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Cosmology

Matters of moderate gravity

from Virginia Trimble

GRAVITATION, while by far the weakest of the four traditional forces, nevertheless nearly always dominates in systems of sufficiently large scale. As a result, there are interesting problems in which general relativity (GR) introduces only small perturbations (bending of light rays by the Sun, for instance), others in which it is the only physics that need be considered (for example generation of gravitational radiation by colliding black holes), and even a few in which it interacts as an equal partner with other parts of physics (nucleosynthesis in the early Universe, for example). GR10 — the 10th International Conference on General Relativity and Gravitation — recorded progress in problems belonging to all three classes*.

In the perturbation regime, R. Hellings (Jet Propulsion Laboratory) reported new analyses of Mercury and Mars radar-ranging data that lead to remarkably tight upper limits on deviations from the predictions of GR. The three post-newtonian parameters $\beta-1$, $\gamma-1$ and α_1 (all zero in GR but not in some other theories)[1] are at most -2.9 ± 3.1, -0.7 ± 1.7 and $0.21\pm0.19\times10^{-3}$ respectively; the rate of change of the gravitational constant, $\dot{G}/G$, is at most $0.2 \pm 0.4\times10^{-11}$ yr^{-1}; and J_2, the quadrupole moment of the Sun (which affects the orbit of Mercury like deviations from newtonian gravity[2]) is $-1.4 \pm 1.5\times10^{-6}$, consistent with the requirements of GR but not with those of competing theories. No additional data of comparable quality can be expected for many years as the Mars Viking lander is now dead.

In the strong-field regime, three long-standing problems have been resolved. The positive energy conjecture has, it appears, been proven to the satisfaction of most workers in the field. That is, we can say that the total energy of a general relativistic system can never become negative, a vital condition for stability of the theory (talks by E. Witten, G. Horowitz and M. Perry, Princeton University). The uniqueness of the Kerr–Newman solution for rotating charged black holes has also finally been established. That is, the Kerr–Newman metric is the only stationary axisymmetric solution possible within GR[3]. And, third, the generalized second law of thermodynamics does not break down in the presence of assorted tricky manipulations of systems previously thought to violate it. That is, a generalized entropy, composed of the usual thermodynamic entropy plus a constant times the surface areas of any black holes in the system considered, is a strictly non-decreasing quantity[4].

In contrast, three other strong-field problems look less straightforward than before. The stability of the Kerr (rotating, uncharged) solution, long generally accepted on the basis of numerical studies[5], and the general validity of the solution, though never fully demonstrated, have been challenged by S. Detweiler and R. Ove (Yale University), who have found what seems to be an unstable analytic mode of the scalar wave equation in a Kerr background. Many of their assumptions will require further consideration.

Second, the cosmic censorship hypothesis clearly breaks down in at least one very special case. According to D. Christadoulou (New York University), the collapse of a dust cloud starting from rest at $t=0$ can lead to cases where light rays emanating from $r=0$ are not all trapped and the singularity is thus, in principle, observable. Other speakers (for example, A. Królak, Copernicus Astronomical Center) pointed out that the case under consideration is very artificial and believe that realistic systems will always completely censor their singularities with horizons. The definitive calculations will be exceedingly difficult, as cosmological systems, at least, approach singularities through a series of ever-growing stochastic oscillations (E. Lifshitz, Moscow University).

Third, the quadrupole formula[6,7] for emission of gravitational radiation by orbiting objects remains a major source of controversy. T. Damour (Meudon Observatory) has treated a pair of compact objects by matching a Schwarzschild solution near each to an 'external' gravitational field obtained by iterating a post-minkowskian approximation scheme that incorporates the condition of no incoming radiation. He finds agreement with the time-honoured formula, while F. Cooperstock (University of Victoria, British Columbia), treating a system of two fluid balls initially constrained by skins and struts, then released from rest, does not. There are additional firm voters on both sides; and the resolution is perhaps to be sought in detailed considerations of the fluid mechanics of real objects (C. Will, Washington University; M. Walker, Max Planck Institute, Munich), placing the problem in our third category.

