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COPERNICUS AND IBN AL-SHATIR: DOES THE COPERNICAN REVOLUTION HAVE ISLAMIC ROOTS?

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I review first the main similarities and differences between the planetary models of Ibn al-Shatir (14th-Century Muslim astronomer) and of Copernicus. I show that important similarities reside in the technical aspects of the orbits constructed by the two astronomers but that fundamental differences are: (*a*) Copernicus adopted a heliocentric model while Ibn al-Shatir (and all Muslim astronomers) assumed a geocentric model, as strictly as possible; (*b*) Copernicus followed a clear inductive method while Ibn al-Shatir remained within the *Zij* (astronomical tables) tradition. On the question of the extent to which Copernicus had benefitted from the 'transmission' of those models and critiques of Ptolemy, I insist that neither Ibn al-Shatir nor any Muslim astronomer accepted, let alone proposed, a heliocentric model. I then briefly discuss the Copernican Revolution and try to assess the extent to which the Polish astronomer might have been influenced by earlier Muslim discussions on the centrality (or not) and immobility (or possible motion) of Earth.

The problem

The Arab Muslim 14th-Century Damascene astronomer `Ala al-Din Ibn al-Shatir (1304–1375) and his important works were only discovered in the 1950s by Kennedy & Roberts[1]. It was quickly realized that he was an accomplished astronomer, able to make sophisticated calculations based on old and new models, construct instruments, and perform detailed observations; he also worked as *muwaqqit* (timekeeper) in the Mosque of Damascus.

Kennedy & Roberts found that Ibn al-Shatir's planetary models, while being firmly geocentric, eerily resembled those of Copernicus, at least in their geometrical construction. This led to a reexamination of the possible transfer to — and influence on — European Renaissance scientists (particularly Copernicus) by late-Muslim-era astronomers; Gingerich, a leading contemporary historian of astronomy, has thus written[2], "Scholars are currently divided over whether Copernicus got his method for replacing the equant by some unknown route from the Islamic world or whether he found it on his own." He added, "I personally believe he could have invented the method independently."

Unfortunately, this discovery and new perspective has also produced a less scholarly discourse of claims that Copernicus took his theory from Muslim astronomers, a discourse which has lately got louder and bolder. Such claims range from the moderate to the extreme. One can find writers and speakers who state that Copernicus "took" his planetary geometry from Al-Tusi and Ibn al-Shatir (although the historical route by which this would have occurred is far from established) and only "added" his heliocentric innovation; one can also find published works where Arab/Muslim authors boldly state that Copernicus "plagiarized" from his Islamic predecessors, and sometimes that Muslim astronomers like Al-Biruni and Ibn al-Shatir did propose Sun-centred cosmologies.

Among the group of moderate authors, those who stress Copernicus' full knowledge of (and thus deep influence by) Ibn al-Shatir and other Muslim astronomers, one may cite Fernini[3]; he writes, "[Ibn al-Shatir's] planetary models *refuted* those of Ptolemy and with the reservation that they are geocentrics, they are the same as those of Copernicus" (emphasis mine). Fernini, an astronomer, does understand the intricacies of the planetary models under discussion, but he does play down the crucial heliocentric–geocentric model difference and tends to ignore the fact that their new geometric model turned out to be completely wrong. He states[3], "This planetary model most likely influenced Copernicus through Byzantine intermediaries and, with the work of Al-Tusi's followers, contains all the novelties of Copernicus' astronomy except the heliocentric hypothesis."

In the second, much more extreme category of authors, one glaring example is Nas E. Boutamina, who titles the sixth chapter of his recent book[4] 'The era of plagiarism and looting', in which he presents in tabular form dozens of (totally unsubstantiated) claims of plagiarism of Muslim works by Renaissance authors and scientists; for example, according to him, Copernicus and Kepler plagiarized their great works from Al-Biruni, Al-Farghani, Al-Bitruji, and Ibn Yunus; Tycho Brahe would have plagiarized from Al-Buzjani, *etc*.

The serious problem of misrepresentation that has developed around the 'similarities' between the models of Ibn al-Shatir and of Copernicus stems from a hasty reading and misunderstanding of the commentaries made by some contemporary historians of astronomy regarding the works of Ibn al-Shatir. For instance, George Saliba, one of today's main experts on Islamic astronomy, writes[5], "Aristarchos [and] Biruni ... did acknowledge that the same phenomena could either be explained by a fixed Earth at the center or by a moving one." He quickly adds, however, "but that did not change the Aristotelian cosmological conditions one bit."

