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Medieval Science in Dante's *Commedia*: Past Approaches and Future Directions

Simon Gilson

University of Warwick

Despite the seminal work of Bruno Nardi and a recent revival of critical interest in Dante's knowledge and use of medieval science in the *Commedia*,¹ there still remains much work to be done in order to identify, contextualize, and appreciate more fully and critically the many different gradations of scientific allusion and reference in the poem. This article aims to provide a critical overview of past findings and approaches to this important and wide-ranging topic, and, in so doing, it suggests some possible directions for further scholarly and critical enquiry. The article itself is divided into three main sections, which examine the meaning, nature, and extent of science in the *Commedia*, consider past approaches to Dante's use of such material, and outline some considerations for future study.

i. Medieval Science and Dante

At the outset, it is important to clarify what is meant by the term 'science' in a Dantean context. In the last thirty years much theoretical discussion has been devoted to the interactions and interrelationships between the variously defined discourses of science and literature.² As a result of this work, there is a better appreciation of the problems involved in defining and delineating science and literature, and of the ways in which definitions of each of these categories are diachronically related to the complex interaction of an array of social, institutional, ideological, and cognitive factors. For our purposes, one of the more important points that arises from such discussions is the appreciation that the history of the overlap between what we now call science and literature is far more extensive than that of their separation. Only in the eighteenth century did their conceptualization into separate categories become firmly established, and it is crucial to be aware that the dichotomy did not exist throughout much of western intellectual and literary culture. Numerous examples of the unity of human *scientia* can be drawn from the activities and writings of intellectuals

in late medieval and early modern Europe. Without even mentioning Dante or Cecco d'Ascoli, the Italian vernacular tradition alone in the years from the birth of Dante to the death of Petrarch yields numerous examples. Several decades before the first cantos of the *Inferno* entered into circulation, lyric poets were using medical doctrines to analyse and describe the love passion, often in a consummately intellectual way.³ Boccaccio had a strong, life-long interest in astrology, which finds literary expression most notably in the *Teseida*.⁴ And while it is true that Petrarch, with all his ambivalence and scorn for medicine, astrology, and the logic-chopping of medieval scholastic science, might be seen as the first humanities man *ante litteram*, it is worth noting that even he will occasionally draw on scientific concepts in his lyric poetry.⁵

It is the longstanding overlap, the oneness of the discourse that is now referred to separately as science *and* literature, which explains the enduring value of C. S. Lewis' *The Discarded Image*, and why any serious student of Dante must at some stage come to terms with the terminology, concepts, and aims of medieval science. The suspicions spawned by a now distant but still suggestive Romanticist distaste for what Keats alluded to as the unweaving of the rainbow as well as more proximate notions of 'Two Cultures' are latter-day accretions which risk distorting enquiry into Dante's preoccupation with medieval science.

To get closer to Dante's concerns and attitudes, then, it is important to realize that, in late medieval Italy, the words *scientia* and *scienza* connoted profound knowledge of any object's nature, its causes, and its origins.⁶ Dante and his contemporaries repeatedly use the noun and its cognate forms in this way, and one commonly finds the early commentators on the *Commedia* referring such terms not only to natural philosophy, arithmetic, geometry, and astrology, but also to a variety of other disciplines such as theology, grammar, dialectic, rhetoric, music, and poetry.⁷ To be more precise and specific about 'scientific' material in the *Commedia* it is, however, more useful still to think of the many passages in the poem that either deal with or are underpinned by a rational understanding of the entire physical universe, both celestial and sublunar, of all its many and various processes, and of the nature and place of inanimate and animate beings within it. In other words, science in a Dantean context is a wide-ranging and finely differentiated philosophy of nature, a largely coherent vision of the natural order, controlled by a set of

philosophical presuppositions, and extending from the spontaneous generation of maggots below the earth to the motions imparted by the pure intellectual substances responsible for rotating the outermost heavenly sphere. Natural philosophy (*philosophia naturalis*) is perhaps a better word to use for this vast field of enquiry – but there is some justification in retaining the word science given that the term *scientia naturalis* was also used in the Middle Ages and that Dante himself uses the word *scienza* to refer to natural philosophy (*Inf.* VII, 106).

Having established the importance of natural philosophy, some consideration must now be given to the kinds and forms of knowledge about the natural world that were available to Dante. Before 1100, the majority of natural lore known to medieval Europe was available largely through rudimentary late Roman and early medieval compendia and encyclopaedic works, as well as through the study of the scientific subjects of the *quadrivium* (arithmetic, music, geometry, and astronomy). The first major impetus to expand and redefine such materials came with the revived interest in cosmology brought about by the recovery of Plato's *Timaeus* (up to 53B) and intense reflection upon it by the masters and students of the Cathedral schools of twelfth-century northern France.⁸ This revitalized interest in the natural world was also accompanied by a new emphasis upon the scientific subjects of the *quadrivium* in the period from 1150 onwards.⁹ The twelfth-century writings and the intellectual humus from which they derive undoubtedly have some influence on Dante's vision of nature. But the kinds of ideas, methods, and modes of argument that Dante repeatedly draws upon derive principally from a form of medieval natural philosophy which was elaborated following the translation, assimilation, and adaptation (c. 1120-1270) of Aristotle's *libri naturales* – his writings on nature and the place of human beings within it.

The *libri naturales* comprise works on change in the natural world (*Physica*), on the heavens and their motions (*De caelo*), on how the four sublunar elements combine (*De generatione et corruptione*), on atmospheric phenomena (*Meteorologica*), on human psychology and physiology (*De anima*, *De sensu et sensato*, and the other short treatises included in *Parva naturalia*), and on the animal kingdom (*De animalibus*, *De partium animalium*, *De generatione animalium*, and *De motibus animalium*). Even though encyclopaedic works, textbooks related to quadrivial subjects, and to a lesser extent the *Timaeus* continued to be studied in the thirteenth century, the

rediscovery of Aristotle's works is the single most significant factor. And it is Aristotle who is the single most important scientific source for Dante, furnishing him with an extensive corpus of information about the physical world, and a related set of analytical concepts and technical vocabulary. It was general texts like the *Physica* and *De anima* which provided Dante and other medieval intellectuals with the framework for directing rational enquiry, controlled by a sophisticated concept of causality, into the essences behind a world of change.

And yet medieval science is far richer and more variegated than the earlier material and Aristotle alone because of the way in which scientific writings were assimilated and the accretions that were made to them. Translations of Aristotle formed one part of a wider effort to translate and absorb the immensely rich and varied Greco-Arab philosophical and scientific heritage. Scholars in the Latin West also ventured both knowingly and unwittingly outside the Aristotelian corpus by including Pseudo-Aristotelian works¹⁰ and making close and detailed use of late Greek, Arab, and medieval commentaries, especially those by Averroës which became available in Latin translations from 1225. Scholastic writers also made repeated reference to independent Arab and medieval treatises on a wide range of scientific topics that were either absent from, or marginal to, Aristotelian natural philosophy. Conceived of in the abstract, then, medieval science includes disciplines such as astronomy and astrology, which are dealt with in part by Aristotle, but were especially developed in the Hellenistic and Arab worlds by authorities such as Ptolemy, Abu'Mashar, Alpetragius, and Alfraganus. It also includes a number of specialist and sub-disciplines, in particular medicine, alchemy, and optics, which again have Greek foundational principles, but were cultivated and significantly refined by Hellenistic and Arab writers, most notably Galen, Avicenna, and Alhazen.¹¹

Of course, to conceive medieval science in the abstract, as a pure realm of disembodied ideas or even as a set of selected *auctoritates* is to fundamentally misunderstand and obscure its development in specific institutional structures and the differing emphases its various branches acquired in different geographical areas, schools, and individual thinkers. Not surprisingly, the world-view put forward by the recovered Greek and Arab learning posed many problems for churchmen steeped in biblical accounts of, and theological commentaries on, the creation of the universe and of man. As is well known, there is a long and tortuous history to the assimilation of this

body of learning by Christian writers, especially at the University of Paris, where several condemnations of theses based on Aristotle were issued in the thirteenth century.¹² At the centre of these conflicts, historians have identified a thirteenth-century intellectual current, now known as radical Aristotelianism or Latin Averroism, which arose in the Paris Arts Faculty and is most closely identified with the philosophical interpretation of Aristotle advanced by Siger of Brabant and Boethius of Dacia. Yet despite the legends of Dante's journeys beyond the Alps and of his scholastic disputations in Paris and even in Oxford, one need in fact go no further than medieval Italy to understand how he came into contact with much of the newly-available scientific writing. In Italy a central role was played in the diffusion of such ideas by the structures that developed around intellectual centres such as Bologna, Pavia, and Padua with their flourishing and highly distinctive lay cultures, which, unlike Paris, studied Aristotle as an introduction to medical studies rather than theology.¹³

Notwithstanding the many difficulties that are involved in establishing Dante's places and periods of study as well as his precise programmes of reading, the text of the *Commedia* provides a good indication of his close acquaintance with various branches of medieval science. As poet of the *Commedia*, Dante shows a detailed understanding of the underlying principles and subject-matter of astronomy, of ideas related to elemental change and meteorology, of the nature and operations of the human soul and the human body, of the animal kingdom, of medicine, and of optics. And he also made use of subjects which today are often deemed pseudo-scientific, especially the very popular and important discipline of astrology, as well as some elements of medieval magical lore and of specialist disciplines such as alchemy, mineralogy, and physiognomy. In the *Commedia*, Dante makes several references to geometry and mathematics, and he shows an interest in using symmetries based on number within the design of his poem. As well as all these subjects,¹⁴ one can also identify certain areas of concern that were not defined as scientific disciplines as such in the Middle Ages but are useful ways of putting together a range of medieval ideas. Cosmology – ideas about the universe as an ordered whole – is an especially good example in this respect, but mention must also be made of the geographical and geophysical conceptions with which Dante shows a close familiarity.¹⁵

