A brief description of my lectures on *Cosmological Parameters*

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A brief description is presented of three lectures given by the author at the Cosmology School in Kielce, Poland, in 2015. The first two lectures (and part of the third) were on the possibility of using the observations of Gamma Ray Bursts to estimate the equation of state. The third lecture was used to illustrate the beginning of the redshift surveys, focussing on research that carried out in the 1970s.

1 Introduction

An excellent discussion of the cosmological parameters can be found in *Modern Cosmology* (Dodelson, 2003) and in *Cosmology* (Weinberg, 2008). In view also of the fact that the topics would have been partially touched upon the lectures on the Cosmic Microwave Background (CMB), I focussed my first two lectures (and part of the third) on the possibility of using the observations of Gamma Ray Bursts to estimate the equation of state. To do that it was proper to briefly describe the state of the art on this matter and detail somewhat the essentials of Gamma Ray Bursts in order to let the students perceive the limitations and the advantages of using such transients up to very high redshifts. I dedicated most of the third lecture, also in view of the program of the following days, to illustrate the very beginning of the redshift surveys, focussing on the research that was carried out in the seventies.

Concerning the first topics, in addition to a very copious literature and to the references that are given in the PDF version of the presentation that has been posted in the web, I suggest reading, among others, the excellent reviews by Piran (2004), Mészáros (2006) and Woosley & Bloom (2006). For the second topics, I presented the full version of the lecture in Stockholm in 2012 at the thirteenth Marcel Grossmann meeting on General Relativity and the written text can be found in the proceedings edited by Robert T. Jantzen and Kjell Rosquist (Chincarini, 2013). It seems to me that the interested student could, following eventually the track of the lectures, read carefully the original literature deepening further the physical and mathematical details forming in this way not only a better understanding but above all forming his/her own ideas on the matters we dealt with and on the present state of the art. Because of this "do it yourself" approach I will use the few pages I am writing for the school proceedings to emphasise a few statements I made during the lectures and to outline my thinking, finally adding a few remarks that I may, or may not, have said during the lectures.

During the last 40 years, thanks to the innovative development of detectors, instrumentation and computers, we have witnessed a tremendous progress in cosmology.

It has been demonstrated that the Universe is flat, it is accelerating and dominated by a form of energy and matter that are completely unknown to us and remain undetected. These are firm facts that have been repeatedly mentioned in these lectures and that leave us very uncomfortable. I find less critical the fact of being close to the epoch at which the Universe started to accelerate and to the epoch during which dark energy started to be a dominant parameter in the density of the Universe in spite of the fact that the why must be asked and understood. The detection of Dark Matter (DM) (see also the controversial detection by the DAMA project) and Dark Energy (DE), therefore, and the derivation of the exact equation of state of the DE are the basic goals for the future years. The future of the Universe depends dramatically on these values and their eventual evolution with time. On the other hand, see the presentation for references and details, the present determinations of the equation of states give within an accuracy of a few percent $w = -1$ and there is not yet enough accuracy to test it at high redshift. To some extent it is scary that we seem to know so well the present and the fate of the Universe.

I did not discuss the various interpretations of the data using physics that does not include DM. It remains a possibility, but it is also a fact that all the attempts have so far failed one way or the other. I only added during the second lecture the rotation curve of the galaxy NGC 3198 published 30 years ago by van Albada, Bahcall, Begeman, & Sancisi (1985). This not only because it is a classic but also in relation to a presentation made at this school, where it was pointed out that we can easily fit the rotation curves of spiral galaxies without invoking Dark Matter. When this is attempted, however, we must refer to the rotation curves that have been observed up to large distances from the center and with high accuracy since at low distances the distribution of mass in the disk may as well do the job.

Following the thought of Einstein, however, it seems that either someone takes a step forward with a new theory based on principles or patching up and modifying relativity does not lead to anything. We must therefore take our observations to the very limit of statistics and accuracy and first test whether GR fails somewhere. Various groups are working in this direction and various were funded to this aim by the European Research Council. To mention one among the copious papers in the field, I refer to the work by Simpson et al. (2012) where the group led by Heymans find that within a few percent accuracy the observed potentials are in agreement with the predictions of GR. That is so far the GR holds on the very large scales of recent surveys. So that in this 100th birthday of GR the theory still look very robust and chances are it will be so for years to come.

