Traveling Around the Empire: Iberian Voyages, the Sphere, and the Atlantic Origins of the Scientific Revolution

Lino Camprubí
University of California, Los Angeles
linocamprubi@ucla.edu

"Who can claim that the ship *Victoria*, surely worth of eternal memory, did not win victory and triumph over the roundness of the world, and still more over that illusory void and infinite chaos that the ancient philosophers placed under the earth, since she circumnavigated the globe and encompassed the great ocean immensity."
(Jose de Acosta, *Historia natural y moral de las Indias*, 1590)

Abstract:

This paper aims at illuminating the links between spherical geography, Catholic empire and the Atlantic origins of the scientific revolution. Boldly put, the theory of the sphericity of the earth stood at the center of Iberian expansion and its imaginary; in turn, imperial patronage contributed to give a new status to that theory and to transform it into one of the sources for the early modern worldview.

Three main moments constitute the previous argument. First, voyages developed along with spherical geography, in which lumps of earth were located in terms of latitude and longitude. Second, Iberian voyages of discovery developed spherical geography by enlarging the Greek known world, or *oikumene,* and gave new ground to the theory of the sphericity of the earth in the midst of medieval competing models, specifically one that held that the sphere of the earth was suspended over a sphere of water too large to be navigated. Third, imperial voyages together with spherical geography, practice merged together with theory, rendered the entire world subject to human measure and exploration. For the first time, it also made clear that the natural knowledge developed from antiquity to the early modern period could and did produce practical power.

Thus, the simultaneous development and mutual nourishment of spherical geography and imperial voyages was a significant source for the scientific revolution.

Key words: Imperial voyages; spherical geography; theories of the earth's sphericity; scientific revolution.

Resumen:

Viajando alrededor del imperio: viajes ibéricos, la esfera y los orígenes atlánticos de la revolución científica

Este artículo busca iluminar los vínculos de la geografía esférica, el Imperio Católico y los orígenes Atlánticos de la revolución científica. Por decirlo brevemente, la teoría de la esfericidad de la Tierra fue central para la expansión ibérica y los modos de entenderla; a su vez, el patronazgo imperial contribuyó a que dicha teoría alcanzase un nuevo estatus y se transformase en uno de los pilares del mundo moderno.

La tesis se desarrolla en tres momentos. Primero, los viajes se han desarrollado de la mano de la geografía esférica, por la cual se localizaban áreas de tierra en términos de latitud y longitud. Segundo, los viajes de expansión ibéricos desarrollaron la geografía esférica, agrandando el mundo conocido Griego, *oikumene*, y afianzaron la teoría de la esfericidad de la Tierra, en franca competencia con modelos alternativos, y especialmente aquel que suponía a la esfera terrestre como suspendida sobre una esfera acuática demasiado grande para ser navegada. Tercero, los viajes imperiales y la geografía esférica, teoría y práctica fundidas, convirtieron al mundo en algo sujeto a medida y exploración. Por primera vez, también demostraron que el conocimiento natural desarrollado desde la Antigüedad hasta el período moderno podía producir, y produjo, poder práctico. Por ello, el curso simultáneo e impulso mutuo de la geografía esférica y los viajes imperiales se constituyó en una fuente significativa de la revolución científica.

Palabras clave: viajes imperiales - geografía esférica - teorías esféricas - revolución científica.

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Introduction

This paper aims at illuminating the links between spherical geography, Catholic empire and the Atlantic origins of the scientific revolution. Boldly put, the theory of the sphericity of the earth stood at the center of Iberian expansion and its imaginary; in turn, imperial patronage contributed to give a new status to that theory and to transform it into one of the sources for the early modern worldview.

Three main moments constitute the previous argument. First, voyages developed along with spherical geography, in which lumps of earth were located in terms of latitude and longitude. This mutual nourishment was related to the geometric concept of the *great circle* that divided the sphere of the earth into two hemispheres. It also defined the maximum circle a voyage could describe, the shortest distance between two points over the surface of the earth, and how to divide the world between Portugal and Spain. Second, Iberian voyages of discovery developed spherical geography by enlarging the Greek known world, or *oikumene,* and gave new ground to the theory of the sphericity of the earth in the midst of medieval competing models, specifically one that held that the sphere of the earth floated over a sphere of water too large to be navigated. As a result, navigators such as Columbus defended the possibility of circumnavigating the Earth. This possibility became central for the project of global expansion of the Catholic Spanish Empire, under whose patronage the first circumnavigation of the earth was accomplished in 1522. The latter allowed Acosta to claim, as in the quote opening this paper, that moderns had taken the Greek theory of the sphericity of the Earth to a new level, a more operational one. The earth's circumnavigation would not have been possible without spherical geography. In turn, an emerging specific genre of travel literature – i.e., geographic, cosmographic and nautical - acknowledged the new operational status that imperial voyages gave to spherical geography, and in particular to the theory of the sphericity of the earth. Third, imperial voyages together with spherical geography, practice merged together with theory, rendered the entire world subject to human measure and exploration. For the first time, it also made clear that the natural knowledge developed from antiquity to the early modern period could and did produce practical power. Thus, the simultaneous development and mutual nourishment of spherical geography and imperial voyages was a significant source for the scientific revolution.

In order to develop my argument, I draw extensively on secondary sources analyzing voyages, spherical geography in the Renaissance, and the origins of the Scientific Revolution. Using the arguments of W. G. L. Randles and Klaus A. Vogel about the meaning of Columbus voyage against competing worldviews, I put them into a broader context of global imperialism and link them to cosmographers writing about circumnavigation and about geometric concepts such as the great circle. I also contrast my thesis to some of the most recent historiography on the Scientific Revolution, particularly authors that are trying to bring materiality and operations, as well as Iberian science and technology, into the more traditional narratives.