Despite a formidable bibliography in certain areas (most notably Dante's astronomy), there still remains considerable work to be done in identifying and contextualizing all the relevant Dantean *loci* that are directly and indirectly informed by the intellectual patrimonies mentioned above. In some subject area, such as the animal kingdom or natural history, relatively little work has been done by Dantists either to appreciate the medieval scientific context or to consider the textual value of Dante's references and their place within the economy of the poem as a whole. Even in an area such as cosmology, which has received critical attention, a wide-ranging reconsideration with attention given to earlier material like the *Timaeus* and its commentary tradition, as well as to the *De caelo* and its medieval commentaries, medieval encyclopaedias, and several other categories of writings (see section III below), would repay detailed study. There are also many passages involving natural phenomena in the *Commedia* where a scientific understanding is implicit but often goes undetected. Much of the characteristic verisimilitude of the poem derives from the fact that similes and other comparisons are subtly underpinned by the poet's own knowledge of medieval scientific ideas and principles. The scientific basis of this Dantean imagery has not always been adequately recognized, and it is therefore relatively easy to provide examples where Dante relies on contemporary discussions of Aristotle's *libri naturales* in passages which are not noted in modern commentaries on the poem. The medieval Aristotelian matrix that informs much of Dante's imagery is, for example, evident in his reference to changes in colour in *Inferno* XXV, 65-66, in descriptions of sound transmission in *Purgatorio* XXVIII, 107-09 and *Paradiso* XIV, 1-8, and in the analogies made between swimming and flying in *Inferno* XVI, 130-36 and XVII, 100-01 and 115-16.¹⁶

ii. Approaches to Dantean Science

Having outlined the meaning of science and the range of subjects it encompasses in Dante, it is now necessary to provide an overview of past approaches to the presence of this material in the *Commedia*. The study of scientific references in the *Commedia* begins with the Trecento commentators, several of whom elucidate Dante's more scientific passages by citing Greek and Hellenist philosophers (Euclid, Aristotle, Galen, and Ptolemy), Arabic astronomers, astrologers, and medical writers (Alfraganus, Abu'Mashar, and Avicenna), and near

contemporaries (Albert the Great), as well as by referring to the disciplines of arithmetic, medicine, perspective, astronomy, and astrology.¹⁷ In the Renaissance, the most widely-known commentary on Dante, the *Comento sopra la Comedia* by Cristoforo Landino (1481), reveals a strong interest in Dante's science, especially his cosmography and astrology, even though this area of his *Comento* has received relatively little attention to date. In the Cinquecento, this emphasis is far less pronounced in Alessandro Vellutello's commentary (1544), but a concern with Aristotelian natural philosophy is still found in Bernardo Daniello's *Espositione* (1568), and the study of certain aspects of Dantean science, including his cosmography, is a very prominent feature of the Florentine Academy lectures and publications on Dante.¹⁸

But it is another great century of Dante criticism, the Ottocento, in which a way of approaching Dante's science emerges which in part still persists to this day and this is the attempt to fragment off the science in Dante and to make him into a mythologized precursor of modern scientific discoveries. The popularity of this approach is such that, in the last one hundred years, critics have argued that certain passages in the *Commedia* anticipate the Newtonian law of gravity, contemporary ideas related to the diffusion of sound, to the formation of the rainbow, and to the visual process, and still more recent theories regarding the shape of the universe as a three-dimensional sphere and the hypersphere.¹⁹ Despite the enthusiasm displayed in several of these articles, it has to be said that such approaches are often profoundly misguided. Modern science is characterized by its non-religious, rational objectivity, its use of experiment to verify theories, its close links with technology in order to manipulate nature, and its concern with providing universal, law-like statements.²⁰ Not surprisingly, if one takes these characteristics and applies them to what might be termed the scientific content of the *Commedia*, then science is indeed a misnomer. Dante's science is, like the medieval science upon which it is based, replete with a-priori notions, lacking in quantitative rigour, and without a consistent empirical foundation. His poem is deeply rational, but it also demonstrates a very strong concern with the realms of transcendence, emotional response, and the quasi-mystical. Dante does give an account of an experiment with three mirrors but this is a bookish imitation as part of a scholastic refutation, not in any sense the experimental method of a Galileo or a Newton.²¹ The only 'manipulations' of the natural order in the

Commedia arise not from technological interventions but as a result of God's direct action on the universe. Dante does allude to early mechanical clocks, but he makes no direct reference to the most celebrated technologies of his age – the astrolabe and spectacles.²² More importantly still, the work of the best scholars of Dante's scientific culture has repeatedly shown that Dante was not the forerunner of great discoveries of the future, but very much an intellectual of his age, an intellectual who was not in fact always fully cognizant of the latest currents in contemporary natural philosophy.²³ If Dante can be shown to be ignorant of some of the more recent developments in medieval science then it seems decidedly absurd to view him as a precursor of modern science.

At the opposite extreme from the view of Dante as precursor, there is also a tendency, which is sometimes voiced from outside Dante studies, either to dismiss or to discredit the scientific elements in Dante precisely because he was not at the forefront of developments in medieval science.²⁴ This is unfortunate because to assess Dante in this way is to fail to take account of his originality in using, as an Italian vernacular poet, scientific terminology and themes that were previously restricted almost exclusively to Latin-educated schoolmen. At a time when scientific, literary, and artistic cultures were in especially close and fertile contact, there is much to be learnt from Dante and other literary texts. And there are also insights to be gained from studying how ideas are (mis-)understood, adapted, transformed, and transmitted in and through literary sources such as the *Commedia*, many of which were widely available to a reading and non-reading public.

A more influential negative approach to science in the *Commedia* has come from within Dante studies itself, and this is the tendency to dismiss scientific passages because they are not deemed to be 'poetic'. Given Benedetto Croce's celebrated distinction between *struttura* and *poesia* with its privileging of isolated lyrical moments over the content of the *Commedia*, the tendency of later *crociani* to devalue and de-emphasize scientific passages should come as no surprise. Traces of these tendencies still persist in modern commentaries and it is not uncommon to find critics who refer to Dante's scientific passage with phrases like 'con passo avviluppato' and 'freddezza scientifica'.²⁵ That Dante does nonetheless create some of his most resonant poetry from the subject-matter of natural philosophy is confirmed by the two most extended scientific passages

in the poem: *Purgatorio* XXV, 37-108 and *Paradiso* II, 64-148. As Vittorio Russo has admirably shown, in both these cantos Dante mobilizes all his poetic resources – alliteration, assonance, consonance, rhythmic variation, harsh rhymes, internal rhymes, unusual verb metaphors, and extended similes – in order to create vibrantly complex phonic and verbal networks which are rich in rhetorical devices.²⁶

The discussion so far has omitted the most scholarly and recognized approach to Dante's philosophical and scientific culture: contextualization. The most notable figures associated with such an undertaking are historians of idea and of medieval philosophy, above all Bruno Nardi (1884-1968) and Etienne Gilson (1884-1978). Both Nardi and Gilson placed a strong emphasis on Dante's eclecticism, recognizing the difficulties attendant on source studies.²⁷ But it was Nardi above all who did more than anyone before him to place many aspects of Dante's philosophy and science within a fuller purview of the intellectual possibilities of his time. Contextualization will undoubtedly continue to form a central strand in future work on Dante's scientific culture, but it is important to realize that, despite Nardi's formidable range and energies, he far from exhausted the field of study (see my comments in the first part of this essay and in the Appendix). In the thirty-five years since Nardi's death, the recovery of minor texts, new editions of existing works, and the revision of previous estimates of medieval science has helped to create a climate which is favourable to extensive study and re-examination of Dante's science.

iii. Science and Poetry in Dante

The work that lies ahead of students interested in evaluating further Dante's use of science in the *Commedia* does not simply involve developing and extending Nardi's work, however. Indeed, perhaps the most urgent task is not so much quantitative as qualitative, not so much the examination of areas of Dante's thought but the consideration of the poetic implications of medieval science. In this respect, Nardi's contributions reveal some limitations which call for comment and qualification. Like other historians of ideas, Nardi devoted considerable energy to identifying various currents within the intellectual recrudescence of the thirteenth century, and the labels he used such as Avveroist, Avicennan, Neoplatonic, Platonic, and

Aristotelian have often been assimilated by Dante scholars. Nardi, Maria Corti, and others have placed much emphasis on Dante's contacts with Averroism (or radical Aristotelianism), the putative intellectual movement which attempted to distinguish and effectively separate philosophical and theological analysis in key areas of doctrine such as divine providence, the unity of the human soul, the influence of the stars, the eternity of the world, and human happiness.²⁸ And yet, despite some of the new insights provided most recently by Corti, it is worth sounding a note of caution in this difficult enterprise. There is no evidence that Dante himself ever thought in these terms, and the intellectual history of the period is so intricate and heterogeneous that one should be restive about invoking too readily such neat and discrete categories. What is referred to as Averroism is often closely bound up with more orthodox uses of Aristotle as well as with other Arabic influences. The medieval Aristotelian tradition itself is in fact permeated with Neoplatonic doctrines, as well as with other interests and authorities, in a way which opens up the term 'Aristotelian' to a multiplicity of possible meanings and applications.²⁹ What is clear is that Dante encountered a very hybrid Aristotle, for he almost always read Aristotelian scientific writings in medieval interpretations that re-adapted and on occasion profoundly altered the original Aristotelian text.³⁰

Following Nardi, Vasoli and Corti have also recently reaffirmed Albert the Great's role as an important conduit in transmitting to Dante Neoplatonic ideas and a variety of scientific teachings.³¹ Such views now seem to have formed part of a critical consensus in Dante studies, supplanting earlier notions of an exclusively (and excessively) Thomist Dante put forward by Neothomist critics such as Giovanni Busnelli and others in the early decades of the twentieth century. But once again some qualification may be necessary, not so much to correct Nardi as to ensure that his emphases, striated as they are with a vein of vigorous polemic, are not taken too univocally by contemporary Dantists. Albert is without doubt an important source for Dante who studied and made poetic use of certain Albertine works on the physical and celestial universe, related phenomena, and the human soul and its operations. Albert's paraphrases and independent treatises with their characteristically lengthy digressions are an especially important element here. It is not unusual to find his treatises punctuated with several consecutive chapters all headed: 'Et est digressio declarans ...'; and a close re-examination of the relevant

treatises in relation to the *Commedia* would undoubtedly produce further results.³² But it is also important to realize that Dante often read Aristotle through more than one commentary and paraphrase, and, as Enrico Berti's studies for the *Enciclopedia dantesca* demonstrate, he seems to have made an equally intensive use of several Thomist commentaries on Aristotle's *libri naturales*.³³ The more literal Thomist expositions also draw on a wide range of sources, including Neoplatonic writings and earlier commentaries, in order to restate Aristotle's text whilst adding clarifications and expansions. Albert thus needs to be located as an important figure in a wider ambit of Dantean readings of Aristotelian scientific texts which also embraced Aquinas' commentaries.

It is also essential to realize that Dante's reading in scientific matters extended far beyond the Aristotelian corpus, Pseudo-Aristotelian material, and related commentaries and *quaestiones* to include several other categories of writing in which scientific ideas play an important part. Dante appears to have been acquainted with Seneca's *Quaestiones naturales* and may have had access to other more strictly encyclopaedic works of both late antiquity and the Middle Ages.³⁴ It is especially important to stress the significance of such excerpted works, encyclopaedias, compendia, florilegia and summa, in which authoritative statements are often separated from their original context.³⁵ These texts, and the styles of reading associated with them,³⁶ are of considerable importance in appreciating Dante's scientific 'lettura', even if he also seems to have engaged – and unusually so for his time – in integral readings of some scientific writings with the assistance of commentaries.

The net of Dante's possible readings can also be usefully cast far wider than is traditionally done to include the doctrinal, philosophical, and scientific information found in literary sources and commentaries on literary works. It is important to remember that, in the Middle Ages, classical poets were often read *physice*, that is, as repositories of scientific learning, as true philosophers learned in natural science (*physici*) who veiled their wisdom beneath fictive coverings (*involucra, integumenta*).³⁷ Dante is certainly keen to adduce classical sources in support of scientific ideas in the *Convivio* (III, iii, 7-8; III, v, 12), and he may have gleaned much information, perhaps especially from Virgil and Lucan, through such readings and related glosses and commentaries. More detailed investigation into this neglected area of study may well produce interesting results.

