Cosmology: Past, present and future*

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This is a broad-brush review of the development of cosmology during the twentieth century. The 'past' deals with the first nine decades of the century while the 'present' deals with the last decade. Although technological achievements have helped the astronomer in better viewing the universe, a 'final' understanding still eludes the search for the correct cosmological model. The article ends with a list of unsolved questions which the 'future' may eventually answer.

LET me at the outset register a mild protest that this seminar is being convened a year too soon. Many commercial enterprises, probably misguided by the much-publicized Y2K syndrome, have declared that the third millennium begins on 1 January 2000 AD, whereas by all logic of counting, it should begin a year later, on 1 January 2001 AD. I had hoped that a community of physicists like ours which sets a premium on exactness, should have got our calendar right. So, modulo whatever exciting that might happen during the year 2000 AD, the last one of the 20th century, (but which has to be left out as I have no crystal ball) here is my brief account of the highlights in the subject of cosmology during this century. Towards the end of this talk I will mention a few outstanding issues that hopefully will be resolved in the future years.

To be more specific, I will make the following break up of the past, present and future: Past: 1901–1990; Present: 1991–2000; Future: 2001– . . . .

I will deal with these time zones in that order.

Expanse of the universe

This century saw a remarkable turn around in the views of scientists about how vast our universe is. Two major views held sacrosanct by the majority of the astronomical community over the nineteenth century, fell by the wayside as the horizons of observational astronomy expanded and theorists became bolder in pushing their extrapolations of laboratory physics to larger systems. Here is a timetable of important highlights.

Observational developments

1900–1915: The first belief to go was that the solar system is at the centre of the Milky Way as originally claimed by William Herschel (see Figure 1). Thanks to more accurate measurements of distances of stars and globular clusters, Harlow Shapley was able to show that the Galactic Centre is considerably farther from the Sun. The currently estimated distance is around 30,000 light years.

1900–1920: A change of viewpoint from the Milky Way-based universe to Kant's island universe hypothesis took place. This was the second of the two long-held beliefs to go. Immannuel Kant (1724–1804) had argued that our Milky Way was just one of the innumerable galaxies populating the universe, all distributed like islands in a vast ocean. This notion was violently resisted by most astronomers, who believed that everything that they observed was part of our Milky Way Galaxy. An example of how the community still resisted the Kantian viewpoint at the turn of the century can be seen from the following quote from a popular book of astronomy of the time:

'. . . The question whether nebulae are external galaxies hardly any longer needs discussion. It has been answered by the progress of research. No competent thinker, with the whole of the available evidence before him, can now, it is safe to say, maintain any single nebula to be a star system of co-ordinate rank with the Milky Way . . .' (Agnes Clerke, *The System of the Stars*, 1905, p. 349).

These nebulae were diffuse, cloud-like in appearance and were widely believed to be systems in our own Galaxy. There was considerable debate between Shapley

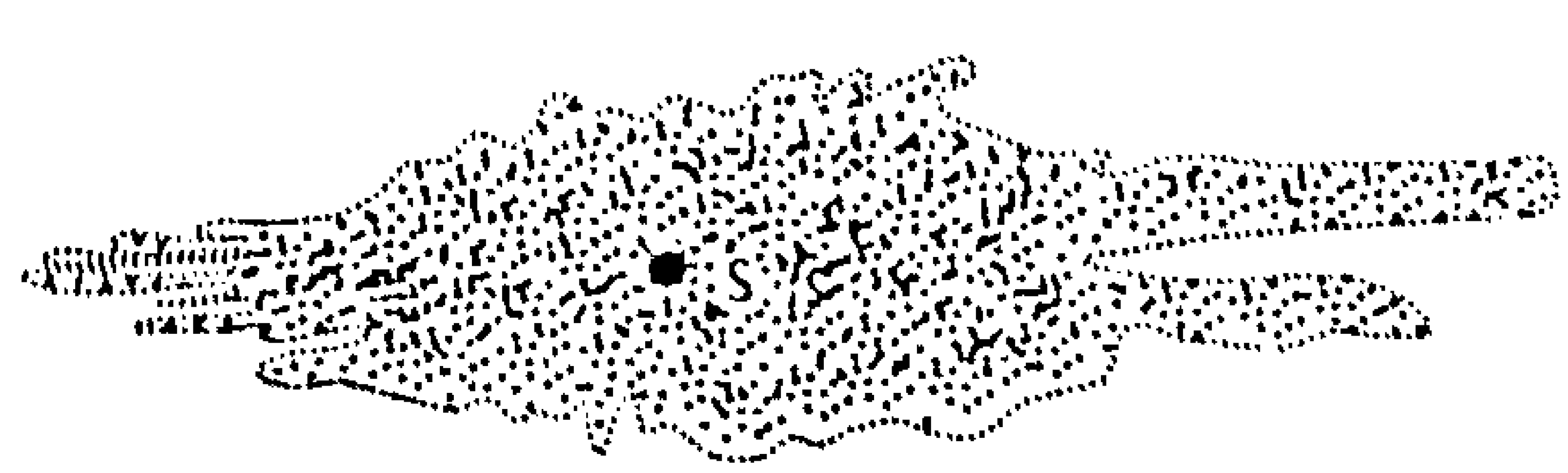

Figure 1. Herschel's map of the Milky Way with the sun (S) shown at the centre.

