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Article body

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Introduction: Durante degli Alighieri, (c.1265-1321), simply Dante, was a major Italian poet of the Middle Ages. His Divine Comedy is widely considered a masterpiece of world literature [1]. During his time, in a Western Europe where the overwhelming majority of texts was written in Latin, Dante preferred the use of the Tuscan dialect, his Mother Language [2]. This choice was essential for the Divine Comedy, that became a precedent of fundamental importance for the Italian writers after him, and for establishing the Italian language [3]. In his works, Dante Alighieri, that was one of the most educated persons of his time, displayed his philosophical knowledge and the metaphysics he developed consequently. He knew deeply the works of Aristotle and the thought of Albert the Great and Thomas Aquinas, "Wise Spirits" in the Heaven of the Sun [4], the Neoplatonic thought and the classic Latin literature. However, for proposing his poetry and philosophy, Dante preferred using the Vulgar than the Latin.

Dante's philosophy was supported by a metaphysics, which is a metaphysics of the Light of Divine Love [5], as we can see from the Divine Comedy, his allegorical journey in the realm of the afterlife. In such a manner, when Dante comes to the Empyreum, the region beyond physical existence and the highest place of his medieval cosmology, the Comedy presents its "sense of a complete harmonization of divine light, divine love, and divine life" [6]. Here we will investigate the influence that the metaphysics of light and the discussions on the nature of light had on Dante Alighieri's thought and works. In particular,

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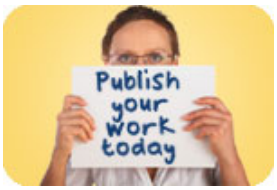

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we will evidence some features linking Dante to Robert Grosseteste, English statesman, philosopher and scientist, that Alistair Cameron Crombie defined as the real founder of the tradition of scientific thought in Oxford [7]. As we will see in the following discussion that both persons, Dante Alighieri and Robert Grosseteste, let the light pervade their vision of the world.

Luce and Lume: We can have a quantitative evaluation of how love and light are pervading Dante's poem, if we use a machine-readable text of the Divine Comedy. Let us remember that Dante based his journey in the realms of afterlife on the medieval model of the world, where the Earth was at the center of the spheres of heavens. In the poem written in the first person, Dante describes his journey through Hell and Purgatory, and then his rise through Heavens, up to the Empyreum and the vision of God. This travel is representing allegorically a soul's journey towards the Divine Love of God. The Comedy is composed of 14,233 lines, divided into three Cantiche: Inferno (Hell), Purgatorio (Purgatory), and Paradiso (Paradise). By means of a digital text, we can easily count the frequency of words in it; in the Figure 1 for instance, we can see the occurrence of Love (Amor) and Light (Luce, Lume) in the poem. The result of counting is given as in a time-series, where "time" is represented by the line of the poem. Note the increasing presence of Light and Love, so that the Paradise is triumph of Light and Divine Love [5]. Let us stress that Dante uses two terms for light: Luce and Lume. Luce is the Latin Lux and Lume is the equivalent of the Latin Lumen.

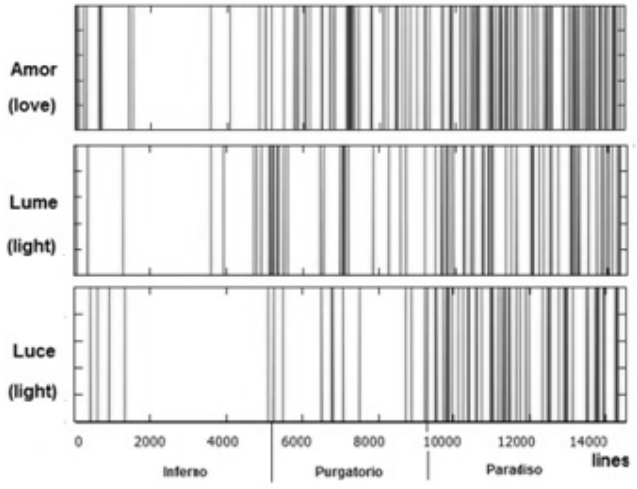

Figure 1: Time-series representing the occurrence of words light (Luce, Lume) and love (amore), in the Divine Comedy. On the horizontal axis, line numbers of the poem are representing "time". Let us remember that the poem is subdivided in three parts (Hell, Purgatory and Paradise). The vertical red lines represent the word occurrences; consequently, the plot produces a barcode-like image. From these barcodes, we can easily appreciate the dominant leitmotivs of the three realms: Paradise is triumph of Light (Luce, Lume) and Divine Love.