The Ptolemaic and the Muslim astronomers' models

Although the idea that the Sun could be the centre of the world was proposed more than once in ancient times, it was the geocentric model (in various versions) that prevailed in most of astronomy's history until Copernicus. Indeed, Aristarchus of Samos (310–*ca.* 230 BC) is often cited for having formally proposed a Sun-centred model of the Universe, but historians know that others before and after him had suggested the same; Copernicus himself acknowledges Hicetas (as cited by Cicero) and others he does not name (though he gives Plutarch as a reference); we now also know that the 15th-Century Cardinal Nicholas of Cusa advanced the idea of a moving Earth by assuming a plurality of the worlds, and it is also quite well established* that Abu al-Rayhan Al-Biruni (973–1048) did consider and discuss the heliocentric hypothesis he had found in Indian books, but ended up rejecting it after noting that the Earth's speed would be so large that effects in nature would be very easily noticeable.

The centrality of Earth in the world was unanimously accepted by Muslim scientists and philosophers. There are two main reasons for that: (*a*) although the Quran does not impose or even clearly promote a geocentric view of the cosmos, it is, however, resolutely anthropocentric, stating clearly that everything in the world was created for Man's benefit; (*b*) the Muslim intellectual tradition was largely Hellenistic in its assumptions and outlook — except for cases like Al-Biruni, who was equally Indian in his background knowledge — hence the adoption of the Ptolemaic geometry and of the Aristotelian physics and (geocentric) cosmology.

The model of planetary motion developed by Ptolemy (*ca.* 90–168 AD) can be found in any textbook of introductory astronomy. Its basic features, illustrated in Fig. 1, are: (*a*) its geocentric nature; (*b*) the circular motions of all objects; (*c*) the addition of 'epicycles', 'deferents', and an 'equant' (a point symmetrically opposite to the Earth with respect to the centre of the deferent), in order to account better for the observations.

The Muslim astronomers worked largely within the Ptolemaic framework but sometimes adopted different values for the orbital parameters or even proposed significant modifications to his scheme, such as imposing a fully geocentric and/or uniform orbital motion for the planets. For example, Muhammad Al-Battani (*ca.* 853–929), one of the greatest Muslim astronomers of the whole era, one who was cited[2] 23 times by Copernicus in *De Revolutionibus*, produced his *Zij* (astronomical tables) strictly within the Ptolemaic model, but with new values for some of the parameters.

It was not unusual for Muslim astronomers to formulate 'doubts' (*shukuk*) or critiques regarding the Ptolemaic system. For example, Ibn al-Haytham (965–1039), the Muslim polymath who is widely considered as the founder of modern optics and who also made important contributions in astronomy and several other sciences, was one of the first to voice such doubts/critiques, but these were often (though not always) made on philosophical rather than observational bases, and they never called into question the geocentric nature of the model. The equant concept was particularly bothersome to the Muslim astronomers, who much preferred a system with the Earth exactly at the centre, and with perfect circles and uniform motions. Ibn Rushd (Averroes, 1126–1998), the great Andalusian philosopher and scientist, strongly objected to the whole system on precisely such grounds and declared it thus to be no more than a mathematical construct that is "contrary to nature." Another Andalusian astronomer, Al-Bitruji

* On the medieval Muslims' views on heliocentrism, the *Encyclopedia of Chemistry* states the following: "In 1030, Abu al-Rayhan al-Biruni discussed the Indian heliocentric theories of Aryabhata, Brahmagupta, and Varahamihira in his *Ta'rikh al-Hind* (*Indica* in Latin). Biruni stated that the followers of Aryabhata consider the Sun to be at the centre. In fact, Biruni casually stated that this does not create any mathematical problems."

