Bull. Astr. Soc. India (1997) **25**, 309–327

Silver Jubilee Article

Quasi-stellar objects, galaxies and the big-bang

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Abstract. This paper has been written in a highly personal vein. It is a resumé of the very modest effort made by the author and his students in understanding some aspects of extragalactic astronomy and astrophysics during the former's tenure at Pt. Ravishankar Shukla University, Raipur. The opinions and conjectures of the author as well as the inferences drawn by him are certainly controversial; they may even be highly biased, and may, ultimately, turn out to be incorrect. Anyway, the paper is a polite apologia of the author.

The paper explores the nature of the redshifts of QSOs, their Hubble diagram, their luminosity and chemical evolution, their role in the evolution of galaxies and the extended nebulosities in which they may be embedded. It discusses a viable mechanism for the production of enormous amount of energy in active galactic nuclei, especially in the QSOs, suggested by the author earlier. It also examines the evolutionary sequence of the extragalactic objects suggested by the author and his students from time to time, gives a brief account of the cause of the Big-Bang suggested by the author earlier, and ends with the author's role in promoting teaching and research in the Department of Physics of Pt. Ravishankar Shukla University, Raipur.

Key words : QSOs, AGNs, evolution of galaxies, Big-Bang

1. Introduction

Ravishankar University, Raipur was established in 1963 with postgraduate departments of Anthropology, Linguistics, Geography, and Psychology. During the IV Five Year Plan the University Grants Commission (UGC) sanctioned, inter alia, Physics and Chemistry Departments to the university. The Executive Council of the University resolved to develop the departments of Physics and Chemistry as departments specializing in Solid State Physics

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and Analytical Chemistry, respectively though the UGC had put no such constraints. Each of these two departments was sanctioned one post of professor, one post of reader, and two posts of lecturer. I joined the physics department in February, 1972.

Before joining Ravishankar University, I had worked on atomic processes in low density astrophysical plasmas, especially in a low-density hydrogen-helium plasma containing hydrogen and helium in the ratio of their cosmic abundance, for my doctoral thesis at the University of California at San Diego (UCSD), La Jolla, and my research supervisor, Professor R.J. Gould, and I had published papers on this topic (Gould and Thakur 1970; 1971). The work involved extensive calculations using computers. However, Ravishankar University had neither any computing facilities nor any literature on astronomy and astrophysics. Consequently, I was constrained to take up problems not involving much calculations, and yet having astrophysical relevance and importance.

During my stay at the UCSD, I had developed interest in extragalactic astronomy, especially in the formation and evolution of galaxies as well as in cosmology though these subjects were not directly related to the topic of my Ph.D. thesis. Hence I decided to pursue research work in these subjects.

In view of the striking similarities between quasi-stellar objects (QSOs) on the one hand and the nuclei of N, Seyfert, and radio galaxies on the other (Burbidge and Burbidge 1967; Burbidge 1970; Ambartsumian 1971), I thought that it might be worthwhile to examine whether QSOs had any role to play in the evolutionary sequence of galaxies. With this in view, I started investigating various characteristics of QSOs and nuclei of N, Seyfert, radio and normal galaxies as well as those of BL Lac objects. However, QSOs can possibly have a role in the evolutionary sequence of galaxies only if their redshifts are cosmological in nature; and they followed the Hubble's law.

2. Hubble Diagram of QSOs

For a homogeneous, isotropic, and expanding universe the redshift z of an extragalactic object is given by Hubble's law

$$cz = H_0 D_L \tag{1}$$

where c denotes the speed of light in vacuum, H_o is the Hubble's constant at the present epoch $t = t_0$ and D_L the luminosity distance of the object. To test the validity of the Hubble's law for a given class of extragalactic objects one has to see whether the redshift z and the luminosity distance D_L follow the linear relation (1). However, accurate distances are seldom known - more so for QSOs. Therefore, the following procedure is adopted.

The absolute visual magnitude M_v, the luminosity distance D_L and the apparent visual magnitude m_v are related as (Lang 1974) :

$$m_v = 5 \log D_L + M_v + 25 \tag{2}$$

where D_L is in megaparsecs. From equation (1) and (2) we get

$$\log (cz) = Am_v + B \tag{3}$$

where,

$$A = 0.2 \qquad \text{and} \qquad B = \log H_0 - 5 - 0.2\,M_v \tag{4}$$

Thus, if log (cz) is plotted against m_v for various extragalactic objects with a fixed value of M_v, then all the points would fall on a straight line of slope 0.2 provided that the Hubble's law is valid. In practice, one gets $A \approx 0.2$ by doing a least squares linear fit because different extragalactic objects of a given class have somewhat different absolute visual magnitudes. If A has a value ~ 0.2, then one can conclude that the Hubble's law is valid for the given class of extragalactic objects and their redshifts are cosmological in nature – i.e. the extragalactic objects are partaking in the expansion of the universe. It may be pointed out here that the foregoing discussion presupposes that the absolute visual magnitude M_v remains constant in time, i.e., there is no evolution in luminosity.

2.1 Plot of log (cz) against m_v for QSOs

Lang *et al.* (1975) plotted log (cz) against corrected visual magnitude m_v for three classes of extragalactic objects – galaxies, radio galaxies and QSOs and obtained the least-squares linear fit for each class of objects in the form of equation (3). As a result, they obtained 0.199, 0.194 and 0.135 for the value of A for normal galaxies, radio galaxies and QSOs, respectively. Thus for the QSOs the value of A differs appreciably from the value expected on the basis of the Hubble's law.

Lang *et al.* (1975) obtained the value A = 0.135 by considering a sample of 265 QSOs. After their work Burbidge *et al.* (1977) published an *An optical catalogue of Quasi-Stellar Objects*. Table I of their catalogue lists 633 QSOs with their measured redshifts. The list contains 626 QSOs for which both emission redshifts and visual magnitudes are given. Sapre and I (Thakur and Sapre 1978, hereafter referred to as paper I) considered this larger sample of 626 QSOs and obtained least-squares linear fit to the [log (cz), m_v] pairs with a view to testing the validity of the Hubble's law. In our calculation we used the *corrected* apparent visual magnitude m_v given by the relation

$$V = m_v + K + A_{abs} \tag{5}$$

where V, K and A_{abs} are the uncorrected apparent visual magnitude, the K-correction, and the absorption correction, respectively. We estimated the K-correction to the apparent visual magnitude by making use of the formula given by Lang *et al.* (1975), namely,

$$K = -0.75 \log (1 + z). \tag{6}$$

Lang *et al.* (1975) obtained this relation by assuming $\alpha = +0.7$ for all QSOs, where α is the spectral index in the power law for the flux of continuum radiation : $f(\nu) \propto \nu^{-\alpha}$. Following

Lang *et al.* (1975), we took $A_{abs} = 0.0$. Thus, on taking a sample of 626 QSOs we got $A = 0.141$. This is an improvement of only 4% on the value of A obtained by Lang *et al.* (1975).