Ancient voyages and spherical geography

The English word 'voyage' encompasses two main meanings. First, it refers to a journey, especially a journey to a distant place. Second, it refers to the literary narration of a trip, especially an exploratory trip. This connection between the voyage and its account tells us some basic things about voyages. In a very immediate way, it tells us that voyagers have often been expected to narrate their journeys to the community they belong to. This implies that voyages are, in contrast to migrations, roundtrips. And that, in contrast to diasporas, only a part of the society of origin departs on a voyage (Cherry, 2001; Pimentel, 2003). A voyage was more than just a spatial motion. It was a temporal journey in which an individual or group of individuals departed from their communities of origin and came back. As a result, voyaging (*via-ticum*) required planning the paths, roads, ways or routes to be taken. The development of geographical maps, drawings and models was related to traveling as much as to the location of resources or dangers around a community. The roundtrip traced on a map did not always use the same path for both ways. More often, routes traced on maps looked like a more or less deformed circle. Voyages were circular, from the point of departure and back again to the point of departure.

When theories of the spherical shape of the earth became widely accepted in Ancient Greece, a new theoretical maximum to the circle that a voyage could follow emerged. Departing from a given point and arriving at the same point by following a straight line was now conceivable. In the terms of Euclidean spherical geometry, this was called a 'great circle.' It was defined either as the maximum circle possible over the surface of a sphere or as the circle of which a segment represented the shorter distance between any two points over the surface of the spherical earth. Traveling around the earth, i.e. performing a globalizing voyage, became a theoretical possibility (Bueno, 2000).

The theory of the sphericity of the earth also changed the way maps were drawn. The Greek spherical treatment of astronomy introduced geometrical relations into what had hitherto (in Babylonia) been arithmetical data. Ptolemy's *Almagest* is considered to be the effective merging point of very precise Babylonian observations and the theoretical principle of the sphere (North, 1994, p.50-115). This mastery of astronomy and geometry allowed him to develop what has been called astronomical or mathematical geography. His famous world maps of the *oikumene,* or Known World, gave specific locations to mapped lands within the spherical system of coordinates. For any given point, it was possible to determine a position in terms of latitude (according to the parallels) and longitude (according to the meridians; for a history of projections, see Snyder, 1997).

The spherical maps of the *oikumene* provided a new context for voyages. *Peri-ploi* or practical accounts of circular voyages grew in number and *periegetes*, guides or descriptions of the world around, became popular. While Pausanias' *Periegesis* described, narrated and theorized about Greece, Dionysius Periegetes' works were taken as one of the most accurate descriptions of the things seen during his roundtrips through the *oikumene* (Cherry, 2001). The relationship between spherical geography and voyages did not come to an end in Ancient times; they triggered each other's development in the fifteenth and sixteenth centuries.

Fifteenth century navigational travels and the expansion of spherical geography

In the first years of the fifteenth century, Portuguese and Spanish expeditions occupied Madeira and the Canary Islands. This expansion south in the Atlantic required ships and techniques very different from those traditionally used in the Mediterranean. Cape Bojador, located some 200km (160 maritime leagues) south from the Canary Islands, was a particularly hard challenge. The difficulty consisted in finding a way of return, since very strong winds from the northwest blew at all seasons. In 1434, under the patronage of Portuguese Henry the Navigator, the cape was rounded. This accomplishment opened the prospects of sailing further south in order to encircle Africa and eventually find new routes to Asia. But it also obliged Portuguese sailors to devize ways of returning against the wind.

Nautical, geographic and astronomical knowledge acquired greater importance. By the last third of the fifteenth century a new genre of literature on vessel building and navigation techniques appeared: the so-called *Regimientos de navegación,* or rules for navigation. Their authors wrote them in vernacular for a public composed of engineers and artisans, rather than university scholars. Treatises on ship construction appeared in this period along with discussions on geography and astronomical tables (López Piñero, 1979, p. 217-254). As we will see, they reached a peak in the sixteenth century. Sailing against the wind not only required new technologies but also new routes. In order to sail towards the wind, a ship needs to describe zigzags. Portuguese fleets needed to trace long zigzags that took them well into the

Atlantic as far as the Azores. Finding ways of return that could take advantage of winds and currents was normally a long process in which many ships were lost. These ways of return would become institutionalized and transmitted over time; they were for instance, used in later years for returning from the Americas.

Mapping techniques were developed in the process of establishing these new routes. The so-called *portolan* nautical charts were considered good enough for coastal navigation in the Mediterranean. They depicted coasts and included prominent coastal references that sailors could easily identify. They utilized some astronomical knowledge. Sailors using *portolans* needed latitude for orientation purposes: boats sailed north or south until they reached the desired height, and then made a 90º turn towards the direction they wanted to reach. In this scheme, latitude measures did not need to be very precise. In order to perform measures of latitude navigators used the compass and the astrolabe, of long tradition before the 14th century. An Islamic tradition made important contributions to this navigational knowledge (González, 1992, p.33-39 and López Piñero, 1979, p.122-127).