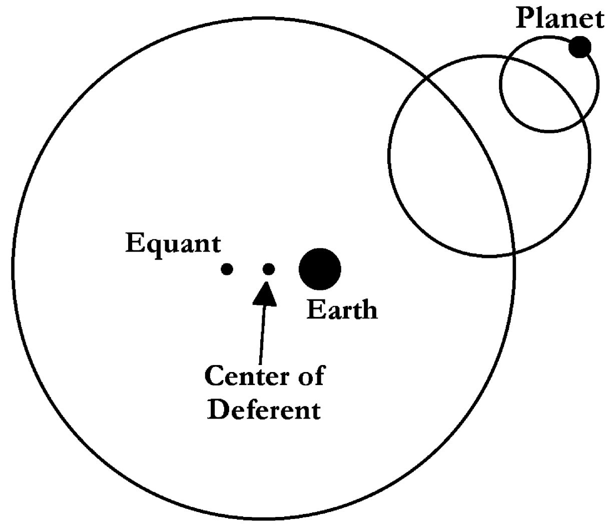

FIG. 1

A Ptolemaic model of a planetary orbit, where in addition to epicycles around a deferent, an 'equant' has been introduced: the Earth is shifted away from the centre of the deferent, and the point symmetric to Earth with respect to the centre is the equant; the planet is then constrained to move uniformly about the equant.

(died *ca.* 1204), whose different order of the planets (placing Venus above the Sun) was cited by Copernicus, went so far as to construct a strictly geocentric model, which led to enormous disagreements with the observations. Al-Tusi (1201–1274), another great astronomer, philosopher, and scientist (for whom Ulugh Khan built the famous Maragha observatory in Southern Azerbaijan, present-day Iran), also got rid of the equant in his model; he did so by adding two small epicycles to each planet's orbit, the famous 'Tusi couple'. Al-Tusi thus launched an influential new 'school' of astronomy; other important members were Mu´ayyad al-Din al-`Urdi and Qutb al-Din al-Shirazi.

Ibn al-Shatir's and Copernicus' models

It is thus in this context that Ibn al-Shatir appeared, barely a century after the radical model of Al-Bitruji and a mere 30 years after the formulation of Al-Tusi's mathematical constructs and theorems. As Ragep stresses[6,7], Ibn al-Shatir must be viewed fully in continuity of the eastern school of Ptolemaic reformulation, *i.e.*, Al-Tusi's, and not the western, Andalusian school, *i.e.*, Ibn Rushd's and Al-Bitruji's, which was much more radical but failed in its programme. To put it succinctly, the trend was to push back for truly geocentric models and to try to stick to perfect (as opposed to eccentric) circles and uniform motions as much as possible.

Ibn al-Shatir, and Copernicus at first (in his *Commentariolus* but not in his *De Revolutionibus*), thus inherited from the astronomy of the times the tendency to get rid of the equant. So Ibn al-Shatir constructed a completely concentric arrangement of the planets by adopting a system very similar to that of Al-Tusi;

he remained fully geocentric and retained the deferent and epicycle circles. He introduced certain changes and new concepts or details, for instance, making a distinction between the 'apparent epicyclic apogee' (*al-dhirwat al-mar´iya*) and the 'true epicyclic apogee' (*al-dhirwat al-haqiqiya*). But none of these modifications can be considered as truly fundamental, much less revolutionary.

Kennedy & Roberts hail the work of Ibn al-Shatir and show remarkable similarities with specific aspects of Copernicus' orbits but insist that neither Ibn al-Shatir nor Copernicus was first in introducing some of the features we find in common between them. It is thus clear that Ibn al-Shatir was influenced by the Maragha School, although he was indeed somewhat novel and ingenious in the system he proposed. It is further possible that Copernicus did not know of Ibn al-Shatir's model and works but rather learned the same lessons from their common predecessors and made a similar development in model construction, which resulted in an analogous system, albeit with some differences. Indeed, as Gingerich tells us[2], "some of the Al-Tusi material is known to have reached Rome in the 15th Century…" but he does add that "there is no evidence that Copernicus ever saw it." One huge mystery that has contributed to the debate (and sometimes suspicions) of whether Copernicus took important elements of his planetary model from his Islamic predecessors is that while he does cite Al-Battani, Al-Bitruji, Az-Zarqali, Ibn Rushd, and Thabit Ibn Qurra in *De Revolutionibus*, he does not mention Al-Tusi or any of the Maragha astronomers, although it has been shown that some of the diagrams and mathematical tools (*e.g.*, the Tusi couple) that Copernicus used are almost literally copied from Arabic sources. Why would Copernicus cite some — many times — and ignore others? Perhaps the answer is that some of the Maragha material that he used reached him without proper reference and/or *via* medieval western sources.