However, it is important to note that Burbidge *et al.* (1977) have pointed out that the published photometric data from which they have compiled their catalogue are very heterogeneous, ranging from very accurate UBV measurements to crude estimates from the Palomar Sky Survey. Those V magnitudes in Table I of their catalogue that are multiples of 0.5 magnitude and for which U-B or B-V colours are not available are usually estimates from the Palomar Sky Survey which, according to the authors, carry magnitude errors of 0.5 to 1.0. Moreover, the emission redshifts of some of the QSOs in their catalogue are uncertain. Such redshifts are included within parenthesis in Table I of their catalogue. In addition, the redshifts of some of the other objects in their catalogue should be regarded with caution; for example, those objects for which no spectral line lists have been published, or those whose redshifts are based on single lines. Thus, after excluding the QSOs for which either the V magnitudes were not accurately known, or the emission redshifts were uncertain, there remained a sample of only 252 QSOs. Using this sample and after applying K-correction to the V magnitudes according to equation (6), Sapre and I (Paper I) obtained the least-squares linear fit to the [log (cz), m_v] pairs again in the form of equation (3). As a result, we obtained $A = 0.165 \pm 0.012$ (p.e.), which was an improvement of 22% on the value of A obtained by Lang *et al.* (1975). We also plotted log (cz) of these 252 QSOs against their corrected apparent visual magnitude. The plot is reproduced in Fig. 1 in which the broken line is the least-squares linear fits to the data in the form of equations (3). Using the value of B so obtained and taking $H_0 = 50$ km s^{-1} Mpc^{-1} we get $\langle M_v \rangle = -25.62$ and $\langle L_v \rangle = 1.46 \times 10^{12} L_\odot$. We see that for QSOs the value of A still differs appreciably from the expected value. This discrepancy has been attributed by Lang *et al.* (1975) to (i) the instrumental errors in determining the (z, m_v) pairs, and (ii) the intrinsic dispersion in the magnitude, σ_M, and the finite magnitude interval, Δm_v, of the available data, the latter being the prominent one, according to them.

However, another important source of the discrepancy could be the uncertainty in the K-correction. On making improvement in the K-correction, we obtained 0.183 ± 0.045 for the value of A (Paper I). But in order to investigate the nature of redshifts of QSOs it was desirable to employ a method in which one did not have to apply the K-correction. One such method could be to plot the Hubble diagram using $H\beta$ fluxes $f(H\beta)$ from QSOs instead of their corrected apparent visual magnitude.

2.2 Plot of log (cz) against log f(Hβ) for QSOs

If the Hubble's law is valid for QSOs, then

$$\log (cz) = -0.5 \log f(H\beta) + B' \tag{7}$$

where

$$B' = 0.5 [\log L(H\beta) - 46.68] \tag{8}$$

in which the $H\beta$ luminosity, $L(H\beta)$, of QSOs is in ergs s^{-1} (Paper I).

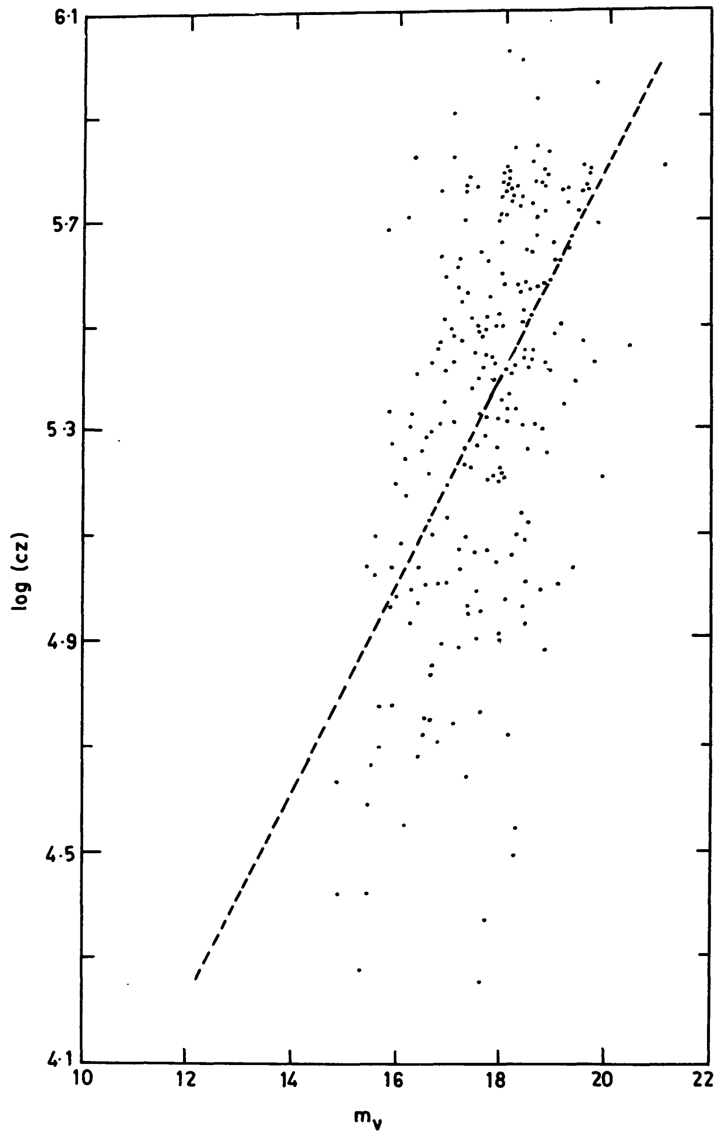

Figure 1. Plot of log (cz) against corrected apparent visual magnitude m_V for a sample of 252 QSOs mentioned in the text. The broken line is the least-squares linear fit to the equation : loz (cz) = $0.2m_V$ + B. In this case the value of B turns out to be 1.823.

Sapre and I (Paper I) plotted log (cz) against log f($H\beta$) for a sample of 52 QSOs for which we could get measured values of f($H\beta$) either directly or indirectly from the values of L($H\alpha$) using the relation L($H\alpha$) / L($H\beta$) = 3, suggested by Baldwin (1977) and obtained the least-squares linear fit.

