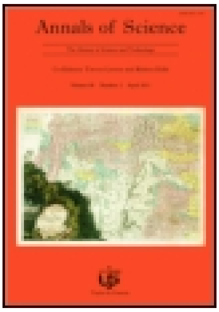

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Jürgen Teichmann [a] & Arthur Stinner [b]

[a] Deutsches Museum and Ludwig-Maximilians-University, München, Germany

[b] University of Manitoba, Winnipeg, Canada

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From William Hyde Wollaston to Alexander von Humboldt - Star Spectra and Celestial Landscape[1]

JÜRGEN TEICHMANN

Deutsches Museum and Ludwig-Maximilians-University, München, Germany
Email: J.Teichmann@deutsches-museum.de

ARTHUR STINNER

University of Manitoba, Winnipeg, Canada

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Summary

The discovery of dark lines in the spectrum of the sun as well as in some fixed stars since 1802 by William Hyde Wollaston, Joseph Fraunhofer and Johann Lamont is a relatively isolated phenomenon in the history of astronomy of the first half of the 19th century. Wollaston's representation of the sun's spectrum of 1802 can be seen as a simplification and reduction of the phenomenon by way of a seemingly clear connection with contemporary knowledge. Fraunhofer's famous colour etching of the dark lines, of about 1817, can be regarded as a meticulous and painstaking representation of the known facts, taken to a high aesthetic level.

Lamont's spectra of the fixed stars from 1836 are the first sketches of all of these phenomena. He emphasized the 'oddness', that is, the chaotic variety of identifiable lines. What was common to all of these representations was the general belief that something new and unimaginable could now be established as a scientific subject. The observations of these lines were coincidental with the thinking in other fields, as for example, in Alexander Humboldt's understanding of nature, in Johann Wolfgang von Goethe's theory of light and his interest in pictorial representations of nature, and in the new concept of landscape of the romantic painters.

Contents

[1] Three papers mainly have stimulated our work. H. Zehe, 'Gott hat die Natur einfach gemacht, sie aber suchen viel Künste', *Sitzungsberichte der Heidelberger Akademie der Wissenschaften, Mathematisch-Naturwissenschaftliche Klasse* (1990), 359–92. R. Häfner and R. Riekher, 'Die Pioniere der Sternspektroskopie, Die stellarspektroskopischen Untersuchungen von Fraunhofer (1816–20) und Lamont (1836)', *Beiträge zur Astronomiegeschichte*, 6 (2003),137–65. K. Hentschel, *Mapping the Spectrum.Techniques of visual representation in research and teaching* (Oxford, New York, 2002).
In our article Fraunhofer, Lamont, Maedler and Soldner are named without 'von', because they were ennobled later in their life (1824, 1867, 1865, 1825).

1. The visible and invisible sky – visual cultures in astronomy

Fraunhofer's own hand-made copper etching depicting the dark lines of the sun's spectrum is certainly well known to scientists and historians. There are two coloured examples at the Deutsches Museum in Munich,[2] and another one at the Goethe National Museum in Weimar (Figure 1).[3] In the publications of Fraunhofer in different journals since 1817 there are only black and white pictures (Figure 2).[4]

It could be argued that Fraunhofer's coloured spectrum – with about 350 painstakingly represented lines – had attained an almost metaphoric significance in the beginning of the modern period of astrophysics after 1859. This became a symbol for a general visual break from the objects of classical positional astronomy, namely star points, and the new objects of spectra. Nothing similar can be claimed for the effect made by the scanty drawings of a few dark lines of Wollaston in 1802. This in itself provides a motivation for comparing the two representations historically: Do pictures have a life of their own?[5] How important were ideas based on aesthetics and metaphorical references? For what purpose were these pictures drawn? Are there connections we can make with other visual art forms of the time? In making such a comparison we will include the unpublished sketches of spectra of the fixed stars by

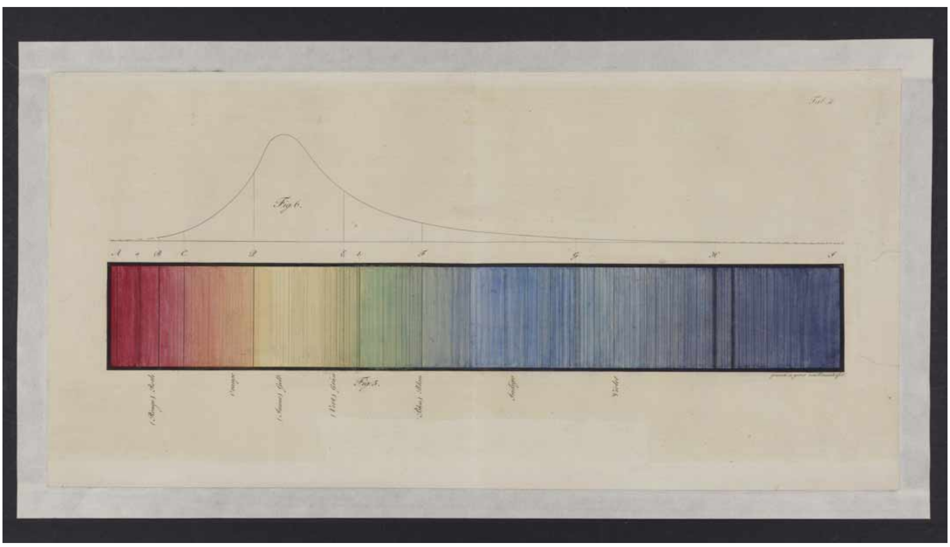

Figure 1. Samuel Thomas Sömmering sent this hand coloured Fraunhofer spectrum to Johann Wolfgang von Goethe in 1827 (now Goethe-National-Museum Weimar, note 3).

[2] J. Fraunhofer, Two solar spectra with lines, around 1817–26. Deutsches Museum, München (archive, No.7809/2 and NL 14–52). Handcoloured etchings. We name them PL and NL.

[3] J. Fraunhofer, Solar spectrum with lines, around 1827. Goethe-National-Museum, Weimar (No. GNF149). Etching coloured by hand.

[4] For the first one see J. Fraunhofer, 'Bestimmung des Brechungs- und Farbenzerstreuungs-Vermögens verschiedener Glasarten, in Bezug auf die Vervollkommnung achromatischer Fernröhre', *Denkschriften der Bayerischen Akademie der Wissenschaften*, 5 (1817),193–226.

[5] In relation to experiments see I. Hacking, *Representing and Intervening-Introductory Topics in the Philosophy of Natural Science* (Cambridge, UK, 1983). In relation to the concept of picture see M. Bruhn:

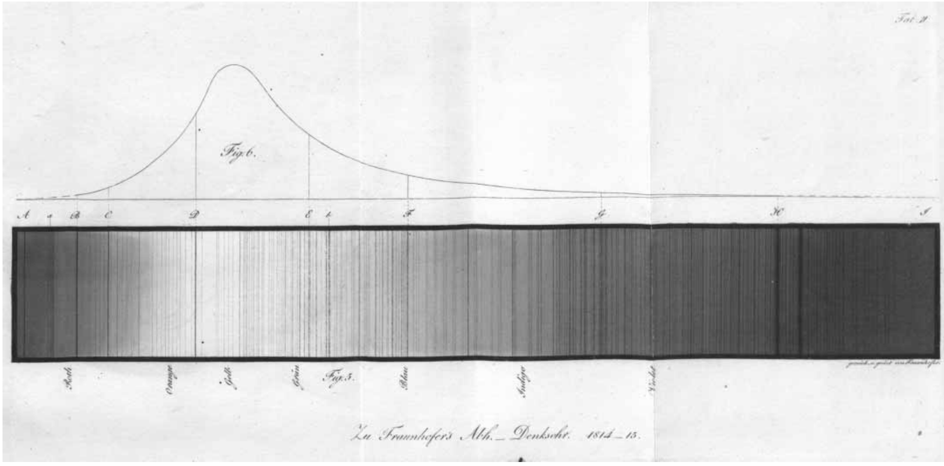

Figure 2. Joseph Fraunhofer's spectrum in black and white, ('Denkschriften' from 1817, note 4).

