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Abhyankar—The scientist

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1. Introduction

There are few people who can study both observational and theoretical astronomy. Few of them are successful and still fewer are successful in the face of adversity. Krishna Damodar Abhyankar belongs to 'such a selective group.

He is passionately devoted to astronomy He has taught and spread astronomy with a missionary zeal. His lucid exposition of intricate ideas makes his lectures so interesting that even a non-expert in the field enjoys them immensely. He has got a thorough understanding and deep knowledge of astronomical observations and a corresponding keen sense of theoretical insight to unravel the secrets shrouded in the observations which look like mere numbers.

He is not only a successful teacher but also an indefatigable research enthusiast. He has taught many students at graduate, post-graduate levels at the Department of Astronomy, Osmania University and guided several students for M. Phil and Ph.D. degrees. He was solely responsible for introducing astronomy at the graduate and post-graduate levels, arranging the experiments, writing the syllabi of various courses, etc. I have had the fortune of being associated with him at the very early stages of my research career and observed him from close quarters. I benefitted immensely from this association with him and learnt how meticulous one has to be in doing research. There is now what is called the Abhyankar school of students, many of whom are working at different places in the country for instance at the Indian Institute of Astrophysics.

He is singularly responsible for the establishment of the Astronomical Society of India. He served it in several capacities including its Presidentship. This organization is playing a major role in bringing ideas together and coordinating programs, which is a great service to astronomy in the country.

He was born on 1928 June 21—the day of the summer solstice—an astronomically significant day. Since his childhood, he showed signs of brilliance. He secured gold medals at high school and colleges. After he finished his M.Sc. from Agra University, he worked for a short period at Holkar College, Indore. He secured a senior research fellowship of the government of India and joined Kodaikanal Observatory during 1952-1954. He worked there with the then director Dr A. K. Das to work on the problems of the sun. He secured a scholarship at the University of California at Berkeley for studying towards his Ph.D. degree. He was asked to take 16 courses in astronomy and he obtained A grades in all these courses—a record which stands unbroken till today! Here, for his thesis, he studied several close binary stars with a view to understanding stellar evolution. In the course of his studies, his thesis supervisor was Otto Struve, a giant among the 20th century astronomers He discovered a short period variable AD CMi His Ph D. thesis work turned out to be a masterpiece and it has been very well quoted.

He returned to India brimming with enthusiasm to spread and pursue research in astronomy He joined as meteorologist grade I, at the Kodaikanal Observatory from where he left for USA a few years earlier This position could neither satisfy his desire for research nor contain his enthusiasm to teach astronomy When there was a position vacant in the newly started department of astronomy at Osmania University, Hyderabad, he immediately joined this department. He was one of the few astronomers at that time who knew what should be done in the initial stages of starting an astronomy department. He worked ceaselessly with unbounded enthusiasm, foresight and thought in preparing the set of course work, observational programs for the graduate and post-graduate levels, recruiting people for various positions, and doing administrative work. In addition to these duties he conducted site survey for the proposed 48″ reflector and selected the present place near Rangapur village.

When the former director of the Nizamiah Observatory Dr Akbar Ali died, Dr A. K. Das the former director of Kodaikanal Observatory, who had retired not long ago, was temporarily appointed the director He too was snatched away by the icy hands of death within a short time Abhyankar was made in-charge director of the Nizamiah Observatory and head of the astronomy department. During this short period of his in-charge Directorship, he brought up the department to the level of a standard that can be compared with standards anywhere in the world He managed the department with a skeleton staff and he himself used to take several classes for B.Sc. and M.Sc. during the day time, and conduct observations during the night time. It was a place brimming with enthusiasm and everyone in the department and observatory was enthralled to work with him. Suddenly, the control and direction of the observatory and the department was snatched away from him and passed into hands which showed only darkness. It was like passing from brilliance into darkness. One can notice that with in a short period the change that took place all that he had so assidiously built up became redundant and an object of ridicule. Astronomy suffered a set back at Osmania.

He left for Canada to work at the David Dunlap Observatory on NRC post-doctoral Fellowship for a year in 1963 He started work on the problems of moving atmospheres. He continued to work on the problems of binary stars. He was made a full professor upon his return from Canada. However, he was unable to pursue research under suffocated circumstances. He proceeded to USA in 1967 on a senior post-doctoral resident research associateship of NRC-NASA of USA at Jet Propulsion Laboratory, Pasadena. In collaboration with A. L. Fymat, he wrote a series of papers on the solutions of the radiative transfer equation. They solved this equation by perturbation techniques in inhomogeneous and non-conservative scattering media. After his return to India, he took a student R. K. Bhatia and they extended this technique to the study of planetary atmospheres.

He served as the director of Japal-Rangapur Observatory and as head of the astronomy department during 1961-63 (incharge) 1973-81, 1986-88, till he retired in 1988. He served the faculty of science of Osmania University in the capacity of dean during 1977-80.

He has been elected Fellow of Royal Astronomical Society (1964), Indian Academy of Sciences, Indian National Science Academy, Member of Sigma Xi of USA in 1955, Member of Astronomical Society of the Pacific, American Astronomical Society, International Astronomical Union He is the Founder member of Astronomical Society of India, Andhra Pradesh Academy of Sciences, and Maharashtra Academy of Sciences.

He had been awarded the best teacher award by the Andhra Pradesh Government, and NSSA award for Patent Rights on a new technique of measuring optical polarization.

2. Scientific achievements

His scientific work can be divided into 3 main areas of activity:

(1) solar physics,

(2) binary stars and variable stars, and

(3) radiative transfer and planetary atmospheres.