These methods of navigation were valid for the well-known coasts and seas of the Mediterranean. However, they proved insufficient for navigating in the conditions of the Atlantic. First, compass indications suffered due to the variations of the earth's magnetic pole with respect to its geographical poles. The compass was technically improved. However, the distortion due to the varying position of the magnetic pole persisted. Columbus first related in his diaries this variation with the position of the ship and inaugurated a tradition of trying to determine specific values to the deviation of the magnetic pole with respect to the terrestrial pole. In 1551, Martin Cortes' hypothesis of the magnetic pole being different than the terrestrial pole, to which I will refer later, was part of this tradition (Columbus, 1989, p.50; Cortés, 1990). Second, when navigating the Atlantic the problems of imprecision in the calculations of latitude at sea could be, and often were, fatal. Moreover, when the Portuguese passed the southern hemisphere in 1471, the tables and stars used for determining latitude were no longer useful. 'A new sky and new stars,' to use their own words, had been discovered (Hooykaas, 1987, p.459). As a result, the solar tables of the Alphonsine tradition had to be improved. They determined the observer's positions according to the height of the sun at different sessions of the year. New tables were constructed using what Portuguese called 'The Southern Cross,' a set of stars located in the South Pole. The 'universal astrolabe' included stars of both the northern and the southern hemispheres. Ways of predicting the position of the moon in unknown latitudes were also improved. This proved important to foresee the heavy Atlantic tides and to try to establish measurements of longitude, which otherwise relied upon rough calculations of distances. John Law does, from a science studies stand point, a good job of analyzing some of these navigational innovations to imperial control and even points, as I will do later, to they being among the first examples of the practical results of scientific knowledge; however, he fails to recognize two points to which much of my paper is devoted: navigational innovations not only used cosmography and empire, but also shaped them in important ways (Law, 1986, p.234-263).

The developments in astronomical navigation triggered the use of astronomical geography. Maps for Ocean navigators were more effective if they could locate lands into the grid of parallels and meridians. Navigators of the last third of the 15th century were eager to connect their techniques of astronomical navigation with Ptolemy's astronomical geography. For instance, Christopher Columbus worked with a printed edition of Ptolemy's *Geography* (Manso, 2006). Moreover, he, as other navigators, used Ptolemaic model and methods but did not feel tied to preserving the actual geographical contents of Ptolemy's *Geography* (Gautier, 2007, p.329). This merging of the astronomical and the geographical tradition and of learned cosmographers with artisan navigators produced important transformations in the theory of the sphericity of the earth. The *oikumene* was expanding and being redefined.

Among these transformations, the most significant for the purpose of this paper is the one concerning the theory of the sphericity of the Earth. Many historians of science would say today that the Greeks already *knew* that the earth was a sphere, and therefore the shape of the earth did not pose any challenge for navigators. However, this is anachronistic in that we would not accept many of the arguments put forward by Ancient astronomers and geographers to prove the sphericity of the earth. Also, it disregards the significant fact, shown by historian Randles, that most late medieval and renaissance scholars pictured the earth as a sphere situated over a second sphere of water with which it would share the center of gravity. In this scheme, championed by Parisian Aristotelian Jean Buridan (1300 – 1358), the *oikumene*, Europe, Asia and Africa, was supposed to be the upper part of the earth's sphere and the only one emerging from water. Everything beyond it would be submerged. If that were the case, a voyage of circumnavigation would not be possible, since the sphere of water was deemed to be significantly bigger than the sphere of earth, thus enlarging distances beyond the limits of existing technologies of navigation. This argument, Randles shows, was based on some ambiguities in Aristotle's theory of the elements - earth, water, air and fire - and their relative disposition in separated spheres, which made medieval scholars picture the spheres of earth and water as actually distinct (for an account of the competing theories of the earth, see Randles, 1994).

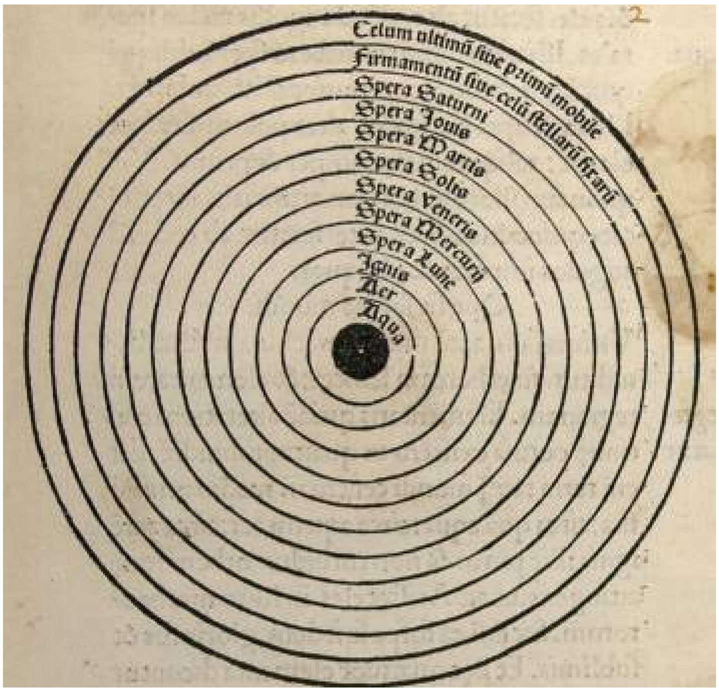

Image 1: Aristotelian division of spheres according to a 15th century edition of Sacrobosco's Spaera. Joannes de Sacrobosco, Spaera mundi, 1478.
With permission of UCLA, special collections.

