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SPECIAL ISSUE
STANDARDS: TAMING KNOWLEDGE?

Domesticating Light: Standards and Artisanal Knowledge in Early Astrophysics

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Abstract: Astrophysics was born in the nineteenth century as a "New Astronomy" (in the words of Samuel Langley, 1884), a knowledge built primarily by amateurs who explored deep space by studying the Sun, stars and nebulae. They were credible enough to interest physicists who did research on the properties of radiation and hence came to constitute a solid and recognised discipline. The aim of this research is to study the contribution of artisanal knowledge in the construction of this new discipline at two distinct moments. The first, when artisans worked to find a standard to normalise the manufacture of the glass with which the lenses of refracting telescopes were manufactured. The most recognised of these artisans was Fraunhöfer. The second moment occurred when the experience of artisan knowledge enabled the manufacture of instruments that improved the traditional classification of the magnitude of the stars. The search for standards led to an alliance between artisans and scientists during the same period in which spectroscopy was carried out. In this case, a unit of luminous intensity was sought that could serve as a standard to classify the stars by their luminosity. Industries, university laboratories and astronomers interested in solar astronomy (such as Karl F. Zöllner), collaborated with the artisan manufacturers of measuring devices, and gave rise to a paradigmatic case of science and industry transfer.

Keywords: Standards; artisans; light; glass; Fraunhöfer; Zöllner

Standardising Light

The history of standards is not quite equivalent to the history of the units of measurement that eventually formed the International System of Units (SI), although there are many points of connection between the two. In general, standards come from traditions of applied knowledge, often linked to the artisanal context where it was accepted that it was necessary to generate coherent systems of units as codes of effective communication between the groups that used them to measure lengths, surfaces or volumes, for example. Custom or some political authority prescribed the exact dimension of each magnitude. However, from the end of the eighteenth century, systems of units adopted epistemic virtues that stemmed from the most authoritative knowledge of the Enlightenment. In this case, the authority came from the new sciences that made it possible to discuss the characteristics of each of the magnitudes and the properties of the unit that measured that magnitude. Thus, the SI base unit meter was related to geodesy in an era of map construction, the kilogram was related to chemistry, as knowledge related to the balance, and the second of time was born from astronomy, in its attempt to determine how to measure *temps vraie* (real time).

For the exact determination of the unit of measurement, the construction of instruments was required, in conjunction with the artisan traditions. Moreover, these first units of the metric system were all additive, following the modes of operation of the mechanical, chemical and astronomical traditions. The discussion centred on determining the precise quantity of each unit, and displaying it by means of an *etalon*, a standard that thus became an object of authority. The magnitudes of extent, amount of matter and time were accepted as a basis for determining each of its units. On the other hand, phenomena such as light, heat, electricity and magnetism attracted the attention of *savants* and artisans, who wondered about the extent of their effects and the possibility of extracting from them the magnitudes that would allow them to be quantified.

This paragraph deals with the difficulties in quantifying light for illumination, or the intensity of a light source, terrestrial or celestial, and also the results obtained by some artisans and physicists in using light as a tool to standardise glass for making astronomical instruments. The question is: how can we measure a phenomenon as everyday as light, luminous flux (lumen) or illuminance (lux)? The truth is that during the eighteenth century, an interest in measuring light effects was born. Light had been the object of study for many centuries before, but at that time, firstly the problem of exactly what to measure of light was specifically formulated, and secondly, how a unit for that magnitude could be defined.

Light was not only of interest to geometricians, it also attracted the attention of astronomers, chemists, industrial artisans and politicians. The skies were filled with new light. Moreover, the century of light needed to illuminate not only intelligence but also the cities. The industrial revolution brought about another form of social organisation and there was a "demand for light," that is, a demand for devices capable of illuminating both private homes and factories, as well as meeting and leisure places.

There was a certain fortunate harmony between the research of the *savants* who wanted to know more about the phenomenon of light on the one hand, and the attempts to build effective lighting systems, lamps and lanterns that would provide better illumination than traditional wax candles, or grease or oil lamps on the other. The new artisans who contributed so much to the industrial changes at the turn of the century devoted themselves to the latter task, and this led to a close relationship between the two communities.

Light was (then and now) manifesting itself as a common phenomenon, too close to the consciousness of the observer to be easily objectified. It belongs to a type of phenomena that fuse the perceived and the organ of perception, which produce epistemological obstacles such as those pointed out by Gaston Bachelard when he pointed out the difficulties in translating into mathematical language phenomena such as the behaviour of a metal bar that is heated at one of its ends, that is, for example the commonplace heating of a fireplace poker.[1] Light is a necessary condition for the act of seeing, but the sufficient condition is the identification by the eye of the intensity of that light. Light illuminates, but not in a metaphorical sense of the century of Enlightenment, but in industrial and everyday life. At the turn of the century, the light that illuminated was either from the sun or from some form of combustion of a flammable material, and therefore lighting was always associated with calorific and chemical phenomena.

In the first chapter of his *Traité*, Lavoisier asked a question that troubled the intellectual *milieu* of the Academy sages: "Is light a modification of the caloric or rather the caloric a modification of light?"[2] He then expresses his conviction that this question will be unanswerable for a long time to come. What is certain is that this association between heat and light stimulated some research carried out some years later by the amateur William Herschel who showed that light had chemical and calorific activity outside the visible spectrum of white light,

[1] Gaston Bachelard, *Étude sur l'évolution d'un problème de physique* (Paris: Vrin, 1928), 15.
[2] Antoine Laurent de Lavoisier, *Traité élémentaire de chimie* (Paris: Chez Cuchet, 1789), 6.

something that did not help to simplify the problem, but rather to complicate it.[3] However, the two phenomena could be studied separately. At least heat could be measured as a singular magnitude by thermometers, which allowed some magnitude of heat to be quantified, even though the temperature was not an additive magnitude.

On the contrary, light had a fascinating and complicated history throughout the standardisation process of the nineteenth century; its relationship with heat was maintained, it was the object of attention of natural philosophers turned physicists, it intrigued astronomers (especially amateurs), it attracted the attention of telescope builders, but it also had its own history in the industrial world. It is perhaps the phenomenon that best expresses the creation of a trading zone between the new sages transformed into scientists and the old artisans turned industrious masters of technical ingenuity.

The Light That Illuminates

Of the seven basic units that today form the International System of Units, the candle or unit that measures the magnitude of light intensity seems to be the most bizarre of them all, both in terms of its name and its history. When it was defined in 1948, it put an end to a development that for two centuries maintained different standards for measuring a magnitude that was difficult to define because the judge that determined it was only the human eye.

Sean F. Johnson called the history of light measurement a beautiful example of "undisciplined science," pointing out that a study of it cannot be performed by describing great intellectual and theoretical challenges, nor by visiting experimental laboratories that do orderly academic work.[4] However, one possible way of telling this story is to stop and reflect on the difficulties of defining the standards that served to measure light intensity. Not only was it the study of the properties of lighting, but also the industrial treatment of light that led to collaborations between industrialists, artisans, engineers and new scientists. These collaborative arenas created new forms of exchange focused on practices that incremented the scenarios to study surprising,

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[3] William Herschel, "Investigations of the Powers of the prismatic Colours to heat and illuminate Objects; with Remarks that prove the different Refrangibility of radiant Heat. To which is added, an Inquiry into the Method of viewing the Sun advantageously, with Telescopes of large Apertures and high magnifying Powers," *Philosophical Transactions of the Royal Society of London* 90 (1800): 255-283; William Herschel, "Experiments on the Re-frangibility of the invisible Rays of the Sun," *Philosophical Transactions of the Royal Society of London* 90 (1800): 284-292; William Herschel, "Experiments on the solar, and on the terrestrial Rays that occasion Heat; with William's comparative View of the Laws to which Light and Heat, or rather the Rays which occasion them, are subject, in order to determine whether they are the same, or different, Part I," *Philosophical Transactions of the Royal Society of London* 90 (1800): 293-326.