It is practically impossible to narrate the whole work here and instead we shall highlight a few points from each of these areas

1. *Solar physics*

Using Bjerkness thermodynamical theory of sunspots, the depth of the sunspot umbral column is calculated from the observed differences in the temperatures at the pole and equator. Bjerkness relation is

$$\frac{\Delta\theta}{\theta} = \frac{2V_E V}{gh}$$

where θ is the surface temperature of the sun; V the circumferential velocity at equator equal to 2000 ms^{-1}; V_E the eastward velocity of the highest circulating stratum, g the acceleration due to gravity; $\Delta\theta$ the difference in temperatures at pole and equator of the sun; and h the thickness of the upper circulating stratum above subphotospheric zonal vortex in the lower stratum in which the sunspot originates.

In collaboration with A. K. Das at Kodaikanal, Abhyankar estimated the temperature difference between pole and equator of the sun by measuring the equivalent widths of the lines λ 4227 Å of neutral Ca and λ 3933 Å line due to ionized Ca atom at the pole and equator [1, 2]*. They employed Woolley's method and found that the pole is hotter than the equator by about 96K ± 18K by employing Pannekeock's continuum absorption coefficients, and the difference is 86 ± 16K with Chandrasekhar's values. Using Bjerkness theory, they derived 125 km or 140 km for the depth of the sunspot umbral column, using the above observed values of temperature differences.

In collaboration with A. S. Ramanathan [3] he determined the excitation temperatures of 4030K, 4200K and 3800K for Cr I, Fe I, Ti I respectively from the spectra of sunspots by using curve of growth method.

In collaboration with K. Anthony Raju, P. V. Subramanyam, he studied several aspects of the solar corona at the total eclipse of 1980 February 16.

*The numbers in brackets refer to those in the list of references.

2. Binary stars, variable stars and related problems

He has studied the stability of straight-line solutions in the restricted three body problem and concluded the following [9]:

(i) Over a wide range of initial distance from L_2, even with the proper initial conditions, the particles make only one revolution around L_2 before they go off. Particles moving near L_3 make two rounds if the distance from L_3 is sufficiently small. The orbits are partly elliptical and their periods and eccentricities are in fair agreement with the predictions of the first-order theory.

(ii) The incipient stability is destroyed even if the initial velocity components differ by about 1% of the velocity components. For bigger deviations the orbits depart more and more quickly from the elliptical orbits of the first-order theory.

(iii) These results are not favourable for accumulation of material near the Lagrangian points L_2 and L_3. Gould had found that the particles leaving either component of a binary system stay near L_2 and L_3 only for a short time during which their orbits are changed from direct to retrograde motion.

(iv) Most of the computed orbits are funnelled into orbits close to each other, which surround both components of the binary system. This result gives support to Gould's conclusions regarding the formation of rings in close binary systems.

(v) A few orbits were computed for the case $\mu = 0.5$. The results were similar to those of L_2 in the case of $\mu = 0.1$.

He worked for his Ph.D degree in the University of California at Berkeley under the guidance of Otto Struve. He decided to study binary stars because of the fact that these are believed to give clues to stellar evolution. In the course of his Ph.D. work, Abhyankar wanted to determine the light curve and orbital elements of AD CMi whose light variability was discovered by Hoftmeister and confirmed later by Zessewitch. Abhyankar noticed that the observations did not indicate that this is a binary but an ultra short period variable with 3 hr period. Further observations [11] by him conclusively proved that AD CMi is a variable (figure 1).

In his Ph.D thesis [8] he studied three binary systems. The purpose of this study was to obtain more information at different stages of stellar evolution by examining their internal structures. For this purpose he chose systems β Sco, AO Cas and HD 47129 (Plaskett star) (see figures 2, 3 and 4 respectively for their radial velocity curves). He obtained the following results for the three systems.

β Sco

The internal structure in terms of density distribution is determined by the motion of the line of apsides. From the observations he calculated the periods of the line of apsides and revolutionary period of the system. The relation by T.E. Sterne connects the internal structure of the component stars with the apsidal motion through the equation

$$\frac{P}{U} = K_1 \left(\frac{R_1}{r}\right)^5 \left(1 + 16\frac{m_2}{m_1}\right) + K_2 \left(\frac{R_2}{r}\right)^5 \left(1 + 16\frac{m_1}{m_2}\right),$$

where P and U are the periods of binary revolution and the apsidal line respectively; m_1, m_2 the masses of the components; R_1 and R_2 the radii of the components; r is the distance between the stars; and K_1 and K_2 are the apsidal constants.

