et al The fundamental assumptions of this method are that galaxies have roughly 1 the same luminosity and 2 their near-infrared colors are modified by cosmic reddening Figure 7. The measured integrated flux is the primary component, while the near-infrared colors adds secondary information. This method is particularly adept at revealing galaxy clusters since the redshift uncertainty declines with the square root of the number of cluster members detected by 2MASS. By assuming that galaxies are standard candles, the distance or redshift is derived from the integrated flux, distance modulus and luminosity distance. Here we correct for Galactic extinction and incorporate the cosmic reddening "k-correction", Figure 7 , into the distance calculation for self-consistency between the measured colors and the inferred luminosity distance. Note that the scatter in the color vs. The histogram peaks at The fall-off in sources at the faint end is due in part to the sensitivity limit of redshift surveys. A comparison of the photometric-derived redshifts with radial-velocity redshifts is shown in Figure 9 , where we plot the redshift as a function of the Ks-band flux. The photometric redshifts appear to accurately predict the mean radial-velocity redshift per mag interval from the brightest nearby to the faintest distant galaxies. However, note the large scatter in the redshift distribution per mag interval -- this is due to galaxies with intrinsically different luminosity -- from the brightest ellipticals to the faintest dwarf galaxies. What this means is that 2MASS-only photometric redshifts provide the correct answer on average, but for any given galaxy the uncertainty is large, which is particularly severe for the faint end of the distribution. The effect is to brighten the colors of nearby galaxy clusters e. Near the galactic center region center of image , the confusion noise completely swamps out detection of background extragalactic objects see Figure 1. Galaxy near-infrared colors as a function of redshift. Cosmic reddening is the result of shifting of galaxy light from the H-band 1. The observed scatter error bars relative to the slope indicates that near-infrared colors alone are an inadequate discriminant of redshift. Luminosity distribution of 92, 2MASS galaxies as computed from redshift-derived distances. The faint end of the curve is subject to incompleteness due to the sensitivity limit of the redshift surveys. These are compared to the radial-velocity redshifts blue points. The error bars represent the scatter in redshift vs. Ks-band integrated flux i. The Cosmic Web -- Figure 1 beautifully unveils the background extragalactic sky from the obscuring foreground Milky Way. Galaxies are color-coded by their inferred redshift or distance from the Sun , thereby providing depth to the surface distribution of galaxies. Figure 2 , a key to the large scale structures. Probing orthogonal to this 3-D surface reveals the redshift distibution along the line of sight; an example is shown in Figure 10 for the Shapley Concentration discussed below. The strong clustering seen at angular scales that span from arc-minutes groups and clusters to several degrees super-clusters confirms the result of Maller et al a who measured the angular correlation function of galaxies in the 2MASS XSC, finding a slope of Their results also indicate that higher surface brightness galaxies are clustered more strongly, consistent with the finding that early-type galaxies dominate massive clusters the "nodes" of the cosmic web. This is more easily seen when each redshift layer is shown separately; Figure The third layer 0. It is unknown whether this ring-like structure is physically associated with the cosmic web or an artifact of projection. The fourth layer 0. The "great wall" of galaxies extends from Coma down toward Bootes and Hercules. The fifth layer 0. The sixth layer 0. The massive size and peculiar velocity field of the Shapley Concentration region suggests that it may be the most dominant "attractor" in the local Universe; indeed the IRAS PSCz dipole Rowan-Robinson et al and 2MASS galaxy cluster dipole Maller et al b are located near this great structure. At these faint flux levels, the photometric redshifts are losing their ability to discern the cosmic web beyond Mpc, smearing and degrading the resolution of the 3-D construct. This is clearly demonstrated in Figure 10 , where we show the redshift distribution for the Shapley Concentration region in a constant declination slice across the equatorial axis. But the intricate web of large scale structure extends well beyond this volume limit, as unmistakably demonstrated by the 2dF and SDSS galaxy surveys. But with the addition of optical and or mid-infrared photometry from future all sky surveys e. Moreover, large redshift surveys e. But perhaps its most important function is to provide the "big picture" context for analysis and interpretation of data concerning galaxy clusters, large scale structure and the density of matter in the Universe.