We got the value of slope A' = –0.497 ± 0.076 (p.e.), B' = –1.404 ± 1.013 and $\langle$log L ($H\beta$)$\rangle$ = 43.80

This showed that the Hubble's law is valid for QSOs and lent support to the hypothesis that the redshifts of QSOs are cosmological in nature.

The greater scatter in the Hubble plots of QSOs vis-a-vis the corresponding Hubble plots of radio and normal galaxies may be attributed to the fact that QSOs may have a wider mass spectrum compared to that of radio and normal galaxies.

3. Evolution of QSOs

3.1 Luminosity evolution of QSOs

Form Fig. 1 it is clear that the majority of the high redshift QSOs lie to the left of the least-squares linear fit, whereas those with the low redshifts lie to the right. From this we conjectured that the high redshift QSOs might be much more luminous than the low redshift QSOs. Therefore, if QSOs are extragalactic objects at cosmological distances, the above feature of the plot suggested that QSOs might very well be evolving in luminosity-being more luminous initially, then gradually decreasing in luminosity. Therefore, to examine the possibility of the luminosity evolution of QSOs we plotted the absolute visual magnitude M_v of the 252 QSOs against their redshift z for the three evolutionary cosmological models of the Universe : the ever expanding Einstein-de Sitter model for which the deceleration parameter $q_0 = 0.5$; the Friedmann-Lemaître closed model, for which $q_0 > 0.5$ (for convenience we took $q_0 = 1$); and the Friedmann-Lemaître ever expanding model, for which $q_0 < 0.5$ (for convenience we took $q_0 = 0.01$). The absolute visual magnitudes, M_v, were calculated from the formula given by Mattig (1958) taking $H_0 = 50$ km s^{-1} Mpc^{-1} and using m_v values for $\alpha = +0.7$ (Paper I). We also obtained the least-squares cubic fit to the data and the relation between M_v and z for the three models of the Universe (Paper I). As the general features of the three plots are the same, only the plot for the Einstien-de Sitter model is reproduced here (broken line in Fig. 2). We obtained the relation :

$$M_v \approx -22.65 - 6.02z + 2.66z^2 - 0.43z^3, \tag{9}$$

and

$$dM_v / dz \approx - 6.02 + 5.32z - 1.29z^2 . \tag{10}$$

Therefore, it appears that the luminosity of a QSO increases with redshift, the rate of increase being more rapid for smaller values of z (Thakur and Sapre 1978). These apparent features are common in all three evolutionary models of the Universe.

It has been pointed out by Schmidt (196^{o}) and others in connection with the plots of absolute visual magnitude M_v against redshift z that the increase in luminosity with redshift may not imply any evolutionary effect. It is argued that an increase in luminosity with redshift is expected without any evolution for sources with a spread in luminosity (Schmidt 1969). At larger z only the sources of highest luminosity can be observed, while at small z one also

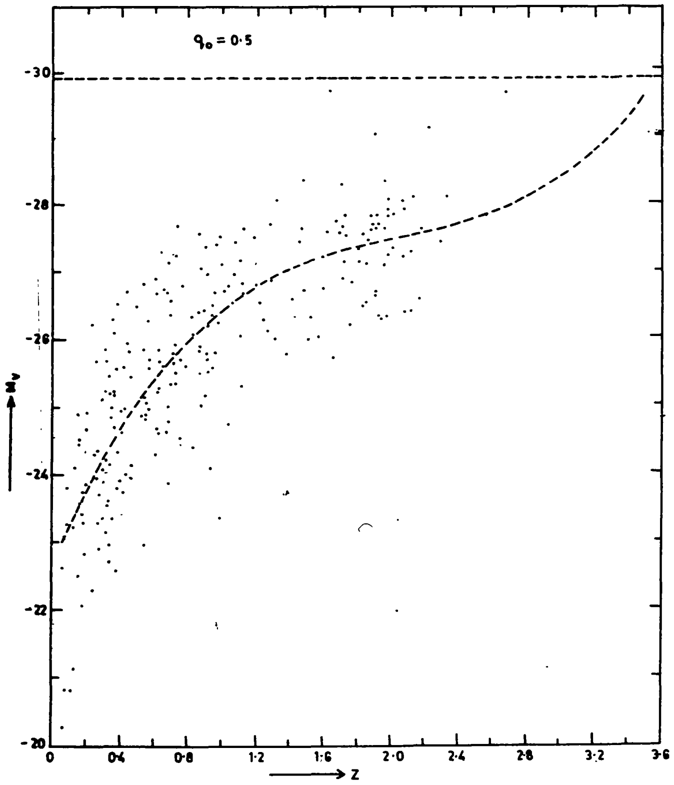

Figure 2. Plot of the absolute visual magnitude M_V against redshift z for a sample of 252 QSOs for the Einstein-de Sitter model of the Universe for which q_0, the deceleration parameter at the present epoch, is 0.5. H_0 has been taken to be 50 kms^{-1}, Mpc^{-1}. The broken curve is the least-squares cubic fit to the data. For $z > 2.2$ this curve is not to be taken too seriously.

observes sources of lower luminosity. If this argument is correct, then the region enclosed between the broken line parallel to the z axis (drawn through the point corresponding to the QSO having the highest luminosity in the sample), the M_V–axis, and the least-squares cubic fit shown by the broken curve, in general, and the top left-hand portion of Fig. 2, in particular, should not have paucity of points. On the other hand, it should have more or less an even density of points. *Although, at large redshifts, only the QSOs of highest luminosity can be observed, there is no reason why the highest luminosity QSOs cannot be observed at low redshifts if there is no luminosity evolution.*

3.2 Chemical evolution of QSOs

To explore the possibility of chemical evolution of QSOs, P.K. Mishra and I (Thakur and Mishra 1977, hereafter referred to as Paper II) calculated relative abundance of carbon with respect to silicon in five QSOs : PHL 957, PKS 0237 – 23, 1331 + 170, 3C 191 and M 132 using the method of curve of growth (Paper II). We also calculated relative abundance of aluminium with respect to silicon in PKS 0237 – 23 and 1331 + 170 as well as that of iron with respect to magnesium in 1331 + 170 and PHL 938. For these calculations we used equivalent widths of absorption lines measured by different observers.

The average values of N(C) / N(Si), N(Al)/N(Si), and N(Fe)/N(Mg) for these QSOs were found to be (5.5 ± 1.6), (0.13 ± 0.03), and (2.6 ± 1.2), respectively.