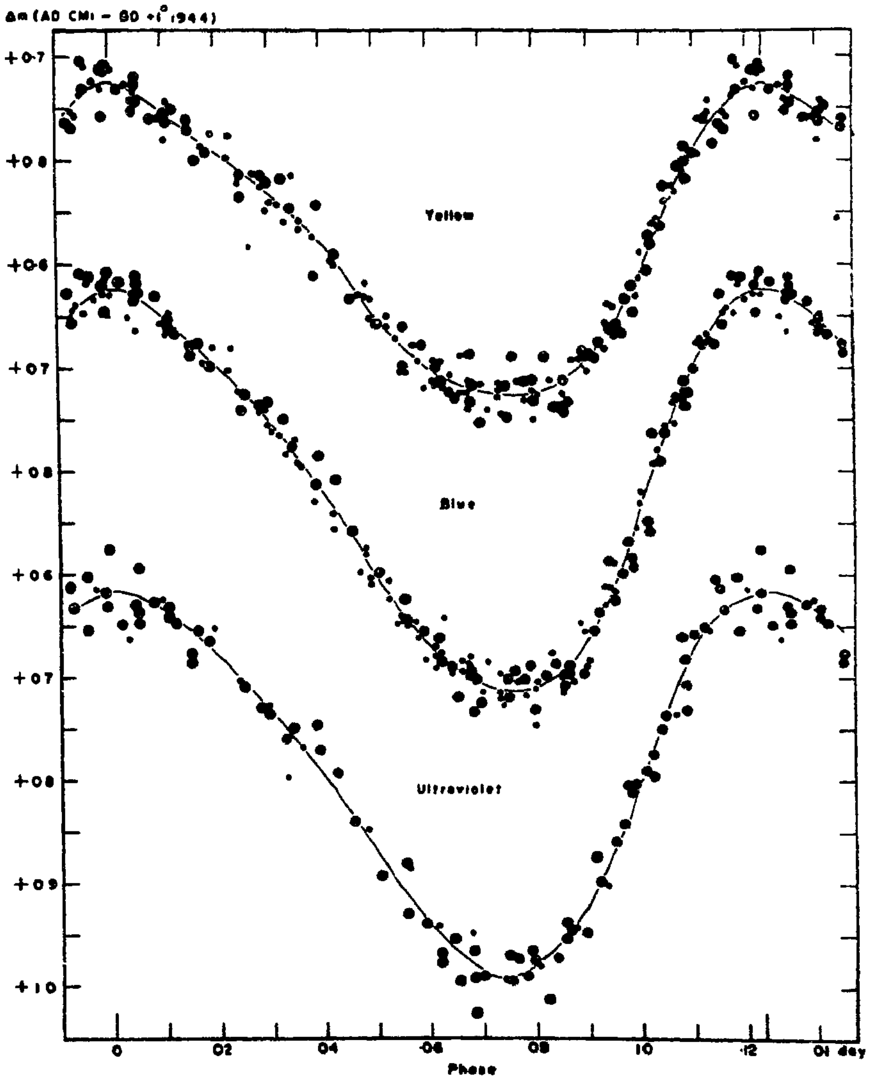

Figure 1. The light-curves of AD CMi. The small dots represent observations on four nights: January 30, February 2, February 3, and February 5, 1959. The larger dots represent observations on three nights: February 28, March 1, and March 2, 1959. The mean epochs for the two sets of observations are separated by about 220 cycles.

Assuming that the two components are similar in their evolutionary characteristics, he set $K_1 = K_2 = K$. By employing the equation of T. E. Sterne, he derived a value of 2.82×10^{-3} for the value of K. This corresponds to n, the polytropic index between 3 and 4. The central condensation defined as ρ_c/ρ (where ρ_c and ρ are the central and average density of the star) was found out to be between 50 and 600.

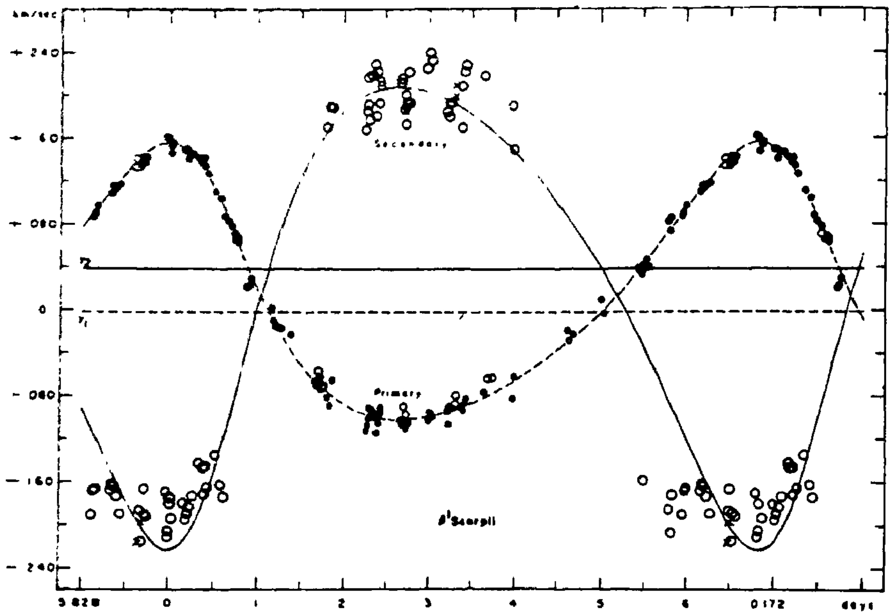

Figure 2. The radial velocity curves for β Sco Open circles (primary) and crosses (secondary) represent measures on more recent Mount Wilson plates.