[4] Sean F. Johnson, *A History of Light and Colour Measurement. Science in the Shadows* (Bristol: Institute of Physics Publishing, 2001), 248.

and until now unthinkable, effects. A classic example is the case of the Bavarian Joseph von Fraunhöfer. Later tradition made Fraunhöfer the champion of precision, but in reality, he was an entrepreneur who manufactured high-quality glass and expressly sought to ensure that the glass in his factory maintained that standard of quality. He proved to be a shrewd experimenter and was able to communicate the results of his work to the scientific and industrial milieu of the time. This was not a unique case but rather a symptom of the circulation of knowledge inherited from the (industrial) Enlightenment. Fraunhöfer took advantage of the peculiarity of the lines of the light spectrum, to use them as a means of ensuring a standard of quality. Other inventors, entrepreneurs or scientists explored the problem of how to compare different light sources, and how to quantify the intensity of a light source. Karl Zöllner in particular should be mentioned as an example of an instrument-building scientist in the post-Fraunhöfer generation. Finally, there was a whole generation of inventors, artisans, and scientists in the nineteenth century who built photometers, devices designed to make measurements of light intensity.

Bougies: From Wax to Platinum

There is no need to go so far back to find the first proposals for a light intensity unit. One only has to go back to the mathematician Pierre Bouguer (1698-1758) and search in his posthumous work *Traité d'optique sur la gradation de la lumière* to find the mention of the *bougie*[5] as the first unit of the magnitude of illumination. Reading the work indicates that the bougie was the first "candle" in the long series of lighting standards. The characteristics of this object refer to an old industry of candle manufacturers, not to an invention made by Bourguer. However, we can take credit for looking at the characteristics of that object so that the flame once lit is stable and constant. At least two traditions converge in the treatment of light intensity, on the one hand, the optics that form the body of knowledge of Bouguer's book and, on the other, the theory of vision that, in addition to other issues, deals with the problems of perception that affect the seeing eye.

In the first tradition, optical problems can be described as projected onto a space, and the results can be shared because they are supposed to be intersubjective. The reader who studies a book on optics sees the representation of the act of vision as a geometric problem that unfolds before him, the eye that sees on one side, the object seen on the other, and the rays of light are represented as lines that join the eye to the object. The act of seeing is reduced to a pure schema. Thus, optics has the same guarantee of intersubjectivity as any Euclidean geometry.

The second tradition studies the acts of vision in which the observer is part of the game. It is

[5] Pierre Bouguer, *Traité d'optique sur la gradation de la lumi*ère (Paris: Guerin & Delatour, 1760), 52 and ff.; Pierre Bouguer, *Essai d'Optique, sur la gradation de la lumière* (Paris: Claude Jombert, 1729).

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clear that the act of seeing both light intensities and even colours depends on the particular eye that sees. Not all eyes see the same thing, but all eyes describe what they see as the same thing, that is, as if the characteristics of what is seen were common. The work done in the last few decades of the eighteenth century was prodigious in its study of vision, and its "anomalies." The best known of these today is called colour blindness. The analyses of this subjectivity of the eyes were very diverse. The best known is that of W. Goethe in his *Farblehre*,[6] and the humblest is that of the *bougie*, but it deserves special attention because it was the first successful attempt to define a standard of luminosity. As opposed to Goethe's reckless attempt to solve all the problems of vision in a treatise, Bouguer's proposal was to define the characteristics of an object that would help us to normalise light intensity.

Light intensity is a phenomenon apparently easily quantifiable. An observer can detect a difference in intensity from different light sources, but it is not easy for him to tell another observer what that difference is or the scale of light intensities. For that reason, it not only made sense for astronomers but also for industrialists to have a standard for measuring the brightness of a light source, and Bouguer was right to propose a standardised object that could serve as an etalon. It is a given that the enlightened ones were aware that two observers could not communicate to other observers exactly the intensity of the lights they saw, but they themselves could tell that two light sources had the same intensity, or that one of them was more luminous than the other. If a candle which is replicable and with well-defined characteristics can be constructed, the intensity of the flame produced in the combustion will be considered the standard of intensity. By comparing that standard with the intensity of a light source, it can be determined whether it is equal or unequal, and if it is unequal, whether it is greater or lesser. Such comparisons can be communicated between observers. Thus, with the definition of the "lighting standard" starts the whole history of contemporary lighting.

Therefore, individuals' eyes that may have the sensation of seeing different light intensities are confident that through the standard an "objective" relation of intensities is available. The difficulty in setting the candle diameter and the composition of the wax define its characteristics. Since different luminosities can be produced depending on these characteristics, the discussion focuses on what diameter the burning wick should have in order to provide a stable flame. Bouguer's candle was used to study the gradations of solar luminosity and to make hypotheses about what the luminosity on the surface of the Sun might be, as well as the attenuation rates shown by the sun's rays until they reach Earth's surface. The Bouguer standard allowed further discussion of luminosity, and although later standards did not resemble candles, the need remained to define an object that would serve as an objective pattern for a phenomenon so closely linked to the diverse perceptions of each eye.

[6] Johann Wolfgang von Goethe, *Zur Farbenlehre* (Tübingen, 1810).

After that first step and during the second half of the eighteenth century illumination gained the interest of ingenious European artisans. In Paris, the first streetlights were erected during that time. The city was a pole of attraction for the savants, but also for artisans and inventors.

Interest in illumination led the *Académie des sciences,* in 1764, to propose an extraordinary prize for the purpose of seeking *Le meilleur moyen d'éclairer pendant la nuit les rues d'une grande ville, en combinant ensemble la clarté, la facilité du service et l'économie* (The best way to provide lighting at night to the streets of a big city, combining clarity, ease of service and economy).[7] According to the news at the time, the State Councillor in charge of the police of the Kingdom of France provided the prize money. None of the proposals presented, according to the Academy's commission, offered a convincing or sufficiently explained solution. However, the comments are enlightening. The Academy classified the works received into two types of proposals. The first one included the memoirs which focused on the physical and mathematical discussions and which proposed different useful means to those, which merely presented their advantages and disadvantages. The second collected the attempts, that had been tested over a long period, to solve the problem of illuminating Paris and that could already be used. The prize was awarded to works belonging to the second class, namely those by Bailly, Bourgeois, and Le Roy. In fact, the lighting system installed in Paris was that of the Bourgeois de Chateaublanc[8] (1697-1781), with a set of lanterns that lasted for decades. Small amounts of money were given to the artisans who collaborated in the development of the lighting system. However, the Academy writings also give prominence to one of the memoirs of the first group, written by Antoine Lavoisier, under the epigraph *Signabitque viam flammis* (*And he will mark the way by means of flames*),[9] giving future significance to Virgil's hemistich. The Academy agreed to publish this report and to award Lavoisier a gold medal in recognition of the merit of his proposal. The text indicates to what extent Lavoisier was close to the work of the artisans and inventors.

As such, the context in which the study of illumination was conducted, reveals a framework where savants, artisans, inventors, and those who practiced their profession with the ingenuity to solve practical problems was one that could have had an undoubted theoretical dimension. It seems advisable not to project into the world of enlightenment the division of knowledge into positive sciences that only became consolidated well into the nineteenth century. On the contrary, the Enlightenment was a time of effervescent ideas that were rapidly exchanged

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[7] Académie Royale des Sciences, *Histoire de l'Académie Royale des Sciences* (Paris: Imprimerie Royale, 1768), 164.

[8] Dominique François Bourgeois, *Mémoire sur une nouvelle manière d'éclairer pendant la nuit les rues de Paris* (Paris: Gueffier, 1765).

[9] All the memoirs that were submitted to the competition had the title of the prize announcement. Lavoisier's is collected in Antoine Laurent de Lavoisier, "Signabitque viam flammis," in volume III of *Oeuvres*, 1-3 (Paris: Imprimerie Imperial, 1865).

among groups of people who could not be classified in the categories of those sciences generated a century later. *Savants* coexisted alongside artisans and inventors, and there was a constant exchange of ideas between them. The result of their work were objects that expressed these forms of convergence.

