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Workshop on

Promoting History of Science in India

ABSTRACTS

Prof. Roddam Narasimha

Barbarous Algebra, Inferred Axioms:
Eastern Modes in the Rise of Western Science

A proper assessment of classical Indic science demands greater understanding of the roots of the European scientific miracle that occurred between the late 16th and early 18th centuries. It is here proposed that, in the exact sciences, this European miracle can be traced to the advent of 'barbarous' (i.e. foreign) algebra, as Descartes called it, and to a new epistemology based on 'inferred' axioms as advocated by Francis Bacon and brilliantly implemented by Isaac Newton. Both of these developments can be seen as representing a calculated European departure from Hellenist philosophies, accompanied by a creative Europeanization of Indic modes of scientific thinking.

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Prof. R.N. Iyengar

Astronomy in Vedic Times:
Indian Astronomy before the Common Era

Astronomy popularly means knowledge about stars, planets, sun, moon, eclipses, comets and the recent news makers namely, asteroids and meteorites. Ancient people certainly knew something about all of the above though not in the same form or detail as we know now. The question remains what did they know and when. To a large extent for the Siddhāntic period (roughly starting with the Common Era CE) the above questions have been well investigated. This has been possible since several texts of the period specifically devoted to astronomy are available for our study. But for the more ancient period we have no exclusive texts other than Lagadha's *Vedānga Jyotisha* (*c.* 1400 BCE), which is a calendar with no reference to eclipses and planets. Hence when one talks of 'Vedic times' several precautions are necessary. Firstly even though for the Pre-Siddhāntic period many texts are available, they are neither specific to astronomy nor are they by particular authors. Second, the texts were all oral and transmitted by memory for generations before some people decided to write them down on palm leaves. This knowledge tradition has come down to us in Sanskrit and in a few other Indian languages. We are here considering only texts in Sanskrit. Three broad classes of BCE texts can be identified namely Vedic, Purānic and Śāstraic. Texts of the first group are preserved unchanged in their original form with practically no variation with time. The same cannot be said about the two Epics, the eighteen and more Purānas, Samhitās of Parāśara and Vṛddha Garga, which might have got edited after CE also. Texts on grammar, prosody, dramas of Bhāsa, Kautilya's *Arthaśāstra*, *Nātyaśāstra*, Jaina and Buddhist literature making up the third group are relatively late but provide insights into Indian astronomy before Common Era (IABCE). In addition to the above clarification, it is essential to bear in mind the time frame of development of the above class of literature which spans some three thousand years starting from the fourth millennium BCE. Hence any discussion on IABCE has to address the question of chronology consistent with whatever verifiable information can be found. Investigation of ancient sky pictures is ethno-astronomy which has enriched the unified cultural history of greater India since the most ancient past. If any of the past celestial events get dated with the help of modern methods known as archaeoastronomy it advances our understanding of historical evolution of Indian scientific thinking.

It is generally observed that Vedic culture personified celestial objects and their actions. Hence the texts carry a background that has to be deciphered for extracting the archaic models of the visible sky. When we read that a demon fell from the sky and went underground, we can safely infer that this picture should have been correlated in time and space with a meteorite fall. This allegorical approach was known to the Vedic tradition as recorded by Yāska (*c.* 700 BCE) who records three types of interpretations for several hymns of the Rigveda. These are the *adhiyajna, adhyātma* and the *adhidaiva;* the sacrificial, philosophical and celestial (divine) meanings respectively. For example the *adhidaiva* meaning of the word Soma is Moon, whereas in a Vedic sacrifice as per the *adhiyajna,* Soma is a creeper of that name. In the Upanishads the philosophical meaning of Soma would be *manas* or mind. The *Śatapatha Brāhmana* (11.1.5) has the esoteric statement:

> *Candramā vai somo devānāmannam tā pournamāsyāmabhisunvanti ||*
> *Moon is Soma the food of gods; they approach him at full moon.*

But Yāska quite clearly says in the *Nirukta* (Ni. 11.4-5) that Soma is moon whom no gods can (literally) eat. It is easy to see that the reference in such cases is to the waning moon said to be consumed by gods on a daily basis starting from full moon.