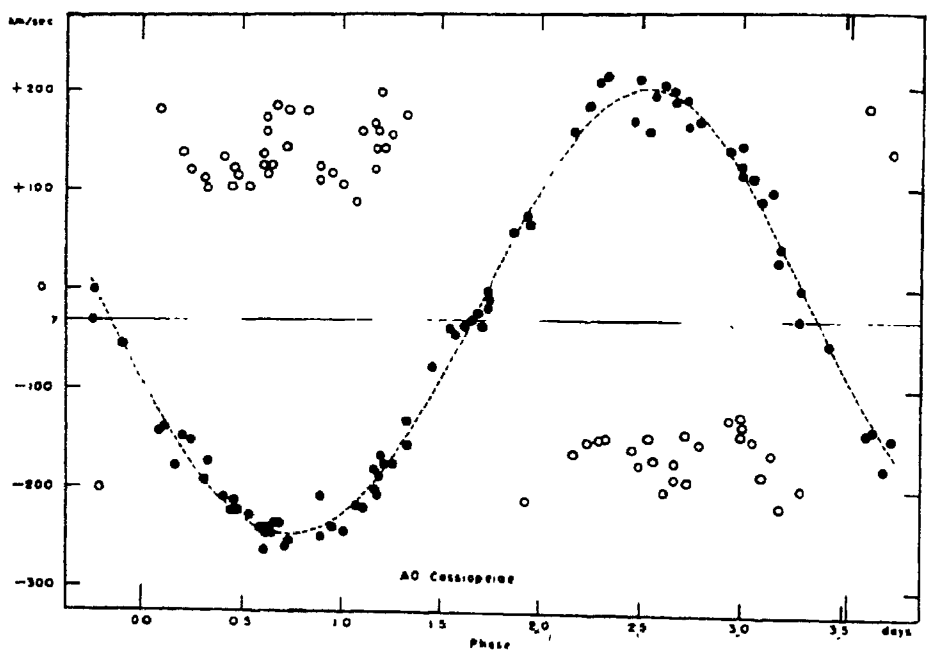

Figure 3a. The radial velocity curves for AO Cassiopeiae.

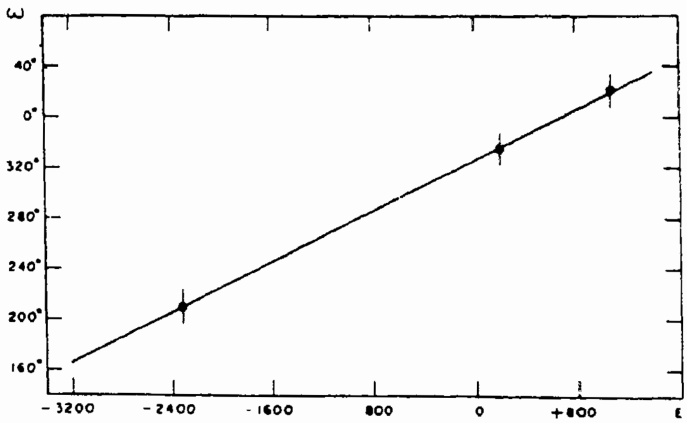

Figure 3b. Apsidal motion in AO Cassiopeiae

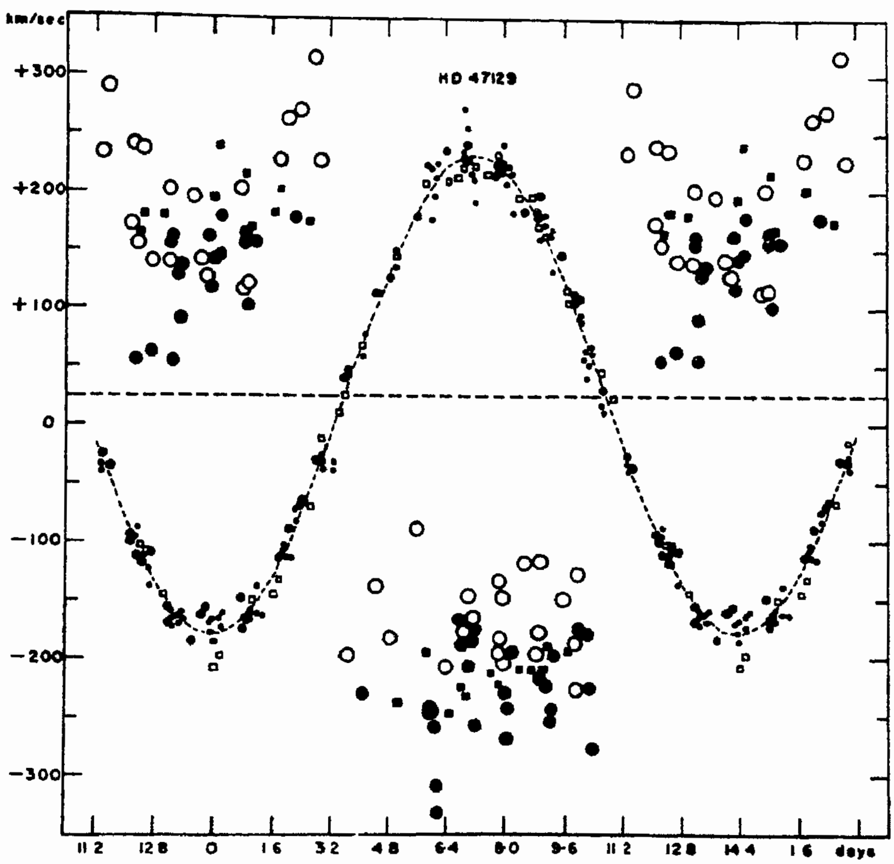

Figure 4. The radial velocity curves for HD 47129

AO Cas

The same procedure as in the case of β Sco is applied to this system for obtaining ρ_c/ρ and the apsidal constants have been derived to be $K_1 = K_2 = K = 0.00065$ and $n \approx 4$ which gave the central condensation to be about 600.

HD 41129 (Plaskett star)

In the case of Plaskett star he derived the mean distance of the envelope and other factors were calculated. Radius of the envelope $\approx 6R_{\odot}$. The abundances of H, He, n_e are found to be $n_H = 1.3 \times 10^{11}$ cm^{-3}, $n_{He} = 0.2 \times 10^{11}$ cm^{-3}, $n_e = 1.7 \times 10^{11}$ cm^{-3}.

He studied the spectroscopic binary ξ CrB A, incollaboration with M. B. K. Sarma [22]. They showed that m_1/m_2 is less than one; and that the secondary has a variable velocity curve and variable line intensities. These observations show that this system might now be in the earliest phase of its development into a stage where the secondary component becomes more and more unstable.