As far as other literary works and commentaries are concerned, Dante undoubtedly draws on Cicero's *Somnium Scipionis*, along with Macrobius' commentary which reads Cicero's text as a poetic covering for doctrinal and scientific truths.³⁸ The twelfth-century philosophical allegories, Bernard Silvestris' *Cosmographia* and Alain de Lille's *Anticlaudianus*, set especially important precedents for Dante by using scientific ideas in poetry and by presenting the natural world as a self-sufficient, ordered reality of physical causes.³⁹ The scientific content of a mid-thirteenth century vernacular poem such as Brunetto Latini's *Tesoretto* and the later *Intelligenza* may also be worth investigating more closely. But perhaps the most important vernacular precedent for the literary assimilation of scientific material is Jean de Meun's continuation (c. 1270-76) of the *Roman de la Rose* which is especially valuable given its wide-ranging and sustained scientific content (especially in Nature's digression) and its close connections with both the Chartrian poets and the intellectual ferment of mid-thirteenth-century Paris.⁴⁰

Such a wide-ranging approach to Dante's scientific culture may appear overly cumbersome and to run against Corti's recent appeals for greater parsimony in approaching Dante's sources.⁴¹ But its value lies, I suggest, in helping to contextualize Dante's ideas as fully and rigorously as possible and thereby allowing one to distinguish commonplace notions and ideas from what may be more specific to an individual author or even original to Dante. In most cases, especially where a common idea or principle is involved, it will not be possible to isolate a single source and in many instances wider contextualization will prevent some of the errors of false attribution that have so bedevilled Dante studies in the past.⁴² But in certain cases it is possible to identify with some precision a more specific intellectual model that Dante is assimilating and re-appropriating and whose provenance can be traced to certain kinds of writing.⁴³ The image of Dante that emerges from Nardi's and Gilson's studies as an eclectic is certainly a valid one and it is especially useful in the distance it stakes out from an emphasis on Dante's *forma mentis* as exclusively Thomist and/or Aristotelian. But all the same, the term 'eclectic' is no more than a convenient label and it may be useful to get beneath this in order to appreciate precisely what kind of materials Dante is using, what choices he is making, and above all how he is using them.

Perhaps the most important concern, one that is not directly present in Nardi's essays, and that needs to be brought to the fore in future studies of science in the *Commedia*, is a finely differentiated and reflective balance between Dante's contemporary context and his own text in all its stylistic, thematic, and structural dimensions. One of the greatest dangers in considering the place of science in any literary work is to rely on a reductive notion of borrowing which places too much emphasis on scientific content alone. As well as the closest possible attention to Dante's ideological context and intellectual culture, then, an equally keen interest needs to be paid to the specific literary uses and formal implications of the scientific material, and this calls for a constant rethinking and refining of our typologies and methods of discussing them. The *Commedia* is a *sui generis* literary work, a text of the most intricate polysemy, with its own syntheses and principles of organization and in it science is incorporated very much for Dante's own purposes and in ways that radically alter the so-called source-material. As has been noted, what one learns by studying Dante in context is that he was actually rather ignorant when measured against the cutting-edge of scientific developments in his time. This is in itself one reason why it is important to contextualize Dante's scientific references: without adequate contextualization, it is impossible to appreciate closely the links and the disjunctions between Dante's ideas and those available to his age. But if we concentrate on the *Commedia*'s poetic re-elaborations of scientific ideas, a very different story begins to emerge. The range of ideas is not only astonishing, but his various references are remarkable for their amazing precision and concision. More significant still is the variety of subtle and complex ways that the scientific material is integrated into the text, ways that are almost always far more than mere ornamentation of a pre-existent material, but take on a vibrant and multi-layered functionality within the economy of the poem. It is this multi-layered functionality that needs to be taken into fuller account in future studies of Dante's science in the *Commedia*. At the most basic textual level, the presence of medieval science in the *Commedia* can be classified by textual configuration alone, ranging from isolated lexical items, to *per brevitatem* similes, to shorter sequences, and onto complex periods that extend across several tercets. But it is also essential to explore the range of precise functions, associations, and resonances that Dante's scientific allusions have in their immediate context as well as the reverberations

that are set up and re-echoed in and across individual cantos, groups of cantos, and *cantiche*. With this task in mind, the remainder of this article offers a series of considerations aimed at promoting study of the various gradations of scientific reference in the *Commedia*. In so doing, my primary purpose is to place a prominent emphasis on the nature and degrees of its textual development and to highlight how such development often works through a series of gradations and interpenetrations.

I would suggest that a first and most basic grade of textual development can be identified at the level of the fugitive allusion to a scientific doctrine which is sometimes no more than a single word, but may extend to a single line, a tercet, and even a longer simile. Such allusions have not always been detected in the standard commentary on the poem. For example, the word *antomata* in *Purgatorio* X, 128 is a technical term derived from medieval Latin translations of Aristotelian biological works. Equally, *volto* in *Paradiso* II, 66 is a calque of the astrological term *vultus* found in Latin translations of the Pseudo-Ptolemaic *Centiloquium*, whereas *plaga* in *Paradiso* XIII, 4 echoes terminology found in Latin translations of Aristotle's *De caelo*.⁴⁴ Other brief allusions may also include very common words which in specific contexts are 're-semanticized' and take on a more precise scientific resonance. Examples of this phenomenon include lexical items such as *cor* in *Inferno* I, 20 and V, 100 as well as words which, in modern Italian, have taken on a very different meaning and lost their technical frame of reference such as *nuca* in *Inferno* XXXIII, 129.⁴⁵ Examples of similes based on scientific sources are Dante's description of the causes of an earthquake in *Inferno* XII, 4-6 and of the skin that covers the eyes of the mole in *Purgatorio* XVII, 3.⁴⁶

A second and more sophisticated level of textual development concerns Dante's use of science in a more recognizable and sustained way, one that is integrated in the wider context and import of either an individual canto or series of cantos and that may either form a recurrent motif or function as a structuring principle in the poem. Three sets of scientific imagery and terminology suggest themselves as being particularly pertinent to this gradation. Firstly, Dante's keen interest in the intricacies of medieval psychology, most notably the image-forming faculty, the *imaginativa*.⁴⁷ This interest not only provides a recurrent point of reference in the many passages in the poem that show a close concern with human perception, but it is also

developed in such a way that it provides the narrative structure for much of the opening sections of *Purgatorio* XVII and *Paradiso* XIII.⁴⁸ A second and more important example is astronomy, which, as is well known, is used by Dante from the opening canto of the *Inferno* and throughout the poem to provide chronological co-ordinates for his journey. Concepts and terminology drawn from this science are especially significant in the *Purgatorio* where astronomical incipits not only perform individual, localized functions by providing time-references and taking on symbolic values, but also function *en masse* in a thematic way in order to emphasize the temporal quality of the second realm of Dante's afterlife. A third example of this level of scientific reference is provided by Dante's use of astrology, which not only provides an important means for understanding and imaging (especially through the light image) the causal relationships between God, the angelic intelligences and the Earth, but also functions, in the *Paradiso*, as a structural principle insofar as the blessed souls in the final *cantica* appear to Dante by descending to the heaven which exercised a strong influence over their dispositions in life.⁴⁹

A further and still more developed textual use of scientific ideas in the *Commedia* is found where a scientifically informed world-view is used to put forward and develop themes that are central to the intellectual and spiritual messages of the entire poem. In this connection, the lengthy discourses in canto XXV of *Purgatorio* and canto II of *Paradiso* are the most important sequences of all, but they are complemented by the learned disquisitions found in several other cantos, most notably *Purgatorio* XVI-XVII, XXI and XXVIII and *Paradiso* VIII and XIII. All these passages have in common the sustained use of technical terms, ideas, and modes of argumentation derived from medieval scholastic science. But what is more significant still is that almost all these discourses, though apparently dealing with a single and isolated issue, help to set out what is in fact a comprehensive vision of the natural and cosmic order, its nature, and its limits. In so doing, the discourses raise fundamental questions about the relationship between a world of natural causes that can be rationally understood and a divine order governed directly by God ('dove Dio senza mezzo governa': *Par.* XXX, 122) and which does not obey natural causes and eludes human understanding. In other words, the discourses take us to the heart of the *Commedia*, to the great themes of the ardent human pursuit of rational understanding about the world and humankind on the one hand, as opposed to the

realm of transcendence, divine limits, and related interdictions, on the other. The fact that all this Dantean material produces some of the most vital and resonant poetry in the entire *Commedia* should no longer be in any doubt, especially after Russo's studies. The relevant passages abound with densely intricate networks of phonic patterning based on assonance, consonance, and alliteration; they are rich in rhetorical devices, and alive with highly visual similes and metaphors.

If these three levels or gradations of scientific allusion in the *Commedia* are to be meaningful, however, it is also necessary to recognize that more than one level can be contained within a given longer sequence, through techniques such as the foreshadowing, interpenetration, and reinforcement of scientific images and related themes. Equally, throughout the *Commedia* one finds various forms of cross-fertilization between scientific language and other imagery, themes, and intertexts (classical, vernacular, biblical, theological, and mystical). Three examples will serve to illustrate the extent to which scientific reference may form part of a larger interlocking textual network. The first example is taken from the opening canto of the *Paradiso* and it relies in part on the Aristotelian doctrine of natural place, a set of ideas which is discussed in his *Physica*, *De caelo*, and *De generatione et corruptione* and their medieval commentaries. According to Aristotle and his commentators, each of the four sublunar elements (earth, water, air, and fire) has its own natural place, the place to which it moves by an inherent force of attraction, in one of four concentric spheres that make up the sublunar world. Beatrice alludes *en passant* to this doctrine in lines 90-92 of *Paradiso* I, by comparing Dante-*personaggio*'s own seemingly unnatural flight through these spheres to the way in which lightning flees from its own natural site in moving downwards towards the earth and hence away from its natural place which is the uppermost sublunar sphere:

Tu non se' in terra, sí come tu credi;
ma folgore, fuggendo il proprio sito,
non corse come tu ch'ad esso riedi.

But as we read on in the canto the seemingly fugitive reference is subsequently woven into a more intricate net of inter- and intra-textual echoes which implicates the Augustinian doctrine of *pondus amoris*⁵⁰ and foreshadows themes that will be elaborated later in the canto when

Dante makes more scientific references to the doctrine of natural place in speaking of the natural instinct which leads all creatures to their allotted places in the 'gran mar dell'essere' (l. 113):

Questi [instinct] ne porta il foco inver' la luna;
questi ne' cor mortali è permotore;
questi la terra in sé stringe e aduna⁵¹ [...]

Non dei piú ammirar, se bene stimo,
lo tuo salir, se non come d'un rivo
se d'alto monte scende giuso ad imo.

Maraviglia sarebbe in te se, privo
d'impedimento, giù ti fossi assiso
com' a terra quïete in foco vivo. (*Par.* I, 115-17; 136-41)

The point is that Dante's movement away from the earth is not in fact away from natural place (like lightning moving downwards), but it is perfectly natural: as a divinely created being his natural place is with God and the later scientific references develop this very idea in an exquisitely reasoned chain of argumentative poetry, clarifying and reinforcing the theme. The brief allusion to natural place in lines 90-92 thus shows Dante's remarkable powers of using science to anticipate in synthesis themes and ideas that he develops later in the canto.

