

## Physical Sciences



Dr S. K. Saha

**D**r Swapan K. Saha is a scientist at the Indian Institute of Astrophysics, Bangalore, India. After obtaining PhD from the Institute of Radiophysics and Electronics, Calcutta University in 1983, he had focused on the development of optical interferometry and spent a year during 1988-89 at Observatoire de la Cote d'Azur (formerly CERGA), Caussols, France, to study the high angular features of stars, using the long baseline optical interferometer that consists of a pair of 1.5 meter telescopes. He has a strong interest in experimental physics and has developed various equipments. Among others, he has developed the speckle interferometer for the 2.34 meter Vainu Bappu Telescope (VBT), Vainu Bappu Observatory, Kavalur, which is used regularly to study the high resolution features of different types of celestial objects. He is a member of International Astronomical Union, as well as a member of Astronomical Society of India. Dr Saha is also a member of the editorial board of Asian Journal of Physics. At the 91<sup>st</sup> Session of the Indian Science Congress held at Chandigarh, he delivered an invited talk on "Astronomical Imaging by Employing Optical Interferometry: The Future".

**NISCAIR:** *Dr. Saha, modern astronomy embraces a variety of researches; what exactly is your field of research?*

**SWAPAN K. SAHA:** My field of research is 'High angular resolution astronomy in optical wavebands'. Optical interferometry is a powerful tool, which can be employed to achieve such a resolution.

**NISCAIR:** *You have mentioned about speckles in your talk. How are they formed? What is speckle interferometer? In what way is it different from Michelson's interferometer?*

**SKS:** The flat wavefronts from a star reaching the external pupil of a ground-based telescope get corrupted due to the atmospherically induced phase fluctuations. They reach with

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patches of random excursions in phase that are attributed to the refractive index fluctuations created by pockets of inhomogeneities in the atmosphere. An atmospheric optical transfer function is defined in terms of its coherence length. The perturbations in the wavefront produce effects similar to optical aberrations in the telescope. The effective angular resolution of most telescopes, irrespective of their sizes, cannot be better than that of a telescope whose aperture diameter is equal to the coherence length. If the integration time is shorter than the evolution time of the phase inhomogeneities, the interference fringes are preserved, but their phases are randomly distorted. This produces the speckle pattern observed in short-exposure images. Its structure in astronomical images is the result of constructive and destructive bi-dimensional interference between rays coming from different zones of incident wave. Speckle interferometer is a high quality diffraction-limited camera where magnified short-exposure images can be recorded.

Michelson's interferometry is based on amplitude division which measures the temporal coherence. Michelson had installed a 7 m steel beam equipped with 4 flat mirrors to fold the beams in periscopic fashion. Apart from the mechanical instability, this experiment had faced various difficulties, such as the effect of atmospheric turbulence, and variations of refractive index above small sub-apertures of the interferometer causing the interference pattern to move as a whole.

**NISCAIR:** *How are the images obtained by speckle interferometer analyzed? What types of pattern variations are obtained as compared to normal astronomical images?*

**SKS:** The sum of several statistically uncorrelated speckle patterns from a point source can result in a uniform patch of light a few arcseconds wide, which is known as the normal astronomical image or conventional image as we call it, while speckle interferometry estimates the modulus of the Fourier transform from a set of short-exposure specklegrams of the object of interest. A specklegram represents the resultant of diffraction-limited incoherent imaging of the object irradiance convolved with the function representing the combined effects of the turbulent atmosphere and the telescope. After calculating the modulus square followed by averaging over many frames, the object autocorrelation is reconstructed. The transfer function of the atmosphere and the telescope is estimated by calculating Wiener spectrum of the instantaneous intensity from the unresolved star. Reconstruction of object autocorrelation in case of the components in a group of stars retrieves the separation, position angle with a 180 degree ambiguity, and the relative magnitude difference. Post-detection image processing algorithms provide the phase information.