Chapter 3 : Ep. Large Scale Structure of the Universe | Astronomy Cast

Another large-scale structure is the SSA22 Protocluster, a collection of galaxies and enormous gas bubbles that measures about million light-years across.

Galaxy Clusters and Large-Scale Structure Groups and clusters of galaxies Galaxies are preferentially found in groups or larger agglomerations called clusters. The Local Group consists of our own galaxy, the larger spiral galaxy Andromeda M31 and several smaller satellites, including the Large and Small Magellenic Clouds. Fornax is a small cluster of spiral and elliptical galaxies near our Local group. Regular clusters have a concentrated central core and a well-defined spherical structure. These are subdivided according to their richness, that is, the number of galaxies within 1. The Coma cluster shown here is a very rich cluster with thousands of ellipticals inside the Abell radius. The central region of the Coma cluster populated with large elliptical galaxies. This is one of the densest known regions on this scale in the universe. An example is the nearby Virgo cluster. Virgo, an irregular cluster, is the nearest large cluster of galaxies. Our own Local Supercluster is centred on Virgo and is relatively poor having a size of 15Mpc. The largest superclusters, like that associated with Coma, are up to Mpc in extent. Measurements of peculiar velocitiesdeviations away from the Hubble flow - are achieved by comparing redshifts and galactic distance indicators. These have revealed enormous coherent motions on scales in excess of 60Mpc. Deep redshift surveys reveal a very bubbly structure to the universe with galaxies primarily confined to sheets and filaments. Voids are the dominant feature and have a typical diameter of about 25Mpc. Galaxy positions are plotted as white points and large filamentary and sheet-like structures are evident, as well as bubble-like voids CfA. Deep field surveys A particularly exciting recent development in the study of large-scale structure has been the advent of very deep galaxy surveys, notably those currently being made by the Hubble Space Telescope. These images below show galaxies just a couple of billions years after the Big Bang. One of the remarkable puzzles presented by this work is that galaxies appear to form earlier than predicted in most theoretical models.

Chapter 4 : Teach Astronomy - Large Scale Structure

In physical cosmology, the term large-scale structure refers to the characterization of observable distributions of matter and light on the largest scales (typically on the order of billions of.