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and Curtis, with Shapley this time on the conservative side. His view is summarized in the following quote:

'. . . Observation and discussion of the radial velocities, internal motions, and distribution of spiral nebulae, of real and apparent brightness of novae, of the maximum luminosity of galactic and cluster stars, and finally of the dimensions of our galactic system, all seem definitely to oppose the "island universe" hypothesis of the spiral nebulae . . .'. (H. Shapley, *Publications of the Astronomical Society of the Pacific*, 1919, **31**, 261).

One reason for the conservative viewpoint to be maintained was the considerable observational work by the senior astronomer Van Maanen who reported significant transverse angular motion of these nebulae. This meant that if the nebulae were really distant, then their physical velocities would be too enormous to be real. And so Van Maanen's measurements of transverse motions implied that nebulae could not be extragalactic. However, eventually astronomers came to discount these measurements, as they could not be verified by any subsequent observations.

1920–1930: Starting with the early spectroscopic measurements of Slipher, and others and the detection of spectral shifts, mostly towards the red end of the spectrum, culminating in the work of Humason and Hubble, the extragalactic nature of nebulae became accepted. The spectral shifts, interpreted as Doppler shifts led to the picture that most of these nebulae are receding from us. Hubble gradually established that these nebulae are galaxies of stars, just like the Milky Way, thus confirming the Kantian hypothesis.

1929: Hubble's Law relating the radial velocity (V) to distance (D) of a typical galaxy was put forward for the first time. Written today as $V = HD$, the constant H is called 'Hubble's constant' (see Figure 2).

1930: The concept of the *Expanding Universe* was established and this was to form the basis for future development of cosmology.

Theoretical developments

1917: Einstein proposed in 1915 his general theory of relativity and in 1917 he applied the theory to construct a mathematical model describing a static, finite but also unbounded universe. He then required a non-zero cosmological constant (λ). He had hoped this to emerge as a unique model of the universe. However, within a few months, De Sitter showed that an empty but expanding universe was also a solution of Einstein's modified field equations. Whereas Einstein's solution had matter without motion, De Sitter's universe had motion without matter!

1922–1924: Alexander Friedmann produced expanding non-empty world models, but these were ignored as mathematical curiosities by Einstein and others. In these models, the space was taken to be of constant curvature, positive, zero or negative. In modern terminology we denote these by a curvature parameter k which takes values $+1, 0, -1$.

1927: Abbe' Lemaitre from Belgium produced similar theoretical solutions, being unaware of Friedmann's work.

1932: Realizing that in the context of Hubble's discovery, a static model was no longer relevant, Einstein abandoned the cosmological constant and in a joint paper with De Sitter, favoured the flat space expanding model from Friedmann's solutions. Therefore this model is often called the *Einstein–De Sitter model*. This model is the simplest of all Friedmann models and has $\lambda = 0$, as well as the curvature parameter $k = 0$.

1933–1936: Eddington and Lemaitre, however, continued working with models having non-zero cosmological constant as they felt that a larger parameter space will be helpful to account for all the observed features including the formation of galaxies.

A range of Friedmann models with or without λ is shown in Figure 3.

Can observations help choose the right Friedmann model?

The next three decades were used by cosmologists to extend their observations to *test* cosmological models, with the hope that observations would single out a spe-