**NISCAIR:** *Can image-processing algorithms be useful in other fields?*

**SKS:** Yes, image-processing algorithms like Monte Carlo system, iterative deconvolution techniques are being employed in bio-medical applications. Re-

sults of imaging through turbid media wherein Jacobian is calculated through perturbation Monte Carlo are also being reported.

**NISCAIR:** *Since the rays/radiation from the stellar objects are affected differently by the turbulence of Earth's atmosphere like wind velocity, irregularities, temperature, humidity etc., can the speckle interferometry be used to study these atmospheric turbulence from the ground, based on the variation of intensity of the radiations received from those objects?*

**SKS:** Yes, the atmospheric coherence length can be determined by speckle interferometry.

**NISCAIR:** *Can this technique be extended to spectroscopic and polarimetric measurements?*

**SKS:** The application of speckle interferometric technique to speckle spectroscopic observations enables one to obtain spectral resolution with high spatial resolution of astronomical objects simultaneously. There was a report on a binary star where the reconstructed spectra revealed that the primary star (Be star) has an HII emission line while the secondary star has an HII absorption line. The high resolution polarimetric studies too have advantages over conventional imaging polarimeter, such as the capability of monitoring the short-time variability of the atmospheric transmission, as well as to get insight into the binary star mechanism. Scientists have found from the polarimetric measurements reconstructed images with 0.11 arcseconds resolution in the HII line, which exhibit a compact structure elongated in agreement with the presence of a circumstellar equatorial disk.

**NISCAIR:** *You have also talked about dark speckles. How are they observed?*

**SKS:** Highly destructive interferences may occur occasionally depicting near black spots in the speckle pattern. This method exploits the light cancellation effect in random field. The observational technique features the combination of both speckle interferometry and adaptive optics (AO) system. It improves the possibility of detecting faint companions of stars.

**NISCAIR:** *What is adaptive optics? How does it help in the observation of stellar objects? Can this system be used in other fields?*

**SKS:** Adaptive optics (AO) system removes the turbulence induced wavefront perturbations in real time by incorporating a controllable phase distortion in the light path, which is opposite to that introduced by the atmosphere. This system allows terrestrial telescopes to achieve their near diffraction-limit and to witness clearly as if they were in space. It is useful for spectroscopic observations, for low light level imaging, as well as for the ground-based long baseline optical interferometry.

Yes, this system can be employed in other branches of physics as well, particularly for bio-medical applications. A camera equipped with adaptive optics allows one to image a microscopic size of single cell in the living human retina.

**NISCAIR:** *What are the other prominent institutes/universities in the country engaged in research in these fields?*

**SKS:** No other institute/university is actively engaged in this type of work at present. Apart from our institute, the Institute for Research and Development Establishment is also developing the AO system for a different purpose.

**NISCAIR:** *Can two or more telescopes be arranged/connected in optical interferometry? If yes, do they take observations separately or in-combination simultaneously?*

**SKS:** The light collected by an array of separated telescopes could be coherently combined. Each pair of telescopes in the array yields a measure of the amplitude of the spatial coherence function of the object at a spatial frequency. Antoine Labeyrie, a pioneer and a discoverer of speckle interferometry, had developed this technique by using a pair of independent telescopes that are run on tracks for variable North-South baseline. It combines the features of the Michelson design and the radio interferometers. These telescopes track simultaneously the same source (star) and send the collected light to the central laboratory where the star images are superposed at the foci in order to produce Young's fringes. The beams from these telescopes are recombined in an image plane after reconfiguring the pupils. Fringed speckles are visualized when a speckle from one telescope is merged with the speckle from the other telescope. These fringed speckles are dispersed and the spectra are recorded at short-exposure using a photon counting detector. At present, several such interferometers using two or more telescopes are in operation. In some cases, large telescopes are being used.