The second example, the opening simile of *Paradiso* XIV, is more imagistic, but it also brings with it a range of thematic connotations which have an effect outside the immediate narrative context. The simile, which describes an experiment in which circular ripples are generated in a vat of water, is closely based upon similar observations in the medieval commentaries on Aristotle's *De anima*. This might seem to be an isolated and decorative device related solely to its immediate context, but it is important to note that the whole canto and indeed the whole block of cantos that deal with the Heaven of the Sun resonate with images of circularity and its connotations of perfection, harmony, and the deity.⁵² More significantly still, the cantos devoted to the Heaven of the Sun provide a fine example – one that is still to be fully documented and understood – of Dante's use of different layers of cultural discourse within individual cantos and groups of cantos. Throughout these cantos, concepts and imagery derived from Aristotelian and other scientific sources are interlaced with non-rationalist imagery and themes deriving from St.

Bonaventure, as well as Solomonic literature and its medieval exegetical tradition.⁵³

The third and final example is the simile of *Paradiso* XXX, 46-51 which is used by Dante to describe his own experience, as protagonist, of the dazzling light of the Empyrean Heaven. In so doing, Dante deftly interlaces a flourish of scientific terms ('discetti', 'spiriti visivi', 'l'atto', 'obietti') around the Aristotelian idea that sensory excess destroys sensation by describing how the eye is blinded by a sudden light.

Come súbito lampo che discetti
li spiriti visivi, sí che priva
da l'atto l'occhio di piú forti obietti (*Par.* XXX, 46-48)

In developing the effects of the light in the tenor of the simile, Dante enacts a remarkable fusion of visual science and scriptural reminiscence, for, as is well known, the word *circunfulse* in line 49 echoes very prominently the Latin *circumfulsit* found in passages from the Acts of Apostles that describe Saul's blinding on the Road to Damascus:

cosí mi circunfulse luce viva,
e lasciommi fasciato di tal velo
del suo fulgor, che nulla m'appariva. (*Par.* XXX, 49-51)

It is no coincidence that this is the same Paul who is evoked at the beginning of *Inferno* II (ll. 28-33) and in the opening canto of the *Paradiso* (I, 73-74), the same Paul who was rapt up to the third heaven and heard unspeakable words, and with whom Dante is now directly associating himself.⁵⁴ The passage as a whole thus provides not only an excellent example of what Nardi called 'quel processo di "contaminazione" del linguaggio biblico con la cultura profana',⁵⁵ but also retrospectively adds greater weight to Dante's earlier analogies between himself and St. Paul, now locating this association within the context of light, blindness and vision that dominates the final cantos of the poem.

Having charted the meaning and application of scientific material in the *Commedia* and examined several of the strengths and limitations of earlier approaches, some concluding remarks are now in order. This essay, especially the opening section, has attempted to demonstrate

the importance and range of Dante's scientific concerns in the *Commedia*, drawing attention to its main subject areas and the multiplicity of sources and traditions that are relevant to their fuller understanding. As has been noted, much empirical work still remains to be done in order to identify and assess all the relevant passages in the poem that bear the imprint of Dante's intellectual context. Aristotle remains his most important source, but he is an Aristotle whose scientific works were mediated in highly specific ways through spurious works, commentaries, and other writings. Further study of these and other related writings should offer additional insights into the intellectual matrices of parts of Dante's poetry. At the same time, it has been suggested that a vast range of other texts, from encyclopaedias and summa to literary works and their commentaries, needs to be taken into account in assessing Dante's own reworkings of his scientific heritage. Such a wide-ranging approach is advocated in order to help to avoid erroneous attribution of commonplace ideas to individual sources while affording a keener sense of the models from which he was selecting and the kinds of choices he was making. Several of the specific subject areas and traditions that may merit further study have been discussed above and some additional comments are made in the Appendix.

However, as later sections of this essay have also made clear, the task of identifying and contextualizing Dante's scientific models, valuable and important though it is, needs to be carefully co-ordinated with a close analysis of the poem itself in all its complexity. Such analysis needs to be located both at the micro-level of the text, that is, in its highly crafted deployment of poetic resources and rhetorical devices, as well as at its macro-level in relation to the wider poetic implications raised by the use of scientific ideas and imagery and their interactions and interpenetrations with other scientific material and with other cultural discourses. The series of gradations proposed and the related examples selected are undoubtedly too neat and schematic and they will be open to further revision and re-elaboration. But it is my hope that at the very least they may provide a means for going beyond contextualization alone in order to build upon earlier discussion of Dante's poetic uses of science so as to allow the critic to deal with the means by which Dante's text structures and assimilates scientific terminology and concepts. The ultimate objective of future enquiry is perhaps best served by being directed towards understanding and analysing how the *Commedia* not only possesses

varying layers of scientific richness but often interweaves these with a remarkable range of other models to form a larger, intricate, and even more remarkable textual structure.

APPENDIX

This appendix provides annotated references to the more important critical contributions on several scientific subject areas that are – or have been found to be – of especial relevance to Dante. In certain cases, the *lacunae* that exist and the possibility for more systematic study have led me to make suggestions for future research. Where appropriate, account is also given of important bibliographical material that seems not to have been used in Dante scholarship. (For studies of cosmology and cosmography in Dante, see the references given in note 15).

(a) Astronomy

There are several important and useful studies (with earlier bibliographical references) including: G. Buti & R. Bertagni, *Commento astronomico della 'Divina Commedia'* (Florence: Sandron, 1966); I. Caliaro, *Poesia, astronomia, poesia dell'astronomia in Dante* (Venice: Istituto Veneto di Scienze, Lettere e Arti, 1985); I. Capasso, *L'astronomia nella Divina Commedia* (Pisa: Domus Galilaeana, 1967); C. Gizzi, *L'astronomia nel poema sacro*, 2 vols (Naples: Loffredo, 1974); P. Pecoraro, *Le stelle di Dante: Saggio d'interpretazione di riferimenti astronomici e cosmografici della 'Divina Commedia'* (Rome: Bulzoni, 1987). For a convenient short summary, see I. Capasso & G. Tabarroni, 'Astronomia', in *E.D.* I, 431-35. Despite their merits, these works have not resolved all the controversies (e.g. *Purg.* XV, 1-9; *Par.* I, 37-42), nor do they always pay sufficient attention to the literary texture and implications of the astronomical material in its wider context. Note also that no-one has attempted to do for Dante what J. D. North has for Chaucer (i.e. to argue that precise astronomical calculations inform the structure of the poem), see his *Chaucer's Universe* (but on the contrast between the astronomical poetry of Dante and Chaucer, see (1) below). See also most recently the important monograph by Alison Cornish, *Reading Dante's Stars* (New Haven: Yale University Press, 2000).

(b) Physics

A lucid general account of the principles of Aristotelian physics (the study of change/motion in natural bodies) with Dante's writings in mind is found in P. Boyde, *Perception and Passion in Dante's 'Comedy'* (Cambridge: Cambridge University Press, 1993), pp. 11-31. In the late Middle Ages, physics was the general science but it also included special sciences such as alchemy, optics, and astronomy (see the article by Claggett cited in n. 9). For further discussion of Aristotelian physics in its medieval context, see H. S. Lang, *Aristotle's Physics and its Medieval Varieties* (Albany, NY: State University of New York Press, 1992).

(c) Meteorology

For a useful overview of most relevant passages, see B. Andriani, *Aspetti della scienza in Dante* (Florence: Le Monnier, 1981), pp. 182-93. A contextualized study with detailed references to the Pseudo-Thomist commentary on Aristotle's *Meteorologica* is P. Boyde, *Dante Philomythes and Philosopher: Man in the Cosmos* (Cambridge: Cambridge University Press, 1981), pp. 74-95. Boyde does not, however, make use of Albert the Great's *De meteoris* (not yet available in the Cologne edition), a work which Dante knew and drew upon elsewhere in the *Commedia* (see n. 46). Close study of this commentary may produce further findings. For a study of one set of imagery based on meteorological optics, see my 'Dante's Meteorological Optics: Reflection, Refraction and the Rainbow', *Italian Studies*, 52 (1997), 41-52.

(d) Human soul and psychology

The seminal essays on the origin of the soul are by B. Nardi, 'L'origine dell'anima umana secondo Dante' [originally 1931-32], in *Studi sulla filosofia medievale* (Rome: Edizioni di storia e letteratura, 1960), pp. 9-68, and 'Sull'origine dell'anima umana', in *Dante e la cultura medievale*, ed. by P. Mazzantini, 2nd edn (Rome-Bari: Laterza, 1983), esp. pp. 142-54. For a good general account, see Boyde, *Dante Philomythes*, pp. 270-81. More specifically on embryology, see L. Minio Paluello, 'Antomata, *Purg.* X, 138 e i testi italiani della biologia di Aristotele', *Studi danteschi*, 50 (1973), 111-50 and S. Bemrose, '"Come d'animal divegna fante": The Animation of the Human Embryo in Dante', in *The Human Embryo:*

Aristotle and the Arabic and European Traditions, ed. by G. R. Dunstan (Exeter: Exeter University Press, 1990), pp. 123-35. On Dante's treatment of the inner senses (the faculties of common sense, imagination, estimation, and memory), see I. Baldelli, 'Visione, immaginazione e fantasia nella *Vita nuova*', in *I sogni nel Medioevo*, ed. by T. Gregory (Roma: Edizioni dell'Ateneo, 1985), pp. 2-11; P. Arvisu Dumol, *The Metaphysics of Reading Underlying Dante's 'Commedia': The Ingegno* (New York: Peter Lang, 1998), ch. 4; S. Pearce, 'Dante and the Art of Memory', *The Italianist*, 16 (1996), 20-61, esp. pp. 28-39; entries in *E.D.* III, 368-70, 441-43, 889-92, V, 164-65, 445. One area that may reward future study is the especially complex and important area of human intellection. The prevailing view is that of Nardi in 'La conoscenza umana' [originally 1921], in *Dante e la cultura medievale*, pp. 135-73. But for more recent estimates of the Arab and Latin traditions, see H. A. Davidson, *Alfarabi, Avicenna and Averroes: Their Cosmologies, Theories of Active Intellect and Theories of Human Intellect* (Oxford & New York: Oxford University Press, 1992); S. P. Marrone, *William of Auvergne and Robert Grosseteste: New Ideas on Truth in the Early Thirteenth Century* (Princeton, NJ: Princeton University Press, 1983).

(e) Animal kingdom/natural history

There is no detailed contextualized study but for important recent articles which draw on certain aspects of animal lore in Dante, see L. Pertile, 'Il nodo di Bonagiunta, le penne di Dante e il Dolce Stil Novo', *Lettere italiane*, 46 (1994), 49-75 (on falconry); R. L. Martinez, 'Dante's Bear: A Note on "Così nel mio parlar"', *Dante Studies*, 111 (1993), 213-22 (on bear-lore); L. V. Ryan, 'Stornei, Gru, Colombe: The Bird Images in *Inferno* V', *Dante Studies*, 94 (1976), 25-45 (on bird-lore). Earlier works include Richard Thayer Holbrook, *Dante and the Animal Kingdom* (New York: Columbia University Press, 1902). A comprehensive study of animal imagery through the Aristotelian works and commentaries may yield further findings as well as casting some light on Dante's conception of man. In this respect Albert the Great's extensive and wide-ranging commentary on the *De animalibus* (cited in n. 46) may prove an especially useful resource. For further bibliography, see the essays on 'Il mondo animale' collected in *Micrologus*, 8 (2000); J. Rebold Benton, *The Medieval Menagerie: Animals in the Art of the Middle*

Ages (New York: Abbeville Press, 1992); W. B. Clark & M. T. McMunn, eds, *Birds and Beasts of the Middle Ages: The Bestiary and its Legacy* (Philadelphia: University of Pennsylvania Press, 1989); T. Goldskin-Préaud, 'Albert le Grand et les questions du XIIIe siècle sur le *De animalibus* d'Aristote', *History and Philosophy of the Life Sciences*, 3 (1981), 62-71; J. E. Salisbury, *The Beast Within: Animals in the Middle Ages* (New York: Routledge, 1992); J. Stannard, 'Natural History', in *Science in the Middle Ages*, pp. 429-60.

