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Marking the 400th Anniversary of Kepler's *Astronomia nova*

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Abstract. Special Session 9 of the XXVII General Assembly (11–14 August 2009, Rio de Janeiro) was devoted to the topic "Marking the 400th Anniversary of Kepler's *Astronomia nova*". During the two-and-a-half day meeting (spread over four days), there were nine invited and three contributed talks, a round-table discussion on the future of Kepler studies and an open session to propose the setting up of a Johannes Kepler Working Group under the aegis of the IAU.

Keywords. History and Philosophy of Astronomy: Johannes Kepler

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1. Kepler's Cosmology

J. V. Field (Birkbeck College, University of London) discussed the geometrical basis of Kepler's cosmology. In Kepler's time, all Christian natural philosophers said God was a Geometer. Kepler went much further. He looked for the explanation of the observed structure of the Cosmos in Euclid's geometry. (In today's terms, this is to say that he saw the Universe as the expression of the nature of Euclidean space.) He found he also needed some geometry-derived arithmetic. However, his final cosmological model agrees closely with observations.

2. Why Should an Astronomer Today Care about Kepler?

Bruce Stephenson (Adler Planetarium) argued that astronomy is, and has been since the time of Isaac Newton, essentially a subfield of physics and questioned how this came to be.

In the pre-Newtonian world, astronomy was one of the seven liberal arts. The physical reality assumed to underlie astronomy consisted of rigid but transparent (hence invisible) spheres, whose rotations carried the visible planets in complex patterns around the centre of the Universe. In the mid-1500s Copernicus had proposed that the centre of the Universe was the Sun rather than the Earth.

Kepler, the first major astronomer to have come of age after Copernicus, believed that Tycho Brahe had disproved the existence of the rigid spheres once thought to carry the planets. Evidently, some force moved the huge massive bodies of the planets around the Sun, through empty space. From his earliest work, Kepler assumed the existence of such a force, and was able thereby to direct his astronomical work to better purpose. The planets all circled the Sun in the same direction, and all moved faster when close to the Sun, so he located the moving force in the Sun's body. A single planet changed its distance from the sun, so he hypothesized a quasi-magnetic force that alternately attracted and repelled planets. The details got messy, largely due to Kepler's assumption that moving

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a massive body required the application of force. Yet he persisted, eventually cobbling together physical theories that accounted for elliptical motion.

Historical study of such developments must begin by setting aside present knowledge of what we count as scientific truth, and evaluating past scientific work within the historical context in which it took place. Current science will someday be past science; it is not "true" in any eternal sense, but must be understood as a snapshot in a historical development

3. Trusting in Tycho: Kepler's Use of Tycho's Data in the *Astronomia nova*

Adam Mosley (Swansea University) described how Kepler's "new astronomy" depended upon his use of Tycho Brahe's observational data, and how he was led to abandon the hypothesis of circular planetary motion because of an eight-minute discrepancy between the longitudes of Mars predicted by his model and the longitudes derived from Tycho's observations. The talk addressed the questions of *why* Kepler placed so much trust in Tycho's data and to *what extent* his trust was warranted: it considered, therefore, not only Tycho's instruments and procedures, but also Kepler's knowledge of them and of the occasions on which Tycho's data had faced and met the challenges posed by other observers and critics. Mosley used sources other than the *Astronomia nova* (Kepler 1609), including Kepler's little-studied *Shieldbrearer of Tycho Brahe the Dane against the Anti-Tycho of Scipio Chiaramonti* (Kepler 1625), to suggest why, despite their intellectual differences and difficult working relationship, Kepler's justified respect for Tycho's observational legacy made the "new astronomy" possible.

4. The Mindset of Uniform Circular Motion

T. J. Mahoney (Instituto de Astrofísica de Canarias) argued that Kepler's immense achievement in establishing the ellipticity of planetary orbits could only be appreciated by understanding the ingrained nature of the paradigm of uniform circular motion. Few of Kepler's contemporaries accepted the idea of elliptical orbits; indeed, Galileo himself remained wedded to the circle throughout his life.

Mahoney mentioned Kepler's correspeondence with Frabricius concerning planetary orbits and Galileo's espousal of circular orbits as outlined in his *Diaglogue concerning Two Chief World Systems* (Galilei 1632).