Since cosmology became also an observable science the big role in the geometry of the Universe and in the distribution, and related evolution, of matter have been investigated via SNe and deep and large field surveys, in some cases all-sky surveys. The distribution of matter (we clearly see only baryonic matter and detect the effects of dark matter) measure cosmology via the cosmic structures and related evolution which depends on the cosmological parameters, while the SNe give us a direct measure of the geometry of the Universe, allowing a direct estimate of the cosmological constants. On the other hand, at present, and for a few years to come, observations of SNe are limited to a redshift of about 1.2. What about other possible distance indicators like GRBs that have been detected up to redshift of about $z = 10$, in the lecture I show the spectroscopic observations at $z = 8.2$, and eventually even larger? Obviously at high redshifts (note that the luminosity of the GRBs fades rather fast) the observations are difficult and the spectrum contaminated by the atmospheric emission and absorption, but since the atmospheric spectrum is observed simultaneously to the source spectrum and through the same optical path with a very large photon statistics the subtraction is very accurate. To understand properly the limitations of these observations and analyses I briefly describe the Swift satellite that allowed a huge step forward in the understanding of the phenomenon and the basics of the gamma ray bursts observations. The student who wants to go deeper on this topics could, using the presentation as a guideline and consulting the literature, learn all the needed details. Here I want to emphasise a basic point about distance indicators.

We all know either directly or from the literature the long story of the estimate of the Hubble constant. After a decay of its early value of about a factor of 10 we assisted a long debate between the defenders of a value of about 50 km s^{-1} Mpc^{-1} and those supporting a value of about 100 km s^{-1} Mpc^{-1} with Allan Sandage and Gerard de Vaucouleurs as the leading players. Shall we base our estimates only on excellent distance indicators or, the point made by de Vaucouleurs, put our money on many horses as to get a higher probability of an unbiased mean value. The excellent work by Freedman and her collaborators based on extremely accurate observations due to advanced facilities solved the matter. The point I want to make is that in order to have a reliable distance indicator we should have a small dispersion of the parameters that are used to define the distance, a very accurate control of the observations, a good understanding of the corrections to apply to avoid systematic effects and enough data to get all the needed statistics. As we mentioned GRBs have the fundamental advantage to be detected and observed at very high redshifts, on the other hand all the method discussed in the lectures have in my opinion some characteristics that may limit their ultimate efficiency. That is 1) we do not have a complete theoretical explanation of the correlations as to derive them theoretically, 2) the Band spectrum (Band et al., 1993) is characterised by a knee function and in this case the integral of the spectrum may in part be naturally correlated with the peak of the function and 3) to correlate the quantities in the rest frame we multiply $E_{\rm peak}$ by $(1+z)$ and clearly $1+z$ is directly related to d_{L2} and this party introduces a correlation in the data. In spite of this it seems that the various methods lead to some estimate, in other words it seems to work, that are not yet competitive however. I mentioned this to get the students to play with some simulations on this matter and understand deeply the methods and eventually the intrinsic limitations. It is a good and useful homework.

In my last lecture I wanted to emphasise the very beginning, 1970 – 1980, of the search for the distribution of matter (the large scale distribution of galaxies) in the Universe, work that has been pioneered using spectroscopy (that is three-dimensional information) by Rood and myself and Bill Tifft, Gregory and Thompson with whom Herb and I often discussed our work and theirs. It is during this period (indeed a bit earlier) that Peebles and collaborators worked on the distribution of galaxies developing and using the autocorrelation function analysis machinery (see also his book *The Large-scale structure of the Universe*, Peebles, 1980) reaching fundamental results. The full version of this part of my lecture has been published in the proceedings of the 13th Marcel Grossmann conference in Stockholm (Chincarini, 2013), so that the presentation that is in the web coupled to the published article, and references therein, are good enough for the student who wants to understand deeper this part. In this extensive summary I will limit myself to briefly discuss two topics: The Camera of Lallemand (I added a slide in the lecture I gave in Kielce) and the importance of the magnitudes limited samples in the spectroscopic surveys, also pioneered by Rood and myself especially thanks to the experience of Herb Rood. I feel these points reflect not only a historical interest but also have strong relevance for science education showing the way to proceed using original data: the only way to discover something observationally new rather than repeat or construct on findings by others is to get original data. And this nowadays is a well known fact.

