MAT 314: Neither Newton nor Leibnitz — The Pre-History of Calculus and Celestial Mechanics in Medieval Kerala

7 — 11 March 2005

Old Main 403 Canisius College: 5:00 — 8:00pm Daily

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Course Abstract for MAT 314

There was a bitter controversy involving Newton and Leibnitz in the seventeenth century over the invention of calculus. Although Newton remains the undisputed giant of the field and the founder of modern physics, it has been since discovered (largely through the historical scholarship of K. V. Sharma) that many of the basic ideas of calculus were known previously to astronomers of a South Indian school. They knew of the theory of infinite series, notions of convergence, differentiation, and iterative methods for solution of non-linear equations. This school, founded by Madhava of Sangamagrama and included as its prominent members Neelakanta Somayaji, Parameswara, Jyeshtadeva and Achyuta Panikkar, flourished between the 13th and 16th centuries-but has its intellectual roots with Aryabhatta who lived in the 5th century.

We will review their knowledge of (pre-Keplerian, epicyclic) astronomy and the problems that they were attempting to solve that led them to such revolutionary mathematical discoveries. We will get a glimpse into the contents of the first calculus textbook in the world, the Yuktibhasha (in the South Indian language *Malayalam*) written by Jyeshtadeva in the 16th century. The spice economy of Kerala and its unique social structure (centered around the temple and its Hindu religious rites) in which this community of scholars existed will also be described.

We will then attempt to place the work of the Kerala school in the modern context: the definitive solution of the ancient problems of celestial mechanics by Newton and his successors and the ever expanding applications of calculus to every field of science.

Some References for MAT 314

(1) **A popular exposition assuming little mathematics knowledge:** George Gheverghese Joseph, *The Crest of the Peacock*, Princeton University Press (2000)
(2) **A scholarly treatise with references to original manuscripts and translations of key passages (hard to get in bookstores):** K. V. Sharma, *A History of the Kerala School of Hindu Astronomy* Vishveshvaranand Institute, Hoshiapur (1972).

Two standard treatises on the history of related subjects:

(3) V. S. Varadarajan, *Algebra in Ancient and Modern Times*, Providence, RI: Amer. Math. Soc., 1998.

(4) B. L. van der Waerden *Geometry and Algebra in Ancient Civilizations* Springer-Verlag (1983)

Scholarly articles by historians of mathematics:

(5) R. C. Gupta, *Madhava's and other medieval Indian values of pi,* Math. Education 9 (3) (1975), B45-B48; *Madhava's power series computation of the sine* Ganita 27 (1-2) (1976), 19-24.

(6) D. Gold and D. Pingree, *A hitherto unknown Sanskrit work concerning Madhava's derivation of the power series for sine and cosine* Historia Sci. No. 42 (1991), 49-65.

(7) Hayashi, T. Kusuba and M. Yano, The correction of the Madhava series for the circumference of a circle, Centaurus 33 (2-3) (1990), 149-174.

(8) C. T. Rajagopal and M. S. Rangachari, *On an untapped source of medieval Keralese mathematics*, Arch. History Exact Sci. 18 (1978), 89-102; *On medieval Keralese mathematics*, Arch. History Exact Sci. 35 (1986), 91-99.

(9) **Original text on Calculus, reprinted by Kerala University from a manuscript in the Oriental Manuscripts Library:**
Jyeshtadeva, *Yuktibhasha* (in Malayalam c. 1550 AD).

(10) **Web site on the History of Kerala**: http://www.keralahistory.ac.in

Biographical Sketch of Professor Rajeev

Professor Rajeev received his B.Sc. in Physics from the University of Kerala, Trivandrum, India (1979), and his Ph.D. in Physics from Syracuse University (1984). He was a postdoctoral fellow at the Massachusetts Institute of Technology (1984-87) before joining the University of Rochester as an Assistant Professor of Physics in 1987. He was promoted to Associate Professor in 1993, and to Full Professor in 2000. Rajeev has held visiting appointments at the Institute for Advanced Study, Princeton (1991), the Research Institute for Theoretical Physics, Helsinki (1991), and the Mittag-Leffler Institute, Stockholm (1998).

Professor Rajeev works on various problems in theoretical physics arising from "High Energy Physics" as well as other fields such as string theory, nonlinear optics, hydrodynamics and quantum information theory. The focus of his most recent work has been on non-commutative geometry and probability theory, which has applications to understanding Yang-Mills fields as well as to string theory and even classical problems in hydrodynamics. Solitons in field theories of High Energy Physics are another theme of Rajeev's research.

