Full Meridian *of* Glory

Perilous Adventures
in the Competition to
Measure the Earth

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I have touched the highest point of all my greatness;
And from that full meridian of my glory
I haste now to my setting.

William Shakespeare
King Henry VIII. Act iii. Sc. 2.

Contents

List of Figures

Introduction

In the spring of 1962 I was studying mathematics and physics at university in England and looking out for something to do in the summer. A notice appeared in the porter's lodge inviting applications to spend eight weeks at the Royal Greenwich Observatory (RGO) on an astronomy course. In the mornings there would be lectures on all the facets of astronomy carried out at the RGO, in the afternoons students would work on a research topic as assistants to the scientists there. The course was residential and students would stay in Herstmonceux Castle in Sussex, where the RGO was based. We would be offered the accommodation and paid a small allowance as well. I had been an amateur astronomer while at school so I would be paid for doing something I liked. This all sounded great! I applied, and was accepted on to the course.

I very much enjoyed this first experience of professional astronomy. My own research topic was to measure the positions and sizes of the spots that represented stars in some photographs of the globular cluster Omega Centauri. I combined my measurements with those that other people had measured on other photographs. I was able to see how the stars moved over time. I could distinguish stars in the cluster from stars in the line of sight in front of and behind the cluster. I could find stars whose brightness changed from photograph to photograph and even discover how some changed rhythmically like a regular heartbeat. I learned how to connect these measurements with the distance of the cluster and to determine its orbit in our Galaxy. It was mindblowing that so much could be learnt from pictures of spots.

It was this experience that made me determined to be a professional astronomer. At the end of the course each student was summoned, one by one, to the office of the Astronomer Royal, Sir Richard Woolley. I entered to see him flipping through what I realized must have been reports on what I had been doing. He raised his head and fixed me with his eyes, glaring over the half moons of his reading glasses. "So what's your story on Omega Centauri?" he barked. I stumblingly described what I had done, he asked me more questions about it, and we traded hypotheses and facts for twenty minutes. "What are you going to do when you go down from Oxford?" he asked. "I want to be an astronomer," I said, with new conviction. "Come and work here," he said. Somehow it didn't seem strange to be offered a job in this way. "OK," I said. "Thanks." My cool reply concealed the exultation within me.

This is the way that I came to work at the RGO in 1963. I started to work on problems that were akin to my student project, about the motions and the positions of stars – so-called positional astronomy. Although I soon shifted my area of specialty towards astrophysics (the study of the internal constitution of the stars, galaxies and planets), I learned more about positional astronomy and its long history at the RGO. Three hundred years before I joined it, the Royal Observatory had been established at Greenwich for the very purpose of measuring star positions in order to help the sailors of the British Royal Navy and the Merchant Navy navigate safely across the sea. When I joined the RGO, although the observatory had been shifted from Greenwich to Herstmonceux, it remained a primary task to continue this work in modern form.

It was a matter of some pride to all of us who worked there that the RGO had this long history and had established its eminence in this work on the world stage. Of course, we all knew of similar observatories elsewhere that had carried out parallel studies, each making their own advances and their own contributions. Foremost among these, but definitely in second place in our opinion, was the Paris Observatory in France. It had been founded before the Royal Observatory in England, in fact, and it had carried out a variety of work similar to that of the work at Greenwich. There had been a certain rivalry between the two establishments, which mirrored the traditional rivalry between the two countries, but both had shifted their focus to modern astrophysics, while still retaining interest in the fundamental studies of positional astronomy.

There was one area in which the Royal Observatory at Greenwich appeared definitely to have been favored over the Paris Observatory, namely in the decision (Chapter 7) to define the Greenwich Meridian as the "prime meridian" of the world, from longitude would be measured, and the associated decision to use Greenwich Mean Time as the world's basic time zone. This decision was founded, as I interpreted it then, on the pre-eminence of the scientific work at Greenwich to measure time and position as a starting point for marine navigation. I took some pride, not much earned by me, that I was a member of the scientific establishment descended from the one that carried out this work.