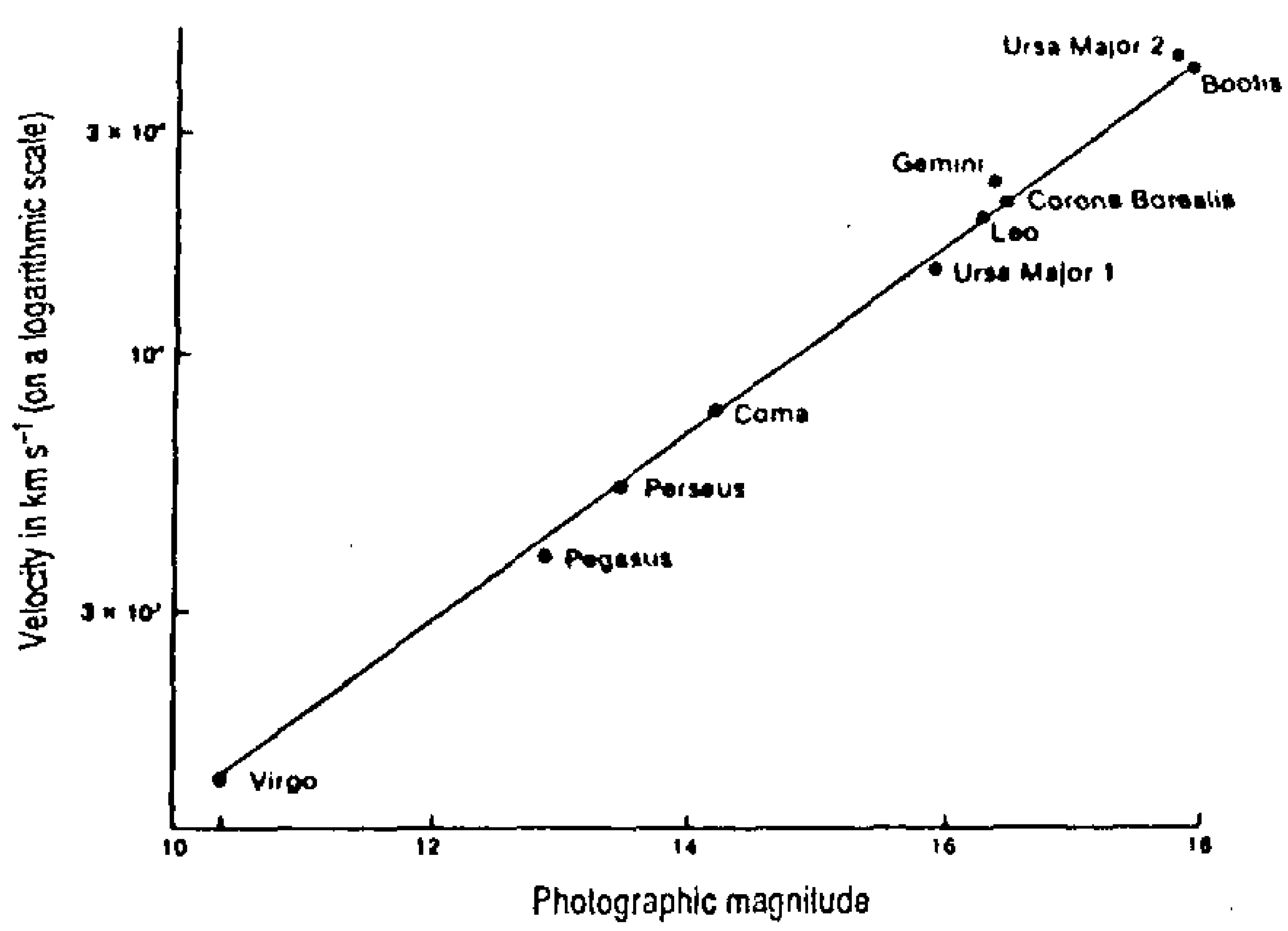

Figure 2. Hubble's plot for the fifth brightest member in clusters of galaxies. The photographic magnitude can be related to distance on the logarithmic scale, while the recessional velocity is obtained by multiplying the observed redshift by the velocity of light c.

cific model as *the* model of the universe. The time table of some specific developments is given next.

1935–1940: Hubble hoped to determine the correct model by counting galaxies up to increasing level of faintness, as it gave a radius–volume relation, that could be compared with the model-dependent theoretical relation. This project was doomed to failure as the number of galaxies to be counted up to distances where curvature differences are noticeable, was too large.

1940–1945: The Palomar Telescope of 200 inch aperture was built for the above key project. However, by the time the telescope was completed, it became clear that the project was unworkable.

1945–1955: The emerging science of radio astronomy went through an early period when radio astronomers thought that all radio sources are stars in the Galaxy. Tommy Gold had argued that a large population of the radio sources may be extragalactic, a conclusion that was violently resisted by the Cambridge radio astronomer Martin Ryle. A few years after the Gold–Ryle controversy, it was realized that a majority of sources was indeed extragalactic and this led to optimism that one could solve the cosmological problem by counting radio sources instead of galaxies. (Radio sources are not as numerous as galaxies.)

1955–1965: Radio source counts were used by Ryle as a disproof of the Steady State Cosmology (SSC). The SSC was proposed in 1948 by Hermann Bondi and Tommy Gold and by Fred Hoyle as a reaction to the apparent shortcomings of the Friedmann Cosmology, namely:

(i) *A singular origin*: The model had a beginning in a primordial event often called the *Big Bang*, a name due to Hoyle himself. We shall refer to the various Friedmann models as part of the Standard Big Bang Cosmology (SBBC). The big bang itself is a physically undefinable and mathematically singular event. That is, all theoretical machinery breaks down at this instant, labelled by the time coordinate at $t = 0$. In a physical theory such an event is therefore indicative of some serious shortcoming of basic formalism.