Kennedy & Roberts do find important differences between Ibn al-Shatir and Copernicus. First they find evidence that the Polish astronomer understood what today we would call "the commutativity of vector addition", while there is no evidence of that in the Damascene astronomer's work. Most importantly, the main work of Ibn al-Shatir that has been found and studied, *Nihayat al-Sul fi tashih al-usul* ('The Final Quest concerning the Rectification of Principles'), resembles Copernicus' *Commentariolus* more than *De Revolutionibus* in that the first one contained only quantitative descriptions of the systems, whereas Copernicus' latter (final) book presented a full analysis leading from the observational data to the theory. Kennedy & Roberts give Ibn al-Shatir the benefit of the doubt in stating that he "may have done the same in his *Ta`liq al-arsad* … but no copy is known to have survived", and so does Saliba, who states[5] that the Damascene astronomer "devoted a whole book (*Ta`liq al-arsad*, meaning 'Accounting for Observations') to this particular relationship between observations and the construction of predictive models", but since the book "seems to be unfortunately lost … we may never know the extent of his theorizing in this regard." Kennedy & Roberts, however, do not lose from their sight the essential difference between the two models, namely that there is no trace of a heliocentric view in the works of Ibn al-Shatir.

The relative importance of Copernicus' two moves, namely his adoption of the Al-Tusi–Ibn al-Shatir geometric orbit constructs on the one hand and his decision to shift the centre of the world from the Earth to the Sun, is not always made very clear. Indeed, Saliba, for instance, tends sometimes to underscore the second idea (of heliocentrism), referring to it as a "genius idea", yet at other times he tends to suggest that Copernicus' adoption of the Maragha School's (and Ibn al-

Shatir's) orbital geometry is extremely important and that it perhaps even somehow paved the way to the heliocentric idea.

Thomas Kuhn, the historian and philosopher of science, has carefully analyzed the Copernican Revolution, which he refers[8] to as an "upheaval in astronomical and cosmological thought". Kuhn remarks that while the opus itself may have been drafted in a very traditional and conservative manner, without realizing it the Polish astronomer had produced "a revolution-making rather than a revolutionary text", and that "within [the] general classical framework [of *De Revolutionibus*] are to be found a few novelties which shifted the direction of scientific thought in ways unforeseen by its author and which gave rise to a rapid and complete break with the ancient tradition."

The roots of the revolution

So then how did Copernicus arrive at this revolutionary idea? And most importantly for us, was he influenced by the Muslim works that preceded him?

Let me first note that it is usually accepted that what led Copernicus to move to a Sun-centred cosmology had as much to do with philosophical and aesthetic reasons as with the mathematics (geometry) of the planetary orbits; indeed, Copernicus criticized the Ptolemaic system as "not sufficiently pleasing to the mind". The Polish astronomer had insisted (in the letter to the Pope with which he prefaced *De Revolutionibus*) that his decision to adopt a moving-Earth model was primarily driven by the fact that "the mathematicians" (his predecessors, the ancient and medieval astronomers) were inconsistent and unable to account for such features as the constant length of the seasonal year (see reproduction of letter in ref. 8). But the man is also known to have been a strong adherer to Neo-Platonism (Kuhn writes[8] on page 141: "a man without Copernicus' Neoplatonic bias might have concluded merely that the problem of the planets could have no solution that was simultaneously simple and precise.") and a lover of the Sun as a quasi-divine object.

A few researchers have tried to retrace the genesis of the 'revolution' in Copernicus' mind. Some have adopted the 'independent proposition' paradigm (that Copernicus came up with it without any hint from his predecessors), and others have tried to find ideas in the predecessors' works that may have pointed him to the new system. For example, Swerdlow is convinced[9] that Copernicus must have been fully aware of the Islamic tradition of reforming the Ptolemaic system, in particular the move to rid the model of the equant. He believes that when Copernicus attempted to remedy to the main anomalies of the 'classical' model, he found that if one tried to avoid eccentric models or mixed (geo/heliocentric) ones where orbits ended up intersecting, the only satisfactory solution was to put the Sun firmly at the centre.