Lamont, made in 1836. These are the first sketches of line spectra of fixed stars that had been found.

For all those (and other) pictures of the sky we use the term 'landscape', as an extension of the concept, which Alexander von Humboldt used in a geomorphological sense - as an analogy and, at once, as a metaphor - at the beginning of the 19th century. He looked at and admired 'the gracefulness of the landscape of the whole southern firmament' (die landschaftliche Anmut des ganzen südlichen Himmels) unfold, or when he contemplated 'the picturesque effect of the landscape of the milky way' (die malerisch-landschaftliche Wirkung der Milchstraße).Those concepts are part of his philosophical intentions to offer a 'description by the painting of nature' (beschreibendes Naturgemälde). Within the contemporary English translations of Humboldt's 'Kosmos' this analogy to landscape was transformed using contemporary terms. 'Landschaftliche Anmut' for example is translated as 'picturesque beauty'.[6] We will reflect on this adoption of Humboldt's concept further at the end of our article.

'Spannungen, Entladungen. Evolutionen und Revolutionen kollektiven Sehens', in M. Bruhn and K.-U. Hemken (eds.): *Modernisierung des Sehens. Sehweisen zwischen Künsten und Medien* (Bielefeld, 2009), 11–24. Bruhn cites J. Crary, *Techniques of the Observer. On Vision and Modernity in the Nineteenth Century* (Cambridge, Mass.,1990). M. Kemp and J. Blasius, *Bilderwissen. Die Anschaulichkeit naturwissenschaftlicher Phänomene* (Köln, 2003).Detailed overview to this matter see M. Hessler, *Bilder in den Naturwissenschaften*. Scoping study (Aachen, 2004). Online access: http://www.sciencepolicystudies.de/dok/explorationsstudie-hessler.pdf (21.12.2010). Results from this project in M. Hessler and D. Mersch (eds.), *Logik des Bildlichen - Zur Kritik der ikonischen Vernunft* (Bielefeld, 2009).

[6] A.v. Humboldt, *Kosmos, Versuch einer physischen Weltbeschreibung* (Frankfurt am Main, 2004). Five volumes of the original edition 1845–62, published in one volume. Vol. 1, 80, 89. Vol. 3, 185, 341. (The quotations are a modern translation and cited from the pages of the original edition.) See also A.v. Humboldt (translated by E.J. Sabine), *Cosmos. Sketch of a physical description of the Universe.* 4 volumes (London, 1849–58). A.v. Humboldt (translated by E.C. Otte), *Cosmos. A sketch of a physical description of the universe* (New York, 1849–58). See also W.H. Brock, 'Humboldt and the British: a note on the character of British science', *Annals of Science*, 50 (1993), 365–72, 366, 367.

We find publications about the history of astrophysics of the first half of the 19th century, beginning with the priority debate about the claims made for the discoveries of Kirchhoff and Bunsen, immediately after 1859 that involved Kirchhoff himself[7]. The aspect of a 'general visual break' is not found in these historical works. They are, partly, priority debates. This early development becomes more important when one considers Wollaston's, Fraunhofer's, and Lamont's representations as possible categories towards an understanding of this general 'visual break' from 1859 on.

The two initial representations by Wollaston and Fraunhofer were the result based on different interests, although both wanted to improve on the measurement of refractive indexes. Wollaston was interested in comparing different substances for physical and chemical purposes, but Fraunhofer's interest lay in the construction of better achromatic refractor objectives. Although both representations were published, only a small group of astronomers and physicists became aware of them. And even to those few scientists who began concentrating on the study of the solar spectrum it was not clear if the lines could be considered real. Solar lines were not easily seen. In 1817 Fraunhofer wrote that using English 'flint glass', (which was the most used glass then) one could only see the strongest lines in the sun's spectrum. Note also the difficulty Charles Babbage had in 1830, to see the lines shown during a private demonstration by John Herschel.[8] It was unclear whether the lines represented an astro-physical or terrestrial phenomenon. Secondly, it was not clear, how they were related to similar phenomena observed in flame spectra. It is clear that almost no one was able, or wanted to observe the spectra of fixed stars before 1860. It was still more difficult to design and use an apparatus for observing these fixed star spectra. Acceptable scientific meaning that connected all of these line spectra to the science of the macro world (and much later also to the micro world) was only possible after the establishment of the fundamental principles of spectral analysis that was worked out, around the above mentioned 'visual break', from 1859 on. This view incorporated a new 'invisible' sky, consisting of thousands of absorption as well as emission spectra.

In 1852 the astronomer Johann Heinrich von Maedler speaks explicitly of a new astronomy of the 'invisible', but by that he clearly does not refer to the curious pictures of the spectrum of the sun, or even the spectra of fixed stars, but to the potential discovery of new planets, for example the planet Neptune or a companion of Sirius – both by way of an exact calculation of the gravitational effect of the neighbouring celestial objects.[9] Similar predictions based on celestial mechanics existed much earlier, for example the prediction of the return of Halley's comet in 1759. However, this was not comparable to the universal collapse of a new world-system that Galileo's discoveries (observations) initiated. Maedler's 'objects' also

[7] Kirchhoff himself reflects on the prehistory in Nov. 1862. G.R. Kirchhoff, 'Zur Geschichte der Spectral-Analyse und der Analyse der Sonnenatmosphäre', *Annalen der Physik,* 194 (1863), 94–111. H. Kayser, *Handbuch der Spectroscopie* (Leipzig, 1900). J.B. Hearnshaw,*The analysis of starlight.One hundred and fifty years of astronomical spectroscopy* (Cambridge, 1986). I.D. Rae, 'Spectrum Analysis: The Priority Claims of Stokes and Kirchhoff', *Ambix,* 44 (1997), 131–44.

F.A.J.L. James, 'The discovery of line spectra', *Ambix,* 32 (1985), 53–70. F.A.J.L. James, *The early development of spectroscopy and astrophysics* (unpublished PhD thesis, University of London, 1981).

[8] H. Zehe,(note 1), p. 361, 379. M.W. Jackson, *Spectrum of belief, Joseph von Fraunhofer and the craft of precision optics* (Cambridge, 2000), 127.