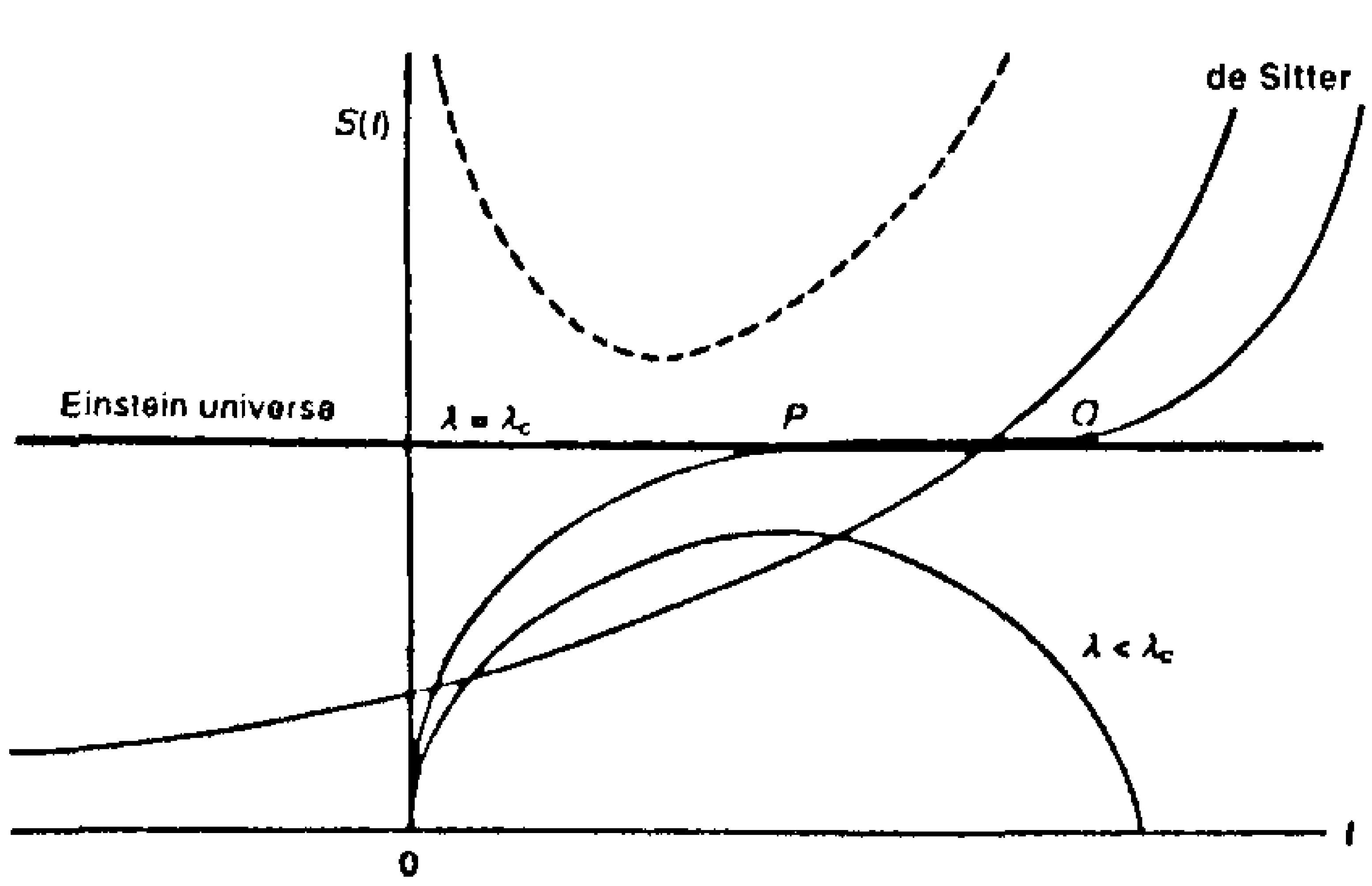

Figure 3. Expanding world models for different values of λ and a positive curvature parameter.

(ii) *The age problem*: Counting the time since the above epoch of 'beginning', the age of the universe at present can be determined for any model in terms of the measured value of Hubble's constant. The answer came out smaller than the ages of many of the oldest stars.

(iii) *The origin of matter not explained*: The epoch of big bang represents creation of the universe. At this epoch the law of conservation of matter and energy breaks down and so the most fundamental of the cosmological issues, viz. the origin of all the matter we see today, is not addressed.

The Hoyle–Ryle controversy of 1961 on source counts and their interpretation marked a major confrontation between the attackers and defenders of the SSC. Eventually, Hoyle's approach turned out to be closer to reality, although not so realized at the time. The SSC, however, made several useful contributions to cosmology:

(i) *Ideas on matter creation and baryon non-conservation*: The theory sought to explain matter creation in the form of baryons, through the agency of a scalar field. At the time a scalar field was not popular with the field theorists, nor could they stomach the idea of the baryon number not being conserved. On both these counts today's theoretical physicists have changed and come round closer to what the SSC had said in the 1950s and 1960s.

(ii) *Massive collapsed objects in galactic nuclei*: One frequently hears of the discovery of collapsed massive objects (glamorized as *black holes*) in the nuclei of galaxies. The idea was in fact first proposed by Fred Hoyle and the author in 1966, at which point the notion was considered bizarre.

(iii) *Superclustering of galaxies*: The hot universe model of Gold and Hoyle in 1958 had shown that structure formation in the SSC would take place through thermal pressure gradients, resulting in typical units of size 50–100 Mpc, characteristic of superclustering of galaxies. Hoyle and the author had used inhomogeneity on this scale to explain Ryle's source counts. In the early 1960s, inhomogeneities on this scale were not considered likely; today they are an accepted part of reality.