Ptolemy's Geography undermined that vision and argued for a unique sphere. Some authors, such as Roger Bacon, had interpreted Aristotle in a more Ptolemaic fashion. Around 1483, some years after Portuguese ships surpassed the equator, Columbus annotated in a copy of Pierre d'Ailly's Imago Mundi, which followed Roger Bacon, that 'Earth and water form one round body.' His project of arriving to Asia going westwards was unthinkable from the point of view of an earth submerged in water since the distances between Europe and Asia were enormous under most calculations that assumed the theory of the two spheres. The moment one was out of the oikumene, the floating part of the earth, one entered the realms of the sphere of water. In fact, most of the astronomers and geographers that evaluated his project from 1480 onwards attacked it for this very reason: they thought impossible to navigate the sphere of water, under which they believed most of the sphere of Earth sunk (Randles, 1990).

As Vogel has put it, Columbus voyage can be seen as an attempt to experimentally prove his hypothesis (Vogel, 2006). This is not to say that Columbus himself acted by some anachronistic scientific method or that his cosmography was always accurate. After all, it is well known that Columbus exaggerated the longitude of Asia, which was already too big in Ptolemy's *Geography* and that in his later life he tried to accommodate his discoveries to his ideas of Eden (on this fruitful errors, Wallis, 1993). But what Vogel provocative claim does is helping to understand the geographic and imperial context in which his project was finally accepted. Columbus' attempts to convince either the Portuguese or the Spanish crowns failed many times. Whenever he used the theories of Ptolemy, Roger Bacon or some passages from Seneca and Aristotle, his critics presented a wealth of Aristotelian commentators that had defended that a large sphere of water was below the sphere of earth. Matters, however, changed after Columbus witnessed Bartolomeu Dias' account to the king of Portugal about his navigation through the Cape of Good Hope. The news made clear that Africa went farther to the south than any of the defenders of the theory of the two spheres could admit. Critics changed files and supported Columbus insistence that earth and water form a single sphere. It was the expansion of the *oikumene* by navigators what had rendered Columbus' theory plausible to the eyes of patrons and cosmographers alike (Vespucci, 1992).

Spanish universal empire and the sphericity of the earth

As a result of the voyages of navigation the world of spherical geography had been expanded. Columbus could now convince his patrons of the possibility of reaching Asia sailing westwards. The Portuguese crown did not support his project. Her sailors had already in 1488 reached Cape of Good Hope. It received this name because it meant that the Portuguese dream of finding a south pass to India was closer to realization. Spanish Catholic Kings were in a different position. After the conquest of Granada, all possible ways of expansion seemed already filled by competing powers. The prospect of describing a circling the earth to get to Asia was very attractive to the Spanish monarchs. Commercially, the enterprise would make it possible to avoid Venetian intermediaries to trade with Asia. Military and politically, it would allow Spanish forces to surround their Ottoman enemy. In this section, I explore further this connection between the Spanish empire and spherical geography.

People all over Europe were discussing the Asian nature of the newly found lands well after Columbus first came back from the West Indies. By contrast, the idea that earth and water forming a single sphere was readily accepted. As early as 1494, Portugal and Spain signed the Treaty of Tordesillas. It divided the New World in the terms of astronomical navigation by defining a meridian located 370 leagues west of Cape Verde. Lands west of the meridian, called the 'line of demarcation', were to belong to Spain, while territories east of the meridian were Portuguese. Consequently, Ptolemaic spherical geography acquired a new political meaning. The *oikumene* was now taken to cover the entire sphere of the earth.

Empires could now plan their expansion over the entire surface of the world (for the relation between longitude and politics, see Goodman, 1988, p.53-65).

This possibility of universal (global) expansion was of special meaning to the two Catholic Iberian empires. Pope Alexander sanctioned the Treaty of Tordesillas with the argument that the Gospel could be now spread through the entire world. Most Christians had shared the idea that the limit of the *oikumene* was the limit of the Mediterranean with the Atlantic. St. Augustine had denied the possibility of the antipodes. Like him, many of his medieval followers warned that the existence of human beings beyond the *oikumene* would mean that Jesus' mandate of spreading the Gospel to *all* people had gone unheard, discrediting the *New Testament* and contradicting the doctrine of the *divisio apostolorum* (for St. Augustine's conception of the sphericity of the earth, see Randles, 1994). Even just north to the equator, in the so-called 'torrid zones,' one was not supposed to find human beings. But navigators had transgressed these boundaries. Around 1516, Charles V chose as his coat of arms the two Heracles pillars with '*plus ultra*' inscribed around them. It was soon interpreted as the celebration of the transgression of the inscription '*non plus ultra*' ('no further beyond') written in the mythological Heracles' pillars, standing on the strait of Gibraltar (on this motto, see Rosenthal, 1971). The Pope, however, was not eager to draw the consequences that Augustine had feared. He accepted the imperial Iberian answer: a new ecumenical approach to the new *oikumene*. Catholicism could impose its universality through the globe thanks to the empire. In the process Catholicism merged with the politics of the empire. The Spanish crown, unlike the Portuguese, saw the new lands as extensions of their kingdoms. They were to be ruled under the same laws that affected their peninsular provinces and their peoples would become subjects of the crown. The monarchy would become universal (Bueno, 1999).