Jamil Ragep[6] has gingerly argued for the existence of some latent concepts of non-geocentric astronomy in the ideas developed by the Maragha School, particularly those of Al-Tusi and of `Ali al-Qushji (died 1474). Ragep recalls that Al-Tusi, contrary to Ptolemy, believed it impossible to decide either theoretically or observationally whether the Earth was fixed or moving. Earlier, both Aristarchus and Al-Biruni had realized that celestial phenomena could be explained either way. Ragep also emphasizes Copernicus' usage of Al-Tusi's arguments against Ptolemy's view of the Earth's immobility, noting that Al-Tusi's position was adopted by the later Maragha astronomers, including Al-Qushji, thus making this "a conceptual revolution that was going on in Islamic astronomy". He adds, "The fact that we can find a long, vigorous discussion in Islam of this issue intricately tied to the question of the Earth's movement should indicate that such a conceptual foundation was there for the borrowing."

It is a rather stretched conclusion to go from "there is no objection to having the Earth rotate or even move" (and Al-Qushji declared[6,7] that "nothing false follows from the assumption of a rotating Earth") to "one may start constructing a heliocentric cosmology". But one aspect of this viewpoint is important, namely the insistence that many non-Ptolemaic ideas (though nothing heliocentric) had circulated among Islamic astronomers, contrary to the situation in Europe.

A crucial question that one should ask in this context, especially considering Saliba's remarks[5] that Ibn al-Shatir's 'geometrically unified model' paved the way for Copernicus' heliocentrism, is simply: why didn't any of the Muslim astronomers ever show any interest in such a model? Saliba answers that the physics of the time (up to and including Copernicus) was Aristotelian, therefore it made no sense for Muslim astronomers to propose such a schizophrenic system as Copernicus did. Saliba "raise[s] the question of the scientific legitimacy of heliocentrism itself in a pre-Newtonian universe, where no alternative cosmology was yet available." He insists that "without the benefit of the Newtonian law of universal gravitation, how could [anyone] have hoped to maintain the system together?" But that amounts to rejecting any non-deductivist development in the history of science, when in fact there are numerous examples of laws that were constructed in a totally empirical way without the slightest understanding of the first principles that led to them; Newton's law of universal gravitation is the perfect example, since it was largely inferred from Kepler's laws, which were completely empirical and for which neither Kepler nor anyone could propose any explanation. In fact Newton's law was long regarded as mysterious by Newton himself, who saw the instantaneous action at a distance as essentially occult. This did not stop Kepler, Newton, and the multitudes of scientists after them from recognizing the validity of those and other laws, which were left to be explained later. To excuse Muslim astronomers and even applaud them for staying true to the physics of their times is not, in my view, a reasonable position.

Finally, we may mention Seyyed Hossein Nasr, the Iranian philosopher of science who has tried to answer the question of why, if a "conceptual foundation" for non-geocentric models had indeed developed in the later periods of Islamic astronomy, the Muslim astronomers didn't come up with anything resembling Copernicus' heliocentric model, let alone Kepler's? Nasr's view[10] is that the Muslim astronomers in effect saw the (full) revolution that was in store should any non-geocentric cosmology develop, and that they simply held back in order to prevent any philosophical and religious upheaval from occurring. It is a purely speculative retrospective view of history, one that has little evidential support.

Summary and conclusions

Let me now briefly summarize the main ideas and findings from this general review of the story of Copernicus, Ibn al-Shatir, and the Copernican Revolution.

(*i*) There are important similarities and differences in the works of Ibn al-Shatir and Copernicus: (*a*) The first main similarity is in their common attempts to make use of 'vectors' (Tusi-type epicycles) that could produce uniform motions. (*b*) Another similarity is in Ibn al-Shatir's insistence on discarding the equant, and Copernicus' acceptance of that. (*c*) The obvious fundamental difference between the two models is that Copernicus' was heliocentric while Ibn al-Shatir's was firmly geocentric. (*d*) The second important difference between the works of the two astronomers is that Copernicus adopted a clear inductive approach (from data to theory) while Ibn al-Shatir seemed to remain within the *Zij* tradition.

(*ii*) Ibn al-Shatir never so much hinted, let alone declared, that the Earth or any planet moved at all (around the Sun or even around itself); on the contrary, the modifications he brought to Ptolemy's model aimed at making it more strictly geocentric.