**NISCAIR:** *Are these optical instruments used for ground-based observations or space-based observations?*

**SKS:** These optical instruments are ground-based. NASA is planning to launch 'Space Interferometry Mission' by 2009.

**NISCAIR:** *If it is ground-based, then how do you filter out the atmospheric effects (such as refractions, reflections, etc.) that deviate the rays emitted by a distant object in the sky in optical wavelength or in infrared wavelength?*

**SKS:** Due to operation at atmospheric pressure, different chromatic dispersions between the two beams occur. This effect is compensated by using, for each beam, two prisms which can slide on their hypotenuse, forming, therefore, a plate with adjustable thickness. This thickness is modified every few minutes, following the variation of the altitude of the observed object.

**NISCAIR:** *Can X-ray or gamma-ray spectroscopic measurement be possible with this technique?*

**SKS:** May be in space, it may become feasible.

**NISCAIR:** *In case of space-based observation, since atmospheric constituents are negligible, what is the need to go for this technique?*

**SKS:** Since the effect of atmosphere is negligible in space, the advantage of using long baseline interferometry in outer space is the ability to observe at any wavelength, and for long periods.

**NISCAIR:** *You have mentioned that with this technique, origin of galaxies and universe, i.e., the stellar systems can be understood in a better way. How?*

**SKS:** The new interferometers with phased arrays of multiple of 8-10 m sub-apertures provide larger collecting areas and higher spatial resolution simultaneously. These instruments fitted with complete AO systems would be able to provide imaging and morphological information on the faint extragalactic sources, such as galactic centers in the young universe, deep fields, and host galaxies. Measurement of such objects may be made feasible by the instruments with a fairly complete  $(u, v)$  coverage and large field of view.

**NISCAIR:** *What is the Keck interferometer that you have talked about?*

**SKS:** Keck interferometer is of heterogeneous type comprising two large telescopes (10 m each) and four 1.8 m 'outrigger' telescopes. A problem arises from the recombination of one large and one small telescope since the signal-to-noise ratio would be the one given by the smaller one. For imaging the main telescopes are used with outriggers to fill in incomplete parts of the  $(u, v)$  plane. It combines phased pupils provided by adaptive-optics for the main telescopes and fast tip/tilt correction on the outriggers.

**NISCAIR:** *What is new in binocular telescope?*

**SKS:** Most of the interferometers use two apertures and are unable to recover the complex visibility. The binocular telescope also uses two mirrors, but these mirrors are co-mounted on a fully steerable alt-az mounting, thus information in  $(u, v)$  plane can be continuously combined or co-added.

**NISCAIR:** *Has any of the Indian institute/laboratory or university made any breakthrough in ideas and discoveries/inventions that have created an impact recently internationally?*

**SKS:** You mean in the field of optical interferometry? Not yet.

**NISCAIR:** *How optical astronomy, particularly, the interferometry can be used for astro-biological research?*

**SKS:** The knowledge of the chemical composition of any planetary atmosphere provides hints about the likelihood of finding carbon-based life. A large space-based interferometer with four or more 25 m telescopes and a large spectrometer

may be able to detect an exo-planet lines of gases directly produced by biochemical activity.

**NISCAIR:** *Can extra-solar planetary measurements like those of atmospheric constituents of the earth be made with this technique?*

**SKS:** With the present day technology, it is not possible to measure such extra-solar planetary constituents.

**NISCAIR:** *Can black holes in the galaxies be detected with this?*

**SKS:** It is a distant dream.

**NISCAIR:** *In this field of optical sciences or optical astronomy, how aggressive should the research be?*

**SKS:** It is worth trying to develop binocular telescope interferometry in India.

**NISCAIR:** *Is there any industry which has come forward to utilize this research output?*

**SKS:** Unfortunately no business is tied up with this research in India. No industry has come forward to utilize this output either.

**NISCAIR:** *What is the status of research in optical science and technology in India? In what way can it help India to be in the forefront of research at international level?*

**SKS:** As far as developing optical science is concerned, we are lagging behind by two decades or so. India has an outstanding group in the field of radio astronomy using long baseline interferometry. We should take an initiative towards developing long baseline optical interferometry as well.

[Dr Swapan K. Saha was interviewed by Dr N. C. Mondal]