So if the matter that originally emitted the oldest CMBR photons has a present distance of 46 billion light-years, then at the time of decoupling when the photons were originally emitted, the distance would have been only about 42 million light-years. Misconceptions on its size[edit] An example of the misconception that the radius of the observable universe is 13 billion light-years. Many secondary sources have reported a wide variety of incorrect figures for the size of the visible universe. Some of these figures are listed below, with brief descriptions of possible reasons for misconceptions about them. While it is commonly understood that nothing can accelerate to velocities equal to or greater than that of light, it is a common misconception that the radius of the observable universe must therefore amount to only This reasoning would only make sense if the flat, static Minkowski spacetime conception under special relativity were correct. Distances obtained as the speed of light multiplied by a cosmological time interval have no direct physical significance. If the whole universe is smaller than this sphere, then light has had time to circumnavigate it since the Big Bang, producing multiple images of distant points in the CMBR, which would show up as patterns of repeating circles. A preprint by most of the same authors as the Cornish et al. This figure was very widely reported. The organization of structure appears to follow as a hierarchical model with organization up to the scale of superclusters and filaments. Larger than this at scales between 30 and megaparsecs [51] , there seems to be no continued structure, a phenomenon that has been referred to as the End of Greatness. Stars are organized into galaxies , which in turn form galaxy groups , galaxy clusters , superclusters , sheets, walls and filaments , which are separated by immense voids , creating a vast foam-like structure [53] sometimes called the "cosmic web". Prior to , it was commonly assumed that virialized galaxy clusters were the largest structures in existence, and that they were distributed more or less uniformly throughout the universe in every direction. However, since the early s, more and more structures have been discovered. The discovery was the first identification of a large-scale structure, and has expanded the information about the known grouping of matter in the universe. It is about 1 billion light-years across. That same year, an unusually large region with a much lower than average distribution of galaxies was discovered, the Giant Void , which measures 1. Based on redshift survey data, in Margaret Geller and John Huchra discovered the " Great Wall ", [54] a sheet of galaxies more than million light-years long and million light-years wide, but only 15 million light-years thick. The existence of this structure escaped notice for so long because it requires locating the position of galaxies in three dimensions, which involves combining location information about the galaxies with distance information from redshifts. Two years later, astronomers Roger G. Clowes and Luis E. Campusano discovered the Clowesâ€"Campusano LQG , a large quasar group measuring two billion light-years at its widest point which was the largest known structure in the universe at the time of its announcement. In April , another large-scale structure was discovered, the Sloan Great Wall. In August , a possible supervoid was detected in the constellation Eridanus. This supervoid could cause the cold spot, but to do so it would have to be improbably big, possibly a billion light-years across, almost as big as the Giant Void mentioned above. Computer simulated image of an area of space more than 50 million light-years across, presenting a possible large-scale distribution of light sources in the universeâ€"precise relative contributions of galaxies and quasars are unclear. Another large-scale structure is the SSA22 Protocluster , a collection of galaxies and enormous gas bubbles that measures about million light-years across. In , a large quasar group was discovered, U1. On January 11, , another large quasar group, the Huge-LQG , was discovered, which was measured to be four billion light-years across, the largest known structure in the universe at that time. It was defined by the mapping of gamma-ray bursts. It was not until the redshift surveys of the s were completed that this scale could accurately be observed. The map is projected with an equal area Aitoff in the Galactic system Milky Way at center. This is a collection of absorption lines that appear in the spectra of light from quasars , which are interpreted as indicating the existence of huge thin sheets of intergalactic mostly hydrogen gas. These sheets appear to be associated with the formation of new galaxies. Caution is required in describing structures on a cosmic scale because things are often different from how they appear. Gravitational lensing bending of light by gravitation can make an image appear to originate in a different direction from its real source. This is caused when foreground objects such as galaxies curve surrounding spacetime as predicted by general relativity , and deflect passing light rays. Rather usefully, strong gravitational lensing can sometimes magnify distant galaxies, making them easier to detect. Weak lensing gravitational shear by the intervening universe in general also subtly changes the observed large-scale structure. The large-scale structure of the universe also looks different if one only uses redshift to measure distances to galaxies. For example, galaxies behind a galaxy cluster are attracted to it, and so fall towards it, and so are slightly blueshifted compared to how they would be if there were no cluster On the near side, things are slightly redshifted. Thus, the environment of the cluster looks a bit squashed if using redshifts to measure distance. An opposite effect works on the galaxies already within a cluster: This creates a " finger of God "â€"the illusion of a long chain of galaxies pointed at the Earth. This indicates that they are receding from us and from each other, but the variations in their redshift are sufficient to reveal the existence of a concentration of mass equivalent to tens of thousands of galaxies. The Great Attractor, discovered in , lies at a distance of between million and million light-years million is the most recent estimate , in the direction of the Hydra and Centaurus constellations. In its vicinity there is a preponderance of large old galaxies, many of which are colliding with their neighbours, or radiating large amounts of radio waves. In , astronomer R. However, it excludes dark matter and dark energy. This quoted value for the mass of ordinary matter in the universe can be estimated based on critical density. The calculations are for the observable universe only as the volume of the whole is unknown and may be infinite. Estimates based on critical density[edit] Critical density is the energy density for which the universe is flat.