(f) Medicine

An earlier but not always reliable work that offers an overview is M. Mattioli, *Dante e la medicina* (Naples: Edizioni Scientifiche Italiane, 1965). For a useful recent overview by an eminent historian of medieval and Renaissance medicine, see N. G. Siraisi, 'Dante and the Art and Science of Medicine Reconsidered', in *The Divine Comedy and the Encyclopedia of the Arts and Sciences*, ed. by G. di Scipio & A. Scaglione (Amsterdam-Philadelphia: John Benjamins, 1988), pp. 223-45. The most comprehensive study to date with contextualization and some attention to literary qualities is Patrizia Bertini Malgarini, 'Il linguaggio medico e anatomico nelle opere di Dante', *Studi danteschi*, 71 (1989) [published 1994], 29-108.

(g) Optics

The foundational essay is A. Parronchi, 'Dante e la prospettiva', *Studi danteschi*, 36 (1959), 3-103. Parronchi argues for Dante's knowledge of Alhazen's *De aspectibus* and later thirteenth-century treatises on vision known as the *perspectivae*. But for a re-evaluation of Dante's likely sources with emphasis upon Aristotelian commentaries, see my 'Dante and the Science of "Perspective": A Reappraisal', *Dante Studies*, 115 (1997), 185-219; and *Medieval Optics and Theories of Light in the Works of Dante* (Lewiston, Queenston, and Lampeter: Edwin Mellen Press, 2000), chs 2-4. On the question of optical structure in the *Commedia*, see Michio Fujitani, 'Dalla legge ottica alla poesia: la metamorfosi di *Purgatorio* XV, 1-27', *Studi danteschi*, 71 (1989) [published 1994], 153-86.

(h) Astrology

For an overview of this topic, see esp. R. Kay, 'Astrology and Astronomy', in *The Divine Comedy and the Encyclopaedia of the Arts and Sciences*, pp. 147-162; and *Dante's Christian Astrology* (Philadelphia: University of Pennsylvania Press, 1994), ch. 1. See also I. Capasso & G. Tabarroni, 'Astrologia' and 'Cielo', in *E.D.* I, 427-31, 1000-04; F. Tateo, 'Dante e l'astrologia', in *L'astrologia e la sua influenza nella filosofia, nella letteratura e nell'arte dall'età classica al Rinascimento* (Milan: Nuovi Orizzonti, 1992), pp. 107-24. Kay's monograph study, which draws connections between *Paradiso* I-XXII and nine medieval texts listing astrological properties, should be treated with some caution; see the review by P. Armour, in *Italian Studies*, 50 (1995), 161-63. Much of the material in Dante has been related to *astrologia naturalis* (the effect of the heavens on the earth and humankind). For the interesting suggestion that Dante was influenced by conjunctionist astrology, see K. M. Woody, 'Dante and the Doctrine of Great Conjunctions', *Dante Studies*, 95 (1977), 119-34.

(i) Magical lore

In the Middle Ages what we would now call pseudo-science, including disciplines such as astrology, was not clearly differentiated from other forms of science. Despite condemning the sin of divination, Dante recognized some aspects of magical lore including the efficacy of precious stones, necromancy, and demons; see my 'Medieval Magical Lore in Dante's *Commedia*: Divination and Demonic Agency', *Dante Studies*, 119 (2001), forthcoming; G. Gorni, 'Le arti divinatorie', in his *Lettera nome numero: L'ordine delle cose in Dante* (Bologna: Il Mulino, 1990), pp. 155-74.

(j) Mineralogy and Alchemy

On mineralogy, see V. Cioffari, 'Dante's Use of Lapidaries: A Source Study', *Dante Studies*, 109 (1991), 149-62; A. Lapinsky, 'La simbologia delle gemme nella *Divina Commedia* e le sue fonti letterarie', in *Atti del I Congresso di Studi Danteschi* (Florence: Olschki, 1962), pp. 127-58; A. Levavasseur, 'Les pierres précieuses dans la *Divina Commedia*', *Revue des études italiennes*, n.s. 4 (1957), 31-100; B. Deen Schildgen, 'Wonders on the Border: Precious Stones in the *Comedy*', *Dante Studies*, 113 (1995), 131-50. See also

R. M. Durling & R. L. Martinez, *Time and the Crystal: Studies in Dante's 'Rime Petrose'* (Berkeley & Los Angeles: University of California Press, 1990), pp. 32-45. On alchemy, treated as a practical and moral issue rather than a philosophical one, some useful observations are found in S. Botterill, 'Dante e l'alchimia', in *Dante e la scienza: Atti del convegno internazionale di studi su Dante e la scienza, 28-30 maggio 1993*, ed. by P. Boyde & V. Russo (Ravenna: Longo, 1995), pp. 203-11 (note also that *lega* in *Par.* II, 139 is an alchemical term). Several esoteric works unreliably posit strong connections between Dante and alchemical teachings, see e.g. J. Breyer, *Dante alchimiste: interprétation alchimique de la 'Divine Comédie'* (Paris: La Colombe, 1957); P. Contro, *Dante templare e alchimista: La pietra filosofale nella 'Divina Commedia'* (Foggia: Bastogi, 1998).

(k) Physiognomy

Derived from a medical tradition associated with the Pseudo-Aristotelian *Physiognomonica* and Polemon (200AD), physiognomy is the interpretation of bodily features so as to draw up a physiognomical type which defines human character, and in the late Middle Ages and Renaissance it was closely related to astrological medicine. The only contributions known to me that deal with this topic in Dante are: G. Bolognese, 'Fra i maghi danteschi: Michele Scotto', *L'Alighieri*, 17 (1976), 72-74; Gorni, *Lettera*, pp. 160-61; R. Kay, 'The Spare Ribs of Dante's Michael Scot', *Dante Studies*, 103 (1985), 1-14. Both Kay and Bolognese contend that Dante's reference to the 'fianchi' of Michael Scot (*Inf.* XX, 115) is derived from Scot's own work on physiognomy. I do not find this argument convincing (the passage quoted appears to be corrupt), but the idea that Dante uses techniques of physical characterization that draw on physiognomical ideas in his delineation of certain characters may well reward further study (see e.g. *Inf.* IV, 112-14; VI, 91-2; *Purg.* IV, 106-08; cf. *Conv.* IV, xxiv, 6). Other thirteenth-century physiognomical treatises include the *Compilatio phisionomie* by Pietro di Abano; see E. Paschetto, 'La fisiognomica nell'enciclopedia delle scienze di Pietro d'Abano', *Medioevo*, 11 (1985), 97-111; J. Thomann, 'Pietro d'Abano on Giotto', *Journal of the Warburg and Courtauld Institutes*, 54 (1991), 238-44. Related ideas were also available in other writings such as Aristotelian commentary and

encyclopaedic works; see e.g. Albert, *De animalibus*, lib. I, tr. 2, c. 3, ed. Stadler, I, 50-60; Vincent of Beauvais, *Speculum maius*, lib. XXVIII, c. 50 (Douai, 1624), I, col. 2026. Physiognomical concepts seem to have played a role in the later presentation of Dante's physical appearance, see L. Freedman, 'A Note on Dante's Portrait in Boccaccio's "Vita"', *Studi sul Boccaccio*, 15 (1986), 253-63; H. Shankland, 'Dante "Aliger"', *Modern Language Review*, 70 (1975), 785, n. 1.

(I) Mathematics

For an overview of relevant passages, see Andriani, *Aspetti della scienza*, pp. 117-53; B. d'Amore, 'Alcuni cenni sulla presenza della matematica nella *Divina Commedia*', *Cultura e scuola*, 32 (1993), 145-61. A quite different set of issues is raised by a number of studies of numerological concern which argue that the *Commedia* has a concealed mathematical structure. It would indeed seem that Dante was interested in symmetries based on numbers, see J. J. Guzzardo, 'Christian Medieval Number Symbolism and Dante', Ph.D. dissertation, Johns Hopkins University, 1975, esp. pp. 279-397; J. Secor, 'Three Dances of Three: The *Imago Trinitatis* in Dante's *Commedia*', in *Medieval Numerology: A Book of Essays* (New York and London: Garland, 1993), pp. 93-104; C. S. Singleton, 'The Poet's Number at the Center', *Modern Language Notes*, 80 (1965), 1-10. However, there is far less merit in numerological studies that concentrate on number symbolism and attribute various and often highly idiosyncratic meanings to Dante's words, and their number and position in the poem, often on the basis of geometrical techniques. On this topic, see M. Hart, 'Dante and Arithmetic', in *The Divine Comedy and the Encyclopaedia of the Arts and Sciences*, pp. 81-94; 'I numeri nella poetica di Dante', *Studi danteschi*, 71 (1989), 1-27; and 'I numeri e le scritture crittografiche nella *Divina Commedia*', in *Dante e la scienza*, pp. 71-90. Even the notion of numerical symmetries can be taken to extreme or unwarranted conclusions, and I remain restive about the image of Dante as a precise calculator and as a poet of arithmetical design and numerological structures for two reasons. First, the evidence of Dante's astronomy seems to suggest that, unlike Chaucer, he was not interested in precise calculation (see North, *Chaucer's Universe*, p. 2; cf. Cornish, *Reading Dante's Stars*, pp. 28-29, 34-35). Second, despite its formidable and highly

organized architecture, there are points in the poem that suggest that the *Commedia* was to some degree a work in progress. For example, contrary to what is suggested by *Inf.* X, 127-32, Dante's future exile is not 'glossed' by Beatrice but by Cacciaguیدا, while comparison between Dante's description of the mediation of divine light 'igualmente' by the angels in *Inf.* VII, 73-76 seems to differ from *Par.* XIII, 55-60 and XXIX, 136-45, where the emphasis falls on the unity of divine light in its source and its differentiation by the angelic intelligences.