It was some years later that I came to realize how the decision to choose Greenwich as the prime meridian had been made and the outstanding scientific work that the rival Paris Meridian had been based on. I was making repeated visits to France and this brought me into closer contact with the country. As well as going to France purely for pleasure, I had a job with the British National Space Centre, which involved frequent visits to the European Space Agency, whose administrative headquarters are in Paris, so I often traveled there. I thus came to learn about the structure and history of French science and the scientific work of the Paris Observatory. It was astounding. I gained a new respect for the Paris Observatory and was rather ashamed of my earlier limited view of the story of the development of the science of navigation, which I had viewed as almost entirely confined to the work of the Royal Observatory at Greenwich.

As part of my job, I had also become accustomed to think about problems of Big Science because of my work with space experiments and large astronomical telescopes. The sums of money are large, the numbers of people are high, the range of skills is huge, and the management tasks are considerable. Scientists get involved in such projects because they are targeted towards scientific goals that they think will be highly rewarding. Usually, because of the special talents that need to be assembled, the scientific teams are international. Additionally, the sums of money are so large that it helps if the costs are shared among several countries. This means that there is an international political dimension involved in such projects. These Big Science projects only succeed because the scientists work well together. They are, however, human beings and they do squabble sometimes.

I found all these features (which I had assumed were mainly modern) in the history of the work of the Paris Observatory to establish the Paris Meridian. The Paris Academy of Sciences had pioneered the concept of scientific *grands projets*. The community of scientists who worked on the Paris Meridian project for over two hundred years was large and international. They knew each other well – some were members of the same family, in one case of four generations. Like scientists everywhere they collaborated and formed alliances to achieve their goals; they also split into warring factions and squabbled over the ways to do so. They traveled to foreign countries, somehow transcending the national and political disputes, as scientists do now, their eyes fixed on ideas of accuracy, truth and objective, enduring values – save where the reception given to their own work is concerned, when some became blind to high ideals and descended into petty politics, small feuds and personal attacks. They organized themselves into effective working teams but also their projects ran over in time and budgets were overspent, just like now.

To establish the Paris Meridian, the scientists endured hardship in atrocious weather as they traveled in rugged, remote places (Chapters 2, 3, 5 and 6). They survived danger and gloried in amazing adventures during a time of turmoil in Europe, the Revolution in France and the Napoleonic wars between France and Spain. Some were arrested and imprisoned. Some were accused of witchcraft. Some of their associates lost their heads on the guillotine. Some died of disease. Some won honor and fame. One found irredeemable fault with his own work and became a depressive loner. One became the Head of State in France, albeit for no more than a few weeks. Some found long-lasting love or brief and dangerous flirtations in foreign countries. One scientist killed in self defence when attacked by a jealous lover and another was himself killed by a jealous lover. A third brought back a woman to France and then jilted her; destitute, she retired to a convent.

It is true that modern adventures in the pursuit of Big Science tend to be less dramatic. I have never had an observing run on a telescope that was as full of incident as Arago's (Chapter 6). But I have seen an astronomer on his way to a telescope on a bus that caught fire desparately searching for his luggage piled in the smoke on the roof of the bus, in order to save the papers that he would need to use to set the telescope. Another astronomer returning from his observing trip survived the incident in 1988 when a Boeing 737 of Aloha Airlines that was flying between islands in Hawaii lost its upper fuselage in flight. And telescopes are built on mountain tops which are always dangerous places to be with high cliffs, thin air, snow and icy weather.

The French scientists of the eighteenth and nineteenth centuries worked on practical problems of interest to the Government, the Church and the People (Chapters

2, 4 and 5). They also worked on the important intellectual problems of the time, including a problem of great interest to their fellow scientists all over the world, nothing less than the theory of universal gravitation (Chapter 3). The Paris Meridian was a construct that tested the theory of gravity, the same theory that drops apples from trees, shapes the Earth, holds the planets in their orbits and, indeed, decides the fate of the Universe.