The Vedic seers personified celestial objects as they beheld some cosmic transcendental unity and pattern through observable natural phenomena. Hence it should not be surprising to find sacrifices, religion and Vedanta philosophy reflecting Vedic sky pictures and descriptions. This type of modelling sky observations can be called scientific naturalism. This has been the basis of many religious practices and festivals prevalent to this day in our country. The descriptions become intriguing particularly when numbers are also associated with the celestial divinities. In this talk I propose to consider two such sky models appearing in the Vedas and the Purānas.

i) The constellation Śiśumāra with *fourteen gods* mentioned in the *Taittirīya Āranyaka* which carried Dhruva the Pole Star at its tail as the last member. The two models are well preserved in the *Brahmānda Purāna* with more details. The observation of the unchanging Dhruva at the end of the Śiśumāra (modern Draco) is dateable to the period 3200–2800 BCE.

ii) Count of 3339 deities in the Rgveda who drink moon *only in the dark fortnights*. The lunar number (3339 x 2 = 6678) was the original eclipse cycle of 18-years with 371 tithis per year. This long count was most likely the basis of the *Vedānga Jyotisha*'s five-year cycle of 366 solar days per year.

iii) If time permits I will talk about *visibility numbers of planets* and comets in the Samhitā text of Parāśara known to Varāhamihira and his commentator Utpala. He records an observational tradition that suspected Agastya (Canopus) to be a planet. He perhaps directly observed that the rise and setting of Agastya was linked to stars *Hasta* and *Rohiṇī* respectively being close to Sun.

All the above three examples have left their strong footprints on the mathematical astronomy of the later *Siddhāntas.*

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Dr. S. Balachandra Rao

Classical Indian Astronomy: An Overview

In the present paper a brief survey of the development of classical Indian Astronomy is attempted. Chronologically, the survey ranges from the Vedic period up to the remarkable contributions of the Kerala school of astronomy.

In the Vedic lore we see concrete references to the seasons, solar months, equinoxes and solstices, the 27 (or 28 including Abhijit) *nakshatras*, durations of day and night etc. The *Vedanga Jyotisha* (c. 12th century BCE) is the textual culmination of this phase of Indian astronomy. The 'siddhantic' period is a long saga of systematic mathematical astronomy starting with the great pioneer Aryabhata I (born 476 CE). Of course, planetary computations must have started two or three centuries prior to Aryabhata as evidenced by the contents of the *Panchasiddhantika* of Varahamihira (505 CE), especially its *Saura siddhanta*.

The successive improvements in the astronomical procedures and parameters, after Aryabhata I, were the contributions of stalwarts like Brahmagupta (628 CE), Bhaskara I (629 CE), Sripati Bhatta (c. 10th century CE), Bhaskara II (born 1114 CE) and a bit later by the galaxy of Kerala astronomers like Madhava, Parameshvara and Nilakantha Somayaji (1500 CE).

Somayaji's revised planetary model was a great breakthrough which turned out to be a reliable working model for planetary positions. In this quasi-heliocentric model the planets move round the sun and the sun himself goes round the earth. Mathematically there is nothing wrong in this hypothesis since what is considered is the relative motion of the sun w.r.t. the observer on the earth instead of the actual motion of the earth round the sun! In fact this very model was adopted, in preference to the Copernican model, much later by Tycho Brahe (1546-1601). It was only the Keplerian model of elliptical orbits with the sun at a common focus that replaced the earlier approximate ones.

Indian astronomers have always given maximum importance to the concordance between the observed results and the computed ones, what they called '*Drig-ganita-aikya*'. They were highly dedicated and astute observational astronomers too as much as mathematical theoreticians! Brahmagupta devotes an entire long chapter, *Yantradhyaya,* to the description of astronomical instruments in his famous and voluminous treatise, *Brahma-sphuta-siddhanta*. The importance of effecting periodical corrections and updating of parameters, based on observations, is emphasized by every classical Indian astronomer.

During the Islamic rule, some Indian scholars were commissioned to translate Persian astronomical texts and tables into Sanskrit and also vice versa. Thus there were crosscultural exchanges occasionally. For example, Kamalakara Bhatta's *Siddhanta-tattva-viveka* incorporated Persian astronomical elements.