NOTES

¹ In the last twenty years, the most important contributions have been made by the historian of ideas, Cesare Vasoli, and the literary scholars, Patrick Boyde and Maria Corti, all of whom are indebted to Nardi's earlier work, but who have provided some important new insights into Dante's intellectualism and his poetic uses of scientific material; see esp. P. Boyde, *Dante Philomythes and Philosopher: Man in the Cosmos* (Cambridge: Cambridge University Press, 1981); *Perception and Passion in Dante's 'Comedy'* (Cambridge: Cambridge University Press, 1993); and *Human Vices and Human Worth in Dante's 'Comedy'* (Cambridge: Cambridge University Press, 2000); M. Corti, *Dante a un nuovo crocevia* (Florence: Le Lettere, 1982), esp. ch. 1 and ch. 3; and *La felicità mentale: Nuove prospettive per Cavalcanti e Dante* (Turin: Einaudi, 1983), esp. chs. 2-3; C. Vasoli, ed., *Il Convivio* (Milan-Naples: Ricciardi, 1988), with invaluable notes and an authoritative introduction (pp. xi-lxxxix). For two collections of edited essays, see *The Divine Comedy and the Encyclopedia of the Arts and Sciences*, ed. by G di Scipio & A. Scaglione (Amsterdam-Philadelphia: John Benjamins, 1988); *Dante e la scienza: Atti del convegno internazionale di studi su Dante e la scienza, 28-30 maggio 1993*, ed. by P. Boyde and V. Russo (Ravenna: Longo, 1995). Unfortunately, both edited volumes, especially the earlier one, are somewhat uneven in the quality and nature of the contributions; the more useful and reliable essays are referred to in my notes and in the Appendix. B. Andriani's *Aspetti della scienza in Dante* (Florence: Le Monnier, 1981) is useful for its overview of astronomy, but it is neither comprehensive (it omits medicine) nor does it always provide detailed contextualization. For a lucid shorter essay which deals with medieval conceptions of poetry

and science and provides some discussion of Dante's minor works, see also B. Martinelli, 'Poesia e scienza in Dante', *Critica letteraria*, 9 (1981), 623-67.

² A useful review of the *status quaestionis* until the mid-1970s is found in G. S. Rousseau, 'Literature and Science: The State of the Field', *Isis*, 69 (1978), 583-91. See also G. Beer, 'Science and Literature', in *Companion to the History of Modern Science*, ed. by R. C. Olby *et al.* (London & New York: Routledge, 1990), pp. 783-98; L. Jordanova, ed., *Languages of Nature: Critical Essays on Science and Literature* (London: Free Association Books, 1986).

³ See B. Nardi, 'Filosofia dell'amore nei rimatori italiani del Duecento', in *Dante e la cultura medievale*, ed. by P. Mazzantini, 2nd edn (Rome-Bari: Laterza, 1983), pp. 1-92; and 'L'amore e i medici medievali', in *Saggi e note di critica dantesca* (Naples-Milan: Ricciardi, 1966), pp. 238-67. For the important place of the medical doctrine of spirits in the early Italian lyric and in Dante, see M. Chiamenti, 'The Representation of the Psyche in Cavalcanti, Dante and Petrarch: The "Spiriti"', *Neophilologus*, 82 (1998), 71-81; R. Klein, 'Spirito Peregrino', *Revue des études italiennes*, 11 (1965), 197-236.

⁴ J. Smarr, 'Boccaccio and the Stars: Astrology in the *Teseida*', *Traditio*, 35 (1979), 303-32. On Boccaccio's astrological knowledge, see also A. E. Quaglio, *Scienza e mito nel Boccaccio* (Padua: Liviana, 1967), pp. 126-206.

⁵ See e.g. Petrarch, *Rerum vulgarium fragmenta* XIII: 'Quando 'l pianeta che distingue l'ore' where, on the basis of an astrological conceit, the 'influence' of the lady's eyes is wittily compared to the 'influence' of solar rays. Petrarch's critique of scholastic medicine and astrology, especially in his *Invective contra medicum* (1355) is well known, see e.g. P. O. Kristeller, 'Il Petrarca, l'umanesimo e la scolastica', *Lettere italiane*, 7 (1955), 367-88.

⁶ On various aspects of the definition of 'science' in the Middle Ages, see P. Boyde, 'Dante e l'esegesi della scienza', in *Dante e la scienza*, pp. 20-21; *Science in the Middle Ages*, ed. by D. C. Lindberg (Chicago: University of Chicago Press, 1978), introduction, pp. xi-xv; J. Weisheipl, 'Classification of the Sciences in Medieval Thought', *Mediaeval Studies*, 27 (1965), p. 55: 'in medieval usage the term "science" was given to every field of intellectual endeavor in which true causal explanations could be discovered'.

⁷ C. 1324-28 Jacopo della Lana refers the word *scienza* to all these disciplines; see *Commedia di Dante Allaghieri col Commento di Jacopo della Lana bolognese*, ed. by L. Scarabelli, 3 vols (Bologna: Tipografia Regia, 1866-67), I, 144, 168 (on *Inf.* IV, 106-08 and VI, 106-08) and II, 197 (on *Purg.* XVIII, introd.). Note also the gloss c. 1400 on *Inf.* I, 67-75 in the Anomino Fiorentino, *Commento alla Divina Commedia d'Anomino Fiorentino del secolo XIV*, ed. by P. Fanfani, 3 vols (Bologna: G. Romagnoli, 1866-74), I, 8: 'E dice, che fu poeta [Virgil], cioè scienziato della scienza di poesia'.

⁸ For a good overview of the new scientific world-view and its difference from earlier conceptions, see T. Gregory, 'La nouvelle idée de nature et de savoir scientifique au XIIIe siècle', in J. E. Murdoch & E. D. Sylla, eds, *The Cultural Context of Medieval Learning* (Dordrecht: Reidel, 1975), pp. 193-212. See also the relevant essays and extensive bibliography in P. Dronke, ed., *A History of Twelfth-Century Western Philosophy* (Cambridge: Cambridge University Press, 1988).

⁹ For an overview and further discussion, see M. Clagett, 'Some General Aspects of Physics in the Middle Ages', *Isis*, 39 (1948), 29-44. On the liberal arts, see the essays collected in *Arts libéraux et philosophie au moyen âge* (Paris-Montreal: Vrin, 1969), especially the essay by Pearl Kibre.

¹⁰ In the later Middle Ages, the following pseudo-Aristotelian scientific works (in addition to the more metaphysical tract, *De causis*) were particularly important and popular: *De elementis*, *De plantis*, *De proprietatibus elementorum*, *Physiognomonica*, and *Secretum secretorum*. Critical essays on some of the Pseudo-Aristotelian material (much of which has a Neoplatonic nucleus) are found in *Pseudo-Aristotle in the Middle Ages*, ed. by J. Kraye, W. F. Ryan & C. B. Schmitt (London: Warburg Institute, 1986).

¹¹ For a general discussion of Arab science and its reception in the Middle Ages, see D. C. Lindberg, *The Beginnings of Western Science: The European Scientific Tradition in Philosophical, Religious, and Institutional Context, 600 B.C. to A.D. 1450* (Chicago & London: University of Chicago Press, 1992), pp. 161-82. See also A. I. Sabra, 'Science, Islamic', in *Dictionary of the Middle Ages*, vol. 11 (1988), pp. 81-89.

¹² For an overview of the key issues, see E. Grant, 'Issues in Natural Philosophy at Paris in the Late Thirteenth Century', *Medievalia et Humanistica*, n.s. 13 (1985), 75-94.

¹³ On Dante's contacts with Bologna, see the essays collected in *Dante e Bologna nei tempi di Dante* (Bologna: Facoltà di Lettere e Filosofia dell'Università di Bologna, 1967). On Dante's references to Bologna and its inhabitants, see also G. Forni, 'Persone e avvenimenti di Bologna in Dante', *Convivium*, n.s. 28 (1960), 8-19. For the presence of radical Aristotelian currents in early fourteenth-century Bologna, see Corti, *Dante a un nuovo crocevia*, pp. 17-31.

¹⁴ The appendix provides a more detailed overview of secondary literature on Dante and all these topics with suggestions of areas for further study.

¹⁵ On Dante's cosmology, see A. Cornish, 'Dante's Moral Cosmology', in *Cosmology: Historical, Literary, Philosophical, Religious and Scientific Perspectives*, ed. by N. S. Hetherington (New York-London: Garland, 1993), pp. 201-15; J. Dauphiné, *Le cosmos de Dante* (Paris: Les Belles Lettres, 1984); J. Freccero, *Dante's Cosmos* (Binghamton, NY: Center for Medieval and Renaissance Studies, 1998); A. Ghisalberti, 'La cosmologia del Duecento e Dante', *Lecture classensi*, 13 (1984), 33-48; G. Stabile, 'Cosmologia e teologia nella *Commedia*: La caduta di Lucifero e il rovesciamento del mondo', *Lecture classensi*, 12 (1983), 139-73. For Dante's angelology which also has cosmological implications, see S. Bemrose, *Dante's Angelic Intelligences: Their Importance in the Cosmos and in Pre-Christian Religion* (Rome: Edizioni di Storia e di Letteratura, 1983). On Dante's geographical knowledge, see the fine essay by Peter Armour, 'Dante e l'*imago mundi* del primo trecento', in *Dante e la scienza*, pp. 191-202 (and see also his n. 14, p. 199 for an extensive earlier bibliography to which can be added Boyde, *Dante Philomythes*, pp. 96-111).

¹⁶ References, in order, to Aristotelian texts and commentary discussions: *Inf.* XXV, 65-66 (cf. Aristotle, *Meteorologica*, III, 4, 374a 3-5; 374b 10-15); *Purg.* XXVIII, 107-09 and *Par.* XIV, 1-8 (cf. medieval commentaries on Aristotle, *De anima*, II, 8, 420b5-421a6); *Inf.* XVI, 130-6; XVII, 100-01, 115-6 (cf. analogies between swimming, flying and the movement of boats in Aristotle, *De incessu animalium* 9, 709b 10-15; 10, 710a 15-20; 15, 713a 3-10). None of these passages are given in modern commentaries on the poem. For a

fuller treatment of Dante's understanding of sound, see my '“Dal Centro al Cerchio”: *Paradiso* XIV.1-8', *Italian Studies*, 54 (1999), 26-33. For the scientific concepts that underpin the descriptions of the supernatural quality of Dante-*personaggio*'s flights in the *Paradiso*, see A. Cornish, 'Cambiamenti istantanei nel viaggio attraverso le sfere', in *Dante e la scienza*, pp. 233-42.

¹⁷ Amongst the Trecento commentators, the most extensive treatments of the poem's scientific content are provided in the commentaries by Jacopo della Lana (1324-28), the *Ottimo Commento* (1329-31), Pietro Alighieri (1340-50), Benvenuto da Imola (1373-88), and Guido da Pisa (1385). Benvenuto da Imola's *Comentum* is especially important for its numerous references to Albert the Great's scientific works.

¹⁸ Landino's interest in doctrinal matters is noted by C. Dionisotti, 'Landino, Cristoforo', in *E.D.* III, 567. For a list of Daniello's citations of Aristotle's *libri naturales*, see *L'Espositione di Bernardo Daniello da Lucca sopra la Comedia di Dante*, ed. by R. Hollander & J. Schnapp (Hanover & London: University Press of New England, 1989), p. 488. On the Dantean interests (often pre-eminently doctrinal and scientific) of members of the Florentine Academy (1540-89), see A. Vallone, *L'interpretazione di Dante nel Cinquecento* (Florence: Olschki, 1969), pp. 141-219. Of particular note is Galileo's work (see pp. 210-15).