MAT 315: Quantum Computation

14 — 18 March 2005

Old Main 403 Canisius College: 5:00pm — 8:00pm Daily

Dr Petrus Potgieter (Instructor)
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Course Abstract for MAT 315

The main ideas behind developments in the theory and technology of quantum computation were articulated in the late 1970s and early 1980s by scientists from the United States and the Soviet Union. Some twenty years later the excitement is palpable as physicists and engineers rush to build quantum computing devices large enough to solve practical problems while computer scientists, operations researchers and mathematicians try to find new algorithms in this paradigm.

For computer science and computer engineering, quantum computation is not an optional topic: with continuing miniaturization, computing devices would sooner or later have to deal with quantum mechanical effects in any case. Mathematics, in turn, has had strong links to mechanical (i.e. non-human) computation since at least 1900—not only (and certainly not initially) with the aim of obtaining numerical results, but rather with the idea of formal computability itself. One need think no further than Hilbert's 10th problem and his *Entscheidungsproblem* for an illustration of this observation. Any development in the scientific concept of computation should therefore be carefully examined by mathematicians for its theoretical and for its practical impact.

Since the appearance of Maxwell's Daemon over a hundred years ago, mathematics, physics and—later—computer science (if you will, algorithmic information theory) have faced some interesting common problems and this interplay is very much alive today. This can be seen in the continuing lively debate around the so-called Information Paradox for black holes, to name just one prominent example related to quantum computation.

The lectures are an expanded and revised version of a similar course given at the Corvinus University in Budapest at the end of 2003, at the invitation of the foundation *Pro Renovanda Cultura Hungariae Alapítvány.* The primary aim of the course is to give the audience a good basic grasp of the theory behind quantum computation, to enable them to understand quantum algorithms and to bring to their attention the very nice interaction between information science, physics and mathematics in this field.

Prerequisites for MAT 315

Students taking MAT 315 for credit will preferably have had at least one calculus course, and some exposure to either linear algebra or discrete mathematics.

A casual acquaintance with the principles of quantum mechanics and formal computability will be advantageous but not strictly necessary as all these ideas will be reviewed in the course.

Lecture Breakdown for MAT 315

MAT 315 consists of five lectures of length three hours each, covering the followings topics, in summary.

Lecture 1:

- Origin of the idea with Feynman and others and why we really need it.
- Reversible and irreversible computation and thermodynamical issues, or *Maxwell's Daemon II*.
- Classical bits and quantum bits (*qubits*) — entanglement and measurement.
- Logic gates and circuits in classical and in quantum computing.

Lecture 2:

- Brief overview of quantum mechanics — operators on finite-dimensional state spaces.
- Quantum logic gates consistent with the laws of physics.
- Finding basis gates for quantum computation.
- An elementary quantum algorithm.

Lecture 3:

- The square root of NOT.
- An overview of quantum algorithms currently known.
- Grover's algorithm.
- A programming language for quantum computing.
- Quantum computing and cryptology.

Lecture 4:

- Quantum evolution for a state in finite-dimensional Hilbert space — vis-á-vis Schrödinger's equation.
- Controlling superposition.
- Classical error correction.
- Decoherence and quantum error correction.

Lecture 5:

- What exactly do we mean by *computation*?
- A million dollar question.
- How does quantum computation fit into computability and complexity theory?
- Other new and/or unusual models for computing, including *Zeno machines* and biological models.
- Prospects for quantum computational theory and technology.

Biographical Sketch of Professor Potgieter

Born in the South African province of KwaZulu-Natal during the decade of relentless economic optimism, Carnaby Street and Uhuru, Petrus Potgieter waited for things to calm down a bit before finishing his university education in the 1990s with a PhD in mathematics at the University of Pretoria, where he had been an undergraduate student before completing an MA at Kent State University in the USA. His academic interests are chiefly in the foundations of computation and computational complexity and in mathematical finance. Underlying both of these areas is the connection with probability theory and the observation that both deal with the interface between an agent (computing device or investor) and a system (human observers or the economy) by means of well defined signals (input or prices, respectively). He is a regular consultant to the South African financial industry, tireless advocate of Open Source operating systems and software, a regular contributor to the Mathematical Reviews and recently elected to the Executive of the Operations Research Society of South Africa. In the course of his academic career he has visited universities on four continents.