The last interactive class includes problems from galaxy formation to black hole accretion discs — and several innovative methods of solution as well. The importance of getting both the relativistic cosmology and the nuclear physics right has long been appreciated by those seeking to understand synthesis of helium and deuterium in the early Universe. The agreement between observations and such calculations within standard Friedmann cosmologies is one of the strong reasons why the simple models are so widely regarded as valid approximations. D. Matravers (University of Cape Town) and V. Canuto (Institute for Space Studies, New York) reported, however, that reasonable agreement is also possible for non-standard models with tilt and decreasing G.

Later in the history of the Universe, initially small perturbations can grow into relativistic hydrodynamic shock waves, whose proper treatment requires inclusion of conduction and dissipation in the gas as well as relativistic self-gravity (A. Anile, University of Catania, Sicily). A first attempt (H. Sato, Institute of Fundamental Physics, Kyoto) suggests that an initial spherical void forms a compressed shell at its edges, acting like an explosive source that may form a shell of galaxies along the lines proposed by Ikeuchi[8] and Ostriker and Cowie[9].

Once galaxies form, some apparently develop supermassive ($\sim 10^8 M_\odot$) black holes in their cores[10]. A star straying too close to this nucleus will be tidally disrupted and accreted. But, in the process, relativistic tidal distortion heats the stellar interior to $\gtrsim 2\times10^8$K, resulting in explosive hydrogen and helium burning according to B. Carter and J.-P. Luminet (Meudon; ref. 11) and G. Bickness and R. Gingold (Mt Stromlo Observatory). Thus, as described by J. Wheeler (University of Texas, Austin), a massive black hole not only eats it dinner, it cooks it and cuts it up first. Correct calculations of the digestion process are critically dependent on getting the gas viscosity right (B. Muchotrzeb-Czerny, Copernicus Astronomical Center, Warsaw).

To cope with these new complex problems, there were some new (also mostly complex) methodologies. K. Thorne (California Institute of Technology) described a membrane paradigm for the treatment of black hole electrodynamic problems, in which fictitious surface densities of charge and current on the horizon replace the (unobservable) conditions inside. And sensible application of modern computational techniques can assist in two ways. First, systems with wonderful names such as SHEEP and CAMAL (discussed by I. Cohen, University of Stockholm) can manipulate a given metric algebraically to extract the Reimann and Ricci tensors and even decide whether it is equivalent to some

*The conference was held on 5-9 July 1983 in Padova, Italy.

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other specific metric. Second, numerical methods have progressed to the point where they can handle, for instance, the initial stages of relativistic collapse of a magnetized star (K. Maeda, Institute of Fundamental Physics, Kyoto). These algebraic and numerical methods are still regarded with some scepticism by the majority of relativists. L. Smarr (University of Illinois at Urbana-Champaign) spoke feelingly of the need for collaboration between the small groups working with these approximation methods and the main body of relativists with their enormous skills at finding and understanding exact analytical solutions. To which, amen. □

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Population

Nations and numbers, 1983

from Robert M. May

THE United Nations Fund for Population Activities is supported by voluntary contributions from member nations, and provides information and technical aid to countries operating programmes of family planning. According to a report recently issued by the Fund (16 June 1983), the number of people in the world is expected to increase annually at a rate of about 2.0 per cent over the period 1980–1985, which represents a significant downturn from the 2.4 per cent annual rate that prevailed in 1965–1970. Gazing to the future, through glasses that in the past have usually proved rose-tinted, the Fund suggests a continuing slowing of population growth throughout the next century, with eventual stability at a global population of slightly over 10^{10} at the end of the twenty-first century; the present global population is around 4.6×10^9.

As reviewed in previous articles (*Nature* **287**, 482; 1980 and **271**, 504; 1978), there are great differences — both at present and in the probable future — between population trends in the developed and the developing (or, less euphemistically, the rich and the poor) countries. According to the United Nations Fund report, smaller families and fewer births are the key to a population's levelling off. In the industrial nations, the average annual birth rate has held roughly steady at around 16 per 1,000 of population over the past decade. In the Third World, annual birth rates are now about 33 per 1,000; this is significantly down from an average of around 37 per 1,000 in the years 1970–1975, but there is a long way to go.

