Astrophysics

Peter L. Biermann

published in

NIC Symposium 2001, Proceedings,
Horst Rollnik, Dietrich Wolf (Editors),
John von Neumann Institute for Computing, Jülich,
NIC Series, Vol. **9**, ISBN 3-00-009055-X, pp. 25-26, 2002.

© 2002 by John von Neumann Institute for Computing
Permission to make digital or hard copies of portions of this work for personal or classroom use is granted provided that the copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise requires prior specific permission by the publisher mentioned above.

http://www.fz-juelich.de/nic-series/volume9

Astrophysics

Peter L. Biermann

Max-Planck-Institut für Radioastronomie, 53010 Bonn, Germany
Department for Physics and Astronomy, University of Bonn, Germany

The detection of the first three waves in the spatial fluctuation spectrum of the cosmic microwave background has allowed us to determine the parameters of any given cosmological model with very high accuracy; already the data analysis requires supercomputers. The modelling of the early phases of the universe, with structure formation, the development of the first galaxies, as well as the first black holes also require the highest level of numerical sophistication and the largest computers. As a result we know today the parameters of today's standard concept for the cosmology of our universe, like the Λ-parameter often referred to as dark energy, the dark matter content, and the baryonic matter content with great accuracy - and yet we do not even come close to a physical understanding: It is generally hoped that particle physics, in this case a cosmic particle physics will provide testable predictions, where the entire universe will disprove or prove a future physical deep understanding as yet eluding us. Two key aspect of young galaxy evolution serve here as examples for the development of our approach to the physics of the early universe: First, the interaction of black holes and the surrounding stars in the cores of galaxies can serve as a testbed for our growing awareness and physical understanding of the environments of the ubiquitous black holes in the centers of galaxies; and second, the probable surviving building blocks for galaxy evolution, dwarf galaxies, their evolution of the stellar population as well as the hot and cold gas content with their chemical abundance distribution is the other example. Both require hierarchical numerical codes used on supercomputers, and in both cases the modelling can be compared in rather great detail with observations at many wavelengths, from the radio to TeV gamma rays across the entire electromagnetic spectrum. It can be expected that the detailed interaction between technological development, observations with the newly developed instruments, and supercomputers modelling together with analytic phenomenological reasoning will lead us further to a much deeper understanding of the world around us.

The very rapid development of new highly sensitive detectors to measure the spatial fluctuations of the cosmic microwave background has advanced a great deal in 2001, with the simultaneous publication of the first three overtones or wave amplitude peaks, by three experiments at the same time; two of these experiments were balloon borne instruments. Here the advance in balloon technology simultaneous with the rapidly improving detector sensitivity was key. The results were outstanding: Using supercomputers it has been possible to test quantitatively the predictions of the standard model of the structure of our universe, and determine the numerical values of a great many parameters simultaneously: We now know that the universe not only contains baryonic matter like stars, gases and people; there is amost an order of magnitude more baryonic matter hidden in black stars or invisible matter - the suggestions have ranged recently from a very large number of white dwarfs to a rather warm gas component, unobservable due to the ultraviolet absorption in interstellar space. Next we know that the universe contains dark matter of a very different form, matter that is clumping and provides the basic gravitational field structure in the universe, usually called “cold dark matter”. And then, using presumed standard candles like supernovae of type Ia, we can find at once that the universe apparently manifests a flat geometry, but also contains “dark energy”, accelerating the universe’s expansion. Here we require supercomputers to model the structure formation, the soap-bubble like web of the universe, visible today both in the galaxy distribution, and also in the radio emission from relativistic electrons. The discovery of the missing solar neutrinos by the Sudbury Mine experiment has clinched the case built from the atmospheric neutrinos observed by the Super-K experiment, suggestimg that the neutrino mass is finite, but that at the same time neutrinos almost certainly do not provide the key ingredient of dark matter.

Apart from pushing ever deeper into measuring ever smaller amplitues and shorter spatial waves in the cosmic microwave background, determining its polarization hopefully soon, we can also focus in towards the building blocks of our optically visible universe, the galaxies and their centers. The two lectures, by Rainer Spurzem and by Gerhard Hensler, are thus examples of this pioneering work.

The centers of galaxies like our own almost always show evidence for the presence of a massive black hole, with a mass of order $2.5\ 10^6$ solar masses in the case of our own Milky Way, up to $3\,10^9$ solar masses in a small number of cases in our cosmic neighborhood, such as in the galaxy M87 in the nearest large cluster of galaxies, the Virgo cluster. As galaxies often merge during their evolution, and so two black holes are expected to spiral in towards each other, strongly modifying the stellar distribution. The gravitational interaction between the stars around the black hole with the black hole itself, the interaction with a second black hole from a nearby galaxy is a great test for our understanding. The resulting cusps in the stellar distribution are observable, and so may turn into tell-tale signs after a detailed numerical exploration of the gravitational interaction of the one or two black holes, their surrounding stars, and quite possibly the distribution of dark matter particles, whatever they may be, with the lightest supersymmetric particle one often favored example.

As a corollary we note that the final stage of two black holes spiralling in towards each other should result in a burst of gravitational waves - not yet observed; observations are planned to begin in 2002.

In the same vein, large galaxies are believed to develop from many mergers, and so it is hoped, that dwarf galaxies may be the purest form of a simple galaxy. Dwarf galaxies should tell us the most about early galaxies, their dark matter distribution, the exchange between hot and cold gas, the gaseous mass loss from a galaxy, and infall, the energy input from supernovae and stellar winds from massive stars, stellar mass loss and star formation out of cold gas, and the slow and fast build-up of the chemical elements. These cycles of activity form also the conceptual building blocks for larger galaxies, when mergers and interaction with the environment may play a bigger and thus complicating role. The early environment around galaxies should be reflected in properties of dwarf galaxies, and so they may help us understand when and how galaxies first formed. Numerical modelling is required to advance our understanding of all these physical processes, and helps us to comprehend which physical concepts are key.

These are just two examples out of the important numerical work being done on supercomputers today; they play an increasingly important role in the advance of knowledge about the universe around us.