His hobbies include learning and thinking about languages and history, the latter especially from a socio-economic point of view. He is a strong believer in the process of civilization, i.e. the (obvious) idea that knowledge and its application has always been and will remain the engine of human progress.

MAT 316: A New View of the Universe

11 — 15 April 2005

Old Main 403 Canisius College: 5:00pm — 8:00pm Daily

Dr Fred Watson (Instructor)
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Course Abstract for MAT 316

Contemporary astronomy is characterized by its access to data from every part of the electromagnetic spectrum. The information now coming to us from observations using gamma-rays, X-rays, infrared and radio radiation has revolutionized our picture of the Universe in recent years. Nevertheless, observations in visible light still play a pivotal role for a number of quite fundamental reasons. Optical astronomy therefore continues to make a vigorous contribution to our understanding of the Cosmos.

This course will explore the way in which astronomers piece together their observations to build up a detailed picture of various astrophysical phenomena, from the life cycles of stars to the structure of galaxies and the large-scale distribution of matter in the Universe. Optical observations will be highlighted but not to the exclusion of other wavebands, the emphasis being on the way our perception of the Universe is developed from the observations.

Specific Topics and Additional Information for MAT 316

(1) Spaceship Earth
(2) HST and the super-telescope league
(3) Forging the elements - the birth and death of stars
(4) The dusty Universe
(5) Riddles of galactic structure
(6) Faster than light? - superluminal phenomena
(7) The biggest lenses in the Universe
(8) Cosmology and the mystery of the invisible matter
(9) Are we alone?

The course will be fully illustrated with spectacular astronomical images, and will be presented against an elementary background of physics and mathematics. Some of the commonly-used mathematical formulations are very straightforward, even in advanced topics like cosmology, and these will be illustrated in the course.

Biographical Sketch of Professor Watson

Fred Watson comes from a long line of Freds, but seems to have been the first in the family to become an astronomer. He was born and raised on the outskirts of

Bradford in Yorkshire, northern England. He went to school at Belle Vue Grammar School for Boys in Bradford, where he became hooked on astronomy.

Fred went to university in Scotland, beginning an academic career that was distinguished only by its longevity. He studied mathematics and physics at the University of St Andrews and later did a masters degree in astronomy there. Later still, in 1987, he gained his doctorate from the University of Edinburgh. The other thing that Fred learnt at university was how to look as if you can sing and play the guitar, and for many years he frequented the folk clubs of Scotland and northern England. This trick still comes in handy on Australia's ABC Radio and at occasions such as "Science in the Pub" (which brings science to pubs [aka bars] in the Australian outback).

Fred's first job was as an optical physicist with the telescope building firm of Sir Howard Grubb Parsons & Co. Ltd., of Newcastle upon Tyne, now sadly no longer in existence. He also worked at the Royal Greenwich Observatory at Herstmonceux and Cambridge (in the 1070s and 1990s) and the Royal Observatory, Edinburgh (in the 1970s and 1980s). These jobs took Fred to telescopes in Hawaii and the Canary Islands, as well as to a new life in Australia during the early 1980s. Here, Fred helped to pioneer the use of fibre optics in astronomy at the start of a new era of statistical studies of stars and galaxies. He was responsible for an instrument called FLAIR on the UK Schmidt Telescope, ancestor of the present 6dF system.

In 1995, Fred became Astronomer-In-Charge of the Anglo-Australian Observatory at Coonabarabran (in central New South Wales, Australia), which is his present job. His particular scientific interests are in the motions of stars and galaxies, and in the development of new instrumentation for astronomy. He is also interested in dark-sky preservation, global virtual observatories and astronomy education. Fred regards it as an important part of an astronomer's work to bring the science to as wide a public as possible, so he often finds himself writing and speaking about the Universe and our place in it. He has several regular astronomy segments on ABC radio in Australia.

When time permits, Fred also carries out research into the history of scientific instruments. He is the author of *Binoculars, Opera Glasses and Field Glasses* published by Shire Books, and was a contributor to the award-winning historical encyclopedia *Instruments of Science*. His new book *Stargazer* on the history of the telescope has just been published in Australia by Allen & Unwin, and will be released in the USA in 2005.

In addition to his regular post at the Anglo-Australian Observatory, Fred is an honorary Full Professor of Astronomy at the University of Southern Queensland and an adjunct Professor in the School of Physical and Chemical Sciences at the Queensland University of Technology.