Later, during Raja Sawai Jaisingh’s patronage to modernizing Indian astronomy, the set of astronomical tables of the famous French astronomer de La Hire was imported and got translated into Persian (as *Zij-e-Mohamadshahi*) as also into Sanskrit (as *Drik-paksha-sarini* by Kevalarama).

Even to this day most of the traditional Hindu calendrical almanacs (*Panchangas*) are compiled annually based on traditional texts like the *Surya-siddhanta* and the *Graha-laahavam*. However, efforts are on to revise and standardize these *panchangas* by adopting elements and procedures of modern scientific astronomy.

Dr. S. Balachandra Rao was a professor of mathematics at the National College, Bangalore. He has authored several books and papers on the history of Indian mathematics and astronomy, and has translated and edited several Sanskrit texts under the aegis of the Indian National Science Academy. He is currently the honorary director at the Gandhi Centre of Science and Human Values, Bharatiya Vidya Bhavan, Bangalore. Email: balachandra1944@gmail.com

Prof. Mayank Vahia

Ancient Astronomy, Myths and Architecture

Intellectual traditions of humans manifest themselves in four distinct ways, namely in creation of myths, religion, architecture, and science. Myths arise largely to understand and explore the various phenomena that occur around them in terms of ideas and forces beyond their control. They carry within them information on human life and activities. In contrast, religion and religious myths carry within them pointers not only to the world around them, but the moral value system and a code of conduct for the people. In that sense, while shared myths give a sense of identity, religion occupies a larger canvas which even covers a moral code of conduct and social organization within which the religion is constructed. In parallel, humans also search for rhythms of life that allow them to organize themselves in a manner which permits them to optimize their interaction with their environment. We broadly call this science and it includes botany and astronomy as well as basic zoology. Humans are also sensitive to death and like to preserve the memory of the dead as well as ensure that the remains of the dead are not vandalized. This idea eventually takes the form of sepulchral and memorial architecture. We will discuss these somewhat distinct but often overlapping developments of human intellect. We will then show how these four streams merge seamlessly in the temple architecture of India.

Prof. Mayank Vahia works in high-energy astrophysics. He has been active in science popularisation, and has contributed studies to the history of Indian astronomy, in particular developments in Indian prehistory and protohistory. He is currently with the department of Astronomy & Astrophysics, Tata Institute of Fundamental Research, Mumbai. Email: vahia@tifr.res.in

Prof. K. Ramasubramanian

Indian Planetary Models

While in the Greek tradition, the science of astronomy was closely knitted with cosmology, for Indians, the science of astronomy (*jyotiḥśāstra*), was primarily a *Kālavidhāna-śāstra*, a 'science that enables to determine the time' (also place and direction). Astronomers of the past had clearly recognized that the only means to keep track of 'empirical' time was to keep track of the positions of celestial bodies, particularly the longitudes of the Sun and the Moon.

Starting from *Āryabhatīya* (499 CE) Indian texts have prescribed detailed analytical methods for calculating planetary longitudes. At times they also discuss the geometric models implied by the computational scheme. Though certain models have been proposed to capture the non uniform motion of planets, from very ancient times there has been a clear recognition that planetary motion can be fairly complex—in any case not confined to uniform circular motions in spheres centered or otherwise at the earth.

Geometrical elements like *kakṣyāvṛtta, mandavṛtta, śīghravṛtta* etc., were of course used in specifying the computational procedure. However, neither their radii, nor the way in which they evolve during the course of the orbit or the planet were taken to be uniform. Application of *manda* and *śīghra* corrections were also prescribed differently by different astronomers. All this invariably points to the fact that the Indian astronomers did not get themselves wedded to a specific model, and more so to their understanding that the actual motion of planets is quite complex. Hence, instead of proposing a cosmological model and discuss it at great length, all they did was to come up with a model that would enable them to predict the planetary positions as accurately as possible.

