Frank H. Shu

Frank H. Shu (University Professor Emeritus, University of California (UC), Berkeley, USA) is one of the world's leading authorities in theoretical astrophysics and star formation. He has made contributions that have brought about paradigm shift in the understanding of how stars and spiral galaxies form. His pioneering work on the origins of stars over a span of 30 years has generated a comprehensive and widely accepted theory that explains the main events in the birth and evolution of a star. His textbook, *The Physical Universe: An Introduction to Astronomy*, has been widely used by both undergraduate and graduate students for 30 years.

Shu was born in Kunming, China and came to the United States at the age of six. He received his B S in Physics at MIT and his Ph D in astronomy at Harvard University. After a 5-year stint at the State University of New York, Stony Brook, he joined the faculty of UC at Berkeley, and served as Chair of the Astronomy Department from 1984 to 1988. He was appointed as University Professor in 1998, an honour bestowed on only 35 faculty members in the UC system since its founding. From 2002 to 2006, Shu served as the President of National Tsing Hua University in Taiwan. He then joined the faculty of the Physics Department at UC San Diego. In 2009, he retired as University Professor.

From 2009 to 2015, Shu devoted all his efforts at Academia Sinica and at the Industrial Technology Research Institute (ITRI), Taiwan to developing alternative sources of energy to replace the burning of fossil fuels in response to the growing crisis of global climate change. In his personal research on molten salt technology with applications to nuclear energy, biofuels and municipal waste management, he has active collaborations with academic research groups at UC Berkeley, the University of Michigan, Ohio State University and City University of Hong Kong. In 2016, Shu formed a company, Astron Solutions Corporation to bring the inventions of his research group in molten salt technology to industrial scale to help mitigate the problems due to climate change.

Shu visited India in December 2017 as the Academy–Springer Nature Chair Professor. In a one-on-one interview held at the Indian Academy of Sciences, Bengaluru, he addressed the following questions that were posed to him.

What motivated you to pursue astrophysics in the first place?

Many astronomers began as amateurs being interested in the sky. But I came into it somewhat by accident. I was a physics major and landed in a summer job with Chia-Chiao Lin at MIT. Lin suggested that I take the course on galactic structures conducted by Lodewijk Woltjer, a distinguished astronomer from the Netherlands who was visiting then. As I began working with Lin, it became clear that traditions in astrophysics were quite different from those of physics. The questions posed by astronomy are enduring and what appealed to me was the fact that, the more we learnt, the more we wanted to know. Moreover, in a way the physics problems presented in undergraduate classes had less appeal.

At present, you work in the area of climate change and sustainability. What got you interested in this field?

Through science and technology (S&T), people have gained enough power to change the environment at an unsustainable pace. Like many scientists, I believed that this is a solvable scientific problem. As I grew older, I realized that the problem was not being solved because it was embroiled with ideology or politics, and was no longer being approached as a scientific problem. Initially, I began by giving lectures in order to educate people. The global CO_2 concentration currently stands at 407 ppm and is expected to reach an unsafe level at 450 ppm. With CO_2 increasing by 2.2 parts per million every year, we are likely to reach the unsafe level in about 22 years. Hence, children born today are likely to face a dangerous situation by the time they graduate, and this is a bleak story to tell. People are willing to do something about it, but not at the expense of breaking the expectation of a better life that S&T has brought to the world. At one point, I realized that I have the technical expertise to do more than to just advice people. I hope to bring technologies that tell a different and happier story. It is time for us to create a transparent process and bring these new ideas to the public, who actually need to support in a constructive way. The whole world has to agree on a plan to be carried forward.

What learning from astrophysics do you carry into the area of climate change and sustainability?