¹⁹ References in order: M. d'Andria, 'Anticipazioni di Dante della nuova dimensione spaziale', in *Dante nel pensiero e nella esegesi dei secoli XIV e XV* (Florence: Olschki, 1975), pp. 485-93; and 'Appunti sulle leggi di gravità nel pensiero di Dante', *L'Alighieri*, 14:1 (1973), 56-64; U. Donati, *Il volo nella 'Divina Commedia'* (Rome: Signorelli, 1942), p. 26 (Newtonian concept of gravity); C. C. Boyer, *The Rainbow: From Myth to Mathematics*, new edn. (Princeton, NJ: Princeton University Press, 1987), pp. 108-09 (theory of the rainbow); *La Divina Commedia*, ed. by U. Bosco & G. Reggio, 3 vols (Florence: Le Monnier, 1979), III, 228 (diffusion of sound); G. Ricchi, 'Il meccanismo della visione secondo Dante Alighieri', *Giornale dantesco*, 10 (1902), 177-79 (theory of vision); M. Peterson, 'Dante and the 3-Sphere', *American Journal of Physics*, 47:12 (1979), 1031-35; W. Egginton, 'Dante, Hyperspheres and the Medieval Cosmos', *Journal of the History of Ideas*, 60:2 (1999), 195-216 (three-dimensional sphere and hypersphere). For other remarks on Dante as a precursor of modern science, see M. Mattioli, *Dante e la*

medicina (Naples: Edizione Scientifiche Italiane, 1965), p. 133; F. Pannaria, 'Dante e la scienza', *Nuova antologia*, 108 (1973), 247-61; M. Peterson, 'Dante's Physics', in *The Divine Comedy and the Encyclopedia of the Arts and Sciences*, pp. 163-80. For a pertinent critique of what he terms the 'pox of precursortitis' in earlier studies of medieval science, see E. Grant, in *Science in the Middle Ages*, introd., p. viii.

²⁰ For relevant discussion of the features of modern science in the context of studying medieval scientific writings, see Lindberg, *The Beginnings of Western Science*, pp. 1-4. See also A. Cunningham, 'Getting the Game Right: Some Plain Words on the Identity and Invention of Science', *Studies in the History and Philosophy of Science*, 19:3 (1988), 365-89.

²¹ On the likely scholastic sources of this experiment (*Par.* II, 94-100), see my 'Dante and the Science of "Perspective": A Reappraisal', *Dante Studies*, 115 (1997), 185-219 (pp. 204-06). Note also that the Latin terms *experimentum* and *experientia* are often used interchangeably in scholastic scientific writings.

²² On the invention of spectacles, first mentioned in Tuscany c. 1308, see E. Rosen, 'The Invention of Eyeglasses', *Journal of the History of Medicine and Allied Sciences*, 11 (1956), 13-46, 183-218; cf. E. Crivelli, 'Il vetro, gli specchi e gli occhiali ai tempi di Dante', *Giornale dantesco*, n.s. 12 (1939), 79-90. On the astrolabe, see J. D. North, *Chaucer's Universe* (Oxford: Clarendon Press, 1988), esp. pp. 40-46. Dante does mention the 'quadrante' in *Purg.* IV, 42 and early mechanical clocks in *Par.* X, 139-43; XXIV, 13-15.

²³ On Dante's scientific backwardness, see B. Nardi, *Dal 'Convivio' alla 'Commedia' (Sei saggi danteschi)* (Rome: Istituto storico italiano per il Medio Evo, 1960), p. 369: 'È mia convinzione che Dante ignorasse molte cose che a suo tempo sapevano altri ben più dotti di lui [...]. Anche le sue conoscenze scientifiche non vanno più in là di quelle che erano notizie comuni'. For one example of Dante's lack of up-to-date knowledge of an important medieval scientific discipline, see my *Medieval Optics and Theories of Light in the Works of Dante* (Lewiston, Queenston & Lampeter: Edwin Mellen Press, 2000), esp. pp. 67-68, 132-33. See also F. Mazzoni, 'Dante "misuratore di mondi"', in *Dante e la scienza*, p. 50: 'Dante è un autore molto "datato" o databile: formato [...] più su testi centeschi e dugenteschi di varia ascendenza e cultura che sulle novità coeve'. In this connection,

it is worth noting that thirteenth-century encyclopaedias often contain rather outmoded scientific ideas because they draw heavily on works from late antiquity and the early Middle Ages. But for the view that Dante was aware of the latest developments yet elected to be purposefully backward-looking, see the important and neglected essay by Eugenio Garin, 'Dante e la filosofia', *Il Veltro*, 18 (1974), 281-93 (esp. p. 289).

²⁴ For example, in a recent and otherwise admirable and exhaustive study of medieval cosmology, one finds almost no mention of Dante; see E. Grant, *Planets, Stars and Orbs: The Medieval Cosmos, 1200-1687* (Cambridge: Cambridge University Press, 1994).

²⁵ For these comments, see A. Momigliano, *La Divina Commedia*, 3 vols (Florence: Sansoni, 1946-51), II, 373 on *Purg.* XV, 22-23 and cf. III, 534 on *Par.* I, 49-54; M. Marti, *Realismo dantesco e altri studi* (Milan-Naples: Ricciardi, 1961), p. 94 on *Purg.* II, 1-6. For other examples of negative judgements on scientific passages in Dante and the influence of Croce, see S. Battaglia, *Esemplarità e antagonismo nel pensiero di Dante*, 2 vols, 2nd edn (Naples: Liguori, 1967), I, 175-200; V. Russo, *Esperienze e di letture dantesche (tra il 1966 e il 1970)* (Naples: Liguori, 1971), n. 2, on pp. 104-05.

²⁶ Russo, *Esperienze*, pp. 103-58 and 161-208. Other important *letture* of these cantos with a strong and informed focus on philosophical and scientific issues are: B. Nardi, 'Il Canto XXV del *Purgatorio*', in *Letture dantesche*, ed. by G. Getto (Florence: Sansoni, 1964), pp. 1175-91; C. Vasoli, 'Il canto II del *Paradiso*', *Lectura Dantis Metelliana*, 2 (1992), 27-51. On aspects of Dante's scientific lexicon and its stylistic effects in the *Commedia*, see also I. Baldelli, in *E.D.* VI, 103-05.

²⁷ On the deficiencies of source-studies, see Nardi, *Saggi di filosofia dantesca*, 2nd edn (Florence: La Nuova Italia, 1967, 1st edn 1930), p. viii: 'questo genere di ricerche empiriche, nella maggior parte dei casi, è impossibile; ma è anche perfettamente inutile. Utilissima, invece, anzi necessaria è la conoscenza dei problemi e delle preoccupazioni intellettuali che formano l'ambiente spirituale nel quale il pensiero filosofico di Dante, personalissimo come ogni vero pensiero filosofico, si maturò nel diuturno sforzo della meditazione'; E. Gilson, in *Giornale storico della letteratura italiana*, 138 (1961), p. 573. Nardi's more important essays with bearing on Dante's cosmology, anthropology and scientific sources in the *Commedia* are:

'Dante e Pietro Abano' [originally 1920], in *Saggi di filosofia dantesca*, pp. 40-72; 'Dante e Alpetragio' [originally 1924], in *Saggi di filosofia dantesca*, pp. 139-66; and the essays referred to in nn. 3 and 31, and the Appendix. For a fuller bibliography of Nardi's writings, see T. Gregory & P. Mazzantini, 'Gli scritti di Bruno Nardi', *L'Alighieri*, 9 (1968), 39-58. Etienne Gilson's principal contributions on Dante are found in his *Dante et la philosophie* (Paris: Vrin, 1939) and the essays collected in *Dante et Béatrice: Études dantesques* (Paris: Vrin, 1974), esp. pp. 23-45, 119-27.

²⁸ See e.g. Nardi, *Dal 'Convivio'*, pp. 87-91, 309; Corti, *Dante a un nuovo crocevia*, ch. 3; and *Percorsi dell'invenzione: Il linguaggio poetico e Dante* (Turin: Einaudi, 1993), pp. 138-40. But see also Battaglia, *Esemplarità*, I, 127; C. Vasoli, 'Avverismo', in *E.D.* I, 479-81. For a critical overview which highlights the inadequacy of the concept of Latin Averroism and its misapplication to thirteenth-century intellectual history, see Gianfranco Fioravanti, 'Boezio di Dacia e la storiografia sull'Averroismo', *Studi medievali*, ser. 3/7 (1966), 283-322.

²⁹ On the place of Neoplatonic influences in scholastic Aristotelianism, see D. C. Lindberg, ed., *Roger Bacon's Philosophy of Nature: A Critical Edition, with English Translation, Introduction, and Notes, of 'De multiplicatione specierum' and 'De speculis comburentibus'* (Oxford: Clarendon Press, 1983), introd., pp. xxiv, xlix and n. 64. Note also that Avicenna, who is an important source for medieval commentators on Aristotle, often interpreted his works on the basis of later Neoplatonic sources. On the problematic term 'Aristotelian', see E. C. Grant, 'Ways to Interpret the Terms "Aristotelian" and "Aristotelianism" in Medieval and Renaissance Natural Philosophy', *History of Science*, 25 (1987), 335-58.

³⁰ For examples of Dante's divergence from, and reinterpretation of, Aristotle on the basis of medieval Aristotelianism, see M. Cogan, *The Design in the Wax: The Structure of the 'Divine Comedy' and its Meaning* (Notre Dame-London: University of Notre Dame Press, 1999), pp. 4-35; my *Medieval Optics*, ch. 2; and '“Dal Centro al Cerchio”', pp. 30-33. On Dante and Aristotle, see further E. Moore, *Studies in Dante: First Series* (Oxford: Clarendon Press, 1969; first edn 1896), pp. 92-156, 305-18; L. Minio-Paluello, 'Dante's Reading of Aristotle', in *The World of Dante*, ed. by C. Grayson (Oxford:

Clarendon Press, 1980), pp. 61-79; M. Corti 'La filosofia aristotelica e Dante', *Lecture Classensi*, 13 (1984), 111-23.

³¹ See most notably B. Nardi, 'Raffronti fra alcuni luoghi di Alberto Magno e di Dante' [originally 1922], in *Saggi di filosofia dantesca*, pp. 63-72; cf. *Saggi di filosofia dantesca*, p. ix: '[le] opere di Alberto Magno, che sono state per lui [Dante] una ricca miniera di informazioni dottrinali'. For further commentary and bibliography, see C. Vasoli, 'L'immagine di Alberto Magno in Bruno Nardi', in his *Otto saggi per Dante* (Florence: Le Lettere, 1995), pp. 117-32.