There was, thus, a deep relation between Catholic empires and geographic discovery. The goal was to become global. The political thirst for geographic discoveries triggered dozens of expeditions. At a much more rapid rhythm than that of later European empires, Iberian fleets reached America, India and the Islands of the Philippines within a few years (Pimentel, 2001). We should not forget, however, that the project of a universal monarchy was deeply related to the new image of the sphericity of the earth. America appeared in Columbus' way to Asia. Still, this did not make the crown abandon the idea of circling the earth and the search for a pass to Asia began shortly thereafter. In 1513, Nuñez de Balboa led an expedition through the Panama isthmus that confirmed the existence of a sea beyond the New World, the Pacific Ocean. Charles V commanded the Portuguese navigator Ferdinand Magellan to find a pass towards the Pacific by encircling America. His expedition departed from Cadiz in 1519 and in 1520 they passed what would come to be called the Strait of Magellan, which lead to the Pacific Ocean. Magellan was killed in fights against the natives of the Pacific Islands and Sebastian Elcano took the lead of the expedition. In 1522, Elcano arrived back to Cadiz coasts with only one boat, the *nao Victoria,* and eighteen survivors. The earth had been circumnavigated.

The first circumnavigation marked a turning point in the relations of the empire to the theory of the sphericity of the earth. It transformed the conceptual possibility of the sphericity of the earth into an actual operational fact. Jose de Acosta's quote with which I opened the paper makes this point. In his words, the "roundness" of the earth had been "made even more manifest by experience than it could be through any philosophical argument of demonstration." Historians of science, each day more interested in practice, should bear in mind that the arguments for the sphericity of the earth that Acosta presented in his ambitious *Natural and Moral History of the Indies* were not Aristotle's philosophical arguments. Rather, they were based on experience: "we who live in Peru need to observe from this hemisphere that part and region of the heavens that turns around the earth and that the ancients never saw." This sense of 'modern' superiority over the ancients is important for the last section of my paper. "I myself have sailed more than sixty degrees from north to south, forty on one side of the equator and twenty-three on the other, leaving aside for the moment the testimony of others who have sailed much farther and reached almost sixty degrees south." Acosta went beyond experience. He stressed the operational nature of the proof: men had 'measured' the earth by sailing it with the *nao* (de Acosta, 1590). This operational dimension was also present in the coat of arms Charles V presented to Elcano (Insua, 2008). In it, a globe was represented with the inscription "*Primus circumdedisti me*" ("You went around me first").

After the voyage of circumnavigation the Treaty of Tordesillas had to be revised. A meridian was not enough to divide the entire globe. The establishment of a 'counter-meridian' provoked long discussions since it required a political agreement over the slippery measures of longitude. The issue was drawing a great circle on a map dividing the world into two semi-spheres. Although a political solution was reached in Treaty of Saragossa of 1524 to complement the Treaty of Tordesillas with the definition of the needed counter-meridian, Portuguese and Spanish crowns kept on competing for the new territories. Understandably, the first thing explorers did after arriving to new coasts was to determine their latitude and to try to determine their longitude (often modifying their results enough to suit the territorial claims of their kings; for an account of this measurements, although strangely silent about the Spanish empire and even the Treaty of Tordesillas, see Seed, 1995).

Thus, spherical geography and cartography became imperial pursuits. In the process, their scientific nature changed and was secured. Now, the relationships of distance, height, longitude and latitude between lumps of earth were beginning to form a 'closed' system. For the first time, one could determine the distance between Cadiz and the Philippines if one knew the Atlantic distance between Panama's isthmus and Cadiz and the Pacific distance between the isthmus and the Philippines. Any geographical phenomena could be now effectively related to any other by means of spherical coordinates (Bueno, 1989). This 'closed' system did not imply any 'closure.' Far from it, it allowed for the systematic search of new geographical objects (lumps of earth) within the new limits of the system. Now that the approximate length and nature of the sphere was known for a fact, blank spots could appear in world maps in those areas that were yet to be explored. Moreover, once that America had been accepted as the fourth part of the world, an addition to the three of the *oikumene*, arguments against the existence of a fifth part became difficult to sustain. In 1606 Pedro Fernández Quirós sailed southwest from Peru in search of the *Terra Australis,* the fifth part of the world. He arrived at an Island, today part of the Republic of Vanuatu and named it Australia (Pimentel, 2003; Randles, 1994; O'Gorman, 1961). By that time, however, the Spanish crown was not in a position of organizing the conquest of the new lands.

Imperial voyages and their literary accounts

At the beginning of the sixteenth century the nature of voyages was different from that of any previous situation. Spherical geography informed them in new ways, so that, for one of the first times, a scientific theory had proven valuable for daily practice. Discussions about the great circle, the poles or how to measure longitude were merged with data about navigation and imperial conquest. This merging had its place on ships and new territories, but also in literary accounts of voyages. At this point, I study the context and content of some of the travel literature produced in this period. In particular, I will look at it from the framework of my argument about the common development of the theory of the sphere, the empire, and voyages.

After unifying the Spanish kingdoms under the flag of the empire, the Catholic Kings, attempted to seize economic and political control over any possible contact with the New World. Concentrating all ships in a single port allowed for all sorts of regulations and controls to be designed and applied. The chosen port was Seville, already a big commercial city legally dependant on the crown and better protected than coastal ones (Pérez-Mallaína, 1992, p.10-15). As part of these mechanisms of control, in 1503 the Catholic Kings created the *Casa de la Contratación* (House of Trade).[1] It followed the model of the Portuguese *Casa da Mina* and

[1] The relationship of Seville with the Americas was explored in the humongous work of Pierre Chaunu (Chaunu, 1955-1960). I thank the anonymous referee that called my attention towards that work. I also thank this referee for pointing

Casa de India but soon reached wider scale and scope. Reports and riches were to cross its gates to be recorded, interpreted and taxed by government officials. In 1508 Ferdinand the Catholic, summoned a group of expert navigators to Seville. He appointed them to design and update a map of the new coasts and lands that all navigators could use. Columbus' son, Hernando Columbus, and Amerigo Vespucci were among the experienced pilots called in for the task. In view of the dangers of sending unprepared fleets to sail West, Ferdinand decided to keep Vespucci in the *Casa de Contratación* and created the position of pilot-major for him. The main function of the pilot-major was to supervise the technical readiness of pilots, ships and instruments before they headed towards America. He was also put in charge of updating a master map or pattern chart of the world (*Padrón Real*). Navigators were obliged to use that world map and to report back any observations or findings that could alter it.