French scientists succeeded in their intellectual work, while touching politics and the affairs of state (Chapters 5 and 6). Their endeavors have left their marks on the landscape, in art and in literature. However, in one regard the chance to leave the mark of their scientific work on everyday life slipped from their fingers. As a result of the international negotiation over 100 years ago, in a decision based on commercial and political values more than scientific ones, the Paris Meridian was not chosen as the prime meridian of the world (Chapter 7). The world might have talked of Paris Mean Time instead of Greenwich Mean Time, and we might have each measured our location on Earth with respect to the Paris Meridian, not the Greenwich Meridian. This did not happen.

In no way did this disappointment detract from the historic scientific importance of the French work. Anyone who visits the Paris and the Greenwich Meridians is making a pilgrimage of great significance, although in both London and Paris the practical significance of the meridian lines has faded with modern developments (Chapter 8). The line in the cobbled courtyard at Greenwich which marks the Prime Meridian memorializes the international agreement that organized time across the whole world and harmonized its longitude systems so that ships could sail more safely, the world acting as one body for the safety and convenience of its human population. The line in Paris is also marked on the ground, across the whole of Paris from one side of the Péripherique (inner orbital road) to the other. It takes the form of a series of over 100 brass disks (Chapters 10), ostensibly a memorial to the astronomer François Arago, who worked to make some of the scientific measurements that defined the Paris Meridian, but also implicitly a memorial to all who worked before, with and after him on that *grand projet*.

The Paris Meridian and this line of disks has recently achieved notoriety as a result of the popularity of Dan Brown's novel *The Da Vinci Code* (Chapter 9) but it should be famous as a testimonial to Arago and the other scientists who worked to define the Paris Meridian, both for its practical utility and for its scientific impact. However, I have to confess that it was reading the *The Da Vinci Code* as a holiday entertainment that rekindled my interest in the Paris Meridian and took it beyond idle curiosity. As a result, like many tourists, I set out one summer's day to follow the Paris Meridian across Paris (Chapter 10). As I walked the line, my eyes towards the ground, scanning in search of the next Arago disk, my imagination soared into the sky, inspired by the science and technology that lies behind the Meridian line and the dedication and brave adventures of people in search of the science of the Universe. I decided to tell this story of the Paris Meridian, complete, here in English for the first time.

The stories in my book are not fiction, they are history. The era that I describe was historical but the scientific work was both ageless and modern. The motives for the endeavors that I describe were neither religious nor conspiratorial, they were scientific. I see the line of the Arago Memorial on the Paris Meridian, not as part of a silly conspiratorial plot (as in Dan Brown's novel), but as an expression of the human spirit of scientific curiosity about the Universe. I intend this to be a work of inspiration, not of original historical research. I write about the Paris Meridian in the spirit of the Serbian proverb: "Mankind! be humble, for you are made from earth; Mankind! be noble, for you know the stars."