Some of our results differed appreciably from those of the other investigators (Bahcall *et al.* 1967; Hartwick 1971; Chan and Burbidge 1971) due to the fact that we used the latest measurements and that our analysis and calculations were more exhaustive.

As regards the origin of the absorption lines two views existed. According to one view the absorption occurred in the gas clouds ejected from QSOs during the course of violent activities in them (Burbidge 1971). According to the second view absorption occurred in the clumps of intergalactic matter which might be protogalaxies (Röser 1975; Smith *et al.* 1979). However, in our work we adopted the first view, especially because of the fact that the absorption redshifts, z_{abs}, were usually very close to the emission redshift z_{em}, for a QSO and as such it was quite likely that the absorption systems might had been ejected by the parent QSO.

We noted that for a given emission redshift the average values of N(C) / N(Si) were different for different absorption redshifts. However, for a given absorption redshift the values of N(C) / N(Si) obtained from different pairs of absorption lines were quite consistent. Then the view adopted by us suggested the hypothesis that the QSOs evolved chemically and that different absorption clouds were ejected by a given QSO at different epochs during the course of its chemical evolution. To examine this hypothesis we plotted the values of N(C) / N(Si) in various QSOs against their emission redshifts. From the plot a mild trend of increase in N(C) / N(Si) with decreasing emission redshift was discernible. We also noted that N(Al) / N(Si) increased with decreasing emission redshifts. Obviously, this lent support to our hypothesis that the QSOs evolve chemically.

Alpana Dasgupta and I (Thakur and Dasgupta 1982, hereafter referred to as Paper III) extended the work of Paper II and calculated abundance ratios in five additional QSOs : Q 1246 – 057, Q 0453 – 423, PKS 0528 – 250, Q 0002 – 422, and PKS 2126 – 158.

4. The spectral indices in the optical continuum of extragalactic objects

It is generally accepted that the mechanism responsible for the radiation in the optical continuum from BL Lac objects, QSOs, and nuclei of N, Seyfert and normal galaxies is incoherent synchrotron radiation by electrons (Demoulin and Burbidge 1968; Burbidge 1970; Oke *et al.* 1970; Burbidge *et al.* 1974; Stein *et al.* 1976). According to Ginzburg and Syrovatskii (1965, 1969) and Pacholzyk (1977), the flux of synchrotron radiation from electrons has a power law frequency distribution given by

$$F(\nu) \propto \nu^{-\alpha} \qquad (11)$$

where α is the spectral index. The increase in the value of α indicates that the activity in the object is slowing down and the object is growing older.

Therefore, in order to study the evolution of BL Lac objects, QSOs, and nuclei of N, Seyfert and normal galaxies Sood and I (Thakur and Sood 1980; 1981, hereafter referred to as Papers IV and V, respectively) calculated the spectral indices in the optical continuum of these objects.

Following Kinman (1976), we defined spectral indices α_{B-V} α_{U-B} in B – V and U – B colours for each of these object by

$$\alpha_{B-V} = 4.13\ [B - V)_0 - 0.1] \qquad (12)$$

$$\alpha_{U-B} = 4.58\ [(U - B)_0 + 0.9] \qquad (13)$$

where $(B - V)_0$ and $(U - B)_0$ are the (B – V) and (U – B) colours corrected for galactic extinction. To obtain $(B - V)_0$ and $(U - B)_0$ we adopted the relations given by Tapia *et al.* (1976) (Papers IV and V).

The difference $\Delta\alpha = (\alpha_{B-V} - \alpha_{U-B})$, between the two indices is a measure of how much the actual continuum flux departs from a power law. On the other hand, the average value, $\langle\alpha\rangle = (\alpha_{B-V} + \alpha_{U-B}) / 2$, measures the steepness of the power law spectrum.

Using equations (12) and (13) we calculated the values of α_{B-V}, α_{U-B}, $\Delta\alpha$ and $\langle\alpha\rangle$ for 227 QSOs, and the nuclei of the 12 N, 62 Seyfert, and 7 normal galaxies for which B – V and U – B colours were available. For BL Lac objects, we used the values of these quantities calculated by Kinman (1976) for a sample of 32 objects.

If the optical continuum indeed arises due to synchrotron radiation from electrons and is represented by the power law : $F(\nu) \propto \nu^{-\alpha}$, then the radiation is expected to be linearly polarized. For an optically thin source, the degree of linear polarization is given (cf. Ginzburg and Syrovatskii 1969; Pacholczyk 1977) by

$$\Pi_L(\text{thin}) = (3\alpha + 3) / (3\alpha + 5). \qquad (14)$$

On the other hand, if the source is optically thick, the degree of linear polarization is given by

$$\Pi_L(\text{thick}) = 3 / (12\alpha + 19). \qquad (15)$$

Hence, we also calculated Π_L(thin) and Π_L(thick) for those QSOs and BL Lac objects for which measurements of the degree of linear polarization Π_L(obs) were available. This was done in order to see, by comparison with observations, whether the source was optically thin or thick for radiations in the optical continuum.

We found that the values of Π_L(obs) were closer to the corresponding values of Π_L(thick). This indicated clearly that the QSOs and BL Lac objects were optically thick for the radiation in the optical continuum. However, the calculated values of Π_L(thick) were, in general larger than the measured values Π_L(obs). This implied that some depolarization effects might be in operation.

The synchrotron radiation in the optical continuum from any one of these objects is contaminated by the line emission and continuum radiation from a hot gas (i.e., by thermal bremsstrahlung). Therefore, naturally a departure from the power law is expected. To see the distribution of this departure in each class of extragalactic objects, in Paper V we plotted number vs $\Delta\alpha$ histograms for different classes of extragalactic objects. For a strictly power law spectrum we should have $\Delta\alpha = 0$, but this was never the case. We found that extragalactic objects could be arranged in the sequence :

BL Lac objects → Seyfert 1 → N galaxies → QSOs → Seyfert 2 → normal galaxies in order of increasing departure from a power law.

5. Nebulosities around QSOs

In order to examine the possibility that QSOs might belong to an early phase in the evolutionary sequency of galaxies, Sapre and I (Thakur and Sapre 1979, hereafter referred to as Paper VI) proposed the hypothesis that in this early phase a galaxy consisted of a highly compact and bright central object embedded in an extended *nebulosity*. This composite system might be what we observe as a QSO. Our hypothesis was based on the striking similarities between QSOs and N galaxies and the fact that Sandage (1973) had already concluded from his observations that N galaxies could be resolved into two such components. In most of the QSOs such *nebulosities* cannot be observed because they are masked by the high luminosity of the central object vis-a-vis their low luminosity.