As voyages to the West Indies intensified, these responsibilities exceeded the capacities of a single man. While the pilot-major was left in charge of the education of pilots, a cosmographer-chief was appointed to take care of supervising instruments and updating the master map. Gradually a body of pilots and cosmographers were incorporated to the *Casa de Contratación*, so that it became one of the first state-funded institutions devoted to the production and dissemination of natural knowledge. Production of instruments and pattern charts was centralized in Seville and monopolized by the state. The same held true for nautical and geographical treatises. Although books of interest to navigators and cosmographers were published in places like Salamanca and Valladolid, Seville was the leading book producer of the empire. It reunited a wealth of public interested in cosmographical, geographical, astronomical and navigational information. It also provided authors and editors with the necessary networks to contact cosmographers and pilots of the *Casa de Contratación* who wrote many of the nautical and cosmographical treatises published in Seville. For any author of the *Casa*, the process of sending a manuscript to print was long, tedious and involved much discussion. Treatises, like master maps, were regarded as a cumulative and collective enterprise. Debates about the information contained in the treatises were often intense, ranging from accuracy of measurements to the political convenience of publishing certain data (Lamb, 1995; historian Alison Sandman argues that the distinction between the levels of secrecy of cosmographers' knowledge and pilot's knowledge helped in making the later more prominent and in obscuring the former: Sandman, 2008).

A strong literature on the *art of navigation* (*Arte de Navegar o Marear*) was produced in this imperial setting. Alfonso X's tables of the 13th century were the first astronomical tables

me to another work that I have been unable to use for this paper but I want, nevertheless, to share with the reader (Siegert, 2003).

written in a vernacular language. Most of the new treatises followed that tradition. As the *Regimientos,* mentioned in section 2 above, these treatises included tables of astrological times and calendars for navigation. They also included information on routes of navigation, geographical descriptions and the uses and designs of instruments and ships and they often included world maps or references to the master map (Carriazo, 2003). Importantly for my argument, many of these treatises devoted its first pages to the theory of the sphericity of the earth (Fernández de Enciso, 1519). In this, they were continuing a Portuguese tradition of the *Regimientos*. These common treatises on the sphere were partly based on John Hollywood's (Johannes de Sacrobosco) *Tractaus de Sphaera* (*Treatise of the Sphere*), written around 1220. Sacrobosco's *Treatise* provided a natural philosophical basis for Ptolemaic astronomy. However, *de Sphaera* could be read as favoring the theory of the separation of the spheres of earth and water. Thus, most of its fifteenth century editors accompanied his Treatise with drawings and illustrations that supported the notion of a separated sphere of water (for illustrations depicting the two spheres, see Randles, 1990 and Vogel, 2006; Randles, 1994, quotes Sacrobosco: "Three of the elements in turn surround the earth on all sides spherically except in so far as the dryness of the land stays the wetness of the water to protect the life of animate beings"). The new context of imperial voyages was, as has been argued, incompatible with this picture, so Fernández de Enciso and Francisco Falerio, rather than just summarizing Sacrobosco (as it has been assumed by many a commentator), eliminated all ambiguities with respect to the unity of the sphere: oceans were separating masses of land, not covering or holding a sphere of earth (Falerio, 1989, p.9-40).

Despite the fact that this view did not originate in the universities, academic scholars were soon echoing it, as well as the empirical support it had. For instance, as early as 1520 the Portuguese professor Pedro Margalho published a *Physices Compendium* in Salamanca. He argued that water could not be a separated sphere since that would make the southern hemisphere larger than the northern hemisphere. If that were the case, a universal spherical grid to measure distances on earth would not be possible. But navigators had proven that such a spherical grid did work; hence, he concluded, earth and water formed a single sphere (Flórez, 1985). Similarly, around 1526 Fernan Pérez de la Oliva authored *Cosmographia Nova* (*New Cosmography*), which he used for his courses on natural philosophy at the University of Salamanca. Despite having spent some years in Paris, Perez's arguments on the sphericity of the earth resembled very little those of the French Aristotelians. He stressed the experiences of navigators and the mathematical measures of the single globe. He also explained the different types of projections on planispheres and how to construct them. In 1524, before composing this manuscript, he presented a work on navigation discussing Magellan's circumnavigation and its effect on cosmography. Accordingly, he was in direct contact with navigators and non-academic cosmographers around the *Casa de Contratación* (for instance, he met Columbus' son, the experienced sailor Hernando; for this and for Pérez's work on the circumnavigation, see Fuertes Herreros, in Pérez de la Oliva, 1985).

The literature I am considering here was becoming scientific by virtue of its relation to the geometrical measures of the earth (there were many other investigations linked to Iberian imperialism, such as linguistic studies; see Suárez, 1992). In the first section I pointed at the connection of global voyages to the concept of the great circle; now, I want to introduce some explicit discussions around the 'great circle' by navigators and authors involved in imperial voyages. In his *Cosmographia nova,* Pérez de la Oliva, who we already encountered inquiring about the voyage of circumnavigation, defined the great circle (*circulus maior*). He used it to calculate distances. Pérez, like other authors of the period, faced the problem of finding what course should a ship follow in order to circumnavigate the earth. If a ship were to follow a 'rhumb line' with the compass, thus cutting every meridian with the same angle and therefore maintaining a constant course with respect to the North Pole, it would not reach its point of departure but instead arrive to one of the Poles. Following a straight line, drawn on a map, towards the east or the west, did not result in the great circle.