Let me give examples of other scientists to indicate why astrophysicists have a unique perspective to offer to this problem. The most famous climate scientist in the world is an astrophysicist named James Hansen. His early research on the clouds of Venus helped identify their composition as sulphuric acid. He later focused his research on earth's climate, especially human-made climate change. He is known for his testimony on climate change to congressional committees in the 1980s that helped raise broad awareness of the global warming issue. Hence, it was an astrophysicist who first called attention to the issue.

The runaway greenhouse effect experienced by Venus 3–4 billion years ago, the reverse greenhouse effect/runaway refrigerator theory of Mars and earth's CO_2 cycle existing in balance between the two extremes of Venus and Mars are well understood by astronomers. Why does the earth have fossil fuels and what events in earth's history created them? Other than a geologist, a good person to answer this question is someone who is more broadly trained than a geologist, like a planetary astronomer. Astronomers also understand how energy is produced and used in the universe, and can take a broad perspective on the same.

As a single discipline, astronomy is perhaps the most interdisciplinary of all sciences. Astronomers study life, chemical processes, physical processes, thermodynamic processes and so on – though not as deeply as a specialist would. In their training they have an interdisciplinary approach to a problem. Hence I believe astronomers are well qualified to work in this field. Since they are well qualified, they have a duty to come forward with good solutions to problems.

In the same context, what do you think is the future of nuclear energy, particularly with respect to thorium?

With a world population of 7.5 billion, we are at a stage in human civilization where we are fast using up our limited energy resources. We continue to burn fossil fuels despite being aware of the side effects of releasing CO_2. However, I do support the growth in aspirations of many parts of the world where people realize that, potentially, they have not received their fair share yet. Developed countries do have a duty to help countries such as India, China, etc.

One has learnt that energy has a hierarchy. The obvious answer is that we must go to the next hierarchy. From astronomy we know what that hierarchy is, and what the possible sources of energy are. Astronomy is largely about energy transformation, i.e. how energy is used to transform matter from one state to another. Hence, it is nuclear energy that is the next higher power. Thorium and uranium are both sources of nuclear energy. However, there is not enough uranium in India to address the problem. Indian scientists like Homi Bhabha explained this concept more than 50 years ago and showed the path. So I am here to talk to Indian scientists and let them know that I agree with their assessment and that I think there is a path forward that we can accelerate.

Your group has developed a synthetic coal, biochar. How did you conceive it and how was it implemented?

We decided to look at the problem of using current biomass and reproducing what the earth has already done. The earth has coal and we can determine when it was formed by radioactively dating the major coal fields of the earth. Most coal was formed approximately 300 million years ago from the remains of trees and other vegetation. The remains of dead trees fell into swamps and were buried in an environment that lacked oxygen. Hence they did not decay. They were pressed into the earth with the temperature increasing by 25°C for every kilometre depth. At 7–8 km below the ground, the temperature is around 200°C. From laboratory experiments we know that biomass carbonizes at 200°C and turns into coal.

Carbonizing biomass is an old technology. The new patented technology provides a way to do it fast and in large quantities, which is the need of the hour. On submerging the biomass into the weakest molten salt, the entire process to obtain the equivalent of coal takes around 10 min. If we raise the temperature to 450°C, the entire process takes around 1 min. The quantity of biochar that can be produced depends on the size of the container. We are able to produce activated carbon with a surface area 530 m^2/g. This is quite close to the 560–570 m^2/g value obtained from a speciality.

Biochar is a perfect replacement to the fossil fuel industry and is a first step in that direction since burning biochar is much cleaner than burning coal. However, not burning it is even better since it results in negative carbon. Though not of very high grade, biochar produced using this technology can be added to soil for agriculture. It can filter water, smooth-out water usage in agricultural land, provide space for beneficial soil microorganisms and improve soil carbon. Also, biochar produced using this technology and available at grocery stores in California is expensive. We are looking to reduce the price by a factor of 15 to make it more affordable to farmers in the US.

S. Priya (*S. Ramaseshan Fellow*), Current Science Association, Bengaluru 560 080, India.
e-mail: priya@ias.ac.in