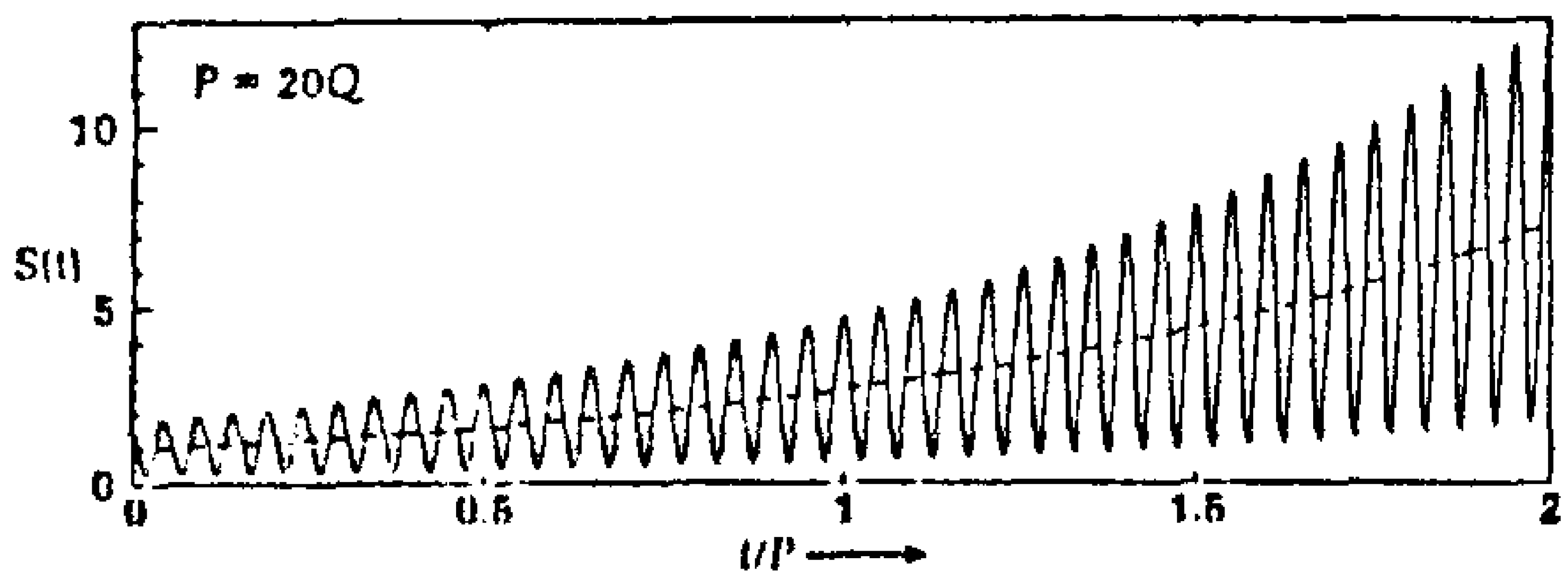

Figure 6. Scale factor of the Quasi-Steady State Cosmology with short-term oscillations (of time scale Q) coupled with long-term expansion (of time scale P).

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.'

Received 30 December 1999; revised accepted 7 January 2000

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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1.2-m located at Japal–Rangapur near Hyderabad and Gurushikhar near Mount Abu; two 1-m located at Kavalur and Nainital) and only one 2-metre class (2.34-m Vainu Bappu Telescope (VBT) at Kavalur) optical telescopes. Even the three upcoming ones, namely the 2-m telescope at the Inter University Centre of Astronomy and Astrophysics at Giravali near Pune[1], the 2-m telescope at the Indian Astronomical Observatory at Hanle in the high-altitude cold desert of south-eastern Ladakh[2] and about 3-m telescope at the UP State Observatory (UPSO), Nainital and Tata Institute of Fundamental Research, Mumbai[3] belong to moderate size only. They are expected to become operational in the next few years. Locations of these new and other existing 1- and 2-m class Indian optical telescopes are shown in Figure 1. They are almost evenly distributed from north to south in the country.