The paper by Humason, Mayall, & Sandage (1956) is a milestone because *a)* it is a complete catalogue of redshifts available at the time; *b)* it shows the exposure that were needed at the time to get redshifts using photographic plates both at Mount Wilson and Palomar and at Lick observatories; *c)* it is a fundamental analysis to the estimate of the Hubble constant that leads to the modern times. In any case it makes the point of the observations before the advent of the electronic devices, it would then take hours of integration even to get the spectrum of a bright galaxy. Photometry was less affected by the sensitivity problem and related calibration since RCA had already developed the 1P21 photomultiplier that every US astronomer was using at the time. In Europe Lallemand, who also developed in his Parisian laboratory some photomultipliers for photometry, at some point had the idea to develop a two dimensional detector capable of recording two dimension images with high gain, for details see *Electrography and astronomical applications* (Chincarini, Griboval, & Smith, 1974). The electron generated by the image formed on a photocathode (2a during operation and 2 during preparation of the camera – see Figure in the presentation) were focussed using an electrostatic optics (9 – 10 in the Figure of the presentation) on nuclear plates (Merle Walker and I were using Ilford L4 because of the very fine grains – plate magazine located in 4 in the Figure). The linearity of the response was granted by the photocathode and the nuclear plates while the large acceleration of the electrons (the electrostatic optics used a potential of about 40 kV) made possible the high efficiency of the device. The operation however was very difficult and only a few, Merle and I in the US and the group of Lallemand in France, were able to use the equipment. The complications were due to the fact that the nuclear plates would destroy the photocathode once in the same environment (water vapour the main agent) so that we had to cool parts of the glass tube with liquid nitrogen, maintain high vacuum inside and operate the plate magazine and the positioning of the photocathode from outside the tube using various magnets (3, 4 and 6 in the Figure) designed to this purpose. In spite of these difficulties with very hard work Merle Walker first and Merle and I later were able to achieve results on the rotation of galaxies and spectrophotometric high time resolution data on variable stars like SS Cyg and AE Aqr that were possible only much later (10 to 20 years) with the advent of the CCDs. In the following years astronomers, and I, used various types of image intensifiers and finally came the CCD. The stay at Lick made me an expert in the image tubes technology and that is the reason why the collaboration with Herbert Rood started when I was working at the Johnson Space Flight Centre under the direction of Thornton Page. I took this opportunity to thank once more Merle F. Walker and the Lick Observatory for forming me as a researcher and for making me understand what research really is.

In the years 1963 – 1968 Zwicky and his collaborators Herzog and Wild published a monumental work: the *Catalogue of Galaxies and Clusters of Galaxies*. The catalogue is complete to the magnitude 15.5 and almost complete to the 15.7 magnitude. The magnitudes listed in the catalogue were rather accurate in spite of the criticism by some. Zwicky was a bit upset about this since, as he told me once, these peoples wouldn't know what it means to estimate thousands of magnitudes and, as we all know, to estimate the magnitude of a galaxy, care, a good definition of magnitude for an extended object and homogeneity in the estimates are needed. Thanks to this fundamental work it has been possible to plan soon after well-defined magnitude-limited samples which allowed proper statistics both in the estimates of the mass to luminosity ratio in clusters of galaxies and on the distribution of galaxies on lager scales (volume-limited samples would need the estimate of magnitudes as well and however reduce drastically the number of galaxies used in a survey). Rood and I started such researches using well defined samples while trying also to estimate and define the diameter of a cluster of galaxies we discovered the supercluster structures in the redshift space and voids, a name that was definitely adopted (also following a discussion on the name with John Cowan) after our Sky and Telescope article: *The cosmic tapestry* (Chincarini & Rood, 1980).

The use of not very well controlled samples or of samples that are an ensemble of inhomogeneous data taken from the literature, without planning and carrying out new observations, may lead to spurious conclusions as may be those (and it would be useful to check again) related to the early discovery of giant voids. Whether this is the case or not it can be verified by the students as homework using the huge amount of observations we have nowadays. In 1986 I wrote a brief research note (Chincarini, 1986) challenging the existence of those large voids, see also Zeldovich et al. (1982). This as well is a very educating and interesting homework.

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