Japan Academy Prize to:

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for “Accelerating Expansion Model
in the Early Universe”

Outline of the work:

The standard model of the big-bang universe is based on the basic assumption that the universe began as a high-temperature fireball, and stars and galaxies formed as the universe expanded and cooled down gradually. In 1981, Dr. Katsuhiko Sato proposed a scenario in which the universe experienced accelerating expansion in the very early epoch and produced a high-temperature fireball after that rapid expansion. This scenario is now known as the “inflation universe model.” The term “inflation” was coined by Dr. Alan Guth, who proposed the same scenario independently but submitted a paper on it a half year after Dr. Sato’s paper.

Since late 1970’s, Dr. Sato has been working on an early universe model based on the grand unified theories of elementary particles. While doing so, he realized that these theories predict the presence of large vacuum energy, which eventually led him to propose the above-mentioned accelerating universe scenario. He pointed out two important consequences of the scenario: (1) At the end of the accelerating expansion phase, vacuum energy was released through a phase transition of the vacuum, causing the universe to become a hot fireball as the standard big-bang model assumes. And (2), the accelerating expansion significantly increased the spatial volume of the causally related spatial region (cosmic horizon), which naturally accounts for the isotropy of the cosmic microwave background.

Dr. Sato also showed this accelerating universe scenario to elucidate two long-standing problems unsolved in cosmology at that time. First, the scenario accounts for the origin of the large-scale structure of the universe through density fluctuations caused by phase transition of the vacuum. This concept has been elaborated through subsequent investigations: The seed of these density fluctuations was shown to be generated by a quantum process in the accelerating expansion phase. Indeed, the predicted feature of the fluctuation spectrum was confirmed by the cosmic microwave background space-mission COBE, launched by NASA in 1992.

Second, the scenario solved the magnetic monopole problem that had been considered to pose a serious contradiction between the standard big-bang universe and the grand unified theories of elementary particles. While the grand unified theories inevitably predict a high abundance of magnetic monopoles, none of them has been observed. This contradiction is easily reconciled by the fact that accelerating expansion of the universe significantly decreased the number density of the magnetic monopoles to the point that their expectation value within the observable universe is much smaller than unity.

As mentioned above, Dr. Sato solved two problems that could not be explained by any conventional big bang theory: Why the universe started as a fire-ball and what the origin is of the large-scale structure of the universe.

Furthermore, his inflation scenario implies that the curvature of the universe becomes negligibly small; namely, that the universe becomes spatially flat and globally isotropic. This prediction was also confirmed in 2003 by a combined analyses of various cosmological data, particularly those from the cosmic microwave background space-mission WMAP. Therefore, the inflation scenario is regarded as a remarkable theoretical model strongly favored in all recent cosmological observations.

In addition, Dr. Sato and his collaborators found that the inflation scenario naturally yields child universes, grandchild universes, and so on. This idea of multi-produced universes has a very important implication in the concept of the universe itself, and is closely related to the notion of multiverse.

Another of Dr. Sato's important contributions to cosmology is his establishment of a methodology to exploit the universe as a laboratory for particle physics. Dr. Sato and his collaborators developed methods for imposing constraints on the mass and lifetime of weakly interacting particles from cosmology and astrophysics. Dr. Sato showed that stringent constraints are imposed on τ neutrinos from cosmology and stellar physics, just after the discovery of τ neutrinos. At present, Dr. Sato's methods are widely employed when obtaining constraints on the mass and lifetime of hypothetical particles predicted by new theories.

In sum, Dr. Sato's inflationary scenario is now widely accepted as a standard model of the origin and evolution of the universe, and his original idea of an accelerating expansion model is highly appraised within the world-wide academic community.

Relevant publications

K. Sato, First Order Phase Transition of a Vacuum and the Expansion of the Universe, *Mon. Not. Roy. Astr. Soc.* (1981), **195**, 467–479.

K. Sato, Cosmological Baryon-Number Domain Structure and the First Order Phase Transition of a Vacuum, *Phys. Lett.* (1981), **99B**, 66–70.

M.B. Einhorn and K. Sato, Monopole Production in the Very Early Universe in a First-Order Phase Transition, *Nucl. Phys.* (1981), **B180**, 385–404.

K. Sato, H. Kodama, M. Sasaki and K. Maeda, Multi-Production of Universes by First-Order Phase Transition of a Vacuum, *Phys. Lett.* (1982), **108B**, 103–107.

K. Sato and M. Kobayashi, Cosmological Constraints on the Mass and the Number of Heavy Lepton Neutrinos, *Prog. Theor. Phys.* (1977), **58**, 1775–1789.