Editor's Note: On the Stability of Cosmological Models

by N. R. Sen, *Zeitschrift für Astrophysik* **9 (1934),** 215-224

The main message of Sen's paper is that the isotropic and homogeneous models of Einstein and of Friedmann (the latter with positive spatial curvature) are "unstable for initial rarefaction". The author came to this conclusion by investigating a perturbation of the velocity field in the homogeneous models while keeping the density distribution initially unperturbed (this is a description in today's terms; the author's own terminology is in places somewhat difficult to follow). To describe the perturbed models, Sen used the solution of Lemaître [1], and the problem was dual to that considered by Tolman [2] (unperturbed velocity field with initial density perturbations). Two features of the paper make it remarkable:

(i) The application of an exact solution of Einstein's equations, by an exact calculation, to a real astrophysical problem (even some very modern textbooks on relativity like to imply that such a task is impossible).

(ii) A near-prediction of an effect that was indeed observed, but more than 40 years later. From today's perspective it does not seem to be a great leap of imagination to reason as follows: the Friedmann models are believed to be *the* models of our Universe, and at least one of them (the one with $k > 0$) is unstable for rarefaction, hence rarefactions (today called voids) may be expected to form.

Unfortunately, nobody ever came to such a conclusion. The voids were first observed in late 1970s, and modelled theoretically only later (see Refs. 3, 4 and a summary in Ref. 5). The descriptions by Occhionero *et al.* [3] and by Sato *et al.* (Ref. 4 is a summary of a larger project) are based on the same Lemaître–Tolman (LT) model [1] that was used by Sen and by Tolman, and are sophisticated advancements of basically the same method.

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One more result of Sen's is noteworthy: that a rarefied region in the Lemaître–Tolman model expands faster than an unperturbed Friedmann region of the same initial density (this is Sen's "minimum property of Friedmann space"). This fits in well with Sato's later finding [4] that if a void is described by a Friedmann model connected by an LT transition region to another Friedmann model of higher density, then the void's edge expands faster than the neighbouring particles of the cosmic medium.

In a follow-up paper [6] Sen investigated the influence of pressure on stability, and the result was: stability may be restored or instability enhanced, depending on the spatial distribution of pressure.

— *Andrzej Krasiński, Associate Editor*

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Sen: a brief biography

N. R. Sen was born May 23, 1894 in Dhaka (the present capital of Bangladesh). He received his D. Sc. degree in 1921 at the University of Calcutta. He was initiated in research in general relativity by Max von Laue in Germany. He was professor of applied mathematics at the Calcutta University (1924–59), Fellow of the Indian National Science Academy and President of the Mathematics Section of the Indian Science Congress (1936). His research interests spread over relativity, and relativistic cosmology, astrophysics, quantum mechanics, fluid dynamics including magnetohydrodynamics, and he was a pioneer in India regarding work on stellar models based on the laws of thermonuclear energy generation and on isotropic turbulence and shock waves.

He died on January 13, 1963 in Calcutta.

— *A. K. Raychaudhuri*

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