As told in [8], also in the Vita Nuova and in the Rime, Dante employs two words to describe the light. To the modem readers, Luce and Lume may appear to be synonyms, but a contextual examination tells us that Dante distinguished them, according to classical and medieval philosophy on nature of light and its components [8]. However, being Dante a poet, he used both terms with a certain degree of creativity, when emphasis was required [8].

The Latin distinguished between Lux and Lumen, even if the words were originated from the same root. We find the two terms widely used in the Bible. Perhaps, one of the most relevant passage is John (8:12): "Iterum ergo locutus est eis Jesus, dicens: Ego sum Lux mundi: qui sequitur me, not ambulat in tenebris, sed habebit Lumen vitae" [8]. The Latin antecedent words of Luce and Lume appear together: Lux is the light of the world, that is Jesus. It is different from the Lumen of life, understood as the earthly illumination in the

human environment. From biblical foundations until Dante's time, the philosophers have constructed theories about the nature of light, its natural and metaphysical features, including distinction between Lux and Lumen [8].

In the century before Dante's death, philosophers such as Robert Grosseteste, Thomas Aquinas, Albert the Great and Bartolomeo from Bologna wrote about light, on its nature as substance and phenomenon, its primacy over other materials during the creation of the world, and the relationship between God and light [8]. In fact, the theories of philosophers of thirteenth and fourteenth century did not agree on these issues, but they shared at least two characteristics, relevant to a discussion of Dante's poetry [8]. First, Lux belongs to heavens and then to God and divine things. Second, Lux is a phenomenon distinct from Lumen, rays, shine, heat and other things that are considered to be derived from Lux [8]. Dante's works indicate that the poet knew at least the principles of the contemporary theories, and then Dante used Luce and Lume, not only for convenience to the rhythm of the text, but also as technical terms with their specificity [8].

Neoplatonism: The notion of light, Lux, linked to divine things was not of medieval origin. It was coming from centuries of philosophical speculations that led to metaphysical and cosmological theories. In particular, the Neoplatonic systems were rich in speculations concerning light [9]. Plotinus (c.205 – c.270) was the major Greco-Egyptian Neoplatonic philosopher who first developed a metaphysics of light, in a cosmos where, from the One, an immaterial light is radiating outward; this light is becoming dimmer and dimmer until it shades off into darkness and matter [9]. Augustine (354 – 430) combined the teaching of Neoplatonism and Plato's Idea of the Good with revealed truths, and accepted the Platonic distinction between sensible and spiritual light [9]. Christ is the spiritual Light, Lux, that enlightens every man, although man is free to turn toward or away from the Light. The Augustine's theory of illumination, the Lux that becomes Lumen, like told in John (8:12), had considerable impact on medieval thought. In later centuries of Middle Ages, an amalgamation of Christian, Jewish and Arabian thought led to a fuller development of the metaphysics of light [9].

Grosseteste: Among the great thinkers who proposed a metaphysics of light, we have mentioned Robert Grosseteste. As we will see in the following discussion, it seems that the Light in Dante's work can be linked to that of Robert Grosseteste, who considered light fundamental for his metaphysics and for his studies on physics.

Robert Grosseteste (c.1175 – 1253) was one of the most prominent thinkers of the Thirteenth Century. Philosopher and scientist, he was Bishop of Lincoln from 1235 to 1253. He was heavily influenced by Augustine, whose thought permeates his writings; from him, Robert drew a Neoplatonic outlook [10]. However, he also made extensive use of the thought of Aristotle, Avicenna and Averroes [11]. As explained in his treatise [12], God is the Eternal Light. He first created 'forma prima' and 'materia prima'. Forma prima is a point of light that, due to its very nature, diffused itself becoming the dimensional form of matter [9,12]. Dragged by light, the matter is expanded into the space to create the sphere of the finite universe. From this spherical boundary, the Light creates a Lumen, luminosity, which is moving inwards, towards the center of the universe where there is the Earth. In a sequence from the outer sphere to the inner one, each of the nine celestial spheres is created. The innermost is the sphere of the moon, which produces through its own Lumen, the four spheres consisting of fire, air, water and earth.