The Portuguese sailor Pedro Nunes and the Spanish cosmographer Martin Cortés were first to identify two reasons why this apparent paradox should be the case (Pérez de la Oliva, 1985: 86). First, Nunes signaled that meridians grew closer to each other in the northern latitudes so that charts with quadrangular projections were deceiving for long distances. He attempted a mathematical description of what would later become the loxodrome, which was defined as the course a ship would follow if it were to cut all meridians with the same angle. By correcting it, a pilot could achieve a great circle, which did no longer look as a straight line in a flat quadrangular projection. Pilots of the *Casa* denounced that the existing maps did not correct those deviations. At stake was not only the position of some important ports in the astronomical grids of the earth, but also the commercial interest of the mapmakers and the imperial interest of the crown (Lamb, 1995).[2] Second, Martín Cortés confronted the problem of the deviations of the compass with respect to the terrestrial pole. He offered the hypothesis of a magnetic pole different from the geographic pole and attempted to determine its location. Then, he tried to establish ways of correcting this deviation so a pilot could keep the course of his ship truly perpendicular to the North Pole (Cortés, 1990).

[2] Mercator's projection of 1569 solved that problem by widening the separation between parallels closer to the poles and Edward Wright published in 1599 the formula for this useful distortion; following this projection, a ship could describe a great circle following a straight line. For the relation of this problem to Thomas Harriot mathematical work, see Alexander, 2002, p.142-48.

Conclusion: The circumnavigation of the earth and the origins of the scientific revolution.

The great circle, as the shortest line between two points of the sphere, was a major concern for navigators. So were measurements of latitude and longitude and calculation of distances. Both pilots and cosmographers of the Iberian empires developed spherical geography together with astronomical navigation and used it for their voyages. They needed to establish circular routes - “mirror”-like routes, as an important treatise of the period put it - and astronomy and spherical geography were two major tools for that endeavor. In the process, these circular Oceanic voyages became models for all voyages (De Chaves, 1983). Vasco da Gama’s finding of the *Volta* from India in 1498, Elcano’s circumnavigation of 1522 and Andrés de Urdaneta’s finding of the *Tornaviaje* from the Philippines in 1565 were among the most valued of these examples. They were, literally, traveling around their empires. Traces of this new ideal voyage could be found in the following centuries throughout various European countries. In early 17th century, English elites used to depart on a *Grand Tour* as part of their education. The French navigator Bougainville called the narration of his trip, one of the best examples of modern and enlightened voyages, *Voyage autour du monde* (1771). Alexander von Humboldt is probably the enlightened traveler who made this debt more explicit (Cañizares-Esguerra, 2006).

It is often argued that voyages became scientific by adopting the rules and methods of the scientific revolution. Thus, enlightened travelers would be reproducing out of doors what Boyle and others had done in the laboratory: interrogate nature experimentally. Put boldly, what I want to defend in this last section is rather the opposite argument: Iberian voyages of discovery became a major resource for the scientific revolution (for a similar argument regarding non-cosmographical accounts, such as Oviedo’s, see Carrillo, 1999).[3] In the last decades, historians of the scientific revolution have shifted their focus from a few disciplines and scientific heroes to a wealth of practices and people. The histories of astronomy, mechanics and dynamics mechanics by Alexander Koyré or Richard Westfall have been completed by B. J. T. Dobbs and others insistence on the way Newton’s involvement with alchemy and theology had come to form an internal part of his mechanics. In the same vein, William Newman has argued that alchemical practices were an important resource for corpuscular theories that ultimately undermined the Aristotelian theory of matter. Mechanist philosophers such as

[3] Travel literature from outside Europe, less engaged with imperial power and spherical geography, had a minor relation with the scientific revolution (Alam & Subrahmanyan, 2007, p.357-363).

Gassendi or Descartes have lost their position of prime movers or at least placed within a richer context of people and things (Koyré, 1939; Westfall, 1971; Dobbs, 1991; Newman, 2006).

This search for new contexts in which to place the rise and diffusion of modern science has often been accompanied by a turn towards practices and material culture rather than disembodied theories. Pamela Smith famously argued that experimentalism could be tracked back to 'artisanal epistemology.' She emphasized not only people hitherto ignored by the historiography of the scientific revolution, but also places and disciplines until then deemed irrelevant. Two major studies develop this approach at its best: Deborah E. Harkness' *The Jewel House* and Harold Cook's *Matters of Exchange*. They approach Elizabethian London and the Dutch Republic looking at how quotidian people dealt in their daily lives with exotic objects coming from the New World, which shifted the values of the time towards the understanding and wonder of things. Studies on more traditional disciplines such as mechanics have benefited from this attention on objects, as it is exemplified by Dominico Bertoloni's work on Italian mechanics and its engagement with instruments. However, the great beneficiaries of the shift have been disciplines such as natural history and places such as imperial metropolis. Four recently edited works, *Merchants and Marvels*, *Colonial Botany, Nature and Empire* and *Science and Empire in the Atlantic World*, have satisfied the plea that Charles Gillispie made years ago for incorporating the age of discovery into the narratives of the scientific revolution (Smith, 2004; Harkness, 2007; Cook, 2007; Bertoloni Meli, 2006; Smith & Findlen, 2002; Schiebinger & Swan, 2005; MacLeod, 2000; Delbourgo & Dew, 2008; Gillispie, 1990: preface to the second edition).