Indeed, such nebulosities had been detected in the QSOs Ton 256 (Silk *et al.* 1973), 3C 48 (Wampler *et al.* 1975), 4C 37. 43 (Stockton, 1976), 3C 249.1 (Richstone and Oke 1977), and PHL 1070 (Morton *et al.* 1978) after Kristian (1973) first searched nearby intrinsically faint QSOs for underlying galaxies. In fact, Morton *et al.* (1978) had shown that the nebulosity around PHL 1070 has a total magnitude, spectral energy distribution, and absorption line spectrum that are consistent with that of a normal galaxy at the redshift of the QSO.

To examine the validity of our hypothesis we calculated the ratio $\underline{a}$ between I $(V)_{Nu}$, the intensity of the central object (Nu), and I $(V)_{Neb}$, the intensity of the outer nebulosity (Neb), in the visual band of wavelengths for a sample of 81 QSOs by the *colour given* method used by Sandage (1973) for N galaxies (Paper VI). This sample of 81 QSOs was drawn from *An Optical Catalogue of Quasi-stellar Objects* by Burbidge *et al.* (1977). The difference in magnitudes of the central object and the underlying nebulosity is given by

$$\Delta m\ (V)_{Neb,\ Nu} = m\ (V)_{Neb} - m\ (V)_{Nu} = 2.5 \log \underline{a}. \tag{16}$$

If $m(V)_c$, $m(V)_{Neb}$, and $m(V)_{Nu}$ are the observed visual magnitudes of the combination, the nebulosity and the central object, respectively, then

$$m(V)_{Neb} = m(V)_c + 2.5 \log (1 + \underline{a}) \tag{17}$$

After calculating the values of $m(V)_{Neb}$, and $m(V)_{Nu}$, from equations (17) and (16), of the 81 QSOs of the sample we determined the corrected magnitudes by applying the K-corrections and the galactic absorption corrections (Paper VI). We calculated the values of the absolute visual magnitudes $M(V)_{Neb}$, and $M(V)_{Nu}$ of the 81 QSOs using the formula given by Mattig (1958) quoted in Paper I, taking $q_0 = +1$, $H_0 = 50$ km s^{-1} Mpc^{-1}.

We plotted log (cz) against $m(V)_{Nu}$ and $m(V)_{Neb}$, respectively for the 81 QSOs and obtained the least-squares linear fit to the pairs [log (cz), m(V)] in the form of equation (3) where $A = 0.2$, which is the expected value of A if Hubble's law holds good. From the values of B so obtained we found $\langle M(V)_{Nu}\rangle = -24.03$, and $\langle M(V)_{Neb}\rangle = -24.08$, which agree closely with the arithmetic means – 24.00 and –24.09 of $M(V)_{Nu}$, and $M(V)_{Neb}$ of the 81 QSOs.

We noted that there was a poor correlation between log (cz) and $m(V)_{Nu}$ as well as between log (cz) and $m(V)_{Neb}$. However, it was interesting to note that the majority of the high redshift objects lay to the left, whereas the low redshift objects lay to the right of the least-squares linear fits. This might be due, at least partly, to the luminosity evolution of the bright central object and the extended nebulosities of the QSOs. In order to examine this possibility, we plotted $M(V)_{Nu}$ and $M(V)_{Neb}$ against redshift z of the 81 QSOs and obtained the least-squares cubic fits to the data. We noted a mild trend of luminosity evolution of $M(V)_{Nu}$ and $M(V)_{Neb}$.

We also gave criteria for the detectability of nebulosity around QSOs (Thakur and Sapre 1979, Thakur and Sood 1980).

6. A viable mechanism for the production of energy in Active Galactic Nuclei

One of the most enigmatic problems that confront astrophysicists today is : What could be the mechanism that can account for the enormous amount of energy (~10^{60} – 10^{62} ergs) released in active galactic nuclei (AGNs) including QSOs?

In order to explain the enormous power output of AGNs, models involving dense star clusters, supermassive stars, stellar collisions, supernova explosions and accretion discs around black holes have been proposed. I (Thakur 1993, hereafter referred to as Paper VII) proposed an alternative mechanism of the production and release of energy in AGNs, especially in QSOs.

I demonstrated that a collapsing supermassive object of mass $M \geq 10^4 M_\odot$ acts as an ultra-high energy particle accelerator and is a precursor of an AGN.

I pointed out that during the collapsing phase of the object, when the interparticle distance $s \sim 10^{-16}$ cm (energy E of the individual particles ~10^2 GeV) in the core of the object, electromagnetic and weak interactions may unify into electroweak interaction, and all interactions, except gravity, may be of the Yang-Mills type with $SU_3^c \times SU_2^{\underline{I}_\omega} \times U_1^{\underline{Y}_\omega}$ gauge symmetry, where *c* stands for colour, $\underline{I}_\omega$ for weak isospin, and $\underline{Y}_\omega$ for weak hypercharge, and the strong interaction may become quantum chromodynamics (QCD). At this stage quark deconfinement may occur as a result of which the entire matter in the core may be made up of spin 1/2 leptons - such as the electron, the muon, the tauon, and their neutrinos which interact via the electroweak force - and the quarks [up ($\underline{u}$), down ($\underline{d}$), strange ($\underline{s}$), charm ($\underline{c}$), bottom ($\underline{b}$), top ($\underline{t}$)] which interact electroweakly as well as through the colour force generated by gluons. In other words, at this stage, the entire matter in the core of the collapsing object might be in the form of quark-gluon plasma permeated by leptons. For this to happen, bulk of the energy released during the gravitational collapse of the core has to be utilized in heating and squeezing further the quark-gluon plasma permeated by leptons. In other words, the gravitational energy released during the collapse of the object might be locked in the plasma.

I also pointed out that the collapse of the object to a space-time singularity is inhibited by Pauli's exclusion principle as well as by Heisenberg's uncertainty principle and that the object would explode before it could collapse to a singularity, thereby releasing the enormous amount of energy locked in the plasma (Paper VII).

7. Evolution of Galaxies

It should be possible to observe the galaxies in their different phases of evolution by looking back in time, i.e., by looking farther and farther out into space. Thus, the earliest phase in the evolutionary sequence of galaxies should, normally, be the farthest provided that the formation of most of galaxies occurred at the same epoch. In order to examine the possibility that the QSOs might belong to an early phase in the evolutionary sequence of galaxies, Dasgupta and I (Paper III) displayed the values of N(C) / N(Si), the relative abundance of carbon - one of the four most plentiful elements in the universe - with respect to Si, in nine QSOs (for which the ratio N(C) / N(Si) could be calculated) and the Galaxy in a bar diagram (Fig. 3). It appeared plausible to us that QSOs gradually evolve chemically into normal galaxies.