5. Kepler's Laws: Some Myths Dispelled

A. E. L. Davis (Imperial College, London) said that Kepler is celebrated, above all else, for discovering the laws of planetary motion (Kepler 1609, 1619). These laws constitute the basis of our modern system of celestial dynamics. It would therefore, said Davis, come as a surprise to many people that Kepler himself had formulated the laws in a kinematic context, in which they were exactly true. He derived them simply by applying ancient Greek geometry in the traditional way. Davis went on to say that further notable features of Kepler's approach were his respect for observations and a conviction that his results should express physical reality. On the other hand, various erroneous opinions had been mis-attributed to him over the years, and these were rebutted by Davis.

6. The Kepler Map in Perspective

Ivan I. Shevchenko (Pulkovo Observatory) described the evolving role of the Kepler map in celestial mechanics. The Kepler map was derived by Petrosky (1986) and Chirikov & Vecheslavov (1986) in the framework of the restricted three-body and four-body problems in order to describe the long-term chaotic orbital behaviour of comets in perturbed, nearly parabolic motion and, in particular, that of Halley's Comet. It is a two-dimensional area-preserving map, describing a comets motion in terms of energy and time. Its second equation is based on Kepler's third law, hence the name of the map. Since the 1980s the Kepler map has become paradigmatic in a number of applications in celestial mechanics and atomic physics. It represents an important kind of general separatrix maps. Petrosky & Broucke (1988) used refined methods of mathematical physics to derive analytical expressions for its parameterization. These methods became available only in the 20th century, so it may seem that the map is inherently a very modern mathematical tool. Shevchenko showed that the Kepler map, including analytical formulae for its parameterization, can be derived by quite elementary methods and, although discovered so recently, it might well already have been derived in the first half of the 19th century. Without formulae for the parameterization it might have been derived even earlier. Shevchenko concluded by saying that one can state that the Kepler map is a direct consequence of Kepler's scientific work and legacy. Modern and perspective applications of the Kepler map and its modifications were discussed.

7. Kepler's *Astronomia nova* as a Rare Book

Jay M. Pasachoff (Williams College, Hopkins Observatory) spoke on Kepler's *Astronomia nova* (Kepler 1609) as of interest not only for its intellectual ideas but also for its physical embodiment as a book. Hundreds of first editions from 1609 are extant. Pasachoff discussed the physical format and variations of several copies of the first edition of *Astronomia nova* as well as of copies of the first editions of Kepler's *Mysterium cosmographicum* (1596), with its magnificent fold-out plate showing his conception of the Solar System as interspersed Platonic solids, and his *Harmonice mundi* (1619), which contained his third law.

8. Kepler's *Dream*

Jarosław Włodarczyk (Institute for the History of Science, Warsaw) discussed the first serious scientific study of the Moon, written by Johannes Kepler in his *Somnium* (*The Dream, or Posthumous Work on Lunar Astronomy*), partly printed in Sagan in Silesia (1630) and completed in Frankfurt in the year 1634. *The Dream* combines a story which is fantasy, with a scientific treatment of lunar astronomy. The fantasy describes a journey to the Moon and is mixed with reflections whose importance has only become generally understood with the advent of the Space Age in the 20th century. The scientific part of the *Somnium*, said Włodarczyk, presents the astronomical phenomena that would be seen by an observer on the lunar surface. Kepler wrote *The Dream* with a clearly didactic intention: his perceptive description of celestial motions as seen from the Moon produced an ingenious argument on behalf of the Copernican theory. However, Kepler's analysis of many subtle effects arising from the motion of the Moon allowed him also to make discoveries that that have been neglected in the modern history of astronomy. Włodarczyk concluded by to urging all to re-read Kepler's *Somnium*.

9. The Great Synthesis: The Multifaceted New Astronomy of Johannes Kepler (1609)

Giora Hon (University of Haifa) noted that *Astronomia nova* (Kepler 1609) is one of the most revolutionary scientific texts ever written. . In this work Kepler developed an astronomical theory that departs fundamentally from the systems of Ptolemy and Copernicus, hence its distinctly approriate title. A comprehensive grasp of Kepler's astonishing achievements requires considering the conceptual, theological, metaphysical, epistemological, methodological and rhetorical elements that can be found in his astronomcal works. Moreover, one has to view Kepler not only as a mathematico–physical astronomer, but also as a designer of instruments and a practising observer.