The report acknowledges that overall population growth rates appear to be outrunning increases in food production in developing countries, and estimates that by the end of this century such countries may have in excess of 400 million more people than they can feed. The report envisages that this problem will yield to a technological solution (use of more fertilizer, more pesticide and higher-yielding strains of crops in developing countries), although I think higher levels of import from developed countries is a more plausible hope.

Four in every ten of the world's people live in China or India today. These two populations — approximately 1,000 million in China and 700 million in India — are in a class by themselves; the next largest populations are those of the USSR and the USA, each roughly one-third that of India. Coale's (*Proc. natn. Acad. Sci. U.S.A.* **80**, 1757; 1983) careful evaluation of the demographic facts for these two countries is therefore especially pertinent to any appraisal of global trends.

At the outset, Coale emphasizes that "Data on population in China and India in the past 30 years are characterized by different kinds of limitation and uncertainty". For India, where 12 censuses have been carried out since 1872, extensive compilations of data are available, but they are inaccurate: ages are often grossly misreported, and births and deaths not always registered. In contrast, for China the record-keeping associated with pervasive government control of daily life and the precision about birth dates associated with traditional beliefs in astrology make the possibility of obtaining accurate data "tantalizingly present"; but little attention has been given to compiling these data.

Estimated average annual birth and death rates per 1,000 in China and India

	China		India	
Decade	Births	Deaths	Births	Deaths
1950s	36	18	45	26
1960s	36	13	41	19
1970s	23	7	39	17

These caveats having been made, Coale presents estimates of the average annual birth and death rates in the two countries, decade by decade, over the 30 years that have passed since their emergence from largely colonial status at the end of World War II. These data are summarized in the table. We see that the average annual rate of population growth in the 1950s was slightly larger in India than in China (about 19 per 1,000, or 1.9 per cent, compared with 1.8 per cent), whereas in the 1960s the reverse was true (2.3 per cent in China compared with 2.2 per cent in India). In the 1970s, however, the average annual population growth rate in China fell to about 1.6 per cent, while remaining 2.2 per cent in India.

Although the two countries are similar in that both are relatively poor and heavily agricultural (in both, 80 per cent of the people live in the country), there are pronounced differences in birth and death rates; these tend to be obscured by the similarities in overall population growth rates. Coale attributes the lower and more improved death rate in China to two main factors. First, the relatively egalitarian distribution of income in China has meant that although "per capita availability of food is only moderately more favorable, those at the bottom of the scale are less deprived in China than in India". Second, the number of physicians per person is roughly three times larger in China than in India, and this relative abundance of physicians is also better distributed (in India, the doctor/patient ratio is eight times higher in cities than in the countryside). As important, Chinese health care is supplemented by paramedical personnel or 'barefoot doctors', and by strong emphasis on preventive medicine (including clean water supplies and the fly-swatter-implemented 'campaign against flies').

The table also shows the dramatic decline in the Chinese birth rate in the 1970s, undoubtedly associated with such centralized coercion as the requirement that couples obtain a 'planned birth certificate' before the wife becomes pregnant. In India, Coale notes, "Despite official support (for 30 years) of family planning, the government of India has not been able to organize a birth control program that regularly provides adequately staffed services to most of the population". In the mid-1970s, attempts at coercive measures not too different in principle from those implemented in China led to the fall of the Ghandi government.

In summary, Coale estimates that if present trends are sustained the population of China may stabilize at about 1,200 million by the year 2020; this represents a 75 per cent increase from the 700 million people present when the birth rate began its dramatic decline in the mid-1960s. India today has demographic parameters rather similar to China in the mid-1960s, and Coale thus estimates that even if fertility in India starts to fall soon the population is unlikely to stabilize below 1,200 million. In short, the two largest populations in the world are fated to become much larger.

In conclusion, Coale emphasizes that "A lower birth rate now is desirable, but the ideal rate is not zero. There are social and political costs of excessive emphasis on the immediate achievement of very small families; the rights and sensibilities of the current population, and the disequilibrating effects of drastic changes in age composition must enter the calculation of desirable population policies". □

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