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OBITUARY

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Professor Mukul Ranjan Kundu, a member of the Editorial Board of *Solar Physics*, died in Colesville, Maryland, on 16 June 2010 at the age of 80 from injuries suffered in an automobile accident. He was known around the world for his pioneering research in solar radio astronomy and was regarded as one of the founding fathers of the field. In 2007, he was awarded the Hale Prize by the Solar Physics Division of the American Astronomical Society for his fundamental contributions to solar radio astronomy. For several years he served as Director of the (then) Astronomy Program of the University of Maryland, as well as on many advisory bodies.

Mukul was born in Calcutta, India on 10 February 1930. In 1949 he received his Bachelor of Science degree in Physics from the University of Calcutta, followed by a Master's degree in Radio Physics and Electronics in 1951. In 1954 he was awarded a French government scholarship and began his close connection with French radio astronomy, first at the École Normale Supérieure in Paris and then with Paris Observatory when the radio group was transferred there. He worked on solar radio astronomy as his Ph.D. thesis topic. He was awarded the degree of *Docteur ès Sciences Physiques* at the Sorbonne in 1957. Then he worked at the University of Michigan (1959 – 1962), and as an Associate Professor at Cornell University (1962 – 1965). In 1965, Mukul returned to India to join the Tata Institute of Fundamental Research. In 1968 he joined the Astronomy Program of the University of Maryland as a full Professor. College Park remained his home until his death.

Mukul's first major scientific achievement was the demonstration of the existence of a close correlation between the solar radio flux at a wavelength of 10.7 cm and the level of ionization of the Earth's ionospheric E-layer. Mukul realized that the 10.7 cm flux was free – free emission from the coronal plasma while the E-layer ionization was due to 10 – 100 Å

ionizing photons from essentially the same material. The 10.7 cm radio flux remains one of the primary diagnostics of solar activity and its influence on the Earth, and one of the most widely-used measures for space weather.

Mukul's thesis work (published in *Annales d'Astrophysique* in 1959, in French) was supervised by J.-F. Denisse and J.-L. Steinberg. Mukul belonged to the pioneering group building the first instruments at the newly established Nançay Radio-Astronomy Station. He constructed a two-element interferometer that was the first such instrument to use Earth-rotation synthesis (*i.e.* using the Earth's rotation to make a sparse array of telescopes look like a filled array) for solar work. Mukul used his telescope to study the properties of the "slowly varying" (timescale of hours to days) component of the Sun's radio emission at a wavelength of 3 cm. He showed that the radio sources exhibited a core – halo structure, *i.e.* they consisted of a narrow, bright, circularly polarized region and of a broader, more diffuse, unpolarized region. The bright cores were associated with sunspots while the large diffuse component corresponded to plage. The observed coronal temperatures of the bright-core sources led subsequently to the conclusion that their opacity was due to the gyro-resonance mechanism in the presence of strong magnetic fields in the corona. This realization provided a powerful tool that is still the best available method for measuring coronal magnetic-field strengths. During the same period, Mukul made a systematic study of the microwave emission of solar flares and proposed a non-thermal origin for impulsive bursts. In 1959, he identified another type of complex broad-band microwave outburst characterized by high intensity and long duration: this was the high-frequency counterpart of the type IV phenomenon identified at metric wavelengths by Boischot and Denisse in 1957. Mukul's contribution to the early development of the Nançay Station was widely recognized among French radio astronomers. For the 50-year anniversary of the Nançay Station in 2002, he was the only foreign colleague invited to the celebration.

From the beginning of his career, Mukul realized that an in-depth understanding of solar phenomena required the joint use of data obtained in different spectral domains. This approach led him to significant discoveries such as the recognition (in collaboration with Kees de Jager) of the close association between microwave and hard X-ray bursts from solar flares. In 1965, Mukul's book "Solar Radio Astronomy" was published. This book has served as an introduction to solar radio astronomy for generations of astronomers and has had a lasting influence; it remains even today a landmark reference work.

Mukul was always particularly eager to try new radio instruments to observe the Sun, even if they had not been constructed for this purpose. Thanks to this approach, several modern large instruments have a solar observing mode. Starting from the late 1960s he used the Kitt Peak 36-foot radio telescope to study the quiet-Sun brightness distribution at millimeter wavelengths. In the early 1970s he used the Green Bank three-element interferometer to observe the Sun at wavelengths of 3.7 and 11 cm and studied the variability of the quiet-Sun radio emission and the properties of radio bursts. In the 1970s the Westerbork Synthesis Radio Telescope was the first large radio array to be built, and Mukul was the first solar radio astronomer to use it. With it, he studied coronal magnetic fields and flares at 6-cm wavelength with unprecedented spatial resolution and sensitivity. In the late 1970s the Very Large Array in New Mexico became operational and Mukul played an important role in ensuring that it was capable of observing the Sun. He was one of the first to use it for solar observations, carrying out numerous studies of active regions and flares.

Bill Erickson and Mukul together were the driving forces for the operation by the University of Maryland of the Clarke Lake Radio Observatory from the early 1970s to the late 1980s, and during this period it was the premier low-frequency radio telescope in the world. With it, Mukul studied the metric radio emission of the Sun in unprecedented detail

and made important discoveries regarding CMEs, fast shocks in the solar atmosphere, and type-III-burst-emitting electron beams. When Clark Lake was closed and the emphasis at Maryland shifted to interferometry at millimeter wavelengths, Mukul initiated the use of the Berkeley-Illinois-Maryland Array for imaging of solar flares at high radio frequencies; his studies revealed that electron acceleration to MeV energies is common to most flares, no matter how small.

In recent years, Mukul was one of the most frequent users of the Japanese Nobeyama Radioheliograph and the French Nançay Radioheliograph. Some of the achievements, which came out of his studies from these data, include the detection of non-thermal emission from weak, transient solar activity, the study of the structure of spiky microwave/millimetric bursts, and of the radio properties of coronal holes.

Last but not least, Mukul throughout his career made important contributions to non-solar radio astronomy. On first arriving at Maryland he worked extensively on supernova remnants, and over the subsequent years he also worked on pulsars, Jupiter's radio emission, and flare stars. This work and the solar research involved a large number of graduate students and post-docs who went on to have very successful careers.

Mukul never stopped his research work, not even after his official retirement from the University of Maryland or major back surgery carried out in 2009. He kept in close contact with and liked to visit colleagues not only in the US, but also in India, Russia, Europe, and Japan. On the day that he died he was working on a proposal for future studies with the Nobeyama Radioheliograph. At the University of Maryland, Mukul built a strong research group. He was a teacher, mentor, colleague, research organizer, and a good friend. He was quick in identifying the right track to proceed in the most complex problems. He knew every detail of the work that others had done before and never missed any recent development. Above all, Mukul had a remarkable capability to perceive the physics behind the phenomena, which he tried to pass on to his students. He knew probably everybody in the solar and radio community worldwide, and everybody knew him. Everybody felt a great respect for Mukul and the pleasure of communication and collaboration with him. Mukul enjoyed these interactions enormously and his hearty laugh was a characteristic feature of any social occasion.

It is hard to imagine the solar radio physics community without Mukul. However, although Mukul is no longer among us, his accomplishments are a cornerstone in the edifice of modern solar physics. Mukul's accomplishments were not only much above those of an ordinary person, but also well above those of many extraordinary people. Mukul is survived by his wife Ranu and their children Krishna, Rina, and Sanjit.

C.E. Alissandrakis
V.V. Grechnev
A. Nindos
M. Pick
S.M. White