During the talk, by presenting an overview of the Indian planetary models starting from Āryabhata to Nīlakantha (15^{th} century), we will also bring out how the latter arrived at the cosmological model purely based on observations, and not by any philosophical speculations, wherein all the planets move around the Sun, which in turn moves around the Earth. We will also try to show that the Indians did not subscribe to any simple geocentric cosmology like the Greeks from the time of Aristotle, nor did they subscribe to more complex versions of it due to Ptolemy or later Islamic astronomers.

Prof. K. Ramasubramanian has contributed studies to the history of Indian mathematics and astronomy. In particular, in collaboration with Prof. M.S. Sriram and Prof. M.D. Srinivas, he has co-edited important texts of the Kerala school mathematics and astronomy. He is currently with the Cell for Indian Science & Technology in Sanskrit of IIT Bombay. Email: kramas@iitb.ac.in.

Prof. M.S. Sriram

Eclipse Calculations in Indian Astronomy

Calculation of eclipses is an important part of any text on Indian astronomy, beginning with *Aryabhatiya* of Aryabhata (c. 499 CE). Eclipses are very sensitive to the positions of the Sun and the Moon, as actually observed by an observer on the surface of the earth. These are dependent on the various parameters associated with the motion of the Sun and the Moon. In addition to this, solar eclipses are sensitive to the position of the observer on the Earth also, through the effect of 'parallax'. It is not surprising that a lot of importance was given to the calculations and observations of eclipses by Indian astronomers. In fact, eclipse observations afford an opportunity to check the parameters and the methods of calculation.

In this presentation, we discuss the basics of the eclipse calculations as described in Indian astronomy texts. As Indian astronomy is algorithmic in nature, and we have algebraic formulae at various stages of the calculation, which are simple and direct, even a non-expert would be able to carry out the computations. In contrast, Greek astronomy lays emphasis on geometrical models and the use of various tables. It is certainly more difficult to implement.

In his *Karanapaddhati* (composed around 1730 CE?), Putumana Somayaji gives a simple method to find the dates on which the eclipses would occur. The Moon has to be near one of its nodes, for an eclipse to occur, and obviously, the dates would depend on the rates of motion of the Sun, the Moon, and its nodes. During our presentation, we plan to discuss this method also, which is based on the method of continued fractions for approximating the relative rates of motion.

Prof. M.S. Sriram, a physicist, has contributed studies to the history of Indian mathematics and astronomy. In particular, in collaboration with Prof. M.D. Srinivas and Prof. K. Ramasubramanian, he has co-edited important texts of the Kerala school mathematics and astronomy. He is

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Dr. Shailesh Shirali

Studying Mathematics through its History

In this talk I wish to focus on the educational possibilities offered by some topics from ancient Indian mathematics.

Here are a few topics I will consider:

1. The Hemachandra-Fibonacci numbers which crop up in the mathematics of rhyme
2. The Bakhshali square root formula
3. The Bhaskara sine approximation
4. The Brahmagupta-Pell equation

Rather than discuss the historical details and the lines along which research has proceeded, I will focus on the educational possibilities offered by the topics. I will show that there are many ways of integrating the topics into the current high school curriculum, and that problem studies are easily devised that draw students into exploration. These explorations are highly enriching, and offer possibilities of graphical and computer-assisted work.

Following this I will touch on the question of why such topics are so completely left out from the curriculum, and why—on the contrary—it is important to dwell on them, not merely as topics in mathematics (though there is joy enough in that) but against the backdrop of Indian philosophy and the current state of the world.

Dr. Shailesh Shirali taught mathematics at Rishi Valley School for more than two decades and has been deeply involved in the teaching as well as popularization of mathematics. He is currently director, Sahyadri School, Krishnamurti Foundation India, Pune. Email: shailesh.shirali@gmail.com

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Prof. S.G. Dani

Geometry in the *Śulvasutras*

Śulvasutras, which are part of the *Vedanga* literature, aimed primarily at describing construction of *vedis* and *agnis*, for the purpose of performance of the *yajnas* that were mainstay of the Vedic times, include also exposition of various geometrical constructions and geometrical principles. In this talk we shall discuss the geometry in the *Śulvasutras*, placing it in a broader context.