The proposal of the candle standard focused the debate on how the etalon of brightness should be described. It seemed that an object such as a candle was too vulnerable both for use in astronomy and in an economy that was beginning to consider the illumination of cities and public spaces from an accountancy and policy perspective. There were many attempts to build new devices that could increase the luminosity of traditional candles.

For those involved in improving the luminosity of the lamps, it was a problem of improving the form of combustion, i.e. the chemistry. Solutions and suggestions were provided to solve the problem of how to achieve more efficient combustion for brighter light. If one reads the memoirs of the French academies of that time carefully, one can find many references to the "lamp problem" and its luminosity. It is worth mentioning Meusnier's memoir published in 1787, which was undoubtedly used in the design of new lamps.[10] In his text, the author, a renowned mathematician and engineer, used Lavoisier's theory of combustion.

In the wake of these works, we must mention a Swiss man named Ami Argand (1750-1803), a traveller who visited Paris and London showing his skill as a gadget maker. Few documentary references are found of his life and inventions, although there is reliable proof of them because they were objects of everyday life in Europe for almost half a century. The populariser of nineteenth century science, Louis Figuier, gave an account of them in his reference collection entitled *Les merveilles de la science* (the wonders of science) where he briefly describes Argand's life as the inventor of a double air circulation lamp that transformed forms of lighting.[11] Thanks to the recent investigations of John J. Wolfe who followed the trail of Argand's correspondence with some of his contemporaries,[12] he places him in the Paris of the Montgolfier brothers who were so successful in the European society of that time and with whom he worked on their hot air balloon experiments. He also had contact with Benjamin Franklin when he visited the Academy of Sciences. Later he moved to England where he met Watt, Boulton and Davy.

Of all the objects designed by Argand, both in Paris and London, his lamp was interesting

[10] Jean Baptiste Meusnier, "Mémoire sur les moyens d'opérer une entière combustion de l'huile, et d'augmenter la lumière des lampes en évitant la formation de suie à laquelle elles sont ordinairement sujettes," presented on March 19, 1784; published in *Recueil des Mémoires de l'Académie Royale des Sciences*, 390-398 (Paris, 1787).

[11] Louis Figuier, *Les merveilles de la science ou description populaire des inventions modernes*, vol. 4 (Paris: Jouvet et Cie. Éditeurs, 1870), 14-15.

[12] John J. Wolfe, *Brandy, Balloons, and Lamps: Ami Argand, 1750-1803* (Carbondale: Southern Illinois University Press, 1999).

because it offered two prominent innovations, the double circulation of air in the capsule where the combustion took place, and the flattened shape of the wick. The truth is that Argand lamp inspired other artisan inventors. In addition, it had the property of giving an illumination "ten times greater than that of a candle." Surprisingly, this statement is found in all the references of the time, in encyclopaedias and in popularisation books, such as Figuier's. They could have stated that the illumination provided by the lamp was "greater," even "much greater" than that of a candle (a standard candle, that is, a candle with a standard wick as its burner) is supposed to be. However, the authors of these publications attribute this reduplication of the intensity of illumination, and they indicate that one of the fundamental problems with lighting is being able to measure it in units that serve to improve the luminous efficiency of the appliances.

One problem with any standard is its stability. A standard/candle is based on combustion, so fuel is required to not run out and that the size of the flame is constant. That means that the wick that burns must always be bathed in fuel. In 1800, a Parisian watchmaker named Bertrand Guillaume Carcel (1750-1812) brought a substantial improvement to the Argand lamp. He did not improve its luminosity but its luminous stability, he equipped the lamp with a small clockwork mechanism that pumped the oil that served as fuel so that the wick was always impregnated with oil,[13] and simultaneously he allowed that the excess of oil returned to the deposit (Figure 1). The lamp was a failure because it was too expensive for the public, but it attracted the attention of the lighting industry and theoretical scholars because it offered the greatest stability in order to become the new standard of brightness. It was used by scientists Aragó and Fresnel in their photometric studies for lighthouses and by Dumas and Renault for the Paris lighting studies.

Thus, the Carcel lamp gave rise to the Carcel standard, widely used in the French lighting industry. However, the truth is that it did not manage to be implemented in other states; the standards were limited to different industrial societies. For example, the Hefnerkerze, or Hefner lamp, was used in German, Austrian and Scandinavian societies. It was designed by the electrical engineer linked to Siemens, Friedrich von Hefner-Alteneck (1845-1904), who used oil as fuel in accordance with the analyses of the *Physikalisch-Technische Reichsanstalt* (Imperial Institute of Physics and Technology – PTR). The discussions on different industrial standards based on combustion are very extensive as stated in the treatise by Adrien Palaz.[14]

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[13] Charles-Malo, *Bazar Parisien ou Annuaire raisonné des premiers artistes et fabricans de Paris* (Paris: Au Bureau du Bazar Parisien, 1822-23), 213.

[14] Adrien Palaz, *Traité de Photométrie industrielle spécialement appliquée a l'éclairage électrique* (Paris: George Carré, éditeur, 1892), 99-155.

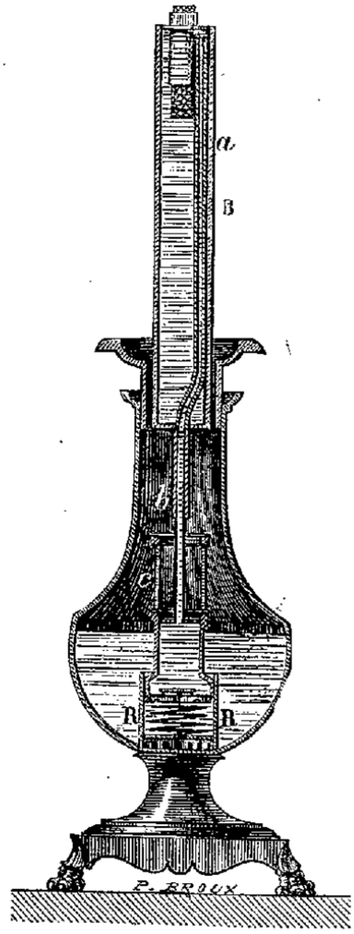

Fig. 23. — Coupe de la lampe à pompe.

Figure 1 - The engraving shows a cut of the Carcel lamp equipped with a pump to keep the fuel level constant. Louis Figuier, *Les merveilles de la Science*, vol. 4 (Paris: Jouvet et Cie. Éditeurs, 1870), 35.

However, the evolution of the standards of luminosity underwent a profound transformation when they went from being based on combustion to being obtained through the action of electricity that heated a piece of metal turning it into an incandescent body, and therefore becoming a light emitter. It cannot be said that it was a "giant step" as it did not replace the standards of combustion lamps, but instead coexisted with them for decades. Nevertheless, the new procedure allowed greater ductility to be applied in problems related to astronomy, and it was in the scientific field where the contemporary standard of luminosity was defined.

The first proposal seems to be due to John William Draper (1811-1882) when he suggested using incandescent platinum in his spectrographic studies. He finally proposed using the light emitted by an incandescent platinum fragment as a unit of luminosity, and proposed so in articles published in 1847.[15] This proposal was followed by that of the Saxon Zöllner who proposed the same idea again in 1858. In the end it was Jules Louis Gabriel Violle (1841-1923) who, after almost a decade of work, presented his proposal for the unit of luminosity for the first time in Paris in 1881 at the *Congrès international des électriciens* (International congress of electricians) and gave the final impetus. A few years later, he saw his proposal for the definition of a unit of luminosity accepted by the *Conférence internationale pour détermination des unités électriques* (International conference for determining electrical units), held in Paris in 1884 and was described as follows:

> The unit of all simple light is the amount of light of the same species emitted in a normal direction by one square centimetre of molten platinum, which is at the temperature of solidification, and the practical unit of white light is the total amount of light emitted in a normal direction by the same light source.[16]

Violle's proposal combined a very precise definition of the unit of luminosity for simple lights (today we would speak of monochromatic), with the possibility of extending it to white lights. The phenomenon he used to measure intensity was very stable and could be replicated in an identical way in any laboratory, both academic and industrial. The same epistemic virtues that had served to appreciate the unity of the Carcel lamps were now applied to Violle's proposal, which became the first international unit of luminosity. Moreover, the phenomenon was no longer confined to an instrument or a combustion device where the debate centred on the conditions of construction, but was freed from them. In fact, it was a long process of establishing this unit. All the devices (objects) that served to define the luminosity from

[15] John Draper, "On the production of Light by Heat," *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 3rd series, 30, no. 202 (1847): 345-60; John Draper, "On the production of Light by Heat," *The American Journal of Science and Arts*, 2nd series, iv (November, 1847): 388-402.