Historians have incorporated the Spanish empire into this new historiography. Among other things, they have shown that two tenets normally related to the scientific revolution, namely experience and institutionalization, were at play in the European Renaissance and especially in the Iberian world (the best edited work about this is Lafuente, Elena & Ortega, 1993). Barrera-Osorio has defended that "the Spanish contribution to the development of science consisted of the institutionalization of empirical practices rather than the theoretical development of science" (Barrera-Osorio, 2007, p.2; for similar but less up-to-date arguments, Rey Pastor, 1970). Empirical methods were developed as private and public enterprises sent ships back and forth across the Atlantic. Also, institutions for the gathering of scientific knowledge were created under the rule of the empire and helped triggering its development (Cañizares-Esguerra, 2006). After all, the famous questionnaires sent to practically every official of the viceroyalties and called *Relaciones geográficas* were followed by similar ones developed in early 17th century Britain and used in some of the early issues of the *Royal Society transactions* (Pimentel, 2003, p. 57). In a context of imperial competition in which Spain was seen as the leading force, it should come at no surprise that other crowns modeled their policies according to the Spanish example. Spanish cosmographer Andres García Céspedes used Charles V's motto *Plus Ultra* in the frontispiece of his *Regimiento* of 1606 in which a ship trespassed Heracles' pillars; as historians have shown, Francis Bacon would reproduce the image in his *New Atlantis* of 1620. Bacon, often considered a key figure in the development of modern science, was making a plea for the institutionalization of natural knowledge and using geographic discovery to model his experimental ideal of science. He imagined an Island south of Peru in which inhabitants spoke Spanish and used natural knowledge to mechanically exploit nature. This utopia resembles the image that Antonio Quirós had spread in his unsuccessful but widely published reports written to convince Spanish monarchs to finance more expeditions to *terra australis* (Cañizares-Esguerra, 2006; Pimentel, 2003).[4]

Nevertheless, these arguments can be misleading if they do not acknowledge the specific contexts for the production of the works and ideas of later landmarks of the raise of modern science, such as Boyle or Newton (for this very different context, Jacob & Jacob, 1980). Therefore, the argument that I want to make in this paper about the Atlantic origins of the scientific revolution is a more modest one in that it is restricted to the theory of the sphericity of the earth, the relation of which to Greek geometry and astronomy, voyages, and the Spanish empire has been the focus of the central part of the paper. At the same time, it is a stronger argument in that it claims that particular scientific contents of modern science, and not just ways of approaching the world, find their origins in Iberian empires. The scientific revolution is not only or even primarily about the creation of new formal methods but about the constitution of new sciences (for this distinction, see Bueno 1991-93). Only in retrospect can we say that those new sciences and their methods became the canon for modern science in general. As I have argued above, the widening of the limits of the *oikumene* led Portuguese and Spanish navigators to consider themselves and their knowledge superior to the Ancient's teachings (Maravall, 1986). They convinced other European countries of the existence of a world unknown to Aristotle and Ptolemy. They also showed them that knowledge about this new world meant power (Goodman, 1992). But they did something else through the mutual nourishment of voyages and spherical geography: they established the shape of the earth as a sphere and fostered the process of mathematization of the earth.

The voyage of circumnavigation meant the practical realization of the hitherto theoretical possibility of the sphericity of the earth. This new status of the theory of the sphere prompted the extension of spherical geography, an essential discipline for navigational

[4] Historian Deborah Harkness (Harkness, 2007) opposes London's 'prosopography' of collectors, artisans and others to Bacon's 'imagined' *House of Salomon*. What I am contending here is that that House was not imagined, but modeled after the Spanish empire: following the Iberian example, in 1564 England created the position of "chief cosmographer of the kingdom;" see Vogel (2006).

purposes. Because of its practical rewards, cosmography became a leading science with much better defined limits. With a unified sphere of earth and water sharing the center of gravity imposing itself over interpretations of Aristotle that contradicted the new experiences, Copernicus could now imagine the earth as one more planet in motion around the sun and Galileo could found his new physics over that assumption (Randles, 1994).[5] Moreover, the sphere defined the limits of the universal empire, an empire in which, as was said at the time with geographic sense, "the sun never set." The entire world became subject to measurement and mathematical transformation into the grids of the cartographic sphere.[6] It also became subject to conquest, thus defining the limits towards which the empire should tend to fulfill its claims of universality. Navigators engaged in Iberian imperialism thus gave a new operational status to the Ancient speculative theory of the sphericity of the earth. In the process, they set one of the first examples in the early modern period of the practical power that empires could obtain from scientific theories, in this case, from Ptolemaic spherical geography.

[5] Klaus Vogel (2006) maintains that the equation of the earth and the water sphere was a 'cosmographic revolution' indispensable' for Copernicus heliocentric system published in 1543. Copernicus' *De revolutionibus orbium coelestium* contains a chapter on 'How Earth Forms One Single Sphere with Water' That referred to the discovery of 'the kings of Spain and Portugal' as proof of the existence of the Antipodes.

[6] David C. Lindberg (2006) has argued that the link of mathematics and physics had been present for centuries in disciplines such as optics, and was not so at odds with Aristotelianism as many scholar of the scientific revolution have defended. Here, I offer a different source for that mathematization: imperial voyages.

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