He obtained elements of several binary systems with UBV observations such as YY LCMi [13, 14], RV DCorvi [48], WX Wridani [56, 58], TT Hydra [57, 58, 62, 70], TT Aurigae [76], RC Ma [81, 90, 91] in collaboration with his colleagues M. Parthasarathy, N. B. Sanwal, M. B. K. Sarma, A. G. Kulkarni, J. Kaul, N. Rajasekhara Rao, B. Lakanandhan, K. R. Radhakrishnan. He studied the period changes in the eclipsing binary stars [63, 65, 68, 71, 75, 84, 87, 92, 93] in collaboration with T. Panchatsaram, T. R. Radhakrishnan, M. B. K. Sarma, R. K. Bhatia, P. Devadas Rao and C. V. S. Sarma. He and Praveen Nagar proved that the secondary components of the Algol systems are more luminous and hotter for their mass, indicating their hydrogen-deficient character [82, 94].

3. *Radiative transfer*

In the early sixties the art of simulating absorption line profiles in moving envelopes of outer layers of stars was at a primitive stage. Abhyankar extended the work of S. Chandrasekhar and developed a numerical method for computing theoretical absorption line profiles in a moving atmosphere [19, 20, 21] during 1963-64. This is a simple and easy to understand technique in which the medium is divided into N discrete layers (see figure 5). He computed a series of absorption line profiles for different scattering functions and optical depths (see figure 6). Later he performed the disc integration of the profiles which makes the profile smooth [24] (see figure 7).

Abhyankars' work [32, 33] with A. L. Fymat has already been referred to.

If it is assumed that the albedo for single scattering $\Omega(\tau)$ differs from a constant value Ω_0 by a small amount

$$\Omega(\tau) = \Omega_0[1 + \omega(\tau)]$$

throughout the atmosphere, the nonlinear singular integral equations for the X and Y functions of Chandrasekhar, and the X and Y functions of Ueno, which describe the transfer of radiation through and inhomogeneous plane-parallel atmosphere of arbitrary stratification, are linearized by use of a perturbation technique. These equations are written in their operator form, and their iterated solutions are expressed as infinite series

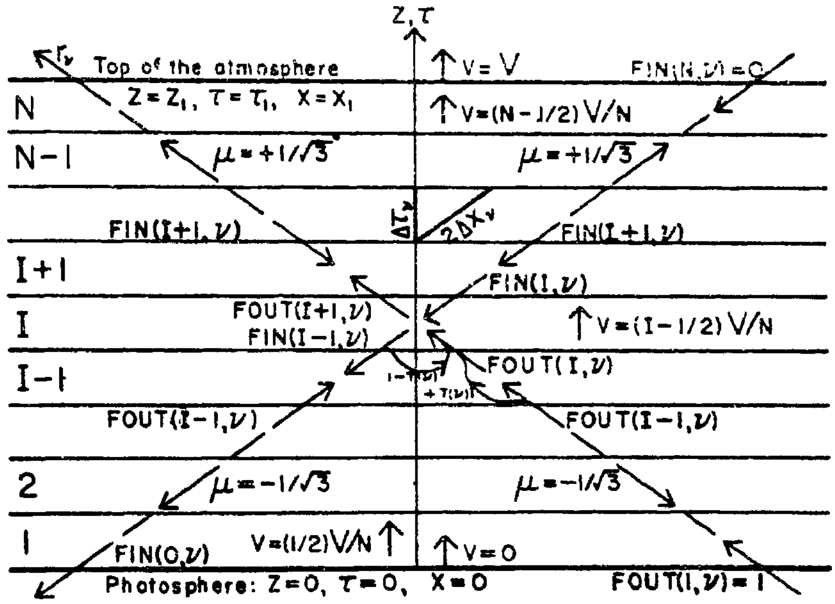

Figure 5. Divisions of the atmosphere into N layers and definitions of various quantities

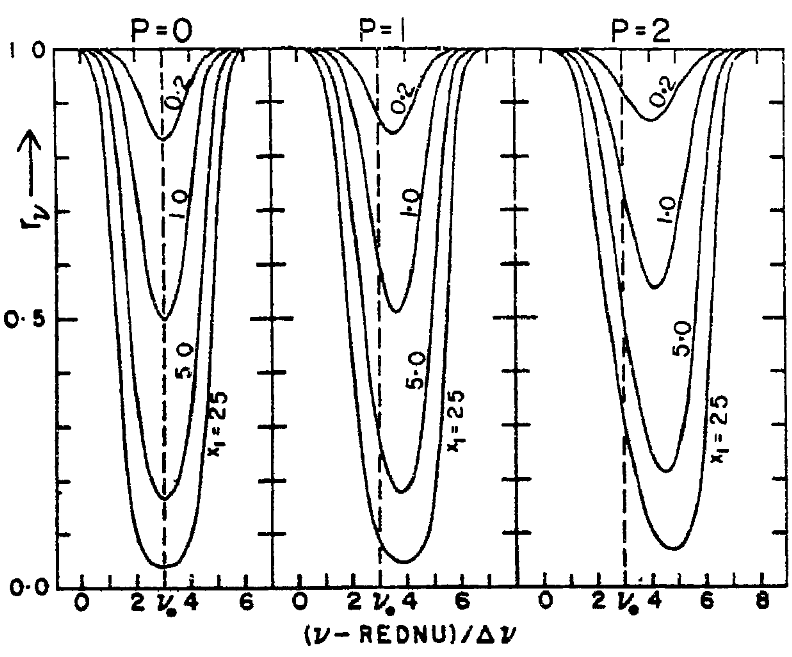

Figure 6. Line profiles for linear-velocity law and Gaussian scattering function.