[16] Jules Louis Gabriel Violle, "Sur l'étalon lumineux," in *Comptes rendus des travaux du Congrès international des électriciens à Paris en 1881*, ed. Ministère des Postes et Télégraphes (Paris: G. Masson, 1882), 352; Jules Louis Gabriel Violle, "Détermination d'un étalon de lumière," in *Procès-verbaux de la Conférence internationale pour la détermination des unités électriques, réunie à Paris en octobre 1882 (Séance 20 octobre)*, 129-136 (Paris: Imprimerie National, 1882), 129; Jules Louis Gabriel Violle, "Sur la radiation de l'argent au moment de sa solidification," in *Comptes rendus hebdomadaires des séances de l'Académie des sciences*, t. 96, 1033-1035 (Paris: Imprimerie de Gauthier-Villars, 1883); Jules Louis Gabriel Violle, "Sur la radiation de l'argent au moment de sa solidification," *Journal de Physique Théorique et Appliquée* 2, no. 1 (1883): 366-369, on 366; Jules Louis Gabriel Violle, *Note sur les expériences effectuées por la détermination de l'étalon absolu de lumière* (Paris: Gauthier-Villars, 1884); Jules Louis Gabriel Violle, "Sur l'étalon absolu de lumière," *Annales de Chimie et de Physique*, 6ième série, t. III (1884): 373-407, on 407; Jules Louis Gabriel Violle, "Étalon de lumière," in *Procès-verbaux de la Conférence internationale pour détermination des unités électriques: 2ième session, tenue à Paris en mai 1884*, 103.

Bouguer's spark plug to the later lamps actually played a very interesting and instrumental role because they revealed ways of working that were inherited from the artisanal tradition, and from the inventors and engineers who participated in the various industrial developments of the nineteenth century. For a large part of the nineteenth century, it was thought that the definition of the unit of light would come from the chemical tradition, as it was in most cases. However, a simpler option prevailed, coming from those interested in various aspects of astronomy, even though they were not professional astronomers. The light was their interlocutor. Their analysis allowed them to learn about properties of light that they did not initially seek and that opened the door to new ways of investigating the starry universe.

Light as a Tool for Creating Standards

In the first part of this article, some of the epistemological obstacles related to heat and light were mentioned. Such obstacles can also be found in the development of highly accredited scientific practices.

In scientific production, even in the most abstract, the activity of scientists meets obstacles that are not reducible to a theory that produces knowledge. In other words, an opposition could be established between facts and theory. Such facts are embedded in theories but are not soluble in them. There are some examples that illustrate this phenomenon. One of them is that the planets circulate in more or less coplanar orbits, that is, they are on the same plane in space. This fact was not interpretable by Newton's theory of gravitation and has maintained the interest in planetology up to our present day. This fact was Laplace's incentive to formulate his cosmogony.[17] This case of the coplanarity of planetary orbits was not connected with any artisanal activity that ought to be mentioned at the time of this study.

Another interesting example is the effect of the "mercurial phosphorus" that provided years of study and work to Francis Hauksbee (1660-1713) and many other barometer builders. This effect appeared as the result of friction in glass vessels where there was actually a vacuum.[18] Although many years passed until there was a standard explanation within a theoretical framework that one could call "successful," the truth is that the work on this effect catalysed research into other effects and promoted the study of unique electrical phenomena.

It would be a mistake to think that the two previous examples became enigmas waiting for a solution, since, in scientific activity - not only in the emerging fields of mechanics or physics - this type of obstacle is abundant, guiding the course of research and building bridges between

[17] Pierre Simon Laplace, *Exposition du système du monde* (Paris: Fayard, 1984), 564-575.
[18] See Terje Brundtland, "Francis Hauksbee and his air pump," *Notes & Records of the Royal Society* 66, no. 3 (2012): 253-272.

the different actors in a scientific field. In the case of Hauksbee, for example, he related the activity of a speculative scientist like Newton to that of an instrument maker, that is, an artisan.

A third emblematic example, in the period between 1800 and 1826, through the work of Joseph Ritter von Fraunhöfer (1787-1826), is the use of lines detected in the light spectrum as a standard. The case study of the light spectrum, and in particular the works of Fraunhöfer, has attracted the attention of historians of science in the last thirty years.[19] The interest in this case is in showing the use of a singular standard that stood outside of the predominant tendencies in standards of the French Republic. This is not to say that it did not develop within the political and industrial influence of the new French state, as it did occur within a work program of that was intended to meet the needs of the Republic first, and the French empire later.

The discovery of certain black lines in the spectrum of sunlight became highly significant years later. However, it hardly worried the scholars of the time. Specifically, in 1802, the English doctor William Hyde Wollaston (1766-1828) observed certain dark lines running across the spectrum when he conducted repeated experiments on the scattering of sunlight through a prism. Thus, in volume 92 of the *Philosophical Transactions* of that year, he described the existence of black lines that were interspersed between colours as if they were separated.[20] Wollaston noted the existence of seven lines: five thicker ones, which he designated with capital letters from A to E; and two thinner ones, which he named with the next two letters, this time lowercase, f and g. Since physicists could treat their discoveries as naturalists, he was not too worried about not being able to explain its meaning in the light of the optical theories then under discussion.[21]

Perhaps for this reason, the Scottish physicist David Brewster (1781-1868), who was most likely in a position to have been able to continue the study of the mysterious Wollaston spectrum, did not do so, no doubt because the theoretical interest in the subject was not apparent. Brewster was a seasoned experimenter in various fields of experimental optics and an ardent supporter of Newton's corpuscular theory. He devoted himself to optical issues such as the polarisation of light and refractive indices. However, the presence of lines in the spectrum was almost exclusively seen as a curious singularity that did not seem to have an

[19] Among them, see the work of Myles W. Jackson, *Spectrum of Belief: Joseph von Fraunhofer and the Craft of Precision Optics* (Cambridge, Mass.: The MIT Press, 2000). Jackson has put Fraunhöfer's work in the sights of historians and philosophers. The present text is indebted to his book.

[20] William Hyde Wollaston, "A method of examining refractive and dispersive powers, by prismatic reflection," *Philosophical Transactions of the Royal Society* 92 (1802): 365-380.

[21] In fact, many of his works were published in journals hosting the work of botanists, geologists, and other natural historians.

easy explanation or interesting application. The truth is that notoriety did not come from that way, but instead because of something that today we would include in the field of recreational physics: the invention of the kaleidoscope.[22]

In Fraunhöfer's hands, the black lines of the spectrum became a tool for analysing the quality of glass for optical lenses. Fraunhöfer did not discover the black lines, nor did he try to interpret them, he just used them and was amazed by them.

On the hundredth anniversary of Fraunhöfer's birth, in the speech by Hermann von Helmholtz (1821-1894) he was recognised as being the father of two important fields of the newly established *Physikalisch-Technische Reichsanstalt*.[23] Firstly, Helmholtz claimed that spectroscopy in the late-nineteenth century came from Bavarian research. Secondly, that the spirit of precision of the new institution was a legacy of Fraunhöfer's work.[24]

This is a beautiful example of an invented tradition at a time of institutional greatness for German physics. First, because spectroscopy was not a field of knowledge that was continually being researched, but was anchored in the pure recognition of black (or white) lines within the spectrum. Second, because it was not part of "German science," but of German artisanal activity.