In order to arrive at a plausible picture of the evolutionary sequence of extragalactic objects Sapre and I (Thakur and Sapre 1980, hereafter referred to as Paper VIII) plotted a histogram between the number and the redshift for each of the five classes of extragalactic objects, namely, QSOs, N galaxies, Seyfert galaxies, radio galaxies and normal galaxies conjectured to belong to different phases in the evolutionary sequence of galaxies. We find :

(i) $(z_{\rm peak})_{\rm QSOs} > (z_{\rm peak})_{\rm Seyfert\ galaxies} > (z_{\rm peak})_{\rm N\ galaxies} > (z_{\rm peak})_{\rm radio\ galaxies} > (z_{\rm peak})_{\rm normal\ galaxies}$;

(ii) Sufficient overlap occurs in the redshift ranges of (a) QSOs and N galaxies, (b) N galaxies and Seyfert galaxies, (c) Seyfert galaxies and radio galaxies, and (d) radio galaxies and normal galaxies;

(iii) In addition to the highest peaks, other smaller peaks also occur in the histograms.

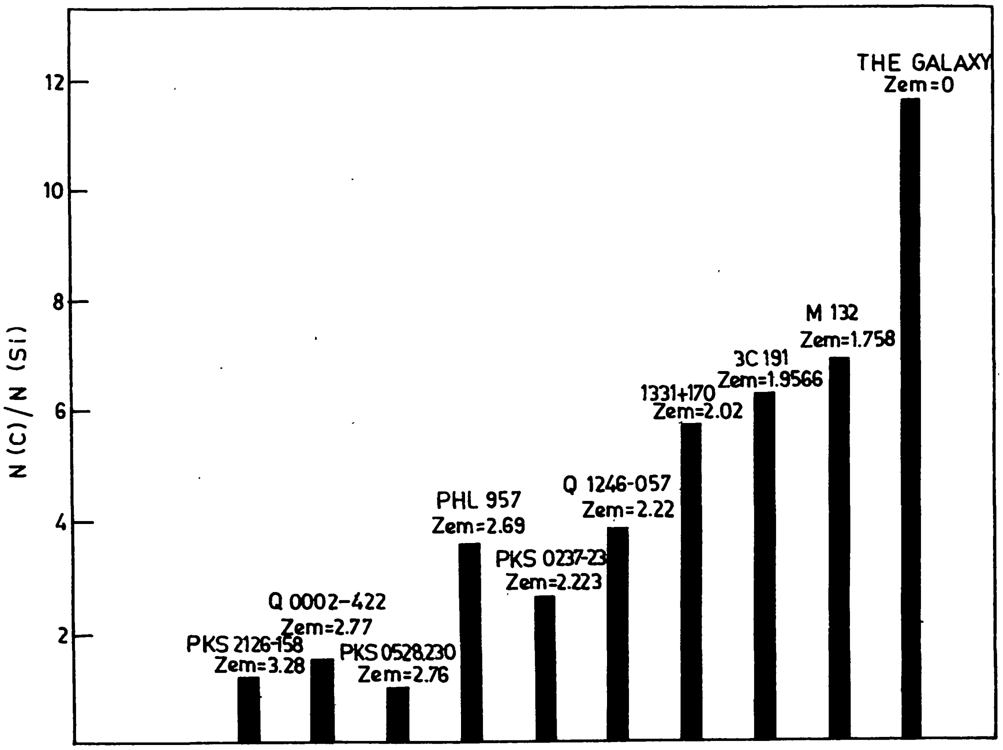

Figure 3. Display of N(C) / N(Si) for nine QSOs and the Galaxy.

The positions of the highest peaks and other smaller peaks tentatively suggest the epochs of bright phases in the evolution of such objects.

The fact that the redshift distribution of the QSOs overlap sufficiently with that of N galaxies suggest that QSOs might evolve smoothly into N galaxies. Similarly, N galaxies might evolve into Seyfert galaxies, Seyfert galaxies might evolve into radio galaxies, and radio galaxies might evolve into normal galaxies. *Without such an evolutionary sequence for the five different classes of objects it would be difficult to understand how a whole class of extragalactic objects suddenly disappears at an earlier epoch and a whole class of extragalactic objects is suddenly formed at a later epoch, there being no traces - in the form of electromagnetic signals that could be detected at optical or radio wavelengths - left in between (Lang et al. 1975).* Hence the plausible evolutionary sequence :

QSOs → N galaxies → Seyfert galaxies → radio galaxies → normal galaxies.

Sapre and I (Paper VI) also displayed, in diagrams, $\langle \log \underline{a} \rangle$, $\langle M(V)_{\rm Nu} \rangle$, and $\langle M(V)_{\rm Neb} \rangle$, the mean values of the ratio $\underline{a} = I(V)_{\rm Nu} / I(V)_{\rm Neb}$, and the absolute visual magnitudes of the bright central objects and the extended nebulosities, respectively for QSOs, N galaxies, Seyfert galaxies, and normal galaxies. This study suggests that the extragalactic objects evolve in the sequence :

QSOs → N galaxies → Seyfert galaxies → normal galaxies.

Because of certain similarities between QSOs and BL Lac objects, it has been suggested that BL Lac objects, especially, the more variable ones, may be young QSOs which have not yet ejected much material from the core region (Altschuler and Wardle 1976; Pollock 1975, Usher 1975, Stein *et al.* 1976). In order to examine this and to explore further the evolutionary sequence of extragalactic objects, Sood and I (Paper V) used the criterion that, normally, the steeper the spectral index of an object, the more evolved it is, and arrived at the plausible evolutionary sequence :

QSOs → BL Lac objects → Seyfert galaxies → N galaxies → normal galaxies,

provided we lump together Seyferts 1 and Seyferts 2 in the same class. This was apparently incompatible with the evolutionary sequence suggested in Papers VI and VIII in that the order of N and Seyfert galaxies was reversed.