[9] J.H. Maedler, *Populäre Astronomie* (Berlin, 4th ed. 1849), amendments from 1852, 19. J.H. Maedler, *Der Fixsternhimmel. Eine gemeinfassliche Darstellung der neuern auf ihn sich beziehenden Forschungen* (Leipzig, 1858),104.

belonged to the landscape of 'positional astronomy'. Positional astronomy was the essential condition for the exact predictions of celestial mechanics. All its objects testified to a sublime aspect of the verified sky that connects us to the order and law-likeness that is mirrored by nature – completely in contrast to the chaotic dark lines of Fraunhofer as first presented in 1817. The astronomer Friedrich Wilhelm Bessel, among other astronomers of that time, considered the measurement of the celestial 'landscape' by 1840 as the only objective of astronomy. He declared: 'Astronomy has only one objective and that is to find and determine the pattern of motion of each star as it moves in ascent and descent at any given time.' Similarly Pierre Simon Laplace had expressed much earlier: The task of astronomy was only,'n'admettre que les résultats de l'observation et du calcul.'[10]

Maedler, symptomatic of the whole of astronomy, ignored Fraunhofer's dark lines as well as the discovery of infrared and ultraviolet radiation in the sun's light in 1800/1801. Immediately after the discovery of Infrared by William Herschel, 1800, the astronomer Franz Xaver von Zach, had discussed this publication, but only in reference to a different temperature rise in lenses by the 'prismatic colours' as interesting for 'practical astronomy'. He did not accept, like Maedler, 'invisible' rays as being of interest for astronomy, he argued that this topic belonged to physics and chemistry.[11] These last discoveries are another sign that the then understood 'astronomy of the invisible' had to change its appearance.

From the predominance of positional astronomy the philosopher August Comte, who also became known as a popular astronomer, drew important philosophical consequences, well known in the history and philosophy of science. He concluded that astronomy like most exact science was based on observation and hence should be regarded as the best example to emulate for all empirical sciences. However, in astronomy we will never be able to experimentally investigate its objects of study, since they are inaccessible and unreachable:

> Les astres ne nous étant accessibles que par la vue . . . . . . Cette inévitable restriction nous interdit donc, pour tous ces grands corps, non seulement toute spéculation organique, mais aussi les plus éminentes spéculations inorganiques, relatives à leur nature chimique ou même physique.[12]

He even questioned the first determination of the distance to a star by Bessel in 1838 — this was clearly the first step into the cosmos beyond the planetary system — although this measurement still explicitly represented the fruit as well as the symbol of the instrumental and theoretical development of classical positional astronomy. As the majority of natural philosophers of the time, he accepted neither the Fraunhofer dark lines nor the discovery of infrared and ultraviolet radiation. His credo remained

[10] F.W. Bessel, *Populäre Vorlesungen über wissenschaftliche Gegenstände* (Hamburg, 1848), 5, 6. P.S. Laplace, *Exposition du Systeme du Monde* (Paris, 1796), 448. See also S. Schaffer, 'Where Experiments End, Tabletop Trials in Victorian Astronomy', in J.Z. Buchwald (ed.), *Scientific practice.Theories and stories of doing physics (*Chicago, 5th ed. 2004), 257–99 (260–7).

[11] F.X. Zach: 'Investigation of the powers of the prismatic colours to heat and illuminate objects etc . . . by W.Herschel', *Monatliche Correspondenz zur Beförderung der Erd- und Himmelskunde*, 3 (1801), 72–6.

[12] A. Comte, *Traité philosophique d'astronomie populaire, ou exposition systematique de toutes les notions de philosophie astronomique, soit scientifiques, soit logiques, qui doivent devenir universellement familières* (Paris, 1844),109. Similarly Comte already earlier, in A. Comte, *Cours de philosophie positive* (Paris, 1835), vols. 2, 8 and 9. See also S. Schaffer, (note 10), 261f.

strictly founded on positional astronomy: 'Research that is not ultimately reducible to simple visual observation would not be allowed in our study of the stars'.[13]

The new science of spectral analysis (which began in 1859) that used the still mysterious 'landscape' of spectral lines as a symbolic language, did not render classical positional astronomy obsolete. However, it severely limited the importance of positional astronomy progressively more and more after about 1900 by extending the new landscape of the spectral method.

Admittedly, the strict requirement of precision and accuracy of positional astronomy had to be sacrificed. As late as 1950 the accounts of frequency calculations of the elements taken from the spectra could be wrong by as much as 100–200%! As late as 2002 one could find in publications inaccuracies as high as 50%. Around 1960 only 18 chemical elements in the sun, together with less than 300 Fraunhofer lines had been quantitatively identified to an exact amount.[14] Every astronomer of the 19th century would have refused to recognize such results as science. The director of the Russian observatory in Pulkowo, Otto Struve, successor to his father Friedrich Georg Wilhelm, as late as 1887 even criticized celestial photography,

> whose perfection [was not still appropriate] to the methods, which had given to practical astronomy the enviable position of an experimental science, whose conclusions – in respect to their precision – can compete with those of mathematical theories.[15]

2. Visual patterns in the worldviews of Johann Wolfgang von Goethe and Alexander von Humboldt

When Johann Wolfgang von Goethe saw Fraunhofer's solar spectrum, he was surprised and impressed but reserved.

Goethe became aware of Fraunhofer's discovery,[16] three months after the publication, when he still had a strong interest in optical phenomena. In 1810 he had published his 'Outline of a science of colours' (Entwurf einer Farbenlehre). Since 1792 he had been involved in researches in physical and later in physiological and psychological optics, far above his poetic interests, mainly influenced by his activities in painting and drawing. In 1809 he said in a talk: 'We should speak less and draw more . . . Our soul plays music, when we are engaged in drawing, a little out of its most inner being . . .'[17]

In the physics of the 19th century most responses to Goethe's optics were negative.[18] Within the recent science of sensory physiology in the 1830s interest

[13] A. Comte 1835 (note 12), 8.

[14] J.B. Hearnshaw (note 7), 439. A. Unsöld and B. Baschek, *Der neue Kosmos. Einführung in die Astronomie und Astrophysik* (Berlin et al., 7th ed. 2002), 223.

[15] B. Sticker, 'Die Bedeutung der Fortschritte auf den Gebieten der Optik und der Phototechnik für die Astronomie im 19. Jahrhundert', Verein Deutscher Ingenieure (ed.), *Geschichte der Naturwissenschaften und der Technik im 19.Jahrhundert* (Düsseldorf, 1971),103–36, p. 110 (Sticker cited from *The International Astrophotographic Congress*, Appendix I, Washington 1889,14). Similarly Struve in 1886. See A.J. Meadows: 'The new astronomy', in O. Gingerich (ed.): Astrophysics and twenties- century astronomy to 1950. Part A (Cambridge, UK, 1984. The General History of Astronomy, vol. 4), 59–72, p. 61.

[16] J. Fraunhofer (note 4). H. Zehe (note 1), 361, 373.

[17] J.D. Falk, *Goethe aus näherm persönlichen Umgange dargestellt* (Leipzig, 1832), 42–3.

[18] With some exceptions, see Thomas Johann Seebeck und Johann Salomo Christoph Schweigger. E.g. see J. Schiff, 'J.S.C. Schweigger und sein Briefwechsel mit Goethe', *Die Naturwissenschaften* 13 (1925), 555–9.

developed.[19] Finally, beginning with the end of the 19th century differences between Goethe's thinking and the narrow interpretations of classical colour physics were stressed.