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Dr. R. Sridharan

Combinatorics in India: A brief overview

Indian combinatorics has its beginnings from very ancient times. It can be traced back to Bharata's *Natya Sastra* and the work of Pingala on 'Chanda Sastra', where, among other things, he deals with the problem of scanning Vedic and classical Sanskrit verses. What started out thus as a problem on metres of Sanskrit verses led Pingala to binary expansion of integers. In fact, this problem of enumeration was tackled by techniques which were called *pratyayas*. These techniques evolved gradually through an evolutionary process to apply to similar problems for moric metres (considerations of which came essentially from Prakrt and Apabhramsa poetry) and led for example to the study of the so called Fibonacci numbers (written explicitly down in his work by Virahanka in the 8th century. Further developments of the same theme of enumeration were applied in India to medicine, architecture, garland making and music. The great musical genius Sarangadeva (13th century) dealt with similar problems for musical tones and *tala* patterns and his work led to some beautiful mathematics.

Thus, the study of combinatorics in India which began in antiquity seems to have had a continued and sustained development and this seems to have lasted till at least the 14th century CE, when Narayana Pandidha wrote his classic treatise *Ganita Kaumudhi*, which gives a general treatment of combinatorics from a purely mathematical point of view.

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Dr. S. Raja

Combinatorics in Narayana Pandita's *Ganita Kaumudi*

The notion of a number is very basic in mathematics and has a very tangled history as George Ifrah tries to show in his books. The ancient Indian mathematician Pingala (circa 3rd century BCE) used two symbols 'l' and 'g' to construct an array (*prastara*) of binary numbers with the idea of applying these concepts to Sanskrit prosody of classical metres. The rows of this *prastara* correspond in a certain way to the binary representation of the row number. Pingala also studied the *prastara* posing various questions providing a framework that later Indian mathematicians used in their analyses of *prastaras*.

Several Indian mathematicians of later generations (to mention one among them, Sarangadeva) made very valuable basic contributions and constructed *prastaras* of different kinds. The rows of these *prastaras* yield representations of the corresponding row numbers in terms of basic units like Virahanka-Fibonacci numbers or numbers of other kinds. These *prastaras* were studied with a view to applications to music, garland making and architecture.

The culmination of this remarkable story as it stands, came in the 14th-century with the work of Narayana Pandita who essentially unified the work of the earlier generations and approached the subject from a purely abstract mathematical viewpoint. We shall talk about Narayana's contribution to combinatorics.

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Dr. Amartya Kumar Dutta

Brahmagupta's *Bhāvanā*: Some Reflections

In this talk we shall discuss two verses of Brahmagupta which occur in the *Kuṭṭakādhyāyaḥ* (chapter on Algebra), the 18th chapter of his magnum opus *Brāhma Sphuṭa Siddhānta* (628 CE), a treatise on astronomy and mathematics comprising over 1000 verses. The two verses describe a law of composition called *bhāvanā*, which is a rule to generate new roots (*x, y, m*) of a certain equation in three variables from two given triples of roots (x_1, y_1, m_1) and (x_2, y_2, m_2) of the equation. This composition principle, described by the great 18th century Swiss mathematician L. Euler as a *theorema eximium* (theorem of capital importance), is of paramount significance in modern algebra and number theory.

Brahmagupta, who was perhaps the first to recognise algebra as a distinct and powerful branch of mathematics, laid the foundations of the subject in his *Kuṭṭakādhyāyaḥ.*

He discussed both determinate as well as indeterminate equations. Earlier, Āryabhaṭa had described the problem of finding integer solutions to the linear indeterminate equation with integer coefficients. Brahmagupta brought a clarity and refinement in Āryabhaṭa's solution and took up the much harder problem of finding integer solutions to the quadratic indeterminate equation $Dx^2 + 1 = y^2$. This equation was to become one of the most celebrated equations in modern mathematics. A thousand years after Brahmagupta, Fermat posed the same problem (1657 CE) to illustrate the beauty and depth of number theory and motivate mathematicians towards it. The *bhāvanā* principle formed the cornerstone of Brahmagupta's partial integral solution to the equation $Dx^2 +1 = y^2$ and played a crucial role in the complete solution developed by subsequent ancient Indian algebraists.