But if we regard Seyferts 1 and Seyferts 2 as two distinct classes of objects, this anomaly is removed, for it is the nuclei of Seyferts 1 whose properties closely resemble that of the QSOs (Weedman 1977). Moreover, the mean value $\langle\alpha\rangle$ for Seyferts 1 is 1.97 whereas for Seyferts 2 it is 3.93. When we compare these values with the mean value of $\langle\alpha\rangle$ for QSOs, namely, 0.67 it is clear that Seyferts 1 are more akin to QSOs than Seyferts 2 and hence it is quite likely that Seyferts 1 and Seyferts 2 may belong to two distinct and separate phases in the evolutionary sequence of galaxies and that Seyfert 1 may not be far removed from QSOs in the pedigree. Consequently, regarding Seyfert 1 and Seyfert 2 as two distinct classes of objects, Sood and I (Paper V), on the basis of the steepness of spectral index, arrived at the following plausible evolutionary sequence :

QSOs → BL Lac objects → Seyfert 1 → N galaxies → Seyferts 2 → normal galaxies which is no more incompatible with the evolutionary sequence suggested in paper VI and VIII. To get a vivid picture, we displayed $\langle\alpha\rangle$, the mean value of $\langle\alpha\rangle$ for QSOs, BL Lac objects and nuclei of Seyferts 1, N, Seyferts 2, and normal galaxies in a diagram which is reproduced in Fig. 4.

However, in this evolutionary sequence radio galaxies constitute a missing link. This is because $\langle\alpha\rangle$ could not be calculated for the nuclei of radio galaxies as their (U–B) and (B–V) colours were not available. But in the light of the evolutionary sequence suggested in Paper VIII, we felt that it is quite likely that the extragalactic objects evolve in the sequence :

QSOs → BL Lac objects → Seyfert 1 → N galaxies → Seyferts 2 → radio galaxies → normal galaxies

Sood and I (Thakur and Sood 1982, hereafter referred to as Paper IX) sought further evidence in favour of the evolutionary sequence of extragalactic objects suggested in Papers III, V, VI, and VIII. In order to do this we calculated $H\beta$ luminosity, L'($H\beta$), of QSOs, Seyfert 1, N galaxies, Seyfert 2 and normal galaxies using photoionization model and assuming that the UV continuum radiation is produced in the cores of the extragalactic objects by synchrotron mechanism and hence is given by a power law (Paper IX) and compared the calculated $H\beta$ luminosity with the observed $H\beta$ luminosity, L($H\beta$).

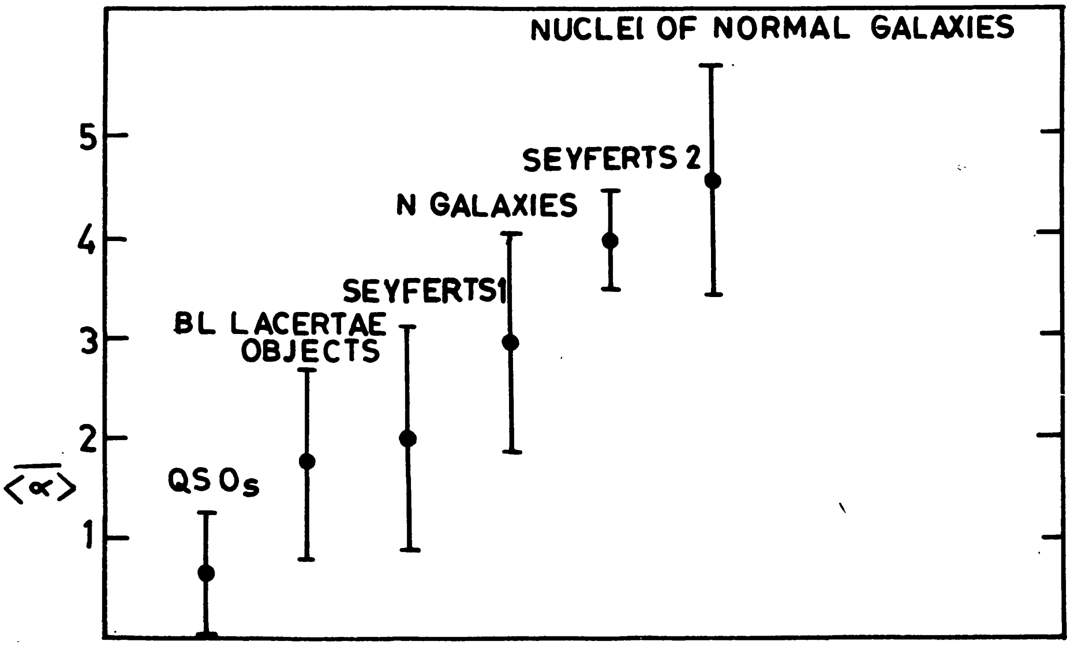

Figure 4. Display $\langle\bar{\alpha}\rangle$ the mean value of $\langle\alpha\rangle$ for QSOs, BL Lac objects, and the nuclei of Seyferts 1, N, Seyferts 2, and normal galaxies.

We found that L($H\beta$) is more than L'($H\beta$) for 4 of the 27 QSOs, 12 of the 26 Seyferts 1, and for all of the N, Seyferts 2 and normal galaxies considered. However, it should be noted that in case of the nuclei of Seyferts 1, N, Seyferts 2, and normal galaxies synchrotron mechanism is not the only mechanism for the production of UV photons. The UV photons may be produced in the hot gas clouds surrounding the stars in the nuclear as well as the extranuclear regions of the galaxies. As a result of this, more UV photons are available than those produced by the synchrotron mechanism in the nuclei of these objects. Therefore, if the surrounding nebulosities are optically thick enough for the absorption of a large fraction of these photons, the observed $H\beta$ luminosity, L($H\beta$), would be more than the calculated $H\beta$ luminosity, L'($H\beta$) of the extragalactic objects. In other words, the more evolved an extragalactic object, the larger is the observed $H\beta$ luminosity as compared to the calculated $H\beta$ luminosity. Using this as a guideline we arrived at the suggestion that extragalactic objects evolve in the sequence :

QSOs → Seyferts 1 → N galaxies → Seyferts 2 → normal galaxies

which is exactly the same evolutionary sequence as that suggested in Paper V but for the omission of BL Lac objects which does not emit $H\beta$ photons. This was particularly obvious from Fig. 6 in Thakur and Sood (1982) (Paper IX) in which the mean values of $\Delta(H\beta)$ = log L($H\beta$) – log L'($H\beta$) was displayed for the five classes of extragalactic objects.