Can all nuclei of elements be made in a primordial process just after the big bang?

Parallel to the development of the SSC, a new direction was being provided to the SBBC by George Gamow who attempted to show that nuclei of *all* chemical elements were formed in the first few minutes after the big bang. The landmarks in this branch of physical cosmology were as follows.

1946: George Gamow initiated work on this problem with his student Ralph Alpher and later joined by another, Robert Hermann.

1948: Affirmative answer by Alpher, Bethe and Gamow to the question as to whether atomic nuclei could be synthesized in the early hot era. This work became known as the α–β–γ (alpha–beta–gamma) theory, after its authors! A modern version of this calculation yields abundances shown in Figure 4. Only light nuclei can be made this way. For all heavier nuclei the appropriate location is inside stars.

1948: Prediction of relic black body radiation background in microwaves was made by Alpher and Herman. This radiation of the early hot era was expected to cool down as the universe expanded: Alpher and Hermann guessed the present temperature of the background as ~ 5 K.

As physicists five decades ago did not take cosmology seriously (nor did the astronomers!) this important prediction was largely ignored both by theorists and observers.

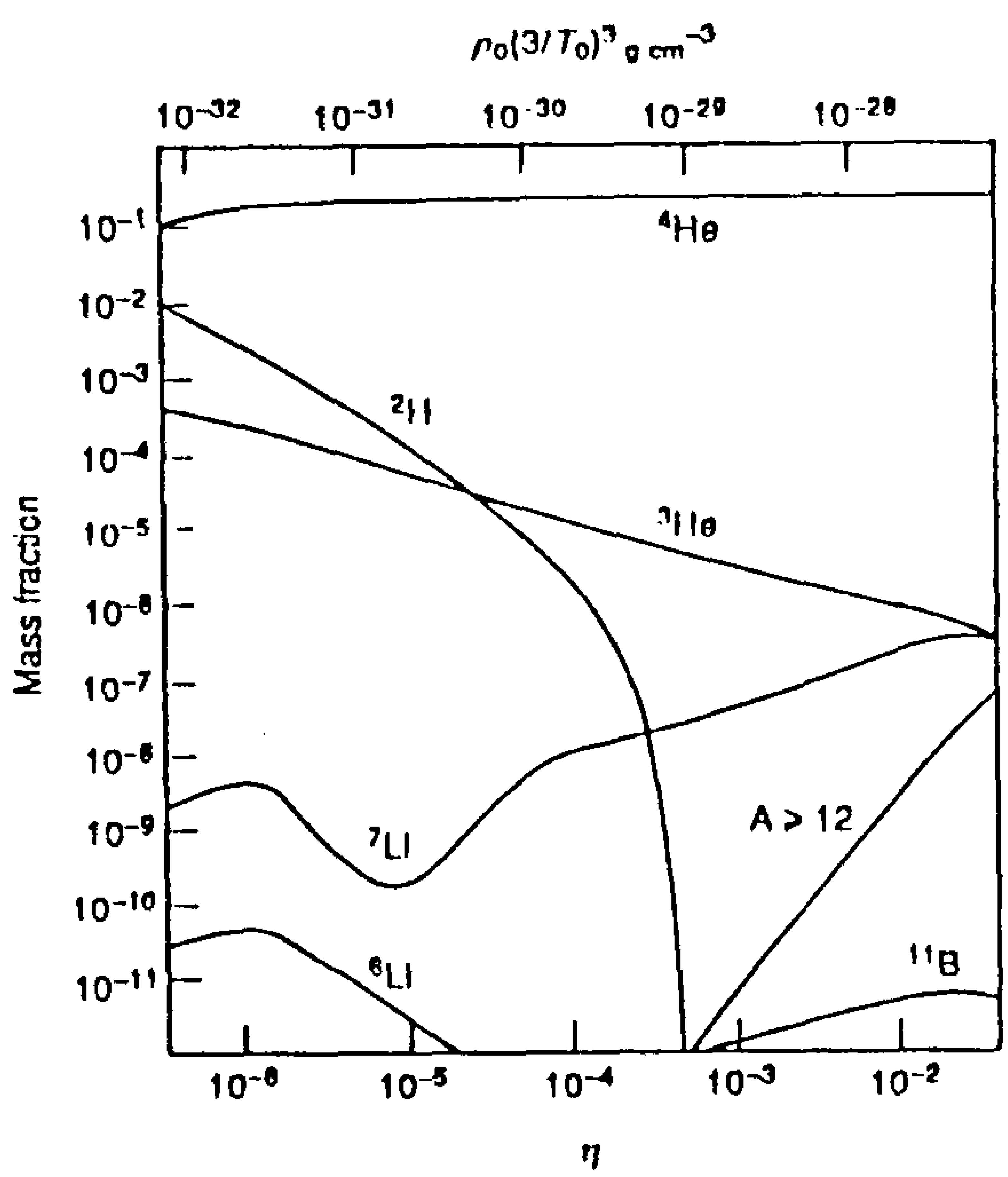

Figure 4. Primordial abundances of light nuclei plotted as a function of baryon density $\rho = \eta\,(T/10^9)^3$, with T measured on absolute scale.