For all these reasons, the current image of Fraunhöfer differs from the triumphant icon conveyed by Helmholtz.[25] Fraunhöfer put the black lines of the spectrum to a unique use. In fact, the history of spectroscopy during the nineteenth century is the history of the unique use of the effects of black (absorption) or bright (emission) lines. Those who used lines to identify chemical elements, or composition of stars in catalogues, did not know much more than Fraunhöfer about their physical significance. They worked on them like a fingerprint, and never managed to place them in a broader theoretical context. In reality, the efforts of each of them - Robert Wilhelm Bunsen (1811-1899), Gustav Robert Kirchhoff (1824-1887), Hermann Wilhelm Vogel (1834-1898), Edward Charles Pickering (1846-1919), and others -

[22] See Jackson, *Spectrum of Belief*.

[23] See David Cahan, *An Institute for an Empire: The Physikalisch-Technische Reichsanstalt, 1871–1918* (Cambridge: Cambridge University Press, 1989).

[24] Hermann von Helmholtz, "Joseph Fraunhofer. Rede bei der Gedenkfeier zur hundertjährigen Wiederkehr seines Geburtstages," *Zeitschrift für Instrumentenkunde* 7 (6 März 1887): 115-122.

[25] It should be clarified that the triumphant physics that Helmholtz described in his 1887 speech was not considered in such a way in the early nineteenth century. It was a reticent (scientific) discipline that contained a lot of artisanal knowledge. Physics came from the *fisicaille*, a knowledge appreciated by carnival folk who exploited the wonders of effects rather than the explanations of the wise. See, for example, the developments of galvanism and its derivatives, which were present in this incipient discipline until the middle of the century. On the other hand, we should not confuse physics and mechanics. The latter was the reigning science, a superior analogue of all mathematical Laplacian physics of the time.

had no common theoretical framework. Each one of them could be considered the precedent of the other in terms of use only.

An Untimely Consideration

The case of Fraunhöfer reveals an independent sequence of artisanal uses of the spectra that dismantles several of the following prejudices associated with the artisanal and the epistemic value of its knowledge:

> a) First prejudice: the artisanal always appears as a primitive knowledge, located in a stage prior to scientific knowledge; moreover, it seems that both spaces of knowledge cannot be mixed, that is to say, that the artisan knowledge always consists of a provisional knowledge and must be treated as a clearly delimited precedent of the scientific knowledge.
>
> b) Second prejudice: reciprocally, science or the scientific cannot use artisanal knowledge in the same context, but only by displacing it. According to this prejudice, scientists are always supposed to express themselves in meaningful spaces and as very consistent languages, so much so that even in them “enigmas” make sense.
>
> c) Third prejudice: the artisanal does not, in the end, produce knowledge, but some kind of skill or know-how (manual) and must “wait” for someone (the neat hand of science) to lift the veil to understand its scope.

In the face of these prejudices, spectroscopy never revealed any veil to produce knowledge. It did not need to engage in a consistent way with any optical theory to produce knowledge. Instead, it served as a tool in different fields of (artisanal) physics.

Fraunhöfer

Let us look at Fraunhöfer’s work as an example of that non-French physics, performed on the periphery of mathematical physics.[26] Was Fraunhöfer a physicist? It is possible, but his activity was strongly artisanal because he explored the possibilities of the uniqueness of the spectrum for manufacturing artefacts with properties also singular. His work was not the culmination of any proposal about the nature of light, nor, as has been said, did he invent spectroscopy. His knowledge of optics was very limited; his education was self-taught - like other artisans

[26] See Michael Eckert, “Ciencia y Sociedad en Baviera, 1750-1850,” in *Después de Newton: ciencia y sociedad durante la Primera Revolución Industrial*, eds. Alberto Elena, Javier Ordóñez, and Mariano Colubi, 147-176 (Barcelona: Anthropos, 1998).

of physic of his generation, including Faraday. Fraunhöfer did all his work applying Snell's law of refraction. During the period from 1813 to 1815, he carried out his most important work. During that time, the most heated debate about the nature of light was taking place among the different communities of scientists: corpuscles versus waves. However, Fraunhöfer did not take part in it. He accepted wave theory for interpreting the behaviour of light in a grid because for the particular phenomenon of grid diffraction the wave explanation was simpler than the corpuscular one. No other reason.

Fraunhöfer knew the rudiments of optics, but only the rudiments, just as Faraday at the same time knew the basics of chemistry or electricity and magnetism. His work was so personal that it was not easily interpretable by the rest of the physicists of his generation, which helped his work and techniques to remain unknown, and even to become industrial secrets for a long time after his death.

A native of the German region of Bavaria and the son of a glassmaker, Fraunhöfer showed exceptional glassmaking skills from an early age that did not go unnoticed by his teachers and earned him the protection of political and scientific authorities. To put things in perspective, however, it should be noted that this was not a case of an isolated genius working alone. It is perhaps not merely anecdotal for understanding why rural and underdeveloped Bavaria, which is not mentioned very often in the histories of Baroque and Enlightenment science, contributed at this time to the development of a technology that would provide decisive tools for the analysis of the nature of the heavens. Allow us a brief parenthesis on this subject.

In contrast to the dense network of observatories and astronomers spread over many different countries, the Bavarian electorate had no prestigious institution directly related to astronomy. Hence, for example, its university, located in Ingolstadt and controlled by the Jesuits, had only been involved in two scientific projects during the Enlightenment period. The first was related to geodesy and, specifically, to a large mapping project of the Academy of Sciences in Paris. The second was related to meteorology insofar as, for decades, the large Bavarian monasteries were also meteorological observatories. In order to find an astronomical observatory in Bavaria, one must wait until the nineteenth century and the French influence. In fact, traditionally an ally of France, Napoleon transformed the Bavarian Electorate into a Kingdom, extending its borders to the lands of the Franconia - even if it lost those of the Palatinate. His new King Maximilian I of Bavaria provided him with such an observatory by re-establishing in 1807 the Academy that had been created in Munich in 1759. Also, he moved the University of Ingolstadt to the city of Munich in 1826 after being located some years in Landshut.

From this date onwards, the University of Munich gradually gained notoriety and became a prestigious institution. Its relationship with Paris was noted in the interest it had in creating chairs of experimental physics, and in differentiating itself from the universities of the

Northern states, which were influenced by the anti-French movements of *Naturphilosophie*. The University of Munich supported the creation of a chair in experimental physics for Georg Simon Ohm (1789-1854).

The arrival of the university in Munich coincided with Fraunhöfer's death, even though the narrative of the later Munich university tradition always treated it as a precedent, albeit a post-mortem one. Despite this appropriation - and without giving it any more value than its nationalist propaganda character - it is worth studying where Fraunhöfer developed his activity not as an experimenter, but as an artisan. Strictly political reasons motivated the state's drive to manufacture optical devices equipped with high quality glass. These reasons point to the above-mentioned alliance of the Bavarians with the French and to the need that the engineers and cartographers of the French army had of having precise topographic instruments for their military cartography works.[27] On the other hand, the surveillance work demanded powerful and achromatic lenses so that the armies could recognise at a distance the colours of their own and enemy flags. It goes without saying, the command posts had to have complete information on the movements of the troops and the colours of the flags they carried. Finally, in the specific development of the manufacture of achromatic lenses in Bavaria, the will of Napoleonic France was decisive in consolidating an alternative to the British glass, and in strengthening an ally, the Bavarians, against an enemy, the English.[28] Hence, new industries proliferated in Munich that benefited from the experimental practices of the monastic tradition of the region after the secularization of the monasteries. In short, reasons both political and military were decisive in the role played by the authorities in promoting applied optics, this being a good example of the confluence of very diverse aspects in the history of science and technology.