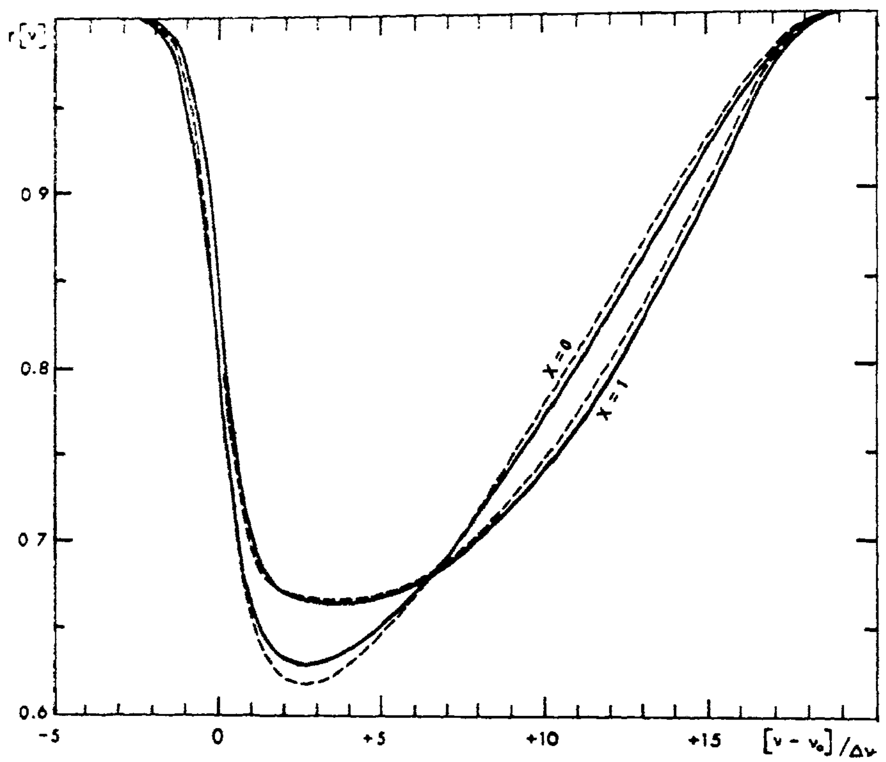

Figure 7. Integrated line profiles for the two phase functions

which, if convergent, would represent the N-solution of the problem. The convergence of the series solutions involving repeated operators was investigated, and the region of convergence delimited for atmospheres of arbitrary optical thickness for various values of Ω_0 and S_2, the maximum fractional perturbation in $\Omega(\tau)$. This region is found to be the larger, the smaller the atmospheric thickness. The curves of convergence are shown in figures 8 and 9 and the error analysis is shown in figure 10. They have extended this technique to Rayleigh phase matrix [39, 40] and tabulated scattering functions for an imperfect Rayleigh scattering semi-infinite atmosphere [43].

The nonlinear singular integral equation for the H-function of an inhomogeneous plane-parallel atmosphere of arbitrary stratification is linearized by using the perturbation method developed in paper 1. The N-solution of this equation is given. The iteration procedure for computing the fractional perturbation $h(\tau;\mu)$ in $H(\tau;\mu)$ is also described. An error analysis is performed, and the relative error in the solution, caused by the neglect of the quadratic term, is computed. Curves showing the maximum relative errors in $h(\tau;\mu)$ and $H(\tau;\mu)$ as functions for the relative perturbation, s, were estimated. These curves will be useful for estimating the errors to be expected in any particular problem. For illustrating the method, H-functions for semi-infinite homogeneous atmospheres with $\Omega = 0.300$, 0.700, 0.925 and 0.975 are computed from the H-function for an atmosphere with $\Omega = 0.900$.

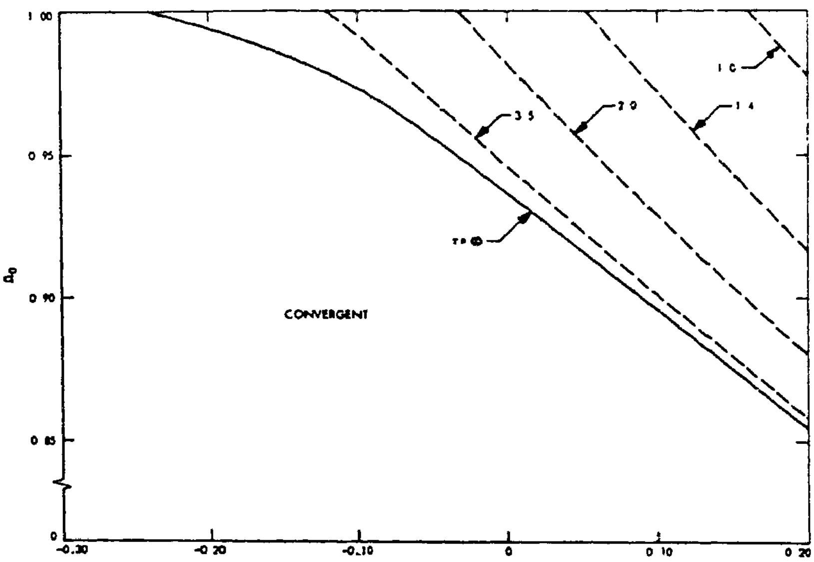

Figure 8. The curves $\Omega_0(S_2)$ which limit the domain of convergence of the solution for various optical depths