What is the significance of the cosmic microwave background radiation?

The microwave background today is considered the strongest evidence for the SBBC. Here, however is a time table of how information about this important component of the universe was put together piece by piece.

1941: McKeller found that CN–molecular transitions imply a radiation background of 2.3 K. This result was, however, largely ignored, partly because of the wartime preoccupations and partly because it was published in an obscure journal.

1948: Prediction by Alpher and Herman came up as reported earlier.

1955: Bondi, Gold and Hoyle estimated the energy density of stellar radiation in the SSC, assuming all helium found in the universe to be of stellar origin. They found that if thermalized, that energy density would be like a black body radiation of temperature ~ 3 K. However, they did not press this point further, partly because they did not see an obvious process of thermalization.

1965: Penzias and Wilson serendipitously found the CMBR of temperature ~ 3.5 K. Their observation was of course at a single wavelength of around 7 cm. But the uniformity of the background was taken to identify it with the relic radiation of the SBBC.

1965–1990: Various surveys culminating in COBE in 1990 subsequently confirmed a black body spectrum of the CMBR with a temperature of ~ 2.7 K. The COBE spectrum is shown in Figure 5.

1977: Dipole anisotropy in the radiation background was discovered and interpreted as arising from the earth's motion against the isotropic background.

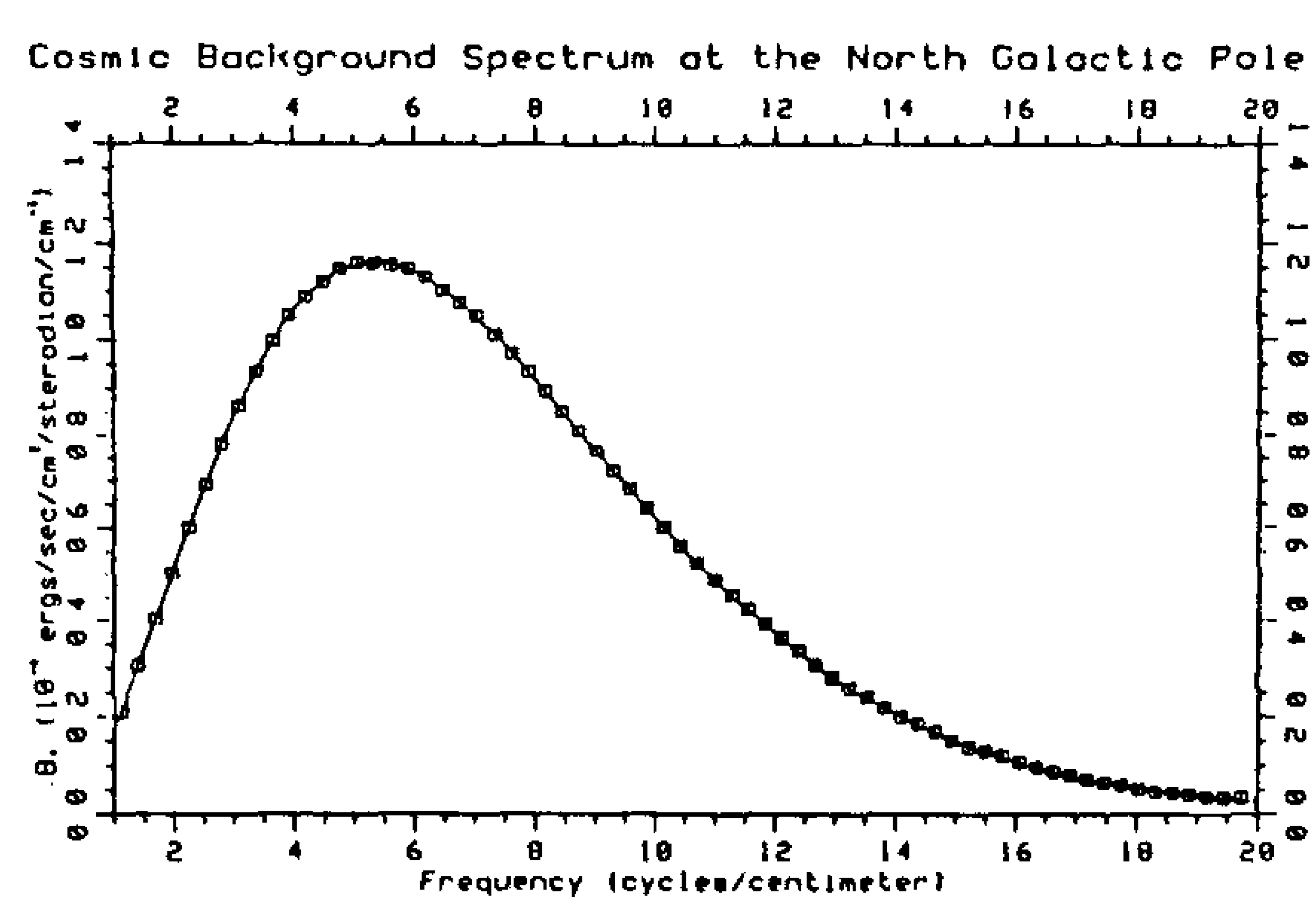

Figure 5. COBE measurements of CMBR spectrum. The continuous curve describes a 2.73 K black body curve passing through error rectangles.