Interest in the design and construction of very large optical telescopes has never been greater than at the present time and there is no shortage of research projects for such instruments. However, financial constraints limit the possibilities to what can be achieved within tight budgets. Fortunately, technology has come to the aid of the astronomer and produced ways and means of doing something worthwhile. New technologies have made telescopes lighter and cheaper. As a result, there are many small and moderate size optical telescopes all over the globe and some are still being built. The obvious question is whether such telescopes produce worthwhile research in the presence of large and giant ground-based optical telescopes and 2.3 m Hubble Space Telescope (HST). The aim of this article is to discuss the role of small and moderate size optical telescopes in contemporary astronomical research with special emphasis on Indian telescopes.

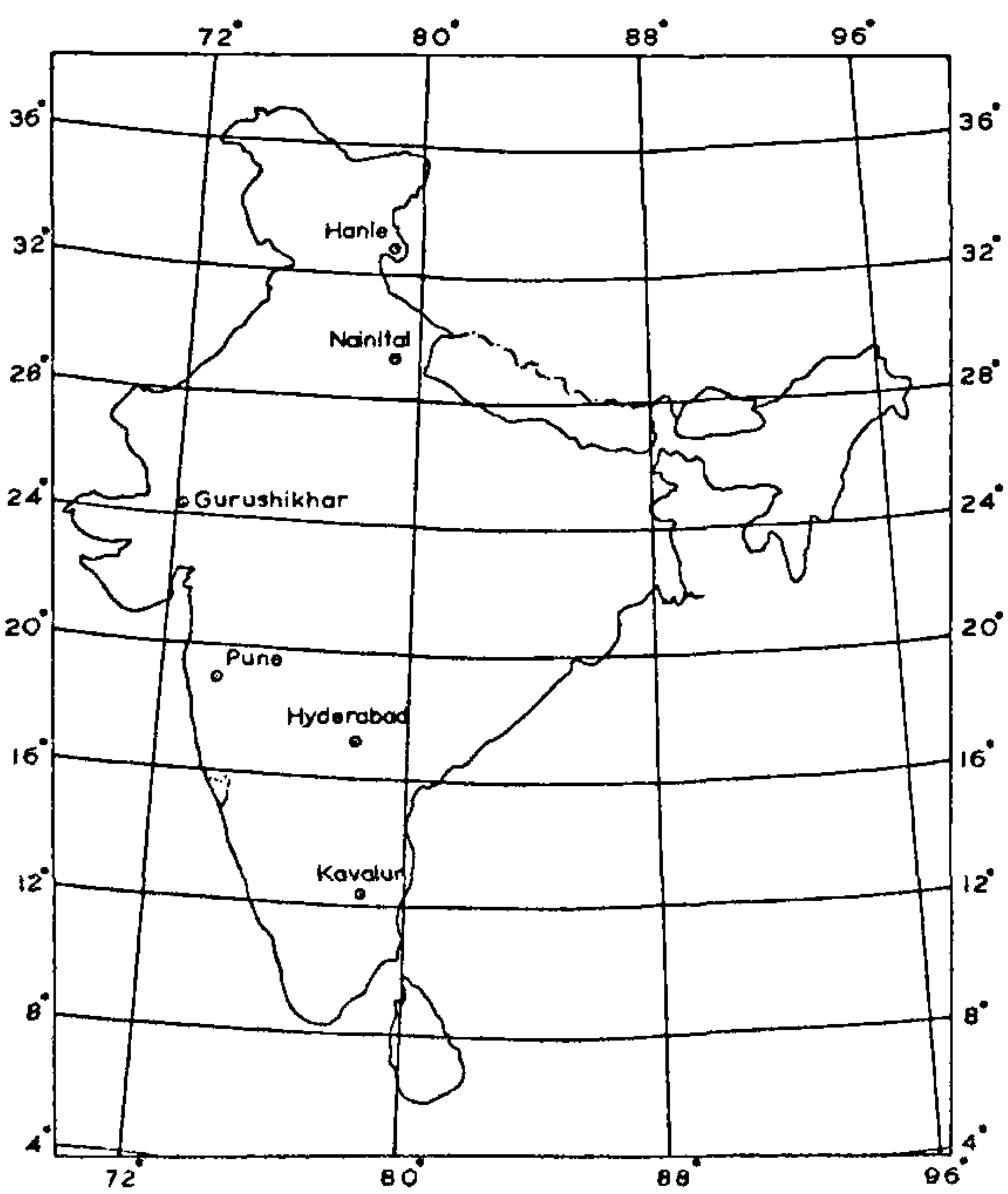

Figure 1. Location of existing as well as proposed one metre and larger size optical telescopes in India.