Goethe was taken in by anthroposophical ideology,[20] he was seen, in a theological sense,[21] as a modificationist,[22] as a theoretician of 'Anschauung', that is a holistic understanding of nature, as an exploratory experimenter and pioneer of modern colour theory, in contrast to the geometrical-mathematical thinking of Newton.[23]

If one tries to select a few essential ideas, those that could also have been decisive in his orientation toward the dark lines of Fraunhofer, it is probably Goethe's

- holistic requirement for observing nature, where the subjective (the observer) and the objective (the phenomenon considered) are inseparable. After 1794, for Goethe, the physical, the physiological and the psychological aspects of colour had to be considered together.
- The concept of polarity[24] was for him an important 'driving force' of nature. In optics this was the opposition between light/darkness. Colours arose by the mediation of opaque objects like glass or (in nature) fog.
  They were not contained in the white color of sunlight, in opposition to Newton's ideas.
  He probably thought that the dark lines of Fraunhofer were closely related to this idea of polarity namely the light/darkness principle, in contrast to the shining colours of the spectrum.
- the principal lack of precision in his concepts. E.g. some definitions were ambiguous. This appeared to him as important as seen from the perspective of natural philosophy. He used the concepts of 'picture' and spectrum as having different meanings. For some phenomena he used various words that suggest the same meaning. However, as a poet, he was able to make sense of this ambiguity.
- He opposed the use of mathematical abstractions, such as the concept of a light ray.
- He was open to all phenomena that resembled the known colour patterns in nature.

The physician Samuel Thomas Sömmering, until 1819 a colleague of Fraunhofer's in the Bavarian Academy of Sciences, who was broadly interested also in physics and

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[19] J. Müller-Tamm, 'Farbe bekennen. Goethes Farbenlehre und die Berliner Wissenschaftspolitik um 1820' in E. Osterkamp (ed.), *Wechselwirkungen. Kunst und Wissenschaft in Berlin und Weimar im Zeichen Goethes* (Bern, 2002), 193–209.

[20] R. Steiner, *Goethes Weltanschauung* (Dornach, 1999. 1st ed. 1897).

[21] A. Schöne, *Goethes Farbentheologie* (München, 1987).

[22] e.g. G.A. Zemplen, An eye for optical theory? Newton's rejection of the modificationist tradition and Goethe's modificationist critique of Newton (unpublished PhD thesis, University of Budapest, 2001) - http://hps.elte.hu/ ~zemplen/PhDthesis.pdf

[23] On the subject of 'Anschauung' see D.L. Sepper, *Goethe contra Newton: Polemics and the project for a new science of color* (Cambridge, 2002. 1st ed.1988). N. Ribe, F. Steinle, 'Exploratory Experimentation: Goethe, Land, and Color Theory' *Physics Today*, 55 (2002), 43–94. F. Steinle, '"Das Nächste ans Nächste reihen": Goethe, Newton und das Experiment' *Philosophia Naturalis*, 39 (2002), 141–72. See also E. Land cited in N. Ribe, 'Goethe's critique of Newton: a reconsideration' *Studies in History and Philosophy of Science,* 16 (1985), 315–35. M. Rang, J. Grebe-Ellis, 'Additiv und subtraktiv. Neue Experimente zur Spektroskopie und Farbmischung' *Phänomen Farbe*, 31 (2011), 36–7. See also the bibliography by F. Amrine (ed.): *Goethe in the History of Science* (New York, 1996). 2 vols.

[24] M. Wenzel (ed.), *Goethe und Soemmering. Briefwechsel 1784–1828. Textkritische und kommentierte Ausgabe* (Stuttgart, 1988), 64. Goethe an Sömmering 7.2.1792. Here we find one of the earliest references of 'polarity'.

technology, sent to him, in1827, a colour copy of Fraunhofer's spectrum and wrote enthusiastically in his letter:

> Authentically it is for our century most definitely one of the most important discoveries, of my late friend, that all the planets, illuminated by the sun, along with the moon, and also certain fixed stars, like Pollux show in their prismatic spectrum the same number of vertical streaks or fixed lines, the same broadness, the same (exact measured) distances from one another at the same places. But Wega and other fixed stars like Castor (as Fraunhofer and Soldner showed me at the observatory) show constant disparity in number, broadness and distance of the fixed lines. Electric light produces instead of the dark, black lines bright ones, similar to lightning. Sometimes I thought: could not this beautiful prismatic spectrum of Fraunhofer reveal the quantity of the shadowy image (skieron), which belongs to each colour.[25]

Sömmering also researched colour sensations. He was in close contact with Goethe already in the 1790s, before the poet started his optical research. Very probably he had a strong influence on Goethe's physiological interests. With the word skieron, written by Sömmering in Greek letters, he referred to Goethe's polarity principle in his colour theory. Did he now understand by 'quantity' the number of lines in each colour or/and their width? In any case, he tried to win the interest of the great poet for this fascinating 'beautiful' phenomenon. His words also prove that the coloured illustration, with its contrasting dark lines, impressed him strongly.

Goethe's first reaction was very positive, as related in a letter to the Duke Carl August:

> 'His (Sömmering's) description is certainly interesting and to see the Fraunhofer spectrum in such detail and hand-coloured in a very comfortable way, is highly welcome. This phenomenon can be seen only under certain circumstances and with some difficulty.'[26]

Goethe was clearly acquainted with the Fraunhofer dark lines already at the time they were published in 1817. He also knew about the Fraunhofer studies of diffraction in 1821/22. However, in his response of 1822 he was clearly critical:

> 'Mr. Fraunhofer in Munich, was excessive when dealing with the phenomenon of paroptic colours (this was Goethe's name for diffraction phenomena), and seems to have used a microscope. He accompanied his experiences with the most detailed depiction, for which we thank him greatfully; but we were unable to discover a new modification of light in his points of shade, which were caused by grids and other obstacles.'[27]

In the same way also the vertical stripes (Querstreifen), that is, the Fraunhofer lines, he argued, were caused by such obstacles (very small apertures).There were similar critical comments made in 1823 and 1824. Then, in the summer of 1826 he suddenly conducted Fraunhofer's experiments (Fraunhofersche Experimente) and studied his publication of 1817 in greater detail.

[25] M. Wenzel (note 24), 130 (letter from mid-March 1827).
[26] M. Wenzel (note 24), 132 (letter from March 23, 1827).
[27] Zehe (note 1),373–4. Aus J.W. Goethe, *Wartesteine* (Stuttgart, Tübingen,1822), 37.

Perhaps the interest shown by Goethe's sovereign Carl August of Weimar-Saxonia in producing better optical glass[28] also shifted the interest of his minister Goethe to those difficult-to-see dark lines - as they were marks for an exact determination of refraction and dispersion.