Institute of Astronomy, Cambridge, Paul Murdin
April 2008

Chronology

1656	Huygens invents his pendulum clock
1661	King Louis XIV takes the throne of France
1665–66	Colbert founds the Académie des Sciences
1668–70	Picard measures the meridian from Malvoisine to Amiens
1669	Cassini I becomes the leader of the Paris Observatory
1671–72	Picard determines the longitude of Hven
1671–72	Jean Richer's expedition to Cayenne; experiments with the pendulum
1672	Paris Observatory completed
1672–82	Picard, Cassini I and La Hire I determine the positions of the coasts of France
1687	First Edition of Newton's *Principia*
1683	Cassini I and La Hire I measure the meridian from Montluçon to Sourdon
1702–13	War of the Spanish Succession
1712	Cassini II becomes the leader of the Paris Observatory
1715	Death of King Louis XIV, accession of his great grandson, Louis XV
1718	Cassini II, La Hire II and Maraldi I measure the meridian from Perpignan to Dunkerque
1725-28	Voltaire visits London
1728	Publication of the *Encyclopédie*
1734–37	Maupertuis, Le Monnier and Celsius measure the degree in Lapland
1735–44	La Condamine measures the degree in Peru
1733	Cassini II and Cassini III measure the East-west axis of France from Brest to Strasbourg
1739	Cassini III, Lacaille and Maraldi II measure the meridian across France
1742	Le Monnier completes the *meridiana* in St Sulpice
1754	Death of King Louis XV, accession of his grandson Louis XVI
1765	Cassini III appointed leader of the Paris Observatory (named director 1771)
1784	Cassini IV becomes Director of the Paris Observatory
1787	Roy, Cassini IV, Legendre and Méchain link the Paris Meridian to Greenwich
1789	Storming of the Bastille

1790	Cassini IV publishes the Cartes de France
1792–3	Overthrow and execution of King Louis XVI and foundation of the French Republic
1792–98	Delambre and Méchain measure the meridian from Dunkerque to Barcelona
1792–1800	The French Revolutionary Wars across Europe
1799	Napoleon Bonaparte becomes leader of France as First Consul (Emperor from 1804)
1806–08	Biot and Arago extend the meridian from Ibiza to Barcelona
1809	Arago returns to France after being imprisoned four times
1808–14	The Peninsular War
1814	Napoleon abdicates, is exiled to Elba
1815	Napoleon escapes from Elba, re-establishes power but is defeated and exiled this time to St Helena
1884	Washington Conference on the Prime Meridian passes over the choice of the Paris Meridian
1911	France adopts the Greenwich Meridian as the basis for longitude

Chapter 1
The *Incroyable Pique-nique* and the *Méridienne Verte*

Places can be admired for what they *are* but they can also be admired for what they *mean*. The White Cliffs of Dover on the north shore of the English Channel between Britain and France are a beautiful seascape, the white, massive, motionless, white chalk cliffs contrasting with the active gray-blue sea. The Cliffs are also a symbol of the island independence of Britain, the bulwark shore that historically kept out potential invaders. For Britons returning via ferries and liners from overseas, the White Cliffs may be the first sight of home after a long absence, providing a warm welcome home. Americans may react similarly to the New York skyline and the Statue of Liberty, South Africans to Table Mountain, and Australians to the Sydney Harbor and its Bridge.

It is not often that people react to an abstraction of a place. The Paris Meridian is the north-south line running through Paris. It is entirely theoretical and there is no one landscape of beauty to react to. Rather, it cuts through a collection of typical French landscapes, the good and the bad proportionately represented. The Paris Meridian runs through the French capital and a sample of its neighborhoods. It breaks out of the capital through the suburbs, some charming, some depressed. It runs north through both rural and industrial France to Dunkerque and the sandy dunes of the northern French coast. It runs south alongside the major autoroute, La Méridienne, and through the mountains of the Massif Central, the central block of elevated land in the middle of France. It then drops through the vineyards on the slopes of southern France. Beyond Perpignan, the southernmost city in France, it rises to the mountains of the Pyrenees and continues into Spain, past Barcelona and into the Balearic Islands.

Perhaps even some French people do not know exactly what the Paris Meridian is. However, they are proud of the magnificent achievements of the astronomers and geodesists who created it, and who, using it as a base, meticulously mapped France and measured the world. This pride in the theoretical was used in the argument two hundred years ago that the distance along the Paris Meridian from the North Pole to the Equator should be used as the fundamental international standard of length – the meter.