Returning to Fraunhöfer, his work was developed in the context described. In order to understand the importance of it, it is necessary to underline the kind of problem he had to face. The final objective was to obtain a glass that would always refract in the same way, that is, that would be homogeneous in its behaviour when faced with refraction. The usual procedure used by English artisans, the most skilled in obtaining high quality glass, was to obtain glass that behaved in what was considered to be a constant pattern when faced with the refraction of a ray of light. Thus, from the theoretical point of view, this required choosing a type of light whose rays were well known in the refraction process. In practice, it was a matter of finding a way to ensure that this light beam behaved in a regular manner.

As repeatedly stated, sunlight (white light) is dispersed in all colours of the rainbow, each having

[27] Napoleon wanted to rearrange the German states, for which he needed appropriate maps to establish the boundaries of the new states.

[28] Great Britain was a traditional power in this area because of the demands of navigation.

a different refractive index. Since this heterogeneous white light beam did not seem to be the most suitable for testing the quality of a glass, the opticians tried to isolate one of the colours of the spectrum, thereby using a homogeneous light beam as a reference beam. However, this was not an easy task, as the colours have poorly defined boundaries when adjacent ones are mixed. Therefore, scholars tended to use the colours at the ends of the spectrum, i.e. red and violet. This explains why infrared and ultraviolet radiation were first discovered beyond visible light, given the repeated research on this area of the spectrum, especially by artisans.

So Fraunhöfer's problem, like that of the other opticians, was to produce coherent light and, better if it was monochromatic, to behave stably in the refractions. His first studies led him to rediscover the lines pointed out by Wollaston. Instead of contenting himself with mentioning the phenomenon as a curiosity, Fraunhöfer wanted to use it to his advantage as a glass manufacturer. He went on to study it in detail. To achieve this, he needed an instrument that would produce the spectrum as precisely as possible in order to isolate the colours. In 1814, he built a completely original spectrometer that produced a clearer and more distinct dispersion than any previous instrument. An important element of this new spectrometer was a scattering grid. He succeeded in engraving grooves in the glass with a density of up to 300 lines per millimetre so that the refraction of the light gave the most accurate image possible. The spectrum went from being a curious phenomenon to one studied with great precision. Without giving much information about how he proceeded in his work, the truth is that he wrote a memoir in 1814-1815 and published it in the form of an essay in 1817 with the title *Bestimmung des Brechungs- und Farbenzerstreuungs-Vermögens verschiedener Glasarten, in Bezug auf die Vervollkommnung achromatischer Fernröhre* (Determination of the refractive and colour-dispersing power of different types of glass, in relation to the improvement of achromatic telescopes) in the *Denkschriften der Königlichen Akademie der Wissenschaften zu München* (Memoirs of the Royal Academy of Sciences in Munich).[29] In this memoir, Fraunhöfer came to a significant conclusion: the *continuous spectrum* of sunlight was not suitable for determining the refractive indices of glass. Moreover, given the difficulty he experienced in producing monochromatic light - that is, to limit to a single colour - he decided to use the new property of the spectrum as a test: if it is not possible with colours, then let us try with the *lines* that seem to divide the mentioned spectrum. His spectrometer proved to be of similar importance to Galileo's first telescope. Later, the Fraunhöfer spectrometer would be improved by other scientists, some of them astronomers like Angelo Secchi (1818-1878) and Edwin Hubble (1889-1953), but also physicists and chemists like Gustav Robert Kirchhoff (1824-1887),

[29] Joseph Fraunhöfer (1814–1815), "Bestimmung des Brechungs- und des Farben-Zerstreuungs – Vermögens verschiedener Glasarten, in Bezug auf die Vervollkommnung achromatischer Fernröhre" (Determination of the refractive and colour-dispersing power of different types of glass, in relation to the improvement of achromatic telescopes), *Denkschriften der Königlichen Akademie der Wissenschaften zu München* (Memoirs of the Royal Academy of Sciences in Munich) 5 (1817): 193–226.

Robert Wilhelm Bunsen (1811-1899) and Johann Jakob Balmer (1825-1898).

With the experimental capabilities offered by this new instrument, the first thing that had to be verified was that the appearance of the seven Wollaston lines was intrinsic to the light itself, and not the result of the intervention of the apparatus used in the experiment. It was therefore necessary to study the optical behaviour of these lines, for which Fraunhöfer began by analysing the type of spectrum produced by sodium combustion lamps. He used the light from six lamps filtered through six slits and which, upon hitting a prism, produced a much greater dispersion than usual, allowing the characteristics of this spectrum to be studied in detail and with precision. The study gave him a surprise that he was unable to interpret. The spectrum he obtained from the sodium lamps was crossed with lines, but not dark, but bright - what today is called the emission spectrum. He then conducted a series of experiments with sunlight (direct or reflected from the Moon and planets) and found that, compared to the seven lines (dark, this time) that Wollaston had pointed out, there were now more than five hundred lines of different thickness![30] Fraunhöfer then modified the experimental conditions, always obtaining an extraordinary and complex spectrum of hundreds of dark lines in the light from the Sun. He definitely thought, and indeed wrote, that these lines belonged to light itself, so in that way they could be used as a test bed to measure with great accuracy the refractive indices of the glass by the different colours that seemed to be separated by them. The areas of the spectrum could be narrowed down by means of these dark lines.

Fraunhöfer measured the position of the most prominent lines and, following Wollaston's example, marked the main ones (the most marked) with capital letters from A to K, being able to calculate the wavelengths of any other line. As well as that, he observed something that could have opened up a new and very fruitful path in the knowledge of the stars: making the light of a star pass through a prism situated in the focus of a telescope and finding that the dark lines of the spectrum were different from those of the light of the Sun. The spectrum of light from the Sun and that of the other star did not coincide, which could indicate significant differences in the nature of the two emitting sources. However, Fraunhöfer did not go that far. His goal as an artisan did not involve itself in the chemical nature of stars. Despite the epitaph that can be read on his grave - *Approximavit sidera* (Approached the stars) - the truth is that, during the Fraunhöfer's lifetime, the work did not result in a better understanding of the physical-chemical composition of the stars, but rather in the calculation of the refractive indices of many types of glass. This in turn led to the manufacture of glass whose standard of quality astounded both locals and foreigners - starting with the French. Every self-respecting European astronomer wanted a lens made of Fraunhöfer glass in his telescope. Although he did not provide complete information about the procedures of its manufacture, its industrial heritage continued throughout the nineteenth century.

[30] Today their number goes up to ten thousand.

Fraunhöfer not only bequeathed a set of glass of excellent quality thanks to the information extracted from the dark lines of the solar spectrum, but also the enigma about the meaning of those lines. In addition, perhaps to his regret given his suspicious character, he left an important clue: the spectrum of sodium lamps show bright lines - later to be called *emission lines* - in some areas where the spectrum of sunlight showed dark lines - later to be called *absorption lines*. What he did not leave behind, however, was information on the entire process of glass manufacture, which was kept only by those who worked in the institution he founded. Fraunhöfer prevented other physicists from learning about these procedures, and when the above-mentioned 1817 article was translated into English in 1823 and 1824 respectively, it attracted the attention of British lens manufacturers, even though they were unable to successfully apply the guidelines contained in the article.[31] Secrecy often accompanied artisanal excellence.

As can be assumed, there was no shortage of attempts to explain the origin of the spectral lines. In general, the scientists of the time were inclined to think that there must be some relationship between the lines of the spectrum of sunlight and the chemical composition of the star itself, or perhaps the Earth's atmosphere. The first of these hypotheses had to be discarded when the Scottish James D. Forbes (1809-1868), on the 1836 eclipse, had the opportunity to prove that sunlight had the same spectrum, whether it came from the corona - an edge that is very difficult to observe except during an eclipse - or from the centre of the solar disk. The constancy of the spectrum meant that the lines could not be formed by solar absorption. The role, however, of the Earth's atmosphere was sufficiently confusing that the only thing known to the scientific community was that it was facing a major unresolved problem.