Goethe's appreciation of Fraunhofer went beyond his specialisation as an optician. This we will even find in his polemic writings, when he mentions him together with Newton - and thereby praising him still higher than Sömmering did in his letter to Goethe:

> 'The name Fraunhofer for me carries just as little weight as the name of Newton does, both men of high intellect but nevertheless given to misunderstandings as anyone else. Newton was not protected by his lofty mathematical thinking to arrive at a concluding hypothesis based only on a double and three times entangled (verschränktes) experiment. Fraunhofer, inspite of his technical mastery, was unable to find the deficiency of a theory, under the influence and protection of which, after all, he had trained himself. Instead of enlarging the aperture he changed it to a barely perceptible cut.'[29]

Nevertheless, in 1826/27, the spectral lines interested him beyond their technical meaning:

- Perhaps as a 'multiplication' (Vermannigfaltigung)[30] of his paroptic (and entoptic) experiments.
- The irregular diversity of the specral lines that seemed to be unyielding to a mathematical analysis provided an additional challenge.
- The polar opposites of the shaded part of the lines and the bright colours must have fascinated him - though he finally interpreted this phenomenon as belonging to the paroptical, that is, diffraction experiments. These lines were additonal qualifications of colours. This helped to deepen the opposition to Newton, who had stated in 1672, that colours especially are no 'qualifications' of light.
- The continuously coloured spectrum in Sömmering's enclosure to his letter was close to Goethe's holistic understanding of nature, in contradiction to Newton's theory, where he tried to separate seven main blocks of colours which was still the conventional picture of physicists in Goethe's time (as Wollaston described it and later was criticized by John Herschel).
- The line spectrum, especially the coloured reproduction version, was close to the 'mimetic' strategy[31] of Goethe, that saw 'the phenomenon as a picture occupying a certain space'. Goethe was very interested in the solar spectrum since Chladni's 'figures of sound' were personally demonstrated to him.

Chladni was interested in astro-physical phenomena. He was the first to argue that meteorites originated in space and not from within the earth's atmosphere. He

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[28] A. Brachner, *Mit den Wellen des Lichts, Ursprünge und Entwicklung der Optik im süddeutschen Raum (München,1987)*, chapter 2.4.7. *See also H.Zehe*, 'Die Ungleichheit der färbigen Räume, im Spectro verschiedner brechender Mittel: (Ein Brief Friedrich Körners an Goethe)', *Sudhoffs Archiv*, 80 (1996), 229–34.

[29] Zehe (note 1), 382.

[30] H. Helbig, *Naturgemässe Ordnung. Darstellung und Methode in Goethes Lehre von den Farben* (Köln, 2004), 340. This is the best book about Goethe's experimental methodology.

[31] Helbig (note 30), 482.

had started publishing these theses from 1794 on. Chladni had friendly contacts with Goethe and also exchanged letters with Fraunhofer. Chladni's 'figures of sound' became well known around 1800: the nodal patterns of vibration of a metal plate became visible in sand. These patterns also presented a special 'landscape' of lines. Sömmering, too, was impressed by them and used them - as an analogy - in his theory of the human brain.[32] The poet Novalis saw them as part of the 'great scripture of ciphers of nature'. In these figures sound 'printed itself, or ciphered itself'.[33] Chladni had demonstrated his figures to Goethe already in 1803, in Weimar (and also his newly invented musical instruments). Goethe repeated these experiments from time to time. He later met Chladni on several occasions. In the year 1815 the physicist Thomas August Seebeck discovered polarization patterns in heated glass objects (thermally induced stress, the so-called birefringence). Seebeck discovered them by following experiments of the French physicist Étienne Malus. Malus had discovered polarisation of light by reflection produced by reflective glass surfaces.[34] Seebeck also had friendly contacts with Goethe. He compared his new-found patterns with Chladni's sound figures (he offered even a coloured figure of his discovery) and explained this in a letter to Goethe. Goethe again was very impressed and added an extended chapter to his 'Outline of a science of colours' (Entwurf einer Farbenlehre), which was published 1820 and had the title 'Entoptical colours' (Entoptische Farben). In this chapter he deepened the analogy with Chladnis figures in a tabular form (this was a short paragraph) and compared formation, and movement. Under the heading of 'beginnings' he also compared 'parabolic lines' in both phenomena. In talks at this time he called Chladni's figures the 'parallelism of his science of colours',[35] meaning that he was predisposed to combine line phenomena and colours. Chladni's figures and Seebeck's patterns indeed became new 'landscapes' in physics. Their visual composition played a decisive role in research on these phenomena for a long time.

But ultimately Goethe saw the Faunhofer spectral lines only as a new attack on his anti-Newtonian theory of colours. Fraunhofer's experiment again, like Newton's, forced white light to press itself through a small opening - now in the form of a slit. Again it was argued, that this light was divided up in colours - for example, contrary to his explanations of the 'entoptical' colours. This terrible Newtonian spectrum now should be peppered with hundreds of black dashes, 'stippled' (durchstrichelt), as he called it. These dashes looked totally irregular, without any structure - this was also contrary to the 'entoptical' patterns and to Chladni's figures. This is why he continued with his explanation, as many scientists did in the next forty years that these lines had to be disturbances caused by the aperture of the slit.[36]

[32] C. Welsh, *Hirnhöhlenpoetiken. Theorien zur Wahrnehmung in Wissenschaft, Ästhetik und Literatur um 1800* (Freiburg, 2003), 61. Review see in http://www.literaturkritik.de/public/rezension.php?rez_id=6776&ausgabe=200402. See also E. Kleinschmidt, *Die Lesbarkeit der Romantik. Material, Medium, Diskurs* (Berlin, 2009), 205. See also letter from Goethe to Sömmering from 28.8.1796 in Wenzel (note 24), 112.

[33] Y. Takahashi, *Die 'geistige Gegenwart' bei Novalis* (unpublished PhD thesis, University of Trier, 2008), 113–14.

[34] T. Seebeck, 'Einige neue Versuche und Beobachtungen über Spiegelung und Brechung des Lichts' *Journal für Chemie und Physik*, 7 (1813), 258–98. E. Trunz, *Ein Tag aus Goethes Leben. Acht Studien zu Leben und Werk* (München, 1999), 34.

[35] Talk with Johann Gottfried Schadow, February 7, 1816. See http://www.zeno.org/Literatur/M/Goethe,+Johann+Wolfgang/Gespräche/[Zu+den+Gesprächen]/1816.

[36] See also J.W.v. Goethe, *Zur Farbenlehre. Polemischer Teil* (Weimar, 1992). Edited by H. Zehe et al., 408.

Alexander von Humboldt's view was close to that of Goethe's. He was interested, contrary to Comte, in 'the qualitative nature of materials, which circulate in the universe', in opposition to the 'sole dominance of the science of motion'[37] that is, celestial mechanics. His concept of science saw nature, between earth and the cosmos, as an epic, broadly illustrated painting. Experimentation and observation communicate this painting to our senses. Therefore, he was open - in principle – to phenomena, like spectra, which held so much promise for the future of cosmic physics. We sense his interest, when he adds in his 'Kosmos' of 1850/1851 one whole page about celestial spectroscopy. He explicitly mentions the different spectra of stars - even different, when the star points glance equally white. He attributed those observations to the Italian optician and astronomer Giovanni Battista Amici. But Amici had never made such observations.[38] This is a remarkable statement by Humboldt. Nowhere in the literature before 1860 do we find discussions about spectra of fixed stars. Humboldt had not only no reservation against this new landscape of lines, he saw nature aesthetically. Similarly, we can follow his aesthetic interests in the forms of specific coastal lines on earth.