Brahmagupta (born 598 CE) is a veritable embodiment of the vibrant intellectuality of the Classical Age of post-Vedic ancient India, a period which witnessed a magnificent efflorescence in philosophy, literature, science, polity, art and architecture. Just as Kālidāsa is the great representative poet of the Classical Age, Brahmagupta is its great representative mathematician, the *bhāvanā* shining as a crest-jewel among his mathematical gems.

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Dr. M.D. Srinivas

The *Cakravāla* Method for Solving Quadratic Indeterminate Equations

In the Kuṭṭakādhyāya of his *Brāhmasphuṭasiddhānta* (c. 628 CE), Brahmagupta discussed the *Vargaprakṛti* equation $X^2 – DY^2 = K$, where D, K are given integers (D, the *prakṛti*, is a non-square integer, and K is the *kṣepa*), and the problem is to find integral solutions for X, Y. This problem seems to be closely related to the problem of finding rational approximations to square-roots which has been of interest to Indian mathematicians since the time of *Śulvasūtras* (prior to 600 BCE). Brahmagupta discovered the important *bhāvanā* property, which enabled him to find solutions for *kṣepa* K_1K_2 once solutions are known for *kṣepas* K_1 and K_2.

The *Bījagaṇita* of Bhāskara II (c. 1150) presents a systematic procedure, the *Cakrāvala* or the cyclic method, for the solution of the equation $X^2 - DY^2 = 1$. An earlier version of this method due to Jayadeva has been cited by Udayadivākara in his commentary Sundarī (c. 1073). A slightly different version of this procedure is discussed by Nārāyaṇapaṇḍita in his *Gaṇitakaumudī* (c. 1356).

In 1657, the renowned French mathematician Fermat posed the problem of finding integral solutions of the equation $X^2 - DY^2 = 1$, as a challenge to other French and British mathematicians. Incidentally, one of the specific examples considered by Fermat, namely D = 61, happens to be a problem which has been solved in the *Bījagaṇita* of Bhāskara. The British mathematicians, Brouncker and Wallis, came up with a method for solving the equation for all the cases considered by Fermat. In the 18th century, Euler made a systematic study of this equation (which he called the Pell's equation). Euler rediscovered the *bhāvana* property, and also came up with the method of solving the equation by expressing $\sqrt{D}$ as a simple continued fraction. That this method always leads to a solution of the equation was shown by Lagrange in 1770s.

In the early decades of 19th century, modern European scholars became acquainted with the *Cakravāla* method of Bhāskara and were duly impressed by the advances made in the subject by Indian algebraists centuries ago. However, it was generally assumed that the *Cakravāla* method was only an earlier version of the more systematic Euler-Lagrange method. It was only in the 1930s that A.A. Krishnaswamy Ayyangar showed that the *Cakravāla* method was indeed different. It corresponds to what is known as a semi-regular continued fraction expansion of $\sqrt{D}$. More importantly, the process is more optimal than the Euler-Lagrange method; it takes considerably less number of steps (about 30% less than the Euler-Lagrange method on the average) in order to reach the solution.

The 'Pell's Equation' continues to be an important topic of investigation in modern mathematics. In our talk we shall endeavour to present an outline of the *Cakravāla* method as discussed by Bhāskara. We shall also briefly summarise the analysis of Krishnaswamy Ayyangar, which also recasts the method in a simpler form that can perhaps be taught to students even at the high school level.

Dr. M.D. Srinivas is a physicist and scholar of the history of Indian science. In collaboration with Prof. M.S. Sriram and Prof. K. Ramasubramanian, he has co-edited important texts of the Kerala school mathematics and

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Michel Danino

Sacred Geometry in Ancient India

The Harappans' obsession with auspicious proportions initiated a long tradition of sacred geometry in India, whose applications range from Vedic sacrifices to temple as well as secular architecture. This presentation examines a few examples from proto- to early history and attempts to make out some of the philosophy behind India's brand of sacred geometry.

Michel Danino, a student of Indian civilization, has contributed studies on aspects of ancient India, including the Indus civilization. He is currently guest professor at IIT Gandhinagar and visiting professor at IIM Ranchi. Email: micheldanino@gmail.com.

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