The inferiority, or derived nature, of the Lumen is clearly indicated by Grossetesta: "Lumen quidem gignitur ex prima sphaera, et lux, quae in prima sphaera est simplex, in secunda est duplicata" [8,13]. Although the details of the philosophy of Light of Grosseteste and Thomas Aquinas (1225 - 1274), are different, the relationship between lux and lumen is similar. Thomas writes: "lux est qualitas activa corporis caelestis, per quam agit […]. Ipsa igitur participatio vel effectus lucis in diaphano, vocatur lumen. Et si fit secundum rectam lineam ad corpus lucidum, vocatur radius. Si autem casetur ex reverberatione radii ad corpus lucidum, vocatur splendor. Lumen autem commune est ad omnem effectum lucis in diaphano. […] Nam cum lux sit qualitas primi alternantis, quod est maxime perfectum et formale in corporibus, illa corpora quae sund maxime formalia et mobilia sunt lucida actu; quae autem propinqua his, sund receptiva luminis sicut diaphana; quae autem sunt maxime materialia, neque habent lumen in sui natura, neque sunt luminis receptiva, sunt opaca. […] (Tommaso d'Aquino, De Anima Commentarium. Liber II, Lectio

XIII [420-422])" [8]. Lux is the highest form, "qualitas active", while Lumen indicates the propagation of light towards Earth, and also when light encounters a transparent medium. According to Thomas, Lumen is the effect of Lux and a means for its dissemination. Unlike Lux, Lumen is not active by itself. Note that this corresponds to what John told: Jesus is Lux, but Lumen Vitae is something possessed by each man [8].

As remarked in [11], the originality of Grosseteste's metaphysics was in his identification of first form with light (Lux). In his treatise On Light, the philosopher starts with an argument for the identification of the forma prima. Grosseteste tells that form prima and materia prima are in themselves simple substances. "Yet first form, corporeity, necessarily results in the extension of matter into three dimensions, thereby yielding a quantified body. A simple form without dimension could only have this effect, however, if it instantaneously multiplied and diffused itself in all directions, thereby extending matter along with its diffusion of itself. But these are characteristic features of light, for light is essentially self-multiplicative and self-diffusive, a sphere of light being instantaneously generated from a point of light" [11]. For this reason, Grosseteste concluded that light is in fact the first form.

As a consequence of such speculations, for Robert Grosseteste, optics was very important such as geometry, necessary to discuss it [9,13]. He studies the light propagating from a point-like source, where it is self-multiplicative like in modern Huygens theory of propagation [13]. Reflection and refraction laws and the intensity of reflected and diffused light were also discussed [13-15], Grosseteste's theory had decisive influence upon the natural philosophers at Oxford and Paris. To a certain extent, he influenced Dante too. In fact, we can find in Dante's poetry several passages concerning the natural phenomenon of light and optics: as told in [16], a reference investigating the Divine Comedy to evidence the passages concerning physics, Dante was a poet of physics, besides being a poet of metaphysics [17].

Before discussing optics, let us talk about Dante's metaphysics a little bit more.

The spherical symmetry: Let us start from the form of the medieval world. Except for a few isolated cases, dictated by a religious aversion to the ancient philosophy, to the medieval Europe, the world was a sphere [18]. To Dante, the Earth is a sphere having at its center Lucifer, who dug the Hell with his fall. The center of the Earth is *"l punto al qual si traggon d'ogni parte i pesi", "the point to which things heavy draw from every side", (Inferno, Canto XXXIV).* To Dante, the gravitation was a power applied to any mass, of which he knew, given its spherical symmetry, the direction towards the center of the Earth, that was also the center of the Universe. Therefore, the gravitation was the principle that constrained the Medieval models of universe, composed of many spheres, to rotate about the center of the world. Using this simple theory of gravitation, Dante was able to solve another quite relevant question of his time. In 1320, in the church of St. Helena in Verona, Dante discussed the question about the two elements of water and earth, concluding that the circumference of water is not larger than that of earth, according to the nature of gravity [16,17]. Let us stress that the medieval scholars had not the concept of force and then could not formulate a law such as that of the universal gravitation, proposed by Isaac Newton in his Philosophiæ Naturalis Principia Mathematica, published in 1687. Dante's cosmology was a medieval cosmology, with nine heavens having the as their common center. Above the starry heaven, there is the crystalline heaven of Primum Mobile, the "first moved", linking God and the universe. The existence of the Primo Mobile depends on nothing else than light and love of God.