Chapter 5 : Galaxies and the Universe - Large-Scale Structure

By its very nature the problem of the large scale structure is one that mixes both observational and the theoretical aspects of cosmology. The plan of the lectures is first to discuss the general theoretical framework for cosmology, and then go on to discuss the impact of key data.

Yup the subject that puts dread in the hearts of many, many an undergraduate. With quantum mechanics there are lots of people that can work the equations but in terms of being able to completely internalize it and have their stomach do it. Your stomach can to kinematics. Your stomach knows you drop a ball. So let me do my official introduction and we can go from there. Quantum mechanics is the study of the very tiny; the nature of the reality of the smallest scale. It is a science that defies common sense and delivers no helpful analogies. Yet it delivers the goods making scientific predictions with incredible accuracy. I think the most straightforward description of it is: What kind of things can you mathematically describe with quantum theory? The entire spectrum of an atom can be described in very detailed ways using quantum mechanics. I can go out and use a telescope to observe hydrogen in many different states all across the universe. I can understand the 21 centimeter line as a very rare flipping of an electron. I can understand how light gets absorbed by gases and scattered in different directions and how lasers and masers work. All of that comes out of quantum mechanics. I can very precisely come up with all sorts of crazy numbers that describe how molecules vibrate. How did quantum mechanics come about? It basically came about from I think this was the original case of someone doing an experiment, having something really crazy come out of it and sitting in their chair and letting out a string of expletives. There were things like if you shoot an incredibly intense beam of red light at a metal plate. The metal plate goes yeah, so, okay and does nothing. But if you shoot higher energy blue light at that same plate you can get electrons getting shot off. The intensity of the light seemed to have nothing to do with what was going on. It had to do with the color of the light. This was finally explained by Einstein with what we call the photoelectric effect where suddenly the light was no longer this continuous intense sea of energy but rather it was discrete packets where the amount of energy in each individual packet was related to the color. That was a revolutionary idea. It forced us to change how we think of things. All of a sudden it was no longer light spreading out in this thinning sea as it radiates away from the sun. Rather it is a bunch of individual photons where the space in-between the photons increases as you get further and further away and the light is forced to spread itself out over a greater and greater area. All of this was new. Most fundamentally, the idea that light could only have certain energies. That was something completely expected that turned out to again be completely true. How did the first early physicists wrestle with this? There were lots of different things that they had to figure out. The first thing that probably got sorted out is that electrons can be bent with electromagnetic forces have very small masses. When they hit fluorescent screens they can give off light. A cathode ray tube was one of the first experiments that forced us to start thinking about electrons as discreet little packets and starting to understand how they worked. You create as complete a vacuum as you can. Then you do various things that cause electrons to be created. You accelerate them through charged plates, through capacitors. Then by adjusting magnetic fields you can change where on a fluorescent fluorescing plate that electron hits. When we first measured it and realized that it was fractions, thousandths of the mass of an atom we realized, wow electrons are these discreet little tiny particles that are extremely small but look at the things we can do with them. But where does the quantum mechanics part of it come into that story? Once we started thinking of things as little tiny here we have an electron, here we have photons, we started probing what is the structure of the atom. It was originally thought that atoms were basically â€" it was the plum pudding model where you had the protons and the electrons all kind of randomly globbed together. There were experiments done where beams of electrons were sent into a gold foil. Had the structure of the atom been a plum pudding basically, where you have these randomized plums â€" the electrons and protons â€" randomly scattered through the atom you would have gotten one set of the way the electrons get reflected as they go through the gold foil. Instead what we saw was a scattering that could only be explained if the protons