Purpose of an optical telescope

An optical telescope is used to image celestial objects at its focus. It is well known that, for sky background limited observations, signal-to-noise ratio at a frequency,

$$\nu \text{ is } \propto \sqrt{\frac{A_{\text{eff}} \times t}{\varepsilon_D \times B(\nu)}},$$

where A_{eff} is the light-gathering power of the telescope which includes the losses due to optics and the quantum efficiency of the detector used at the focus of the telescope; $B(\nu)$ is the sky background intensity; t is the integration time and ε_D the solid angle formed by the diffraction limited image of a telescope of diameter D at wavelength λ, is an Airy's disc of size $\sim \lambda/D$. For many purposes the power of a telescope is therefore $\propto (A_{\text{eff}}/\varepsilon_D)$. A 2.5-m telescope with 0.5″ image is thus equivalent in performance to a 5-m telescope with 1.0″ image, if other conditions are similar. This is true only for telescopes located in space like HST. For ground-based telescopes, however, the image degrades due to turbulence in the earth's atmosphere which is measured in terms of angle and is called *seeing* by astronomers. Most of the recorded seeing measurements indicate that during a large fraction of ground-based observing time, seeing is more than 1″ at visual wavelengths. The seeing spreads the image thereby diluting the concentrating action of ground-based optical telescopes of sizes larger than about 15 cm. The seeing limited stellar image thus formed is much bigger than ε_D. More turbulence in the earth's atmosphere at a place, therefore, increases the deterioration due to seeing and hence degrades the image formed by an optical telescope. This results in much longer hours of observations for recording any faint image or spectrum by a ground-based optical telescope in comparison with its counterpart in space. For example, HST records images of celestial objects in a relatively shorter time than the ground-based telescopes of similar size. It is therefore clear that small and moderate size optical telescopes can provide neither angular resolution better than HST nor collect more photons per image element than the large and giant size optical telescopes. Even then they not only contribute significantly to the optical observations of present-day research but are also cost effective, as assessed recently by Gopal-Krishna and Barve[4] and earlier by others[5,6]. It has been found that in the optical band almost half of the first rate results were obtained using moderate size optical telescopes. The main reasons for this are given below.

Utility of small and moderate size optical telescopes

In present-day astronomical research, utility of small and moderate size optical telescopes has increased many-fold mainly due to the need of multi-wavelength astronomical observations and because of the advent of modern detectors like charge coupled devices (CCDs) and the advancement in technology of optical telescopes, instruments and computer facilities.

Modern astronomy: Marriage of multiple wavelengths

While the optical band remained our sole window to the universe throughout most part of history, the past 5–6 decades have witnessed the genesis and dramatic progress of other branches of astronomy, encompassing the radio, sub-millimetre, infrared, X-ray and γ-ray bands. The short wavelength astronomy owes its rapid growth, in particular, to the advent of the satellite era in the recent decades, and space astronomy is likely to play an increasingly prominent role at practically all the wavebands in the coming decades. As celestial objects radiate across the entire electromagnetic spectrum, the various wavebands provide complementary information. This has been the impetus behind the present era of multi-wavelength astronomy. The advent of new observational astronomy at wavelengths other than optical has enabled the discovery of a number of new celestial objects and phenomena, e.g. the possibility of finding a black hole, the discovery of binary X-ray sources, γ-ray bursts and quasars, etc. However, to establish their identity and meaning in astrophysical terms and also to arrive at more definitive and clearer conclusions, optical observations are indispensable, as the optical band contains extra-ordinarily rich concentration of physical diagnostics which have developed from the accumulation of over a century of observations, associated laboratory experiments and theoretical work, though it covers quite a narrow wavelength range. A wealth of knowledge of atomic and molecular transitions of common species that are found in typical astrophysical environments occurs at the optical/infrared wavelengths. Because of its unique ability to measure red shifts, wide angle coverage with high angular resolution, and high spectral throughput, optical astronomy continues to play a key role in unravelling the structure and physical properties of the astronomical objects on all scales. The crucial determination of distance, age and chemical abundance of nearly all astronomical objects remains firmly rooted in the techniques of optical astronomy. For example, distances and other important parameters of γ-ray bursts could be estimated only recently when optical observations of their afterglows could be taken[7,8], though the phenomenon was discovered in the late sixties. Therefore, optical telescopes are needed not only for the observations motivated by optical properties of the objects, but also for the objects and phenomena which are discovered/observed at other wavebands. The demand on the optical observations is often acute enough to keep even small and moderate size (but well-instrumented) optical telescopes fully occupied. For example, observing time on the 2.34-m VBT located in Kavalur (see Figure 1) is generally over-subscribed by a factor of 4 or more.