"La natura del mondo, che quieta / il mezzo e tutto l'altro move, / quindi comincia come da sua meta; / e questo cielo non ha altro dove / che la mente divina, in che s'accende / l'amor che il volge e la virtù ch'ei piove." (Paradiso, XXVIII, 106-111). "The nature of that motion, which keeps quiet / The centre and all the rest about it moves, / From hence begins as from its starting point. /And in this heaven there is no other Where / Than in the Mind Divine, wherein is kindled / The love that turns it, and the power it rains." (Longfellow's translation), Time has its origin from the motion of this heaven, as Beatrice tells to Dante: *"E come il tempo tegna in cotal testo / Le sue radici e ne li altri le fronde, / omai a te può esser manifesto." (Paradiso, XXVIII, 118-120). "And in what manner time in such a pot / May have its roots, and in the rest its leaves, / Now unto thee can manifest be made." (Longfellow's translation)*

As told in [4], "in the metaphysics of Grosseteste, we have found the creation through light

radiated from a point. Dante does not speak of such a primeval point of created light; he does describe creation as a radiation of divine light or will (Paradiso. XIX, 89-90)." Dante explains the motion and functioning of universe, as believed to operate by means of divine and created light. And then, Dante tells us that a ray of divine light strikes the Primum Mobile (Paradiso. XXX, 100-108), which is completely and uniformly diaphanous. *"Lume è là su che visibile face / lo creatore a quella creatura / che solo in lui vedere ha sua pace. / E' si distende in circular figura, / in tanto che la sua circonferenza / sarebbe al sol troppo larga cintura. / Fassi di raggio tutta sua parvenza / reflesso al sommo del primo mobile, / che prende quindi vivere e potenza." "There is a light above, which visible / Makes the Creator unto every creature, / Who only in beholding Him has peace, / And it expands itself in circular form / To such extent, that its circumference / Would be too large a girdle for the sun. / The semblance of it is all made of rays / Reflected from the top of Primal Motion." (Longfellow's translation)*

Note that Dante is telling that light propagates in circular form. The Primum Mobile takes vitality and power from Lumen: in this sphere, the light is changed into material energy which is transmitted below to the sphere of fixed stars. "Since each star has a unique composition, it receives (from above) and in turn transmits (below)" (Paradiso, II, 112-123) [4]. "God's light is imparted to the nine orders of angels, each of which conveys this light to the sphere of the material universe in its charge. Subsequent to God's initial act of creation, and apart from the highest part of each human soul, everything on earth is created and governed by means of light and power given off by the planets and stars (Paradiso, VII 130, XIII, 52, Convivio 2.6.9)" [4]. Therefore, Dante was undeniably influenced by the metaphysics of light, but scholars disagree as to how strictly Dante adhered to these theories.

Reflection and refraction of light: Robert Grosseteste was profoundly interested in optics, and wrote of it in many treatises, discussing some laws of this science [13-15]. After metaphysics then, we can ask ourselves what was Dante's knowledge of optics. To find an answer, we have a quite useful reference [16]. The author, Giovanni Bottagisio, was a landowner with a passion for Dante's works that led him to write a work on the scientific aspects of the Divine Comedy. Ref.16 is giving us some passages on optics.

In Purgatory, Dante uses a similitude from the reflection of light. *"Come quando dall'acqua o dallo specchio / salta lo raggio all'opposita parte, / salendo su, per lo modo parecchio / a quel che scende, e tanto si diparte, / dal cader della pietra, in igual tratta, / si come mostra esperienza e arte: / cosi mi parve da luce rifratta / ivi dinanzi a me esser percosso. (Purgatorio, XV, 16-23). "As when from off the water, or a mirror,/ the sunbeam leaps unto the opposite side, / ascending upward in the selfsame measure / that it descends, and deviates as far / from falling of a stone in line direct, / as demonstrate experiment and art, / so it appeared to me that by a light / refracted there before me I was smitten." (Longfellow's translation)*

The light of an angel, who appeared to Dante, hits him in the face as the ray of light, descending from the sun, hits the surface of water, or a mirror, and is reflected to the other side. It is coming out on the same way that it went down, that is, forming equal angles on both sides. Therefore, the reflected ray departs with an angle equal to the incidence angle, "dal cader della pietra", from the "falling of a stone", that is, from the line perpendicular to the reflecting surface, "as experience and art are demonstrating". Here we find that the perpendicular line is called the "falling of a stone" by the ancient scholars; Bottagisio tells that this metaphor was used by Albertus Magnus. That is, the perpendicular to a reflecting surface is like the "falling of the stone" to the surface of the ground.