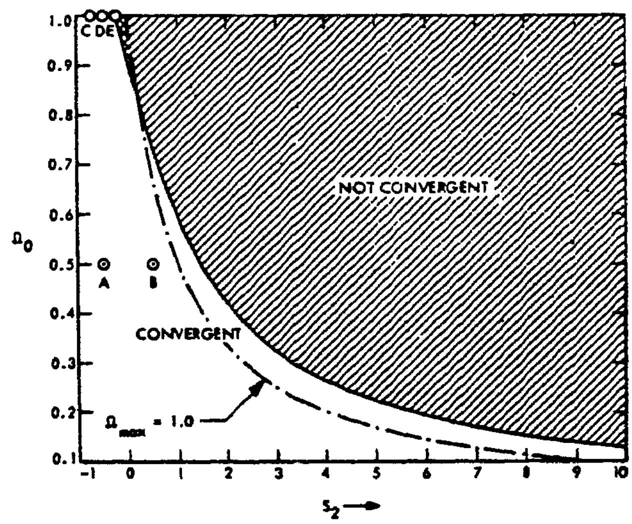

Figure 9. Region of convergence of the linear solution for Rayleigh phase matrix

In order to describe the transfer of partially polarized radiation through an inhomogeneous semi-infinite atmosphere, they have introduced a matrix N-function by considering the limit of the K-function as the optical thickness of a finite atmosphere becomes infinite. The non-linear singular integral equation satisfied by N, generalizes the scalar H-equation of Sobolev for the fields in which the state of polarization must be taken into account. This equation is solved by the perturbation method in the form of a Neumann series.

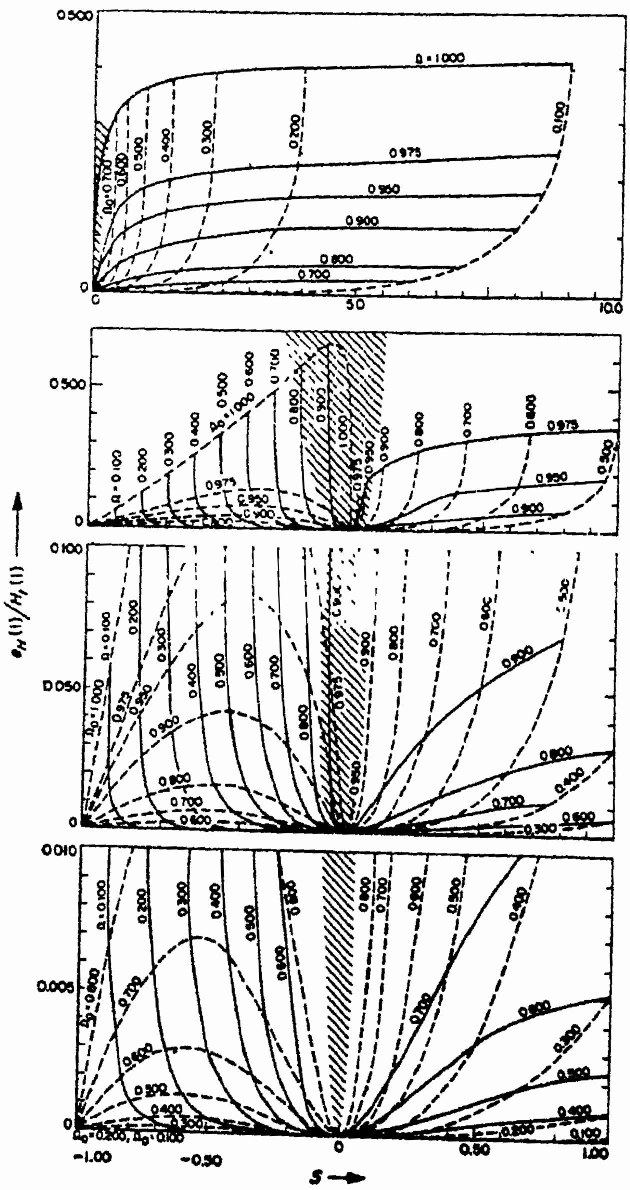

Figure 10. Maximum relative error in $H(\mu)$ as a function of s for various values of Ω_0 (dashed) and of $\Omega = \Omega_0(1+s)$ (solid curves). H attached areas,, regions where the linear solution is not convergence (note the different scale of abscissae in the top diagram).

Abhyankar has studied the scattering of visible radiation around the spherical atmosphere of venus and concluded that the main contribution to be observed, is that the brightness of venus at inferior conjunction comes from matter which scatters one order of magnitude more efficiently in the forward direction than a Rayleigh scatterer. By considering the variation of extinction coefficients with wavelength and variation of efficiency factor with colour, he concluded that these particles could be water particles [26].

His collaboration with one of his students R. K. Bhatia on planetary atmospheres produced many interesting results [64, 69, 77, 78, 79, 80, 83, 88, 89]. It would be difficult to narrate all these results here. The interested reader is referred to the original papers for details. They calculated the absorption and polarization line profiles and the curves of growth in the integrated light of a planet over a large range of phase angles assuming a semi-infinite atmosphere with Rayleigh phase matrix (see figures 11 and 12).