Limitation of ground-based optical observations

Another contributing factor to the *time squeeze* on optical telescopes is the simple fact that ground-based optical observations of celestial objects are mostly confined to night time and even there, a good deal of time is lost due to clouds or poor seeing conditions. In contrast, radio observations, for instance, are far less susceptible to such natural factors. A reflection of this contrast is the fact that so many small and moderate size optical telescopes that were set up a few decades ago (but have been upgraded with modern instruments and detectors) continue to be in demand even today. In short, the productive life-span of optical telescopes turns out to be remarkably long.

Cost effectiveness

The cost effectiveness, E, of a telescope or collection of telescopes can be considered from several points of view. A detailed comparison of a large telescope versus an array of smaller ones working on the same kind of observations by Disney[5] indicates that large and giant telescopes are disproportionately expensive to build and require equipment which are more complicated to use to yield the best return. Also, the flexibility of operation of the array will yield much more first-rate astronomy than a single large telescope of the same cost. Warner[6] has defined E as the annual return on capital investment. Construction cost of a telescope generally follows the power law of its size. The exponent is 3 for traditional designs but may be 2 for new technology, as it has made telescopes cheaper. Considering the number of significant publications produced by a telescope in a year, it is concluded that to build four half-size telescopes is at least as profitable as one full-size telescope. These factors perhaps prompted astronomers of European Southern Observatory to build the world's largest 16-m optical telescope in the form of an array of four 8-m telescopes.

Efficiency

Large telescopes are often designed to be as versatile as possible and hence multipurpose instruments are used. This makes them not always efficient at their tasks. In contrast, a small or moderate size dedicated telescope can be optimized for a single purpose using, for example, special optics, super-reflective coatings or distinctive mounting. Furthermore, the permanent installation of an instrument on a dedicated telescope ensures stability of performance, improved monitoring of calibrations and reduced loss of time from instrument malfunctions associated with equipment changes. A site with several small or moderate size telescopes, each dedicated and optimized, is an ideal arrangement; there can even be a large telescope if desired.

Need of observations over extended period

It is common at major observatories to find that the large and giant telescopes are inevitably over-subscribed and as such time on them is at a premium. As small and moderate size optical telescopes are larger in number and also less in demand, the observing time available on them constitutes a major research resource. It is here that they outclass the large and giant telescopes. There are several astronomical studies which require sustained observations of the same source over a long period or systematic surveys of large areas of the sky for specific type of sources; for example, studies of long-period variables, short-period variables with complicated frequency spectra, for photometry of standard stars or for general photometric and spectroscopic survey. These observations are as much needed for progress in our understanding of the universe as the studies of the more exotic objects reported by the Keck 10-m telescope or the 2.3-m HST. The best example of this is the discovery of microlensing events towards the Magellanic Clouds and the Galactic bulge[9–12] using 1- to 2-m class optical telescopes. The very low microlensing probability requires several millions stars to be monitored daily to observe a significant luminosity increase and hence observations are required for a short time each night but over a long period. Also, serendipitous and speculative observations are excluded from large and giant telescopes but they can be carried out on small and moderate telescopes. The discovery of the Crab pulsar is a fine example of the reward of speculative observation.