One last word about Fraunhöfer. Without a doubt, his life was that of an industrialist and an artisan, even an entrepreneur, and although educated and a lover of science he was far from the stereotype of a scientist. He was even a jealous industrialist who kept his knowledge and secrets, so much so that today we struggle to reconstruct the way he worked. In spite of all this, the astronomers of his generation benefited from his optical technology and thanks to it, they were able to measure, for example, the parallax of the first star. Although some physicists of later generations considered him to be the first contemporary experimental physicist in a very characteristic sense - perhaps because of the low prestige of the artisanal in Humboldtian universities - the truth is that Fraunhöfer was only associated with experimental and applied science through the prestige of precision in the laboratories. Furthermore, we can ask ourselves the following question: did Fraunhöfer study new phenomena, or did he analyse them with new eyes?

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[31] Joseph Fraunhöfer, "On the Refractive and Dispersive Power of different Species of Glass, in reference to the improvement of Achromatic Telescopes, with an Account of the Lines or Streaks which cross the Spectrum," *Edinburgh Philosophical Journal* 9 (1823): 288-299; and 10 (1824): 26-40.

When it comes to finding the scientific tradition that led to quantum physics, the study of radiation is often mentioned, and it is often said that the systematic study of radiation began in a stuttering way with Fraunhöfer. This does not make this figure a scientist, but rather offers well-founded suspicions that the origins of a science such as quantum and astrophysics have some artisan roots that are rarely explored.

As we have briefly tried to show, the case of Fraunhöfer is an illustrative example of artisan knowledge that helps us to understand how complex processes of standardisation in science were configured in the nineteenth century. This was an emblematic case, but not the only one.

An Instrument for Measuring Starlight

The study of light produced by a light source helped to define successive standard units of light. Subsequently, Fraunhöfer and his successors used light as a tool for manufacturing crystals that had stable optical properties. In this case, light was used to standardise the glass from which all observation instruments and many measuring instruments were made.

Light was a necessary ally of astronomical observation that was primarily devoted to scrutinising the bodies close to the observer in astronomical terms, formed by the Sun, the planets and their satellites. The backdrop against which these nearby bodies moved was a space full of stars and other bodies about which little was known. In the nineteenth century, the results obtained by Fraunhöfer led to a growing interest in the observation of the stars, which seemed to be sources of light. Spectral analysis showed that stars were light sources of very different kinds. It had been true since ancient times that stars were lights of different intensities, so stars visible with the naked eye were attributed a different "magnitude." It is Ptolemy in his *Almagest,* books VI and VII, who attributes the classification of the stars by magnitudes to Hipparchus.[32] In that work six magnitudes are proposed, the sixth being for the stars of weaker luminosity. However, from the eighteenth century onwards this classification proved to be insufficient.

The introduction of the telescope extended the catalogue of magnitudes of the stars visible through the new observing apparatus. Above all, work was done to determine the magnitudes of stars that were not visible to the naked eye, referring to magnitudes that were weaker than the sixth. In addition, an attempt was made to specify intermediate magnitudes, fractions of magnitude, given that there were stars of variable brightness and it was therefore necessary to specify the magnitude of each one of them. As Mari Williams[33] indicates, the publication of

[32] Gerd Graßhoff, *The History of Ptolemy's Star Catalogue* (Berlin: Springer, 1990), 129 and ff.
[33] Mari Williams, "Beyond the Planets: Early Nineteenth-Century Studies of Double Stars," *The British Journal for the History of Science* 17, no. 3 (1984): 295-309.

Struve's catalogue of double stars in 1837 was the culmination of the stellar work carried out by the astronomers of the most accredited observatories in Europe during the first third of the nineteenth century. Without intending to do so, it opened the door to the question of what the physics of stars was, and what their behaviour was. None of these questions attracted an astronomer who was primarily interested in positional astronomy. However, eighty years later, in 1914, the director of the Harvard observatory Edward Pickering claimed funds in *Science*[34] to investigate what seemed to be the primary objective of the new astronomy, the universe of stars.

In barely eighty years, the perspective of astronomy had changed, widening so much so that it considered that its principal object of study should be the stars. At the same time, throughout the nineteenth century, there was an increasing interest in the development of instruments for classifying stars, that is, instruments that would help to standardise them. Throughout the century, several prizes were offered to encourage the invention of light meters, photometers that would allow a more refined classification of stars. The prize awarded in 1857 by the Vienna Academy of Sciences deserves a special mention. The proposal for the prize was convincing: *It is required to present photometric determination of the brightness of the fixed stars with are as numerous and as accurate as possible, in such a way and extent that our present knowledge of stars makes a significant step forwards*.[35] Recently moved to an imperial headquarters, the Vienna Academy wanted to stimulate the study of stars that would end up being the lure of the imperial sciences of the second half of the nineteenth century.

In fact, inventiveness was being encouraged in order to manufacture a photometer, one which needed to be very large, that could help determine the intensity of the stars. The challenge interested a new generation of scientists who were heirs to artisan traditions that merged with the new experimental physics. One of these scientists was Karl Friedrich Zöllner (1834-82), who is worth mentioning because of the significance of his work on photometry. We have few original documents about him because a large part of them were lost in fires caused by the bombing of Germany in 1944 and 1945. He has always attracted more attention from astronomers and engineers than from historians. However, we have his published work and the references of the instruments he designed in the early part of his life. In addition, very valuable works about Zöllner have been published recently that allow us to appraise his contributions in their context.[36]

Originally from Berlin, he began his studies of physics at the university founded by Alexander

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[34] Edward Pickering, "The Study of the Stars," *Science*, new series, 39, no. 992 (Jan. 2, 1914): 1-9.

[35] "Es sind möglichst zahreiche und genaue fotometrische Bestimungen von Fixsternen in solcher Anordnung und Ausdehnung zu liefern, daß der heutigen Sternkunde dadurch ein bedeutender Fortschritt erwächst." Cited in Dieter B. Herrmann, *Karl Friedrich Zöllner* (Leipzig: Teubner, 1982), 16.

[36] Christian Sterken and Klaus Staubermann, eds., *Karl Friedrich Zöllner* (Brussels: VUB Press, 2000).

von Humboldt in the autumn of 1855 where he became interested in problems of photometry. A pressing question was how two sources of light could be compared. Zöllner dealt with this problem, but applied it to astronomy. Even then, he considered it useful to study the light emission of a platinum wire that is heated by the action of a galvanic current. That was the idea that guided him to propose the unit of light intensity. In 1857, he moved to the University of Basel as he found a more favourable environment for his laboratory work there. That same year he published his first articles in the *Annalen der Physik und Chemie* (today, known and catalogued as *Poggendorf's Annalen*). They attract attention because they are the result of a student's work.[37] In his doctoral thesis, presented in December 1858, he continued in the same direction. His title is eloquent: *Photometrische Untersuchungen, inbesondere* über *die Lichtentwicklung galvanisch glühender Platindrähte* (Photometric investigations, especially about the light development of galvanically glowing platinum wires).[38] After completing his doctoral work, he did not return to Berlin, but remained in Basel. His publications attest to his interest in measuring starlight. He was aware of the difficulty of building a photometer that could accurately measure the intensity of starlight. On the one hand, he considered it interesting to apply his work on the emission of platinum light to the measurement of stellar luminosity, which would allow him to establish a precise stellar catalogue by magnitude. He was also aware from the very beginning of the importance of detecting the "colour" of the light source.

One can understand Zöllner's interest in the prize of the Vienna Academy of Sciences. He lived in a time of great effervescence in photometry. In fact, various types of visual photometers were built, that is, photometers that compared the luminosity of the object to be examined with a source that served to establish the measurement. For this reason, they were called comparison photometers. The photometer built by Karl von Steinheil (1801-1870), an inventor and astronomer who ended up working in Munich, came to be recognised. He was commissioned by the Kingdom of Bavaria to develop standards for weights and measures, and to impose standardisation processes on industries. To some extent, he followed in Fraunhöfer's footsteps by designing a new type of photometer[39] with which he managed to measure the luminosity of thirty stars very precisely. Zöllner sought to exceed that number of stars, to this end he designed and built a new photometer during his student years in Berlin, which he

[37] Karl Zöllner, "Photometrische Untersuchungen, die Constante g/r betreffend," *Annalen der Physik und Chemie* 100 (1857): 381-394; Karl Zöllner, "Nachtrag zu den Photometrischen Untersuchungen, die Constante g/r betreffend," *Annalen der Physik und Chemie* 100 (1857): 474-475; Karl Zöllner, "Nachtrag zu den vorigen Hefte beschriebenen photometrischen Untersuchungen," *Annalen der Physik und Chemie* 100 (1857): 651-653.