³² As far as Albert's writings on natural philosophy are concerned, Dante's knowledge can be demonstrated (see Vasoli, *Il Convivio*, p. lxviii) for a number of paraphrases on Aristotle's *libri naturales* (*De physica*, *De caelo et mundo*, *De generatione et corruptione*, *De meteoris*, *De anima*, *Parva naturalia* [i.e. *De sensu et sensato*, *De nutrimento et nutritibili*, *De memoria et reminiscencia*, *De intellectu et intelligibili*, *De somno et vigilia*, *De spiritu et respiratione*, *De motibus animalium*, *De iuventute et senectute*, *De morte et vita*], *De animalibus*), two important paraphrases of Pseudo-Aristotelian works with a strong astrological tenor (*De natura loci* and *De causis et proprietatibus elementorum*), and an independent treatise on the origin of the soul (*Liber de natura et origine animae*). Of these works, all of the important treatises in the *Parvanaturalia* and *De meteoris* have not yet been edited in the *editio Coloniense* and can only be read in the earlier and often unreliable editions of his *Opera omnia*, ed. by P. Jammy (Lyon, 1651) and A. & E. Borgnet (Paris, 1890-99). For an edition of Albert's *De animalibus*, see n. 46. A valuable resource in evaluating Albert's contributions to many branches of medieval science is the volume of collected essays, *Albertus Magnus and the Sciences: Commemorative Essays, 1980*, ed. by J. A. Weisheipl (Toronto: Pontifical Institute of Mediaeval Studies, 1980). On Albert's own explanation of how his digressions serve to clarify difficulties in Aristotle and to add to his thought, see *Physica*, lib. I, tr. 1, c. 1, ed. by P. Hossfeld, 2 vols (Münster: Aschendorff, 1987-93), I, 1: 'digressiones faciemus declarantes dubia suborienta et suppletes, quaecumque minus dicta in sententia Philosophi obscuritatem quibusdam attulerunt'. It is not unusual to find entire books devoted to such digressions as is the case with the second and third books of Albert's *De vegetabilibus et plantis*, ed. Jammy, V, 367-95.

³³E.D. II, 325, 331, 364-65, 387-88, 934. The importance of the Thomist Aristotelian commentaries (most notably on *Physica*, *De caelo*, and *De anima*) is noted by K. Foster, 'Tommaso d'Aquino', in E.D. V, 633-34.

³⁴ On Dante's likely knowledge of this treatise, see R. M. Durling, 'Io son venuto: Seneca, Plato, and the Microcosm', *Dante Studies*, 93 (1975), 95-129; G. Mezzadrolì, *Seneca in Dante: Dalla tradizione medievale all'officina dell'autore* (Florence: Le Lettere, 1990), pp. 87-100.

³⁵ For an important critical reassessment of Dante's encyclopaedism with earlier bibliography, see Z. G. Baranski, 'Dante fra "sperimentalismo" e "enciclopedismo"', in *L'enciclopedismo medievale*, ed. by M. Picone (Ravenna: Longo, 1994), pp. 383-404.

³⁶ See Z. G. Baranski, 'Dante commentatore e commentato: riflessioni sullo studio dell'iter ideologico in Dante', *Lecture classensi*, 23 (1994), 135-58 (esp. pp. 144-45). Baranski's essay provides an important set of considerations on Dante's intellectual development and is especially valuable for the attention it gives to the non-rationalist aspects of Dante's intellectual formation, the epistemological layers in the *Commedia*, and Dante's treatment of poetry as a form of knowledge (see esp. pp. 155-56). On the complex question of Dante's intellectual development, however, Baranski's tripartite division of this (p. 151) into the period of the early lyrics, the rational Aristotelianism of the *Convivio*, and the period of the *Commedia* seems to raise more questions than it resolves. While I accept the view now associated with Corti (but already found in Nardi) that elements of more radical Aristotelianism are present in the *Convivio*, I believe that it also is important to stress the continuities between this work and the *Commedia*, especially with regard to both the important doctrinal themes (cosmology, the generation of the human soul, human perception and intellection, and the preoccupation with ethical matters) and the vigorous intellectualism common to both works. For suggestive comments on the close connections between the *Convivio* and the *Commedia*, see L. Pertile, '“La punta del disio”: storia di una metafora dantesca', *Lectura Dantis*, 7 (1990), 3-28 (esp. p. 24).

³⁷ See e.g. the commentary on the *Aeneid* attributed to Bernard Silvestris (?), *Commentarium super Aeneid*, ed. by J. Ward Jones & E. F. Jones (Lincoln & London: University of Nebraska Press,

1977), lib. I, pp. 5, 8, 11. For a wide-ranging study of medieval uses (in Latin poetry, encyclopaedias, and Albert the Great) of passages in Ovid's *Metamorphoses* related to scientific questions, see S. Viarre, *La Survie d'Ovide dans la littérature scientifique des XIIe et XIIIe siècles* (Poitiers: Université de Poitiers, 1966).

³⁸ Cf. Macrobius, *Commentarii in Somnium Scipionis*, lib. I, c. 2, §§ 17-18, ed. by M. Regali, 2 vols (Pisa: Giardini, 1983-90), I, 44. For an overview of the principal Dantean borrowings, see G. Rabuse, 'Macrobio', in *E.D.* III, 757-59.

³⁹ For isolated but pertinent comments on the Chartrian background and Dante, see P. Dronke, 'Tradition and Innovation in Medieval Western Colour-Imagery', *Eranos Jahrbuch*, 41 (1972), p. 78; B. Stock, *Myth and Science in the Twelfth Century: A Study of Bernard Silvestris* (Princeton, NJ: Princeton University Press, 1972), p. 277. See further the comments in Garin, 'Dante e la filosofia', pp. 288-90.

⁴⁰ On this point, see Garin, 'Dante e la filosofia', pp. 290-91. For studies of the scholastic context of Meun's ideas about humankind, nature, and the cosmos, see F. W. Müller, *Der 'Rosenromans' und lateinische Averroismus des 13. Jahrhunderts* (Frankfurt-am-Main: Vittorio Klostermann, 1947); G. Paré, *Les Idées et les lettres au XIIIe siècle: Le Roman de la Rose* (Montreal: Publications de l'Institut d'Études Médiévales, 1947); L. Polak, 'Plato, Nature and Jean de Meun', *Reading Medieval Studies*, 3 (1977), 80-103. See also L. Vanossi, *Dante e il 'Roman de la Rose'. Saggio sul 'Fiore'* (Florence: Olschki, 1979), pp. 346-48.

⁴¹ Corti, *La felicità mentale*, p. 65. For a pertinent discussion of Dante's intertextual practices in his use of sources in the *Convivio*, see also pp. 63-71.

⁴² Cf. S. J. Tester, *A History of Western Astrology* (Woodbridge, Suffolk: Boydell, 1988), p. 159: 'In almost any age and culture there is a set of ideas, of principles and of knowledge, which is common to most if not all educated people'. See also the quotation from Nardi in n. 23.

⁴³ Despite his assertions to the contrary, Nardi himself often indicated precise sources for Dante, see e.g. *Saggi di filosofia dantesca*, pp. 34-37 (on Iamblichus mediated through Aquinas as the likely source for the moon-spots doctrine expounded in *Par.* II).

⁴⁴ The relevant scientific passages are: Aristotle, *De generatione animalium*, III, 9, 758a30-759a 7 (*antomata*); Pseudo-Ptolemy, *Centiloquium*, 9 (*vultus*); Aristotle, *De caelo*, II, 7, 289a 23ff (*plaga*). For further discussion of the first two examples, see L. Minio Paluello, 'Antomata, *Purg.* X, 138 e i testi italiani della biologia di Aristotele', *Studi danteschi*, 50 (1973), 111-50 and Nardi, *Saggi di filosofia dantesca*, n. 21, p. 9 respectively.

⁴⁵ On the technical sense of 'cor', see P. Bertini Malgarini, 'Il linguaggio medico e anatomico nelle opere di Dante', *Studi danteschi*, 61 (1994), 58-59. For 'nuca', see Nardi, *Nel mondo di Dante* (Rome: Edizioni di Storia e Letteratura, 1944), pp. 247-58. For other terms such as 'intelletto', 'memoria', 'voluntade', 'potenza', and 'vertude' that may take on more precise scientific acceptations in given contexts, see Russo, *Esperienze*, pp. 146-47. Further examples include 'giudicio' and 'segno' which both have technical astrological senses in *Purg.* VI, 100 and *Par.* XXII, 110.

⁴⁶ For the Albertine source of *Inf.* XII, 4-6, see Albert, *De meteoris*, lib. III, tr. 2, c. 18, quoted in C. S. Singleton, ed. and trans. *Inferno: 2. Commentary* (Princeton, NJ: Princeton University Press, 1970), p. 185. The *De meteoris* (lib. I, tr. 4, c. 8) is also the source for *Inf.* XIV, 31-36, see P. Toynbee, *Dante Studies and Researches* (London: Methuen, 1902), pp. 40-42. On the skin covering the mole's eyes, see Albert, *De animalibus*, lib. I, tr. 2, c. 3, ed. by H. J. Stadler, in *Beiträge zur Geschichte der Philosophie des Mittelalters*, 15-16 (1916-21), p. 51.

⁴⁷ See the references given in section (d) of the Appendix.

⁴⁸ On the *imaginativa*, see *Purg.* XVII, 1-45; cf. *Inf.* XXXI, 22-27; *Purg.* XXIX, 43-50; *Par.* XIII, 1-21. For its structuring role in *Purg.* XVII, see K. Foster, *The Two Dantes and Other Studies* (London: Darton, Longman & Todd, 1977), pp. 108-13. For *Par.* XIII in relation to imagination and *cogitatio*, see A. Cornish, *Reading Dante's Stars* (New Haven: Yale University Press, 2000), pp. 95-107.

⁴⁹ Selected references in order: astronomical incipits: *Purg.* II, 1-9; IX, 1-9; XV, 1-9; XIX, 1-6; XXV, 1-3; XXVII, 1-5; XXX, 1-6; astrological structure of *Paradiso* I-XXII: esp. *Par.* III, 50-57; IV, 34-48; VI, 112-13; IX, 32-33; cf. XXII, 112-20. For studies of astronomy and astrology in Dante, see sections (a) and (h) of the Appendix.

⁵⁰ On the Augustinian echoes (*Confessiones*, lib. XIII, c. 9), see Cornish, 'Cambiamenti', p. 234; H. Shankland, 'Dante "Aliger"', *Modern Language Review*, 70 (1975), p. 765.

⁵¹ For the natural movements of fire and earth, see Albert the Great, *De generatione et corruptione*, lib. II, tr. 1, c. 11, ed. by P. Hossfeld (Münster: Aschendorff, 1980), p. 184: '*ignis simpliciter est levis et ideo simpliciter fertur sursum. Et terra simpliciter est gravis et ideo fertur ad locum qui simpliciter est ad medium*' (italics in original).

⁵² On the sources and implications of this simile, see my 'Dal Centro al Cerchio'.

⁵³ For discussion of the Solomonic and Bonaventurian influences in *Par.* X-XIV, see P. Nasti, 'The Wise Poet: Solomon in Dante's Heaven of the Sun' in this volume; A. G. Meekins, 'The Study of Dante, Bonaventure, and Mysticism: Notes on Some Problems of Method', in *In Amicizia: Essays in Honour of Giulio Lepschy*, ed. by Z. G. Baranski & L. Pertile, Special Supplement to *The Italianist*, 17 (1997), pp. 83-99 and esp. p. 90, where she notes the ideological complexity of the Heaven of the Sun. See also A. G. Meekins, 'Reflecting on the Divine: Notes on Dante's Heaven of the Sun', *The Italianist*, 18 (1998), 28-70.

⁵⁴ For fuller treatment of this passage, its Aristotelian background, and related scenes of blinding in the *Commedia*, see my *Medieval Optics*, esp. pp. 86-87.

⁵⁵ Bruno Nardi, *La caduta di Lucifero e l'autenticità della 'Quaestio de aqua et terra'* (Turin-Genoa: Società Editrice Internazionale, 1959), p. 12.