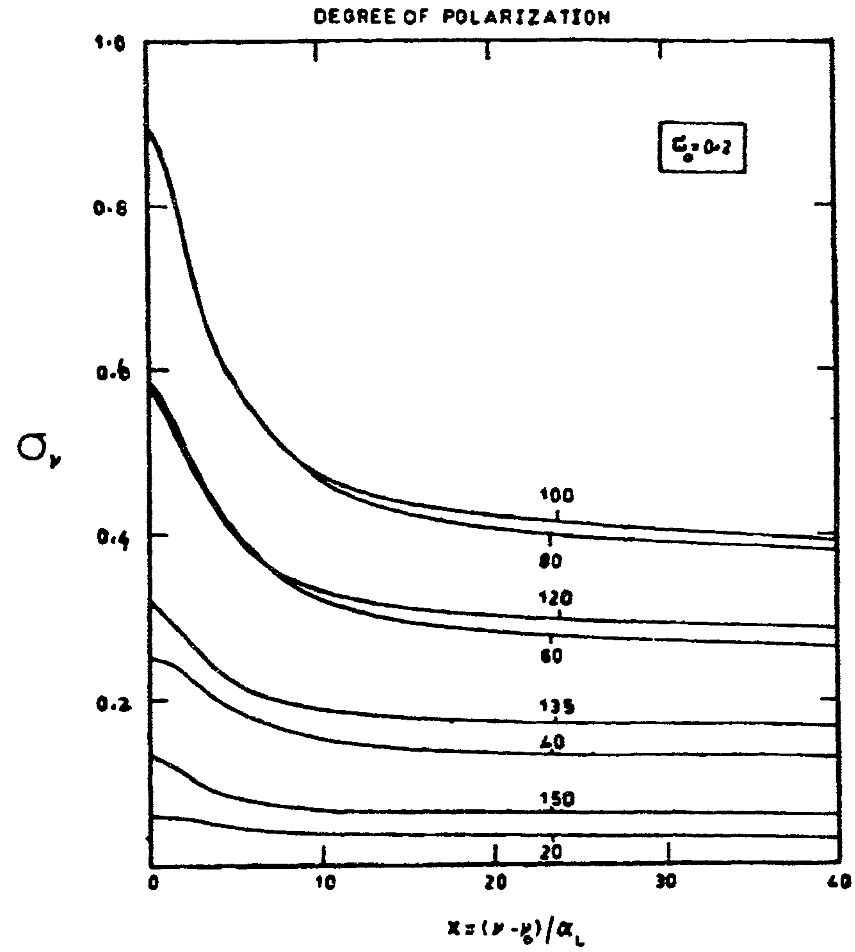

Figure 11. Polarization line profiles at different angles ($\tilde{\omega}_0 = 0.2$).

Abhyankar is an example of determination and commitment and a paragon of scientific virtue. He maintains scientifically inclined relationship with his colleagues, and others who are known to him through scientific research. He is uniformly warm towards all his students.

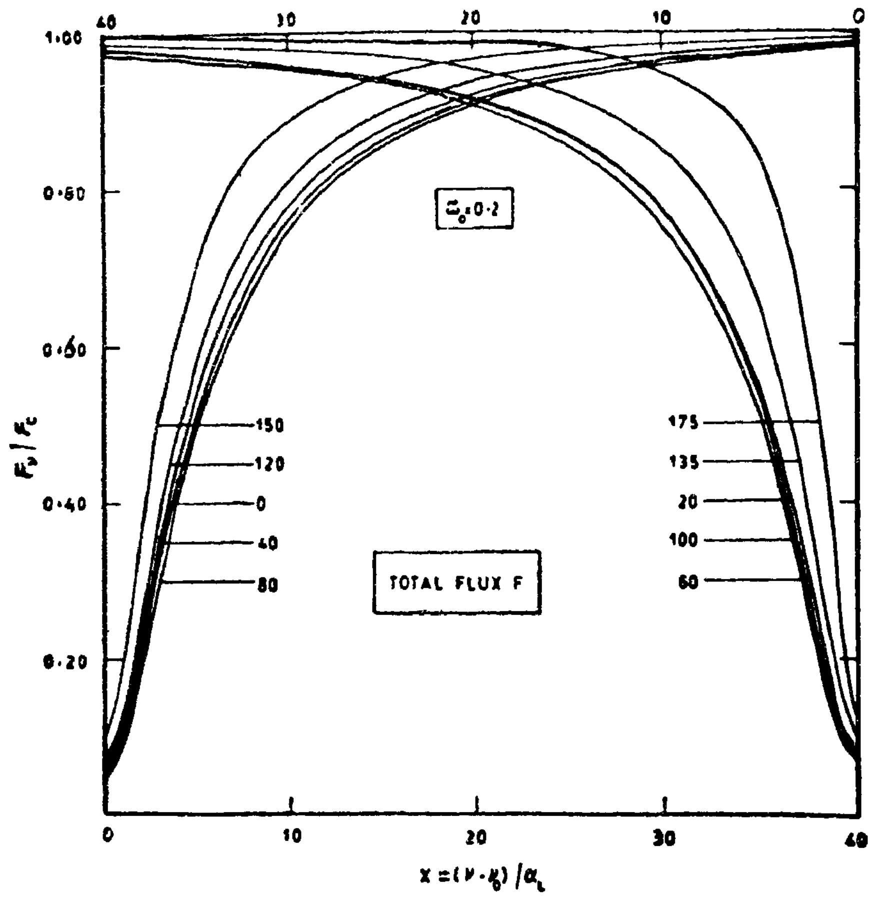

Figure 12. Line profiles for the total flux F in the case of a strong line with $\tilde{\omega}_0 = 0.2$ at different phase angles.

After retirement he has been appointed UGC Emeritus Professor. He is full of ideas and programmes and engaged in research as actively as he was used to earlier. Now that he is free from University administrtive duties, we can expect much more from him in the future.

We all wish a healthy and happy time for Mrs Abhyankar who is always so pleasant to talk to and Professor Abhyankar.

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