1992: First detection (by COBE) of small-scale inhomogeneities in the CMBR generated considerable excitement and euphoria in the big bang community as these were perceived as the indicators left on the background by the process of structure formation.

Can surveys of the universe to high redshifts determine the correct world model?

1950–1980: Two groups, Sandage *et al.* and de Vaucouleurs *et al.*, continued to improve the determination of Hubble's constant, but also continued to differ by a factor 2, with Sandage and co-workers advocating a lower value.

1960–1980: Sandage carried on measurements of the Hubble relation to high redshifts with the hope of measuring the deceleration parameter, i.e. how fast the universe was slowing down; but systematic errors and evolutionary corrections proved insurmountable. Thus the goal of determining the correct model still eluded observers.

1960–1990: The angular diameter–redshift relation also was beset with many uncertainties and evolutionary effects and could not settle the cosmological problem.

Thus the improvement of observational techniques only served to remind the observer that several pitfalls lie between observations and interpretation. Even the counts of galaxies obtained by computerized reading of plates for a large number of galactic images made it clear that a clear-cut conclusion of the kind expected by Hubble fifty years earlier is still not possible.

Can high energy physics usefully interact with the SBBC to resolve mutual problems?

1968: The electroweak unification raised hopes of a *grand unified theory* (GUT), but particle physicists needed a high energy laboratory where such a theory could be tested.

1977: The only such laboratory was provided by the SBBC if one could confidently extrapolate close to the big bang. Thus particle physicists teamed up with cosmologists.

1980–1981: Out of such wedlock was born the idea of *inflation* first suggested by Kazanas, Guth and Sato independently; and it has played a key role in the agenda of the SBBC.

1970–1990: Astronomical observations indicated existence of a large quantity of dark matter which the SBBC required to be largely non-baryonic and hence cosmologists began to get inputs from various ideas in particle physics, ideas like GUT, super-symmetry, strings, etc. for candidates for such matter.

This now brings me to the present decade.

Thrust areas in cosmology in the last decade of the 20th century

The present work in cosmology is mainly in the following areas:

Structure formation: Given the primordial seeds in the pre-inflationary era, attempts are made to see how they would grow and lead to the presently observed galaxy → cluster → supercluster format of large-scale structure, together with their peculiar motions as well as their imprints on the CMBR. This is a multi-parameter exercise which folds in such items as the nature of dark matter, biasing, N-body simulations, etc.

Redshift surveys: These will tell us how matter is distributed around us out to greater distances so as to know about structural hierarchy.

Universe at large redshifts: Observations of discrete source populations at redshifts going up to $z \sim 5$ tell us about how the universe has evolved in the last few Giga-years and thus put constraints on cosmological theories.

Baryogenesis: A fundamental issue has been to understand how baryons, etc. formed in the early universe. A particularly interesting issue still to be understood is the apparent predominance of matter over anti-matter, and the overall dominance of radiation as exemplified by the large photon to baryon number ratio.

Alternative cosmologies: As the present observational constraints are already proving severe for the SBBC, it is worth exploring alternative cosmologies.

In 1993, Hoyle, Burbidge and Narlikar proposed an alternative cosmology called the *Quasi-Steady State Cosmology* (QSSC) which has the following positive features:

1. It explains creation of matter in non-singular minibangs in a universe without a beginning, and without violating any conservation laws. The minibangs essentially 'drive' the universe which has a long-term exponential expansion superposed with short-term oscillations. The oscillations are generated by the on/off switching of mini-creation events. A typical oscillation lasts for ~ 50 Gyr while ~ 20 oscillations take place in one *e*-folding time of the long-term expansion. (see Figure 6)
2. It accounts for the origin of the CMBR along with its observed temperature as thermalized relic starlight. Stars are born and burn out during one oscillation. Thus there is relic starlight from all previous cycles.