He concluded his page about dark lines in spectra with the prediction that they will open up 'a vast and important field of future researches'. In a footnote, many pages later, Humboldt, on the other hand, is sceptical about whether 'rays of a certain refractive index' really were 'lost' in the solar atmosphere.[39]

We may judge that the 'scenic loveliness of the whole firmament' finally was closer to his sentiment and thinking than a totally new landscape which was only mediated by complicated physical instruments. The human eye, remained for him in a scientific and metaphoric sense an 'organ of worldview' (Organ der Weltanschauung). It should be mentioned that photography did not play a role in his 'Kosmos'.[40]

The spectroscope, whose prism separates all light into colours, delivers a reality, which cannot be understood as a simple extrapolation of seeing by the naked eye. The community of astronomers, in which Humboldt had many friends (for example Bessel), disregarded spectra totally. And physicists/chemists thought very controversially about line spectra in general. Ironically, the insight into the physical and chemical uniformity of the cosmos, which was made possible after 1860 by star spectra, would have been a very impressive answer for Humboldt's 'unity in totality', for which he was searching in all his explorations.

The last decades of the 19th century finally accepted the new landscape of lines, not as a codified language anymore, not as an abstract representation of a strange reality, but, in the form of photographed spectra, as actual existing objects of astrophysical research. In 1873 Henry Draper characterized the early printing of one of his photographed spectra this way: 'The spectrum is absolutely unretouched.

[37] A.v. Humboldt, (note 6), vol. 1, 57, 58.

[38] A.v. Humboldt, (note 6), vol. 3, 62–63. Personal communication by Amici's biographer Alberto Meschiari , 6 July 2010, *'I did not find any notes in the over 12 000 Amici papers, which confirm his [Humboldt's] assertion."*

[39] A.v. Humboldt, (note 6), vol. 3, footnote, 396.

[40] A.v. Humboldt (note 6), vol.1, 154, 86, vol. 3, 341/342. The emphasis on the eye is part of Humboldt's mimetic strategy of representing nature. All sense experiences are supposed to be transmitted and translated through the eye. He followed the development of photography with great enthusiasm.
K. Barck: 'Umwandlung des Ohrs zum Auge. Teleskopisches Sehen und ästhetische Beschreibung bei Alexander von Humboldt', in: B.J. Dotzler (ed.): *Wahrnehmung und Geschichte. Markierungen zur Aisthesis materialis* (Berlin, 1995), 29–42, 32, 34.

It represents therefore the work of the sun itself, and is not a drawing either made or corrected by hand.'[41]

3. Fraunhofer's solar spectrum from 1817

To observe solar light, Fraunhofer used a narrow slit, slightly more than 0.5 mm wide, a prism of glass and a small telescope, originally a geodetic theodolite, which he had modified for his purposes. Essential for his discovery of some hundreds of dark lines in his spectrum was the quality of his prism, the very exact slit and the observations using his specialized telescope. He drew more than 350 lines, described qualitatively as 'about 574' and saw 'almost innumerably many'. In the Weimar spectrum, which is the best preserved of the three coloured etchings, we can count 363 lines. (Between 1895and 1897 Rowland catalogued about 20000 between 297,5 and 733 nm wavelength.)[42] Fraunhofer 'drew and etched' these lines himself, as we may confirm by his signature on the existing copper etchings.

In relation to the three existing coloured copies we may ask if he coloured these himself. We do not know. They were probably ordered by him. We know about an account of Fraunhofer, where there is contained an order for 'painting in water colours' (tuschen) 437 copies of his spectrum. This meant that the shading in black and white of his spectra, accumulated in a continuous gradation to the red and violet edges. We find this shaded spectrum in his publication in the 'Denkschriften' of 1817. This edition of the 'Denkschriften' apparently was printed with the same number of items.[43]

The shading should demonstrate the increasing darkening of the real spectral observation from the red toward violet edge, because of the lesser sensitivity of the human eye to these colour regions. He also was the first to measure quantitatively the curve of this sensitivity, which we find in the upper part of his etching. This was technologically important, because an achromatic objective lens system consisted of two lenses. With two lenses the chromatic aberration could only be corrected for two, chosen, intervals in the spectrum. Here Fraunhofer looked for those two, where the eye was most sensitive.[44] In almost all parallel publications of his 1817 work we do not find this shading.[45]

To colour single spectra (three in our case) it was necessary to use printouts without shading. But this colouring also was darkened toward the red and violet edges, analogous to the shaded black and white copies.

The astronomer John Herschel tells us in1828, about coloured pictures of the solar spectrum, which Fraunhofer had 'published in the first essay' and in which 'the

[41] H. Draper, 'On Diffraction Spectrum Photography', *The American Journal of science and arts* 6 (1873), 401–409, 401. K.Hentschel, 'Zur Geschichte visueller Darstellungen von Spektren', *Naturwissenschaftliche Rundschau*, 55 (2002), 577–87. See also K. Hentschel, 'Photographic Mapping of the Solar Spectrum:1864–1900', *Journal for the History of Astronomy,* 30 (1999), 93–119, 201–24, 208, on how Henry Rowland understood his photographed spectra the same way.

[42] R. Tousey, 'Solar Spectroscopy from Rowland to SOT', *Vistas in Astronomy,* 29 (1986),175–99. G.K. Sweetnam, *The command of light. Rowland's school of physics and the spectrum* (Philadelphia, 2000).

[43] K. Hentschel (note 1), 170.

[44] J. Fraunhofer (note 4), 211–15.

[45] In German, in the Annalen der Physik; or in the English translations by David Brewster. An exception is the French translation J. Fraunhofer, 'Détermination du pouvoir réfringent et dispersif de différentes espèces de verre, recherches destinées au perfectionnement des lunettes achromatiques', *Astronomische Abhandlungen,* 2 (1823), 13–45.

tints are seen to pass into each other by a perfectly insensible gradation'. But in all publications of Fraunhofer's work from 1817 we only find black and white etchings. It is possible that Herschel, during his visit with Fraunhofer in 1824, was presented with coloured spectra, as those are the three which we possess today. He visited Fraunhofer mainly to get some information about the secret of his glass production, but without success. He admired the technology of Fraunhofer in producing excellent refractors. The coloured spectra he must have remembered some years later as being very spectacular, mainly in comparison with the publication of Wollaston in 1802:

> These colours, too, he [Wollaston] conceives to be well defined in the spaces they occupy, not graduating insensibly into each other, and of, sensibly, the same tint throughout their whole extent. We confess, we have never been able quite satisfactorily to verify this last observation, and in the experiments of Fraunhofer, (which we had the good fortune to witness, as exhibited by himself in Munich), where, from the perfect distinctness of the finest lines in the spectrum, all idea of confusion of vision, or intermixture of rays is precluded, the tints are seen to pass into each other by a perfectly insensible gradation; and the same thing may be noticed in the coloured representations of the spectrum published in the first essay of that eminent artist, and executed by himself with extraordinary pains and fidelity.[46]

If one analyses the two Munich colour copies, we can find at the one (PL) in contrast to the other (NL), underneath the areas of colours, some faint indications. They had become necessary for the black and white copies and should have been covered on the copper plate used for the coloured copies: '(Rouge)Roth', 'Orange', '(Jaune)Gelb', '(Vert)Grün', '(Bleu)Blau', 'Violet'.

At least some letters can be read, if enlarged by a lens. These indications of colours we find explicitly printed in the Weimar copy (and one indication more: 'Indigo'). That means that PL and the Weimar copy were printed from the copper plate, which had been modified by these indications for the publication of the spectrum in the French publication in Astronomische Abhandlungen 1823. In Fraunhofer's first publication of 1817 in 'Denkschriften' we only find the German indications of colours.