In regarding BL Lac objects to be more evolved than QSOs, Sood and I (Paper V) were guided by the fact that the spectral indices of the former are steeper than those of the latter. We thought that, unless all of a sudden violent activities erupt in the cores of BL Lac objects as a result of which they pass over to QSO phase, the QSOs may precede BL Lac objects in the pedigree. However, we (Paper IX) realized that this view needed revision; especially because of the absence of spectral lines in BL Lac objects. We surmised that it is quite likely that a BL Lac object is formed as a result of condensation under self gravitation of a density perturbation or an inhomogeneity in primeval plasma and that during this process a part of these gravitational energy released is utilized in energizing the charged particles in the plasma – especially, the electrons – which in turn, may emit continuum radiation by synchrotron mechanism. In this phase the electron may not be as energetic as in the QSO phase as the gravitational energy released in the formation of a BL Lac object may be much less than the energy released in the core of a QSO by violent activities and as such the spectral index of the BL Lac object may be less than that of a QSO. Subsequently, the core of the BL Lac object may be condensing further into one or more compact objects analogous to supermassive protostars. During this condensation the temperature of the core may rise to the threshold value for the occurrence of the nucleosynthesis, and thus some of the elements may get synthesized in course of time. Later, one or more of these comparatively short-lived supermassive star-like objects in the core may explode violently thereby ejecting gas clouds around the core. The remnant of the core after explosion may correspond to the compact, bright central object and the ejected cloud to the extended nebulosity of the QSO in the hypothesis of Paper VI. Therefore, the evolutionary sequence :

BL lac objects → QSOs → Seyferts 1 → N galaxies → Seyferts 2 → normal galaxies is more tenable than the one suggested in Paper V.

The plots of log L($H\beta$) against the spectral index α, and L'_{NT}, the logarithm of the calculated nonthermal optical luminosity, for five classes of extragalactic objects reinforce the suggestion that the extragalactic objects evolve in the sequence :

BL Lac objects → QSOs → Seyferts 1 → N galaxies → Seyferts 2 → normal galaxies.

The radio galaxies might lie somewhere between N galaxies and Seyferts 2 or between Seyferts 2 and normal galaxies. At present there seems to be no definite reason for choosing between the two. However, in view of the fact that N galaxies are also radio sources like radio galaxies, the latter may not be far removed from the former in the pedigree and hence it is more likely that the radio galaxies lie between N galaxies and Seyferts 2 in the evolutionary hierarchy. Consequently, in Paper IX we finally suggested that it is quite likely that the extragalactic objects evolve in the sequence :

BL Lac objects → QSOs → Seyferts 1 → N galaxies → radio galaxies → Seyferts 2 → normal galaxies.

The fact that this evolutionary sequence is in agreement with the evolutionary sequence suggested in Papers III, V, VI and IX on the basis of altogether different considerations enhances its likelihood.

8. The origin of the Big-Bang

Various variants of the hot Big-Bang (HBB) model, including the inflationary models, presume explicitly or implicity that at t = 0 a gigantic explosion, the Big-Bang, occurred as a result of which the Universe was heated to an enormously high temperature. However, these models do not attempt to answer the intriguing question : What caused the Big-Bang? Or, what physical process heated the Universe to an enormously high temperature?

Addressing myself to this question I (Thakur 1992, 1995) proposed a singularity free model of the Universe which readily accounts for the origin of the Big-Bang and, at the same time, retains all the useful features of the HBB model, and yet resolves, in a very natural way, all the problems with which the original model is plagued including that of the space-time singularity. Furthermore, it gave for the first time a physical explanation of the enormous amount of energy released in the Big-Bang.

9. Promotion of teaching and research in astronomy and astrophysics at Pt. Ravishankar Shukla University, Raipur

A compulsory paper on Astrophysics and Plasma Physics has been introduced at the M.Sc. (Final) level in the Department of Physics. An elective project work on astronomy, apart from that in solid state physics, has been introduced in lieu of a conventional, old fashioned, routine type of physics practical course for M.Sc. final students. The department has a 6" Carl Zeiss meniscus reflecting telescope and 14" computerized Celestron telescope housed inside a dome of fiber glass fabricated by ACRIPROD of Allahabad. M.Sc. (Final) students use these telescopes in conjunction with SSP-3 and SSP-5 photometers for their project work. Even research work on variable stars is being carried out with the Celestron telescope using solid state photometers.

The Udaipur Solar Observatory fabricated a coelostat for the department and a concave grating was imported from USA for spectroscopic work with the coelostat and the grating. However, despite our earnest efforts we could not acquire 6" lens needed for the coelostat. Hence the coelostat is lying idle. Nor could we acquire Rowland mounting for the grating and hence it is also lying unused.

Over the years a small group of research workers in astronomy and astrophysics has been formed which is facing impending danger of distintegration.

In the beginning the university was not subscribing any journal in astronomy and astrophysics. Later, we had a golden period when the university subscribed Astrophysical Journal and its Supplements, Monthly Notices of the Royal Astronomical Society, European Journal of Astronomy and Astrophysics, Astrophysics and Space Science, Astrophysics

Letters, and Nature, apart from the Bulletin of the Astronomical Society of India and the Journal of Astrophysics and Astronomy, and acquired back-sets of all these journals. However, the golden period did not last long; for the past several years no journal in astronomy and astrophysics, except Indian ones, is being subscribed by the university due to paucity of funds.

Among the products of the university who are still actively engaged in research in astronomy and astrophysics, names of Dr. A.K. Ambastha, Dr, Sunetra Giridhar, Dr. Nandita Srivastava, Esfhan Alam Kherani, Gulab Chand Dewangan – who are working at various Institutes and Observatories – and those of Dr. A.K. Sapre, Dr. D.K. Chakraborty, Dr. S.K. Pandey, Padmakar Singh Parihar, Devendra Kumar Sahu and Parijat Thakur who are working in the university itself - may be mentioned.

The university also played a significant role in popularizing astronomy by arranging sessions on observing astronomical objects through the telescope and by showing 16 mm movies and 35 mm slides of astronomical objects as well as by arranging popular lectures on astronomy by such luminaries as Professors J.V. Narlikar, K.D. Abhyankar, S.M. Chitre, M.S. Vardya, J.C. Bhattacharya, A. Bhatnagar and others including teachers of the university.

The university also organized UGC sponsored summer Institute on General Relativity and Cosmology in 1984 and the XII Annual Scientific Meeting of the Astronomical Society of India in 1987. It also organized IUCAA sponsored workshop on Quasar Continuum and Line Radiation in 1991.

Acknowledgements

I am thankful to Ranveer Kumar, Ravindra Kumar Gupta, D.K. Sahu and Parijat Thakur the research scholars in the School of Studies in Physics – formerly, Department of Physics – of the University for typing the paper. I am also thankful to Dr. A.K. Sapre for going through the MSS carefully and checking the typescript meticulously.

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