One of the great innovations of the *Astronomia nova* is its explicit dependence on the science of optics. The declared goal of Kepler in his earlier publication, *Paralipomena to Witelo whereby The Optical Part of Astronomy is Treated* (Kepler 1604) was to solve difficulties and expose deceptive visual illusions which astronomers face when conducting astronomical observations with optical instruments.

What was the nature of the Keplerian revolution? At the centre of Kepler's revolutionary move is the transformation of theoretical astronomy, which was understood in terms of orbs (spherical shells to which the planets were attached) and models (called *hypotheses* at the time). Instead, Kepler introduced a single term: "orbit" (*orbita*); that is, the path of a planet in space resulting from the action of physical causes.

Kepler's *Astronomia nova*, concluded Hon, combines coherently and in a revolutionary way many layers of different kinds of knowledge that together offer a most powerful system of enquiry, whose scientific fruits we still enjoy today.

10. Galileo's Telescope and Kepler's Optics

Sven Dupré (Ghent University) said that the year 2009 jointly marks the 400th anniversary of the publication of Kepler's *Astronomia nova* as well as of Galileo's observations with the telescope published in *Sidereus nuncius* (Galilei 1610). His talk addresses the issue of the influence of Galileo's telescope on Kepler's work on optics. In *Paralipomena ad Vitellionem* (Kepler 1604) Kepler developed a new theory of vision; *Dioptice* (Kepler 1611) offered its reader an optical theory of the telescope. Is *Dioptrice* based solely on the concepts developed in *Paralipomena*, asked Dupré, or did Kepler learn something from his experiences with the telescope or Galileo's observations? The communication and relationship between Galileo and Kepler are often protrayed in terms of social failure and intellectual misunderstanding, from Kepler's mocking of Galileo's name to Galileo's rejection of Kepler's elliptical orbits. But this portrayal of the two men, said Dupré, misses their intense "conversations" in the period following Galileo's announcement of his telescopic observations.

11. "Third Man in the Middle": Kepler between Astronomy and Astrology

Sheila J. Rabin (St. Peter's College) explained how, combining the ideas of Copernicus and Tycho Brahe, Johannes Kepler concluded that the Universe was physical (Kepler 1610). That created a problem for his acceptance of astrology. Traditionally, belief in astrology had been grounded in the Aristotelian distinction between a physical sublunar world and the non-physical heavens. The celestial world could guide what happened on Earth because its lack of physicality made the celestial world superior. A physical

Universe meant that the celestial world lost its superiority and the consequent ability to guide us. Therefore, concluded Rabin, Kepler set about to reform astrology so that it would conform to his belief in the physical Universe.

12. Kepler and the Star of Bethlehem

Sidney Bludman (Universidad de Chile) questioned a number of astronomical explanations for the Star of Bethlehem. Dating Jesus' life is important for religion, for history and for understanding the goals and methods of ancient astronomy. he explained. The principal problem is to reduce naked eye observations of the Sun, Moon and planets from the concurrent Jewish lunar calendar to our Julian solar calendar. The Crucifixion took place on the 14th or 15th day after the new moon of Nisan, as determined by the first visibility of the lunar crescent in the evening sky. Allowing for atmospheric extinction by Rayleigh and Mie scattering and for stratospheric absorption, Bradley Schaeffer arrives at Julian dates AD 30 April 7 or AD 33 April 3, in agreement with established historical records.

The Star of Bethlehem is much more problematic, and may be entirely apocryphal. It is dated to about 1–10 BC, only by "historical" accounts, written about AD 80–90 by the evangelists Matthew and Luke, for Christian Jews gathered in Antioch. Nevertheless, astronomers since Kepler have tried to identify their brief gospel account, with some astronomical spectacle: an unusual planetary conjunction (7, 3, 2 BC), comet, eclipse, nova (March/April 5 BC), or supernova. All such astronomical interpretations fail to explain why the Magi saw the star in the east, but travelled west to Jerusalem; and why no one in Jerusalem sighted the spectacular event. Instead, Michael Molnar (1995, 1999) argues that the Greek texts needs to be read as an astrological horoscope, written to be understood non-scientifically, by Jews and their first century rulers. He argues for an astrological interpretation of a Sun-Moon-Jupiter-Mars-Venus alignment, in Ares (not Pisces), that would go unnoticed in Jerusalem, on 17 April 6 BC, but would give a regal horoscope, alarming King Herod. If the gospel account is anything more than a parable, Molnar's interpretation is supported by a contemporary Antioch coin (Molnar 1992), and is certainly more historical than any astronomical interpretation.