It is very probable that the copper plate — surely there was only one existing — was modified three times. At the beginning there did not exist any indications of colours. One printed copy of this version was used to colour the spectrum NL. Thereafter the German indications 'Roth' to 'Violet' were etched in the plate. From this version more than 400 copies were printed for the 'Denkschriften'. Then the French indications '(Rouge)' to '(Bleu)' were added for the publication in Astronomische Abhandlungen. One printed copy of this version was used to colour the Weimar spectrum. Finally, all the indications were, more or less, driven out of the plate, probably by hammering from the back side. From this version we got the spectrum PL. But we don't know if the colouring of the Munich and Weimar spectra happened in the same chronological order.

[46] J.F.W. Herschel, 'On the Theory of Light', in *Encyclopaedia metropolitana,* 4 (1828), 341–586, 410. M.v. Rohr (several archival material in respect to Fraunhofer), *Zeitschrift für Instrumentenkunde, Beilage Forschungen zur Geschichte der Optik*, 1 (1928–1935), 2–6. M.W. Jackson (note 8), 124, 125.

The Weimar spectrum definitely came to Weimar in the year 1827. It also seems probable, that other coloured spectra existed around this time. But we are unable to date the two Munich spectra.

What was the intention of those coloured copies? Possibly, they were to impress immediately not only Fraunhofer's visitors (often there was no chance to demonstrate a solar spectrum by direct observation), but mainly the members of the Mathematical-Physical Class of the Bavarian Academy of Sciences. They were not specialists, except the astronomer Soldner and the physicist (and jurist) Julius Conrad Yelin. They could be easily impressed - for example, as Sömmering and Goethe were. And similar enthusiasm in the Academy started later on about Fraunhofer's diffraction work. The engineer Franz von Baader, said enthusiastically after Fraunhofer's lecture about his diffraction work: 'It is beautiful, to distribute ((verbreiten)) so much light about light'.[47]

But also his business partners and scientific friends and opticians in Munich could have been targets for the coloured copies, where the exact position of so many lines was exposed in an extraordinary visually impressing way. (From 1814 to 1819 Fraunhofer and the entrepreneur Joseph Utzschneider were the only owners of the optical institute in Benediktbeuern.[48])

Was Fraunhofer himself influenced by aesthetic interests? He had been apprenticed for five and a half years as a 'grinder of ornaments in glass' (Glas-Zieraten-Schleifer), and for a shorter time as an assistant to his master. He developed some fine abilities in craftwork of this kind. He also had tried to become an independent entrepreneur by producing copper plates and calling cards. Therefore he was able, and it was a pleasure for him, to etch more than 350 fine lines. But he had not learned to produce coloured paintings. Therefore he, very probably, employed other specialists, as he did for the shading of his black and white etches in 1817.

Perhaps his method of examining the exact form of optical lenses (coloured Newton rings between a master lens and the examined one), had prepared his mind for the discovery of solar lines as an autonomous phenomenon.

About his later diffraction work we hear that he needed a very long a time to produce the copper plates for the very impressive pictures of his experiments: 'He needs two years, to get ready with the pictures on copper, two plates are almost finished.'[49]

Despite Fraunhofer describing his experiments and observations without almost any personal emotion, we find, in his first diffraction publication 1821/22, enthusiasm for the 'beauty' of this phenomenon. As far as the diffraction pattern of a grid with large numbers of quadratic holes is concerned (which he produced by crossing two line grids) he wrote that this is 'one of the most beautiful optical phenomena' (Figure 3).[50]

At the end of this publication he believed — still hesitantly — that the new wave theory of light could be used to explain the results. This was a new visual world,

[47] E. Voit, 'Joseph von Fraunhofer', *Bayerisches Industrie- und Gewerbeblatt* (1887), no. 3, 140–60, p. 158. See also H.-P. Sang, *Joseph von Fraunhofer* (München, 1987), 122.

[48] M.v. Rohr, *Joseph Fraunhofers Leben, Leistungen und Wirksamkeit* (Leipzig,1929), 154.

[49] E. Voit (note 47),159. H.-P. Sang (note 47).

[50] J. Fraunhofer, 'Neue Modifikation des Lichtes durch gegenseitige Einwirkung und Beugung der Strahlen, und Gesetze derselben', *Denkschriften der Bayerischen Akademie der Wissenschaften,* 8 (1821), *Classe der Mathematik und Naturwissenschaften*, 1–76, 70.