Dante tells that the law of reflection was proved by "experience" and "art", and then we can imagine, as Bottagisio is telling, that Dante had saw some instruments designed to make experiments of geometrical optics. Let us note that the "refracted light" in this Dante's passage is actually a "reflected light"; Dante was using the language of ancient physics, which was not using two different terms for reflection and refraction. We can find the same use of term "refraction" in Robert Grosseteste's works on optics. According to both Dante and Grosseteste, to prove the laws of optics, besides the experience, the Latin "experimentum", we need also the "art", which at Dante's time was known as "catottrica" [19].

As observed in [4], some of Dante's most scientific discussions of light are in his Convivio (The Banquet [2]). In Book 3, Dante distinguishes the sensible light into three features:

Luce, Raggio and Splendore. He tells that the philosophers call Luce the light as it exists in its original source (in quanto esso e nel suo fontale principio), as it is in the sun or in a flame of a candle [4]. Raggio is the ray of light, as the light which exists in the medium between its source and the first body which it strikes (in quanto esso e per lo mezzo, dal principio al primo corpo dove si termina). Rays are in fact describing the propagation of light in geometrical optics. Splendore is the light when it is reflected in the space by an object, which it had illuminated (in quanto esso e in altra parte alluminata ripercosso). Dante then was aware of the medieval distinction of the features of light.

According to [20], the scientific sources that Dante used in the Comedy and in the Convivio were the encyclopedic compilations. For his astronomical knowledge, Dante used the Liber de aggregatione scientiae stellarum of Alfraganus and the Sphera written by John Sacrobosco. The interest of Dante for optics and physics and for the metaphysics of light indicate a knowledge, probably a direct knowledge, of the work of Bartholomew of Bologna [20], who was influenced by Robert Grosseteste. Bartholomew of Bologna, who died about 1294, was an Italian Franciscan scholastic philosopher, follower of John Pecham [21]. Among his works we find the Tractatus de Luce, on optics and the metaphysics of light. Already in 1290, several chapters of the Tractatus de Luce were reported by the Franciscan Servasanto da Faenza, in his work De Exemplis naturalium [22]. In Bartholemew's work, we can find an Oxonian origin of his luministic theory. In the Tractatus de Luce, this theory appears as a natural aesthetic legacy, an aesthetic legacy that in Dante is quite clear. The Tractatus de Luce evidences the Oxonian influence either through explicit references to Robert Grosseteste's work, readable in it, either through the clear symptoms of a lesson entirely absorbed by Dante and rendered in his Convivio [22-24].

Further features of Light: Dante's Paradiso begins at the top of Mount Purgatory. After ascending through the sphere of fire, believed to exist in the earth's upper atmosphere (Canto I), Dante enters the heaven of the moon. The moon welcomes Dante within herself, without opening, like the surface of the water when it is receiving a ray of light. On the Earth, tells Dante, we cannot understand how a solid body can penetrate into another solid body, without suffering any change. *"Pareva a me che nube ne coprisse / lucida, spessa, solida e pulita, / quasi adamante che lo sol ferisse. / Per entro se' l'eterna margherita / ne ricevette, com'acqua recepe / raggio di luce, permeando unita. / S'io era corpo, e qui non si concepe / com'una dimensione altra patio, / ch'essere convien se corpo in corpo repe, / accender ne dovria più il disio / di veder quella essenza in che si vede / come nostra natura e Dio s'unio." (Paradiso, Canto II, 30-42). "It seemed to me a cloud encompassed us, / luminous, dense, consolidate and bright / as adamant on which the sun is striking. / Into itself did the eternal pearl / receive us, even as water doth receive / a ray of light, remaining still unbroken. / If I was body, and we here conceive not / how one dimension tolerates another, / which needs must be if body enter body, / more the desire should be enkindled in us / that essence to behold, wherein is seen / how God and our own nature were united." (Longfellow's translation)* What is the nature of light, material or immaterial? This was the question that Dante was considering, when writing these lines of the poem.