and neutrons were concentrated in a very small nuclei surrounded by a huge swarm of an electron cloud. This started to become very problematical. It was in trying to sort out that problem and in looking at the allowed wavelengths of light where we also ran into problems there of as the wavelength gets shorter and shorter the amount of energy should go to infinity. All of a sudden we have warm objects giving off infinite amounts of light. This is the ultraviolet catastrophe. Eventually you just run out and things go to zero in the ultraviolet. So the energy goes to zero and the wavelength becomes infinitely small. We were able to solve these problems by doing something extremely unsatisfying and saying energy is discreet and can only have certain given values. When you say energy is discreet and can only have certain given values this is the quantum part of quantum mechanics, right that energy comes in packets of a very specific amount. Yes and this is where we say energy is equal to a constant times the frequency of the light. Then the smallest theoretical amount of light you can have is one packet, right? Then we also started having all these other weird things. De Broglie was one of the ones who noticed that electrons have wavelengths too. We were not happy but could almost cope with the concept that light is both a particle and a wave. It has no mass, it acts in weird ways, it hurts but okay we can move on from this. One of the things we knew is you can take beams of light and send them through slits and get amazing patterns on the wall, interference and diffraction patterns. This has to do with the wave nature of light. The same way waves going through rocks going towards the shore you can end up with a completely straight wave hitting these rocks turning into perfect sections of a circle radiating away from the slit through the rocks. People started doing experiments, oh dear electrons interfere as well. What would be the apparatus? What would be the experiment to see an electron interfere with itself? If you have thin enough slits and you send beams of electrons, one electron at a time through the slit you instead of getting two perfect images of the slit on some screen in the distance â€" which is what your stomach would say should happen, you shine electrons on a slit they go through the slit, they hit a detector on the back, and you get an image of the slits. Right they either get bounced because they hit the sides of the slits or they go right through the slit and you get them hitting the detector. Yes, no big deal. And interfering with itself. And interfering with itself to create this pattern. This is the really weird thing. Electron hit directly in line from the slit. Electron hit over from the right; another electron over on the slit. They build up over time and it is one electron at a time that they build up this interference pattern. They build it up with a perfect distribution of the majority of the electrons landing where you have the highest probability. This is the same pattern that you see with photons but it is quite astonishing you see it with electrons, right? This was when we started to realize that the actions of light and particles are dictated by probability. I should interfere with something and that something may be coming later. Yeah, now you can keep going, right? What ends up happening is as you get to larger and larger physical objects their wavelengths start being smaller than they are. The wavelength of a human being is way smaller than a human being. One of these is the Heisenberg uncertainty principle. The idea behind this one is waves carry energy in them. As a wave is traveling through space if it hits something it can impart that momentum and do work basically. The way to think about it is if I concentrate its position into a point then I no longer know anything about its wavelength. Suddenly the wavelength information is completely gone. The same thing goes with an electron going around a proton? You can know its momentum or its position? This applies to lots of different ways of looking at these particles. We have the most common way of looking at it is looking at it in terms of position momentum. We can also look at in terms of energy in position. Energy is another way of looking at wavelength. We also have once we start looking at things in terms of relativity we start running into energy and time uncertainties. All of these things tie together and it leads to a place where we can only know half the information at any one point. Anyone who is deeply in love with kinematics and the notion that if you know the position and velocity of everything at any one moment you can predict to the complete unfurling of the rest of the universe. No instruments could ever be made good enough to know those two pieces of information at the same time. There are different ways of cheating the system.