[38] An extract from the thesis was published in 1859 with the title "Photometrische Untersuchungen," *Annalen der Physik und Chemie* 109 (1860): 244-275.

[39] Karl Von Steinheil, *Elemente der Helligkeitsmessungen am Sternhimmel* (München: K. Bayer Akademie der Wissenschaft, 1836).

perfected during his stay in Basel. With it he made measurements of more than two hundred stars and presented his work to the previously mentioned Vienna Academy Award. May 31, 1861 was the date agreed by the Academy for the award ceremony for the prize that Zöllner had competed for. None of the three proposals submitted won the prize, but the judgement of Zöllner's project was very positive, although it did not, in the opinion of the committee, meet one of the main requirements: having made a sufficient number of measurements of the brightness of the stars. Furthermore, the report pointed out that the sample of stars in the proposal was not justified, was too random, and did not point to any stars as a reference for the brightness of all the others.

Although the Academy had offered him to publish the photometric work he had submitted for the prize, he preferred to publish it in Berlin in 1861 under the title *Grundzüge einer allgemeinen Photometrie des Himmels* (Outlines of a general photometry of the sky). The work became an obligatory reference for visual photometry. Furthermore, in the prologue, he warned of the difficulties in the comparative observation of the luminosity of the stars due to two reasons: firstly, the variable character of this luminosity that seemed to be intrinsic to the stars; but also because there were physiological difficulties in the act of observation due to the problems of the eyes of the observers.[40]

Despite not winning the Academy award, the Zöllner photometer was widely used in observatories in Central Europe and North America (Figure 2). It was constructed so that the brightness of the artificial star in the photometer, produced by a small kerosene lamp, could be compared with the light from the star to be analysed. The light from the lamp was dimmed by means of polarisations until the eye of the observer judged the two lights to be equal. In addition, an attempt was made to compare the colour of the star with the coloured light of the artificial star. This was the work of a physicist who took up the tradition of instrument makers, extending the Central European artisanal traditions into the nineteenth century. It is worth noting the great effort made recently to recover this artisan spirit by trying to replicate the instruments of the nineteenth century, mainly due to the work of Klaus Staubermann.[41] Not all the difficulties encountered by this originator are due to the intrinsic difficulties of replicating the instruments, in particular the Zöllner photometer, but to the change that has taken place in artisanal inventing from the middle of the nineteenth century until now. Staubermann warns that the replicated photometer is possibly more precise than the one built in Zöllner's time, simply because it has not been possible to recover each and every one of the nineteenth century artisanal practices and, almost inevitably, technological shortcuts have been made

[40] Karl Zöllner, *Grundzüge Einer allgemeinen Photometrie des Himmels* (Berlin, Mitscher & Röstell, 1861), VI.

[41] Klaus Staubermann, *Astronomers at Work. A study of the replicability of 19th century astronomical practice* (Frankfurt am Main: Verlag Harri Deutsch, 2007); Klaus Staubermann, "The Trouble with the Instrument: Zöllner Photometer," *Journal for the History of Astronomy* XXXI (2000): 323-338.

with contemporary techniques. However, there is no doubt that the Zöllner/Staubermann photometer provides valuable information on how astronomers observed the stars and measured their intensity and colour. It was the threshold of a huge project to standardise the huge number of stars that were displayed before the eyes of observers.

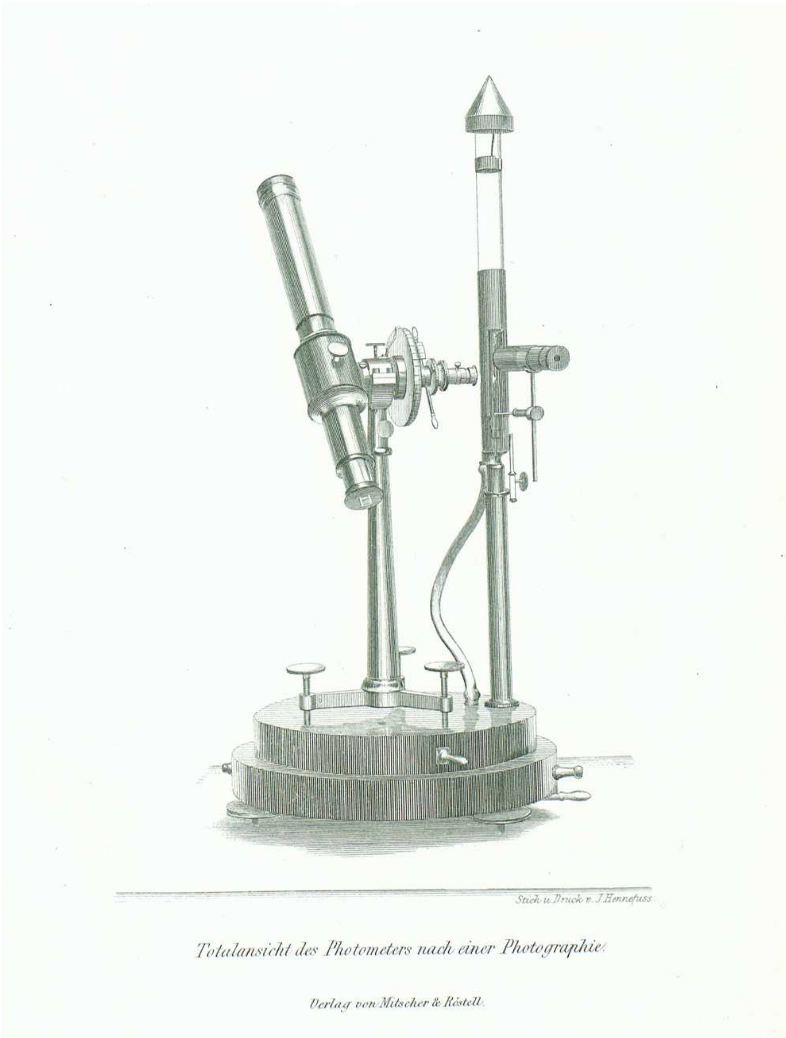

Figure 2 - Engraving made from a photograph taken from Karl Zöllner's original Photometer. Karl Zöllner, *Grundzüge einer allgemeinen Photometrie des Himmels* (Berlin, Mitscher & Röstell, 1861), Tafeln IV.

Zöllner's fate had a rather surprising final coda, as he was the first proposed for a chair in astrophysics at Leipzig University, which was endowed in 1865. He called it a professorship in astrophysics, which as of then was a non-existent science. The influential Bessel was opposed to creating a science that would share the object of study of traditional astronomers with those who believed that emerging physics had a say in investigating the luminosity of stars. However, the truth is that in 1865 he published his best study on photometry and laid the foundations for what would later become astrophysics.[42] After this positive beginning, he began to have difficulties with his colleagues in Berlin because he followed a drift towards irrationalist philosophical positions that clashed with the group of Berlin physicists.[43]

Taking Zöllner's contribution into account, a clear line can be drawn that connects with Fraunhöfer's work. From the beginning of the eighteenth century to the last third of the nineteenth century, collaboration between artisans and scientists can be traced back through standardisation or the production of standardised materials. Light opens the path to a unique understanding of the world.

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[42] Karl Zöllner, *Photometrische Untersuchungen mit besonderer Rücksicht auf die physische Beschaffenheit der Himmelskörper* (Lepizig: Engelmann, 1865).

[43] Christoph Meinel, *Karl Friedrich Zöllner und die Wissenschatskultur der Gründerzeit. Eine Fallstudie zur Genese konservativer Zivikisationskritik* (Berlin: Sigma, 1991).