This light further increases the desire for reaching the highest Heaven. After thanking God, Dante asks Beatrice, the soul of his beloved woman that is accompanying the Poet in Paradise, to explain the phenomenon of the dark spots of the Moon. He believes that these spots depend on the different density of this celestial body. Beatrice confutes his argument, by an experiment. The experiment is on the role of distance, between an observed and surfaces reflecting the light. We can take three mirrors, placed at unequal distances from a light source; we will see them equally resplendent, that is, with the same splendor. *"Da questa instanza può deliberarti / esperienza, se giammai la provi, / ch'essere suol fonte ai rivi di vostra arti. / Tre specchi prenderai; e due rimovi / da te d'un modo, e l'altro più rimosso / tr'ambo li primi gli occhi tuoi ritrovi. / Rivolto ad essi fa, che dopo il dosso / ti stea un lume, che i tre specchi accenda, / e torni a te da tutti ripercosso. / Benché nel quanto tanto non si stenda / la vista più lontana, li vedrai / come convien, ch'egualmente risplenda." (Paradiso II, v. 89-105). "From this reply experiment will free thee / if e'er thou try it, which is wont to be / the fountain to the rivers of your arts. / Three mirrors shalt thou take, and two remove / alike from thee, the other more remote / between the former two shall meet thine eyes. / Turned towards these, cause that behind thy back / be placed a light, illuming the three mirrors / and coming back to thee by all reflected. / Though in its quantity be not so ample / the image most remote, there shalt thou see / how it perforce is equally resplendent." (Longfellow's translation).*

Bottagisio explains that the distance is not changing the quality of the light reflected by the three mirrors. Ottavio Fabrizio Mossotti (Italian physicist, 1791-1863, known for the Clausius–Mossotti relation), in a letter to the Editor of Bottagisio's book, has a relevant observation about this experiment [25]. "It seems to me that Dante, by the experiment of the three mirrors, wanted to point out the principle that flat surfaces, which emit or are illuminated in equal degree, appear to have the same brightness at any distance they are placed. This happens because the size of their image and the amount of light that receives the eye from each point are both decreasing as the inverse of the square of the distance. Therefore, there is a compensation, and each element of equal apparent extension of the image is always represented by the same amount of light reaching the eye at any distance you observe the surface. … (The light source must be supposed to be at a large distance, comparatively to that at which the mirrors are between them). … The theoretical principle of Dante is right, and for that time had to be a sublime truth and not common knowledge". Mossotti's brightness is the ratio of the light reaching the eye to the apparent size of the object. These both diminish with the square of the distance, so the brightness remains constant.

After proposing the experiment with the three mirrors, Beatrice continues with her explanation, which becomes more metaphysical: the brightness of the celestial bodies varies as the force of virtue varies from star to star. This virtue is the heavenly power, that we can find in Grosseteste's metaphysics of light too [12]. Let us also note that Dante, through Beatrice's words, is summoning the use of an "experimentum". The same we can find, for example, in the works of Robert Grosseteste (1175-1253), considered the founder of the scientific thought in the medieval Oxford. The Grosseteste's "experimentum" of his medieval physics, like that of Dante, was obviously different from an experiment of modern physics; it was referring to a thought experiment (Gedankenexperiment) or the experience of a related natural phenomenon.

The rainbow: Robert Grosseteste wrote on reflection and refraction in his treatise entitled De Iride (on Rainbow) [14,15], where, after a discussion on the propagation of light he proposed his explanation of such natural phenomenon. The rainbow was a subject very attractive for Dante too. In the Divine Comedy, we find *"E come l'aere, quand'è ben piorno, / Per l'altrui raggio, che 'n sé si riflette, / Di diversi color si mostra adorno." (Purgatorio XXV, v. 91-93). "And even as the air, when full of rain, / By alien rays that are therein reflected, / With divers colours shows itself adorned." (Longfellow's translation).* In fact, if we imagine that the meaning of Dante's reflection was that of a refraction, it seems that the poet was in agreement to Grosseteste, who told that it is "necessary that the rainbow is created by the refraction of the sun's rays by the humidity carried by the cloud" in its convexity [7]. "Necesse est ergo, quod iris fiat per fractionem radiorum solis in roratione nubis convexae" [8].

Also the double rainbow is present in the Dante's Comedy, with the second rainbow being the image of the first reflected by the cloud. *"Come si volgon, per tenera nube, / Du' archi paralleli e concolori, / Quando Giunone a sua ancella jube, / Nascendo di quel d'entro quel di fuori." (Paradiso, XII, 10-13). "And as are spanned athwart a tender cloud / Two rainbows parallel and like in colour, / When Juno to her handmaid gives command, / The one without born of the one within." (Longfellow's translation).*

These Dante's passages on rainbow are reinforcing what we have previously told on the scientific treatises that he knew. May be, he had not a direct knowledge of Grosseteste's works, but in Dante's works we can see some of the Oxonian theory of light rendered in poetry. It seems evident that Dante adhered to a general philosophy of light that was shared by several thinkers of the Middle Ages, but his interest for optics, which is displayed by the Comedy and the Convivio, is illuminating a strong link between the Poet and Robert Grosseteste.

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