Chapter 6 : Large-Scale Structure | University of Oxford Department of Physics

ROBES OF LARGE SCALE STRUCTURE. Under construction. Within a few years the 3D distribution of galaxies in our local universe will be mapped, and that structure can be matched to the early-time snapshot provided by the CMBR.

The absorption lines have varying strengths or optical depths and are seen superposed upon a background continuum emission from the quasar. These lines are thought to be due to absorption of the quasar continuum by clouds along the line of sight which contain sometimes trace amounts of neutral hydrogen. For further information follow this link. This forest of Lyman-alpha lines was discovered over 25 years ago. Originally studied to learn about the intergalacitc medium and interpreted as small 10kpc pressure confined clouds of pristine hydrogen gas left over from the epoch of recombination, they are now interpreted within a broader cosmological framework and thought to provide important clues about the formation of large-scale structure, the nature of dark matter and the shape of the matter power spectrum which has important implications for inflation. Coma is about 80Mpc from us, and has a size of about 3Mpc. Clusters of galaxies are the largest gravitationally bound systems in the universe, with sizes of a few Mpc a Mpc is about 3 million light-years. A typical cluster contains hundreds or thousands of galaxies, but most of the mass is in the form of a hot intracluster gas. This gas is heated to high temperatures K or several keV in the potential well of the cluster. Clusters are rare objects: The two most obvious means of studying clusters of galaxies are by observing the light emitted from the constituent galaxies or the X-ray emission from the hot intracluster gas. Recently it has proved possible to observe clusters of galaxies in two other ways which in combination with the traditional methods should prove exceptionally powerful. This leaves a decrement or deficit in the number of photons at low-frequency or a hole in the microwave sky for some examples, see the Viper SZ survey or the APEX SZ experiment. One can also study the mass of clusters by their gravitational bending of light. These 4 methods, plus a new generation of X-ray satellites Chandra and XMM should allow us to learn a great deal about clusters of galaxies in the next few years. Clusters can teach us a great deal about cosmology see e. Obviously clusters trace out the large-scale structure of the universe just as do galaxies. However there are several cluster properties that are interesting in and of themselves. The present number density of clusters is a measure of the amplitude of fluctuations in the universe on scales of around 8Mpc see also this paper. The evolution of this number density vs mass or temperature with redshift can determine the mass density parameter Omega and possibly determine the equation of state and nature of the dark energy believed to be causing the expansion of the universe to accelerate. Recently it has been argued that the number of giant arcs , caused by strong gravitational lensing of background galaxies by the cores of clusters, can be used to determine Omega also. For a recent short review of high redshift clusters, follow this link. We have performed a number of cosmological hydrodynamic simulations from which we can extract a catalogue of galaxy clusters. The following Quicktime movie illustrates the complex formation process of clusters in modern theories of structure formation. Some movies and pictures from the Los Alamos group can be found here , including an MPEG movie of the formation of a cluster. Weak Lensing Weak gravitational lensing denotes that regime where the gravitational deflection of light is so small that one does not see multiple images. Instead the images of background objects galaxies are sheared and magnified. The amount of this shear and magnification depend on the integral of the gravitational potential along the line of sight, times a function which depends on the redshift of the source and peaks midway between the source and the observer. By studying the shear of many galaxies one can statistically infer the amount of dark matter as a function of position and time to constrain its properties, spatial distribution and evoltion. Just as one can study the clustering of galaxies, one can also study the clustering of other objects. Many such objects have been studied, but Quasars hold a special appeal because they have been observed to very high redshifts early time. Both the SDSS and the 2dF have measured the positions and redshifts of hundreds of thousands of quasars, allowing one to probe large-scale structure out to COBE scales, test the nature of the initial conditions that formed structure and measure the evolution of clustering and constrain the dark energy. The 2dF QSO Redshift Survey web site contains information on their survey and the science that can be done with surveys of quasars. See here for more information on high-z quasars and follow this link for an in depth theoretical discussion of how to measure the cosmological parameters using quasar clustering.

Chapter 7 : Structure of the Universe - Universe Today

Large-Scale Structure. de Vaucouleurs long argued for the physical reality of a flattened distribution of nearby galaxies centered on the traditional Virgo cluster, extending well past our distance from the center - the Local or Virgo Supercluster, extent 50+ Mpc.