Advantages of geographical location of India

The longitude of India locates it in the middle of about 180 degree wide longitude band having modern astronomical facilities between Canary Islands (~ 20°W) and Eastern Australia (~ 157°E). Because of this and existence of good astronomical sites, small and moderate size optical telescopes located in India can make a unique contribution to astronomical research, particularly involving time critical phenomena. The observations which are not possible in Canary Islands or Australia (during daylight hours), can be obtained from India. Two examples when this was vital were when the rings of uranus were discovered[13,14] and the optical observations of GRB afterglows were made[8]. Furthermore, time series observations of astronomical objects sometimes require a 24-h coverage to understand complex phenomena, e.g. pulsation of white dwarfs[15]. Such coverage is possible, as a few 1-m and one 2-m class optical telescopes exist in India. This situation will improve significantly once all the upcoming Indian moderate size optical telescopes become operational.

Impact of modern detectors and instruments

The enormous improvement in astronomical detectors, the availability of highly sensitive spectrographs, the active and adaptive optics, all make a modern optical telescope far more efficient today than its counterpart a couple of decades ago.

Role of modern astronomical detectors, computers and softwares

The kinds of detectors available to astronomers have always limited the accuracy and efficiency of measuring the light from stars that can be gathered by a telescope. They have constrained, if not dictated, the direction of the advance of knowledge in the area of astronomy. Though Galileo invented the telescope in the early 1600s as a tool to collect more light, the detector at its focus was only the eye until late in the 19th century. Then came the era of photographic plates/films which are not more sensitive than the eye, but they have the great advantage that they can build up a picture of a faint object by accumulating light for a long time. After World War II, photomultiplier tubes became widely available for measurements of the brightness of astronomical objects. They have several advantages over photographic emulsions, for example, unlimited exposure times, larger sensitivity and linear output. The major disadvantage of the photomultiplier tube is that it can observe only a small part of the sky; as a result, stars must be measured one at a time, and extended objects such as galaxies must be sampled point by point, a task that is very costly in terms of telescope observing time. More recently the technology of television and electronic image amplification has been adapted to astronomy, with an aim of combining the accuracy and unlimited exposure time of the photomultiplier tube with the extended field of view of the photographic plate. The CCDs are one of such devices and in fact were developed for astronomical use first. Now they are also used in many other areas. In recent years, photographic emulsions are therefore rarely used for recording astronomical information and in fact they have become out-dated. A comparison of the most important intrinsic properties of these two detectors is given in Table 1.

Table 1. Comparison of photographic emulsion with CCD.

Property	Photography	CCD
Response	Nonlinear	Linear
Size (single piece)	> 30 cm × 30 cm	Max 3.1 cm × 3.1 cm 24 cm × 24 cm with mosaicing
Dynamic range	Small (~ 1 : 100)	Large (~ 1 : 10,000)
Usability	Only once	Re-usable
Quantum efficiency	~ 4%	60–90% at peak sensitivity
Cost	Low	High
Resolution	Smallest grain size (few µm)	Generally ≥ 10 µm

In spite of several drawbacks of CCD in comparison to photographic plate/film, namely their small areas, the high rate of detection of cosmic-ray induced events, and producing enormous amount of data which need more sophisticated computer hardware and software for their aquisition and analysis, respectively the former are preferred over the latter because they offer a combination of qualities like excellent linearity, high quantum efficiency, large dynamic range, low system noise and dark current, and good overall system stability. Hence CCDs in combination with 1-m class optical telescopes are capable of capturing as faint objects as photographic plates can record on a 3–4-m size telescope in a relatively shorter time.

In order to extract even the last bit of information as well as to produce the best possible astronomical results from the CCD imaging, powerful computers and reduction procedures are as important as modern detectors. The best examples of this are doing stellar photometry in crowded regions like globular clusters and estimating completeness of data as a function of brightness in the studies of luminosity functions. Such studies could not be done earlier. The key ingredient in the new software is replacement of fixed-aperture techniques with a point spread function semi-empirically defined from uncrowded images in each frame or image. In this way, the signal-to-noise ratio is maximized and deconvolution of overlapping images becomes feasible. The extensive and time-consuming numerical analyses used in these data reduction procedures could be carried out due to availability of powerful and cheap computers in recent times.