13. Round Table Discussion on the Future of Kepler Studies

One of the main purposes of the special session was to propose the setting up of a Johannes Kepler Working Group within the IAU. A round-table discussion was held among the invited historians to consider the following topics:

- Translation into English of Kepler's major works
- Translation into English of Kepler's correspondence
- Publication of an undergraduate-level textbook on Kepler's life and work
- Obtaining funding for future Kepler conferences
- Preparation of secondary-level educational material
- Representation of the WG at international level with other organizations
- Making enquiries concerning the future of the *Kepler-Kommission* offices and library

S. Rabin explained that Kepler's astrology gives insights into his views on nature, and that Kepler had difficulty in reconciling his astrology with his astronomy, so that further study of Kepler's astrology is crucial to understanding the decline of astrology.

B. Stephenson seconded Rabin's views and added that further study of Kepler's religious views, which were fundamental to his whole scientific outlook, was also required.

J. Włodarczyk pointed out that Kepler's theory of the moon was an important part of the history of selenography and needed to be pursued further. He also urged that the *Bayerische Akademie der Wissenschaften* (hosts of the now defunct *Kepler-Kommission*) be represented on the WG and stressed the importance of setting up a website for the WG.

G. Hon asked why we always speak of a Copernican revolution but never a Keplerian revolution. He recommended that Kepler studies be broaden to incorporate the philosophy of science.

A. E. L. Davis felt that making Kepler's name as well-known as Galileo's in the history of astronomy would result in a truer understanding of the subject. She also stressed the necessity to maintain access to the contents of the *Kepler-Kommission* library and the remaining unpublished manuscripts. Davis also advocated revision of the index of the *Johannes Keplers Gesammelte Werke* to make it more user-friendly.

S. Dupré said that a study of how *Dioptrice* was received by craftsmen and instrument builders was needed. An English translation of *Dioptrice*, including Kepler's marginal notes, was needed.

A. Mosley stressed the need for more translations into English of Kepler's works. He further indicated that investigation of the reception of Kepler's works and more studies of Kepler's contemporaries were vital, as was an up-to-date historiography of Kepler studies.

J. V. Field said that an English translation of *Stereometria* was needed and commented that the ongoing Copernicus project should help to shed light on Kepler.

14. Proposal for a Johannes Kepler Working Group

On the final day of the special session, the following persons drafted a formal proposal to Commission 41 for the setting up of a Johannes Kepler Working Group:

- T. J. Mahoney (Spain, IAU) Chair
- A. E. L. Davis (UK, IAU)
- S. Dupré (Belgium)
- J. V. Field (UK, IAU)
- E. Hoeg (Denmark, IAU, C41)
- G. Hon (Israel)
- A. Mosley (UK)
- J. M. Pasachoff (USA, IAU)
- J.-C. Pecker (France, IAU, C41)
- S. J. Rabin (USA)
- B. Stephenson (USA)
- J. Włodarczyk (Poland, IAU)
- G. Wolfschmidt (Germany, IAU, C41)

The aims of the proposed working group would be to promote Johannes Kepler awareness and studies through:

- Representations at international level with other organizations and institutions, specifically ICSU and its member organizations (e.g. the IUHPS)
- Promoting the digitization of Kepler's published works and unpublished manuscripts
- Promoting the maintenance of paper editions of the KGW (e.g. via print on demand)
- Establishing an IAU WG website dedicated to Johannes Kepler
- Establishing contacts with the *Bayerische Akademie der Wissenschaften* to secure continued access to the rich Kepler resources of the defunct *Kepler-Kommission*

- Producing and encouraging relevant publications (e.g. textbooks and monographs)
- Raising funding for projects relevant to Kepler studies

The proposal was handed presented to Clive Ruggles, Secretary of C41, immediately after the closure of the meeting.†

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† The proposal has since been accepted by Division XII on the unanimous recommendation of Commission 41.