Standardization helps unite a political region. For example, In 221 BCE in the Eastern Zhou region of Asia the Emperor Qin (or Chi-in) unified seven of the warring states, subjugating rival states through ruthless centralization and imposing standard

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legal codes and bureaucratic procedures. His idea, soaked in the blood of his enemies, was that he would unify the country to which his name is given – China – by establishing standard forms of coinage, weights and measures. He also standardized the various spoken languages in his kingdom into written pictures drawn the same no matter what their spoken form so he could receive reports that he could read from his officials throughout the country. He even established a standard length for the axles of carriages so that it was possible to drive through archways and over bridges along roads from border to border. These measures made it possible to communicate and trade across the whole of the empire, knitting the country together.

Similarly, when the new government of France took command after the French Revolution late in the eighteenth century, it took on the problem of the development of a system of weights and measures to unify the French people across the entire country. Gallic logic and communard feeling suggested that standards of weights and measures should be not based on arbitrary diktats laid down from above, especially not based on such a transient thing as the size of a monarch's body. Standards of measurement should also not be considered matters of national authority (a stance which practically guarantees that the standards would not be internationally adopted). International standards, making it possible to develop both trade and communication between different people, should be based on natural quantities that belonged to no one and to everyone. This was the origin of the meter and the metric system of units. The French people have continued this historical direction for two hundred years and even now are pushing to improve trading standards across the European Union.

THE MERIDIAN also played a part in making what some would argue was the most significant discovery of science – the law of gravitation. Curiously this scientific law of remote celestial bodies was a turning point, not only for the abstract science of astronomy but also for science in general. Sir Isaac Newton's mathematical law of gravity changed our perception of the laws of nature. It made understandable in mathematical form rules of nature that otherwise seemed arbitary. It enabled scientists to predict the future, even the return of a comet after 74 years invisibility in the far reaches of the solar system. It set the standard to which scientists now aspire in developing the truths in their own science.

Newton's theory also altered our perception of ourselves and the Universe we live in. Since the law of gravitation applies equally to the planets and to objects on the surface of the Earth, such as a falling apple, it puts us into the Universe; we are *a part* of the way that it works, not *apart* from it. This scientific perspective found resonance in the political and social egalitarianism of the revolutionaries and the humanists.

The Paris Meridian played a role in changing scientists' minds about gravitation. Measurements along the meridian of the shape of the Earth were instrumental in showing that Newton's Theory of Gravity was convincingly correct. But for the French there is also a bitter sweetness about the Paris Meridian. First created in the seventeenth century, and an admired scientific work, its status fell at the end of the nineteenth century when it was passed over as the choice of the Prime Meridian of the world. Following France, many countries had developed maps based on meridians through their national observatory thus causing great confusion among sailors when they sailed from one map to another issued by a different authority. The development of international trade across the world created a demand for a unified, standardized system of coordinates of latitude and longitude. Latitude was easy; everyone agreed that it was measured from a zero-point at the Earth's equator but the zero-point of longitude – the "Prime" Meridian – was not as obvious. People asked should it be one of the national meridians or should it lie through some natural or artificial feature (such as the Great Pyramid in Egypt)?

In 1884 a conference was convened in Washington to decide the issue. The Paris Meridian was an obvious contender because of the work that had been put into its accurate definition and its key place in scientific development, and so was the Greenwich Meridian (for similar reasons). The logic for the definition of the meter was that a neutral meridian should be chosen. Just as the meter favored no individual person as the basis of a scale of length (the reach of a king's arm, for example, or the length of his foot), the choice of a neutral meridian as "Prime" would favor no particular nation. This logic was ignored, though, and for practical reasons the Greenwich Meridian was chosen as the Prime Meridian of the world.

The status of "Prime" Meridian was wrested from Paris and given to Greenwich. Some say this was by the logic of nineteenth century commerce and power, some say that the USA achieved its objectives by bringing the quarreling Europeans together and forcing them to a conclusion, and some say that the Prime Meridian was established at Greenwich by an anglo-phone conspiracy against France that was formed between Britain and the USA. Sometimes French, British and American people see contemporary events in a similar way.