At a relatively smaller scale, we know that galaxies are made up of stars and their constituents, our own Solar System being one of them. By understanding the hierarchical structure of things, we are able to gain a clearer visualization of the roles each individual component plays and how they fit into the larger picture. For example, if we go down to the world of the very small, we know that molecules can be chopped down into atoms; atoms into protons, electrons, and neutrons; then the protons and neutrons into quarks and so on. But what about the very large? What is the large-scale structure of the universe? What exactly are superclusters and filaments and voids? Although there are some galaxies that are found to stray away by their lonesome, most of them are actually bundled into groups and clusters. Groups are smaller, usually made up of less than 50 galaxies and can have diameters up to 6 million light-years. In fact, the group in which our Milky Way is a member of is made up of only a little over 40 galaxies. Generally speaking, clusters are bunches of 50 to 1, galaxies that can have diameters of up to megaparsecs. One very peculiar property of clusters is that the velocities of their galaxies are supposed to be too high for gravity alone to keep them bunched together â€¦ and yet they are. The idea that dark matter exists starts at this scale of structure. Dark matter is believed to provide the gravitational force that keeps them all bunched up. A great number of groups, clusters and individual galaxies can come together to form the next larger structure â€" superclusters. Superclusters are among the largest structures ever to be discovered in the universe. The largest single structure to be identified is the Sloan Great Wall, a vast sheet of galaxies that span a length of million light-years, a width of million light-years and a thickness of only 15 million light-years. At that level, we see a universe made up of mainly two components. There are the threadlike structures known as filaments that are made up of isolated galaxies, groups, clusters and superclusters. And then there are vast empty bubbles of empty space called voids. You can read more about structure of the universe here in Universe Today. Want to read about the cosmic void: Here are a couple of sources there:

Chapter 8 : Large Scale Structure

[/caption]The large-scale structure of the Universe is made up of voids and filaments, that can be broken down into superclusters, clusters, galaxy groups, and subsequently into galaxies.

So far, we have only looked at a few nearby examples: The Local Group is surrounded by a few other groups that we have discussed, and the Virgo Cluster is only one of a few nearby clusters. What we find when we study the distribution of galaxies in more detail is that groups and clusters are common throughout the Universe. For example, the Coma Cluster is another galaxy cluster, but it is different from Virgo in that it is a very massive, very dense cluster that contains about 10, galaxies. However, most of them look similar to the images you have seen so far of Virgo, Coma, and Perseus. Since we now know that the redshift of a galaxy is a measurement of its distance, after we take an image of a part of the sky, we can take spectra of all of the galaxies in that image to determine their distances. What we have found is that galaxies tend to clump together. Astronomers have invested a lot of effort in doing this not just in deep fields, but in large swaths of sky. In this way, we have not only mapped out the distances to the clusters themselves, but to the galaxies in front of, behind, and around these clusters. So, what do we find? Well, for example, look at the plot below of the distances to a large number of galaxies from the Sloan Digital Sky Survey. A plot of sky coordinates vs. So Earth is at the center of the image. Each point on the plot is a galaxy. The direction to that point indicates its location on the sky, and the distance from the center of the image indicates its distance from Earth. Another group completed a similar survey of the galaxies in the Universe called the 2dF Redshift Survey. These pie slice diagrams show the distances to all of the galaxies in a narrow strip of sky. The densest groups of points are the locations of clusters like Virgo, Coma, and Perseus. What you should notice is that the distribution of galaxies is not random. That is, the clusters appear to form clusters of clusters! The structure that you see in the pie slice diagrams is often described as being like soap bubbles. That is, the galaxies lie along the walls of the bubbles, and inside the bubbles are voids where very few galaxies are found. The voids are not completely empty. For example, the Hubble Deep Field image was taken in the center of a void. The poor groups like the Local Group lie in the voids. The Cosmological Principle So far, we have been considering cosmology mainly from an observational standpoint. That is, we have been looking at the distribution of galaxies in the Universe and the relationship between their distances and their velocities. However, we can also consider cosmology from a theoretical standpoint. That is, given what we know about the laws of physics, how should the Universe behave? In the early part of the 20th century, scientists like Einstein were using the theory of General Relativity to describe the behavior of the Universe. Astronomers studying the Universe made a simplifying assumption that is now known as the Cosmological Principle. On the largest cosmic scales, the Universe is both homogeneous and isotropic. Homogeneity means that there is no preferred location in the Universe. That is, no matter where you are in the Universe, if you look at the Universe, it will look the same. Isotropy means that there is no preferred direction in the Universe. That is, from your current location, no matter which direction you look, the Universe will look the same. In other words, the galaxies in one direction are not distributed in exactly the same way as the galaxies in another direction. When we study the most distant objects we can find at much larger distances from Earth, the structure appears to smooth out and become more homogeneous on the largest scales. For example, the all-sky map of the locations of objects detected by radio telescopes shown below reveals a much more uniform appearance. These objects are mostly expected to lie at higher redshifts than the ones in the pie slice diagram above, suggesting that when we consider the largest distance scales, the Universe appears to be homogeneous and isotropic. Thus, we currently find support for the Cosmological Principle in the distribution of galaxies in the Universe. An all-sky map of the locations of objects detected by radio telescopes.