Impact of new technology telescopes

Towards the end of 1980 there was a major step forward in the technological capabilities of telescopes. First, availability of sophisticated computer control changed the telescope mounting from equatorial to the much more compact alt-azimuth. Second, thin mirror technology took a quantum leap forward with active control of the shape of the primary mirror and positional control of the secondary, together enabling better imaging performance[16]. Third, the developments in dome and building design and environmental control have reduced the earth's atmospheric turbulence around the telescope and hence improved the seeing and thus the quality of the images. Fourth, major breakthroughs are taking place in adaptive optics, which effectively control flexible mirrors at frequencies of 10–20 Hz in order to remove the effects of the blurring of images caused by the turbulence of the earth's atmosphere[17]. A combination of these improvements means that a new technology ground-based optical telescope has the capability of approaching the ultimate in angular resolution, namely the diffraction limit of the telescope itself. This kind of performance is normally associated with telescopes in space, but is now achievable with ground-based optical telescopes at a fraction of the cost of a space mission. In the optical region the gap between the capabilities of space and ground-based telescopes is therefore gradually being narrowed. The introduction of active optics in the European Southern Observatory's 3.6-m new technology telescope which was completed in 1988 has improved ground-based image quality significantly. Wilson[16] and Ortolani *et al.*[18] have clearly demonstrated what is achievable with ground-based new technology telescopes on a night of excellent seeing. In fact, it has revolutionized the ground-based imaging.

During the next few years it is expected that the use of adaptive optics will enable us to obtain diffraction-limited images with ground-based optical telescopes. This will make a vast difference in the faintness of the object that can be recorded with them. Increased angular resolution benefits many areas of astronomy.

Multi-object spectroscopy

Most of the astronomical spectrographs were used to take spectra of a single object till about two decades ago. As the field of view of a telescope is generally more than 30′, the observing efficiency was thus very low. The image of a star at the focal plane of the telescope (i.e. at the slit of the spectrograph) is extremely small (only ~ 100 µm) compared to the total length of the slit which is generally more than a couple of centimetres. With the advent of new technologies, it has become possible to use full slit length of the spectrograph and take spectra of more than one object at a time. Such spectrographs are therefore called multi-object spectrographs. Presently, spectra of a maximum of 400 objects located within ~ 2° can be taken simultaneously with the facilities available at the 3.9-m Anglo-Australian Telescope located at Siding Spring, Australia. In this, developments in fibre optics system, computers and electronics have played important roles. With the use of this type of spectrographs, the observing efficiency of a telescope has increased many-fold.

In order to cover a wide spectral range, at many observatories astronomers are using double beam spectrographs. This also increases the observing efficiency of a telescope.

To achieve high spectral resolution, astronomers generally install heavy and large size spectrographs at the Coudé focus of a telescope. This requires many reflections and thus the loss of light collected by the telescope. To overcome the difficulties with such arrangements, fibres have recently been deployed in astronomical spectrographs.

In the light of above, one can say that astronomical spectrographs have taken full advantage of the latest development in technologies. This has increased the overall spectroscopic observing efficiency of optical telescopes.

Observational programme

It is impossible even to list here all the observational programmes which can be carried out with the modern small and moderate size optical telescopes. They have been discussed extensively in the literature as proceedings of symposia and workshops[19]. The programmes range from solar to cosmological studies. The topics covered are studies on planetary systems, star formation and stellar evolution, astroseismology, galaxy formation and its evolution, structure and kinematics of the galaxy and gravitational lensing, etc. Studies related to large-scale structure and dynamics of the universe and its evolution and cosmology can also be carried out.

Conclusions

Improvement in the observing efficiency of an optical telescope due to use of present-day technology in electronics, computers and light detectors has made the small and moderate size telescopes very useful instruments in the contemporary context. There has been significant improvement in the angular resolution capabilities and signal-to-noise ratio of the image/spectrum obtained using modern techniques. It has also pushed the limiting magnitude of observations to much fainter objects than what was possible a decade before, with a particular size of optical telescope. Consequently, those measurements that were undreamt of 50 years ago and were only a vague hope about 2 decades ago or could not be carried out due to lack of observing time on large and giant telescopes can now be carried out using small and moderate size optical telescopes. Hence, there are big opportunities for the small and moderate size optical telescopes in the contemporary astronomical research. In fact, research programmes on these telescopes not only complement but also go hand in hand with those on large and giant telescopes. Funding to build more moderate size optical telescopes in India is therefore timely and fully justified.

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Received 18 December 1999; revised accepted 11 February 2000