(*iii*) Copernicus did construct a model that was in its technical (geometric) aspects very similar to that of Ibn al-Shatir, especially for the Moon, but also to a large extent for Mercury and Venus, but that whole model was later shown (by Kepler) to be utterly wrong and replaced by a model of simple elliptical orbits with the Sun at one of the foci.

(*iv*) There is no evidence that Copernicus read Ibn al-Shatir and chose never to mention him. If Copernicus acknowledged and cited Al-Battani 23 times and mentioned Al-Bitruji and other Muslim astronomers, it would really be an amazing, deliberately ill-intentioned act on his part to leave out Ibn al-Shatir altogether. The more likely explanation is that both men were influenced by the Maragha School's models and made modifications and developments that led to very similar models (technically), although conceptually very different. In this regard, one should note that Hartner[11] has convincingly shown that Copernicus essentially copied (with someone else's help, since he didn't know any Arabic) Al-Tusi's proof of his 'couple', replacing the Arabic symbols with Latin ones, without duly crediting the Muslim astronomer; again, perhaps Copernicus never read any of Al-Tusi's works, that he found the Maragha astronomer's theorem somewhere else and used it without correct referencing.

Still an important underlying question remains to be addressed: since it has become quite clear that Copernicus was indeed influenced by the Maragha School's 'new astronomy' and since there was in Europe up to that point no tradition of criticism toward the Ptolemaic planetary system, how could a classically-minded medieval European come up with a theory that would truly revolutionize astronomy and usher in modern science and a new world view? I explained that in the absence of sufficient historical data, researchers have adopted one of two positions: (*i*) a 'conceptual foundation' had started to be built among the Islamic astronomical community that substantial modifications to the Ptolemaic system needed to be made, and Copernicus became fully aware of that; his subscription to Neo-Platonism and the special place of the Sun in his philosophy led him to formulating the heliocentric hypothesis; (*ii*) Copernicus remained firmly within the classical astronomical tradition (as the *Almagest*-like structure of his book shows) and only proposed a Sun-centred model because it looked simpler and more aesthetically pleasing than the cumbersome and thoroughly imperfect Ptolemaic system.

Finally, I would like to conclude by commenting on the contemporary problem of the continued erroneous presentation of the 'similarities' between Copernicus' model and those of his Islamic predecessors. Indeed, there has been a growing insistence in the Arab/Muslim world (at least among the non-expert but educated society) that the Copernican revolution was explicitly or implicitly "in the works" of Muslim astronomers and that Copernicus at best dotted the 'i's and crossed the 't's.

I believe that despite many efforts at unearthing and presenting to the (Muslim and western) public the wealth of scientific works that the golden-era Muslim scholars produced, there is still serious ignorance as to exactly what was done. Most of the discourse on the 'Islamic civilization' has remained superficial and ill-informed. And that is why we hear academics proclaiming that Al-Biruni and Ibn al-Shatir proposed that planets orbit the Sun and that Copernicus took his theory from the Damascene astronomer. Gingerich could not have put it more clearly when he wrote, "The Islamic astronomers would probably have been astonished and even horrified by the revolution started by Copernicus."

Gingerich, Kennedy, Kuhn, Kunitzsch, Ragep, Saliba, and such researchers do their work with great care and attention, reading and analyzing the sources, following the historic trail and crediting each scientist with due measure. It is hoped that all writers on such topics adhere to such rigorous methodology, making only measured and substantiated claims instead of extrapolating from superficial readings of secondary and tertiary sources.

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REVIEWS

Thomas Hardy's Novel Universe: Astronomy, Cosmology and Gender in the Post-Darwinian World, by P. Gossin (Ashgate Publishing, Aldershot), 2007. Pp. 300, 24 × 16·5 cm. Price £50 (hardbound; ISBN 978 0 7546 0336 8).

[The Editors have elected to publish two reviews of this work: the first, by Allan Chapman whose knowledge of Victorian astronomy is unsurpassed, emphasizes the scientific context; the second, by David Wright — who drew our attention in these pages (**118**, 301) to Hardy's astronomical interest in astronomy — concentrates on Hardy's writing.]

Over the past few decades the novels of Thomas Hardy have come to enjoy a new lease of life, with TV adaptations of some of the most popular, being as they are full of passion and conflict, and set within a magically-evoked world of Victorian Wessex. Yet what is less well known about Hardy is his lifelong passion for science, especially for the then new science of astrophysics, and the way in which it, geol-