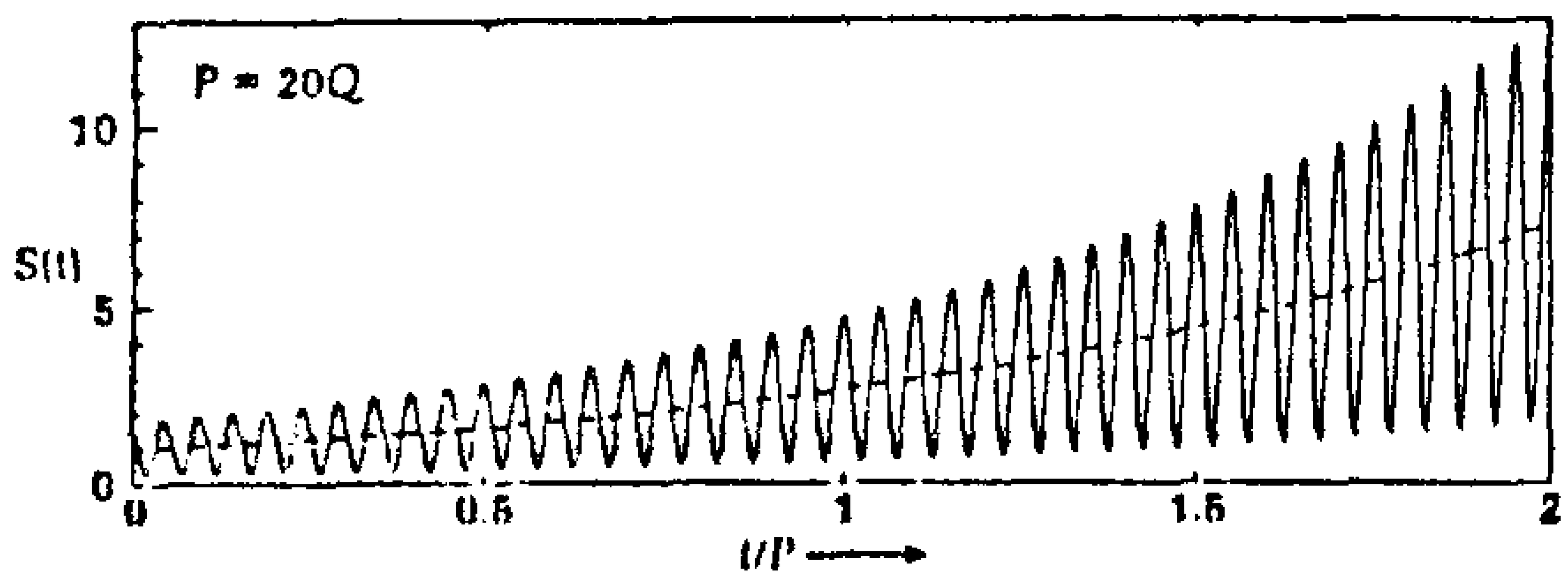

Figure 6. Scale factor of the Quasi-Steady State Cosmology with short-term oscillations (of time scale Q) coupled with long-term expansion (of time scale P).

3. It explains dark matter as relic stars of earlier generations.
4. It accounts for light nuclei as created in minibangs and in stars, with abundances consistent with observations.
5. It is consistent with large redshift observations of discrete source populations.
6. It seems to have a viable theory of structure formation through minibangs.

Naturally this cosmology needs to be further investigated for conformity with all the available data about the universe.

Issues for the future

I now end with a few issues that will need attention in the coming years. Future work will tell us many new facts about the universe, and hopefully answer some outstanding questions of the present, for example:

1. What, if anything do minute-scale inhomogeneities of the CMBR tell us about how large-scale structure formed?
2. Did an inflationary phase occur in the very early universe?
3. Is a cosmological constant necessary? If so, how did it originate?
4. How did the universe develop an asymmetry between matter and antimatter?
5. Is the Hubble interpretation of redshift universally applicable to all extragalactic redshifts? The cases of *anomalous redshifts, redshift periodicities*, etc. reported by Arp, Tifft and others are growing in number. These are difficult to fit within the framework of Hubble's law.
6. Will the SBBC survive with minimal modifications, or will we need radically different alternatives like the QSSC for our understanding of the universe?

Perhaps, for those cosmologists who think that they have everything settled and worked out about the universe, I should end with a cautionary remark of J. B. S. Haldane:

'The universe is not only queerer than we suppose, it is queerer than we can suppose.'

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Importance of small and moderate size optical telescopes

Ram Sagar

Small and moderate size optical telescopes have advantages over large and giant ones in the areas of efficiency, availability, flexibility and serendipitous and speculative observations. Recent developments in astronomical detectors and instrumentation along with the growth in computers and softwares have increased their capabilities many-fold. They are therefore responsible not only for a number of recent discoveries in astronomy, e.g. detection of microlensing phenomenon, but also for providing valuable optical observations of celestial objects and phenomena discovered at other wavebands, such as radio, infrared, X-ray and γ-ray. All these factors make well-instrumented, small and moderate size optical telescopes highly relevant in contemporary astronomy despite competition from 6 to10 m class ground-based optical telescopes and from the 2.3-m Hubble Space Telescope. Such telescopes in India have an added advantage of geographical location.

AN optical telescope is classified after the size of its objective which is either reflector-(mirror) or refractor-(lens) type. In this article, optical telescopes are arbitrarily classified according to their sizes into four groups namely 'small' for telescopes of sizes up to 1 m; 'moderate' for sizes between 1 and 3 m; 'large' for sizes between 3 and 6 m and 'giant' for sizes larger than 6 m. Throughout the world there are many large but a few giant size optical telescopes but more than a dozen of moderate and a large number of small size optical telescopes. In our country, there are four one-metre class telescopes (two

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