Chapter 9 : The Large Scale Structure of Space-Time by Stephen Hawking

Large Scale Structure: Tracks and Traces: Proceedings of the 12th Potsdam Cosmology Workshop, Potsdam, Germany 15 - 19 September Understanding the largest physical structures in the universe is essential for the comprehension of the cosmos as a whole.

Published in Observational and Physical Cosmology, eds, F. For a PDF version of the article, click here. For a Postscript version of the article, click here. Jones Astronomy Center, Sussex University , UK and Reality is a question of perspective; the further you get from the past the more concrete and plausible it seems - but as you approach the present, it inevitably seems more and more incredible. The goal of these lectures is to introduce and explain the current debate on this issue. By its very nature the problem of the large scale structure is one that mixes both observational and the theoretical aspects of cosmology. The plan of the lectures is first to discuss the general theoretical framework for cosmology, and then go on to discuss the impact of key data. In this article, I shall try to build up the essential concepts from simple starting points. More details can be found in a number of books and review articles. There are many fine books on cosmology. These are becoming somewhat outdated owing to the rapid progress in cosmology in recent years, but they do discuss the fundamentals of the subject. At a pedagogical level, the book by Berry , Principles of Cosmology and Gravitation is highly recommended. This last book contains a fine review article by White on Physical Cosmology and another on inhomogeneities in the universe and in particular their contribution to microwave background anisotropy, by Efstathiou There are numerous conference proceedings and reviews on the subject. An outstanding conference book is the "Vatican Study Week: There is also a recent review on the large scale structure by Kashlinsky and Jones It is of course impossible to discuss everything about the large scale structure of the universe, and even less possible to cite all the appropriate references. My strategy has therefore been to provide a background against which some of the major issues can be addressed, and to give enough recent references to enable the reader to get into the bibliography on those issues. I have tried to stick to the question of the large scale structure and not get drawn into issues of galaxy formation or even galaxy cluster formation. There is no doubt that these have an important bearing on large scale structure, but they have not as yet played a decisive role. For example, the question of the biasing of galaxy formation has so far been tackled in a rather simplistic way and there may now be a need to go into the details of the process by looking more carefully at the galaxy formation process. On the other hand I have gone a little way into the question of inflationary universes and the origin of the fluctuation spectrum since this is a major issue as regards the scale of the largest structures. I shall endeavour to use "Universe" whenever I mean the place where we live, and "universe" for a model of the Universe. Similarly, "the Galaxy" is the "galaxy" where we are situated. I shall try to avoid abbreviations, but the following bits of jargon are frequently encountered and may slip into the text: Generally MWB and CBR are used interchangeably, despite the fact that there are many background radiations that are not in the microwave band such as the X-ray background, but that would be an "XRB"!