Even if the Paris Meridian lost its status in these considerations of *realpolitik* (politics based on practical rather than logical or ideological considerations), it retains its status in the French psyche. Laid out on a map (Fig. 1), the meridian has a geometric cleanliness, running directly across the center of the hexagon of the entire country.[1] and at lunch time on the premier French national holiday, Bastille Day (14 July) in the year 2000, someone looking down on France from space would have actually seen that axis of the Hexagon. Thousands of French people – couples, families and groups of friends – congregated on the Paris Meridian, braving the rather poor weather that day and gathered to the borders of kilometer-long strips of traditional red and white checkered cloth. They were like tablecloths, laid down on the grass and on picnic tables. People set out bread, opened bottles of wine, unwrapped cheese and local specialities and ate lunch. This was a mass meal, called *L'Incroyable Pique-nique*, and a celebration at the start of France's new millennium.

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[1] Seen from above, France has the outline of a hexagon, with two opposite corners to the north and the south. To the west, running roughly north-south from Brittany to the Spanish border, is the Atlantic coast of the Bay of Biscay. To the north-west, from Brittany to the Netherlands, is the coast of the English Channel, or, as the French understandably prefer to call it, La Manche (the Sleeve). To the north-east, the hexagon's side runs along the borders of the neighbouring countries from the Netherlands, to northern Germany. To the east, the border continues southwards to the Mediterranean. The Mediterranean coast forms the south-east side of the hexagon, and the border with Spain completes it to the south-west. In French, the country of France is sometimes metaphorically referred to as the *Hexagone*, because of this shape.

Fig. 1 Map of France showing the Paris Meridian and places mentioned in the text

This "Incredible Picnic" was the human part of a more general, more permanent project in France, called *La Méridienne Verte* (the Green Meridian). In this project, French organizations, national, regional and local administrations, environmental groups, and estate owners planted trees along the same axis, across the Hexagon from north to south. It was the idea of the architect Paul Chemetov (1928-), whose major work in Paris is the courtyard of Les Halles. The plan was to plant 10,000 saplings, and the species were chosen appropriately to the region and the climate as it changed from the North Sea to the Mediterranean. In the north the trees were oaks, cedars and chestnuts, in the south olive trees. The idea was that in time the line of trees would become almost continuous, visible from space as the axis of the

Fig. 2 The location of the Méridienne Verte is marked by the side of the road on Route Nationale 152 near Manchecourt opposite to a stone obelisk erected to mark the position of the meridian of 1748 measured by César-François Cassini. Manchecourt is a village between Malesherbes and Pithiviers, south of Fontainebleau. There are few trees actually planted in this area to implement the Green Meridian concept! Photo by the author

Hexagon, making the Paris Meridian plain to see. From time to time as one travels on French highways across the Paris Meridian he or she will see by the side of the road a notice calling attention to the Méridienne Verte (Fig. 2).

WHAT WAS the reason for the choice of the location for the picnic and the trees? What is the significance of the axis of the Hexagon? What *is* the Paris Meridian?

On Earth every point is defined by two quantities – its latitude and its longitude. These are angles measured in degrees on Earth's near-spherical surface as seen from its center. If one knows the latitude and longitude to accuractly to 1 arc minute (1/60 degree), then one knows where he or she is to about 1 nautical mile (about 2 km). Latitude is defined relative to the Earth's equator, in degrees north and south. Longitude is measured in degrees west or east of a north-south line on the Earth's surface that passes through both poles, but there is no natural line that is the zero point.

In order to help their ships navigate across the sea and to measure where they were in latitude and longitude, the maritime nations of the seventeenth to nineteenth centuries individually set up such lines through astronomical observation. Even landlocked countries set up meridians to help locate their cities and towns in latitude and longitude, although the need to define where the cities are in those terms is not so pressing. However, there is certainly a strong bureaucratic need to define areas