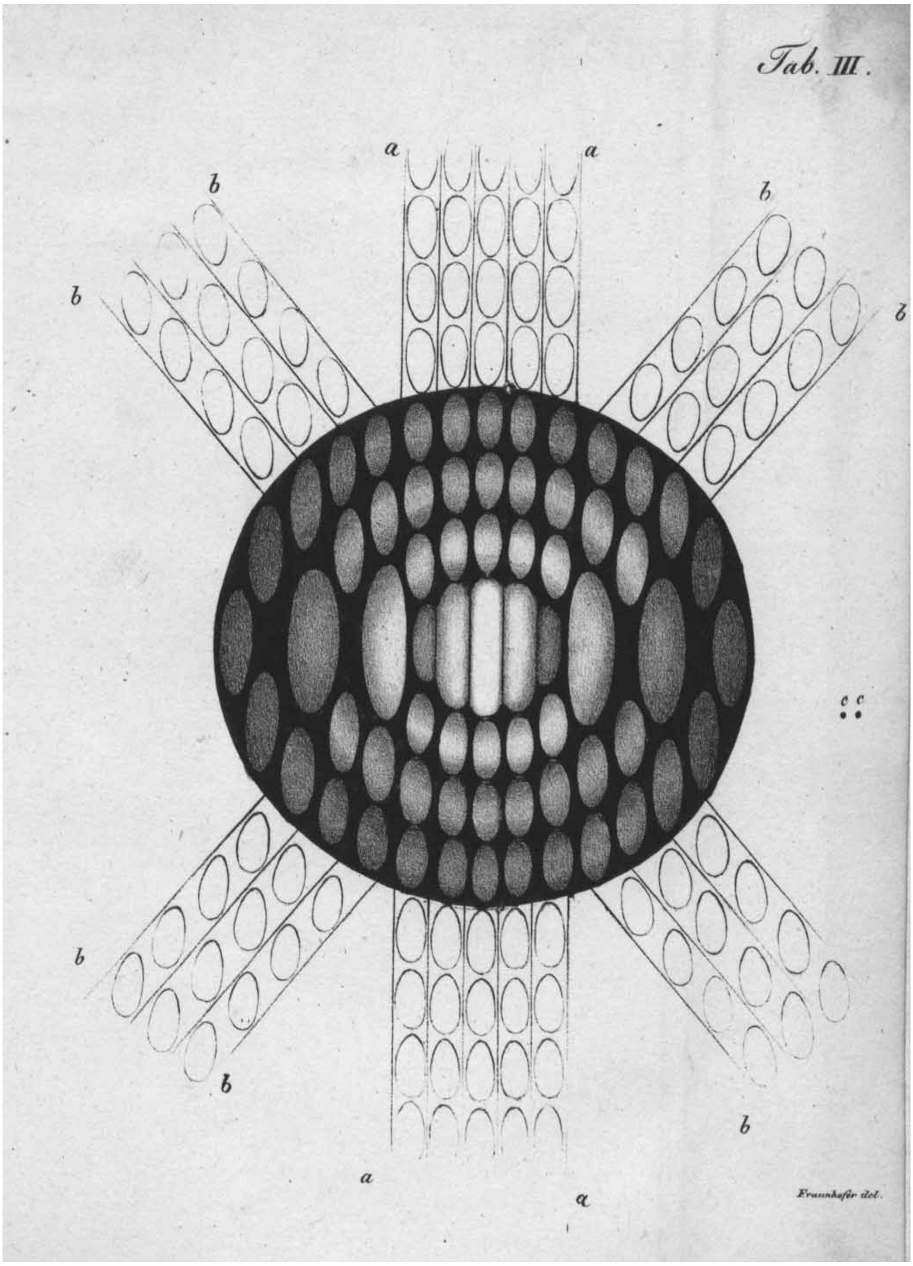

Figure 3. Illustration by Joseph Fraunhofer, showing interference patterns by two holes (Denkschriften from 1821, note 50).

which only a few scientists at this time had adopted. He is even sure that the lines of his solar spectrum can also be explained by wave principles (perhaps even as any complicated kind of diffraction at the slit edges?). This is surprising. In 1817 he was just convinced, by experiments, that his lines could not be the result of any disturbances produced by instrumental effects: A few fixed stars, which were observable without a slit, showed lines. A slit and a hole showed the same lines in the solar spectrum.

In a next diffraction publication, in 1823, this independence of instrumental effects seems again to be the basis for his thinking. There is no mention made anymore of lines based on possible wave patterns.[51] The short remark of 1821/22 may show how surprised also the optician Fraunhofer was about this new scientific world. In general, the landscape of dark lines looked totally strange and did not appeal to his habit of thinking quantitatively.

Perhaps, by using coloured etchings he wanted to neutralize the impression of total irregularity and chaos - at least for others.[52] This irregularity certainly was the main reason why the scientific community did not accept the new cosmic landscape. As late as 1847, textbooks still wrote about the 'great irregularity' and 'confusion' of these lines. The chaotic plurality of lines did not allow any analogy to be made with known orders, though there were unsuccessful attempts to find mathematical rules for the line sequences. Thomas Young, for example, discussed this with John Herschel.[53] This irregularity made it easy for many to interpret them as instrumental errors, perhaps disturbances in the earth's atmosphere,

Immediately after Fraunhofer the question remained open whether light from different sources and, particularly, light from different fixed stars, was equally refracted. This problem then led to further observations of spectra of fixed stars by Fraunhofer and Soldner, in 1819/20.[54]

Fraunhofer's painstaking etching of more than 350 lines in his coloured spectrum strongly suggests that he accepted them as an independent optical phenomenon, beyond his technical interests. He underlined the importance of these lines for further research by 'competent natural philosophers'. That he accepted the impression as an independent image, we also may conclude from the importance gained by this picture - in black and white - in his publication of 1817.He was also interested in this phenomenon in further publications and in his unpublished notes.

It is very probable, that the workaholic Fraunhofer would have done more optical research besides - or instead of - his workshop duties, had he not died so young. This we can conclude from his scientific publications in the years immediately before his death in 1826 and from his last will, drafted shortly before his death, to transfer the optical workshops to the Bavarian state. The state was interested, because the instruments meanwhile had gained international reputation. By this transfer Fraunhofer hoped to gain more freedom for his personal work. That he was really interested in basic research, we can confirm based on a letter to Chladni from January 1823. There, Fraunhofer mentions his experiments about diffraction and about the 'refraction of star light'. The instruments for these experiments would consume a lot of time and money. Therefore:

> . . . you have to earn money in another way, before you can use it for researches, which yield nothing. So far I live in relationships, which allow me to follow up

[51] J. Fraunhofer, 'Kurzer Bericht von den Resultaten neuerer Versuche über die Gesetze des Lichtes und die Theorie derselben', *Annalen der Physik,* 74 (1823), 337–78.

[52] In respect to irregularity see e.g. J.F.W. Herschel in M.A. Sutton, 'Sir John Herschel and the Development of Spectroscopy in Britain', *The British Journal for the History of Science,* 7 (1974), 42–60, 47. This is a comment about spectra of fixed stars.

[53] F.A.J.L. James 1981 (note 7), 40–3. See also Th. Young, 'Théorie des couleurs observées dans les expériences de Fraunhofer', in: *Annales de Chimie et de Physique,* 40 (1829), 178–83.

[54] Published in 1823, as appendix to J. Fraunhofer (note 51). Letter by J.G. Soldner to Carl Friedrich Gauß, March 23,1820, in F.J. Müller, *Johann Georg von Soldner, der Geodät* (München, 1915), 126–128.

> these experiments, I will continue with them. This field seems to become more extensive the further you work in it.[55]

In Fraunhofer's manuscripts we also find further research about the solar spectrum. For example, he believed that the double line D is possibly split in four lines. He thought that in principle changes within several years would be possible and recommends further research. Maybe he had seen some weaker lines, which were not printed before Gustav Robert Kirchhoff's solar spectrum of 1861.[56]

In the year 1821 Fraunhofer became 'extraordinary visiting' member of the Bavarian Academy of Sciences - despite that there had been strong opposition.[57] He soon adjusted to this scientific appointment. Based on his diffraction work he, as an optician acquainted with astronomy, found a way to do basic physical research. That is, the brand new and still controversial wave theory of light, where he, for example, intensively studied the work of Augustin Fresnel.[58] To change from astronomy to physics was unusual at this time, and even considered heretical. He chose a new but not yet accepted field in physics, whose 'beauty' he liked, and which also allowed him to experiment with line spectra. From a retrospective view it is very probable, that he would have dared to explore this field further.

Fraunhofer's hand-coloured spectra themselves are new scientific objects, crossing the boundary to a new visual world in the sky, which also could be seen in an aesthetic way. The spectra gain an aura, which goes far beyond the immediate scientific importance as an optical problem - and of course beyond the technical use of some lines in it. These hand-coloured spectra are symbols of a new code, a new language, a new landscape of the sciences.

4. William Hyde Wollaston's dark borders of colours from 1802

Wollaston's etching from 1802 has to be interpreted in a different context than Fraunhofer's solar spectrum from 1817.

Wollaston was a medical doctor, but changed to chemistry in 1800. By producing pure platinum he gained great wealth. At the same time he was interested in optics and optical technology.[59] In his publication of 1802[60] he was measuring refractive indices of colours in different substances, by a new and innovative method (integrating total reflection), taken mainly in fluids like oil and acids, because this he saw as useful for many 'philosophical inquiries', for example, 'for discovering the purity of essential oils'. He used a slit and a prism, made by glass plates and filled

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[55] Fraunhofer Papers. Staatsbibliothek Preußischer Kulturbesitz, Berlin. Box 3, correspondence. Letter to Chladni, January 19, 1923. Similarly also in his petition to the king of Bavaria, to get a honorary job, July 8, 1823.

[56] Fraunhofer papers (note 55), Box 2, March 14, 1819. M.v. Rohr (note 48), 59–61. G.R. Kirchhoff, 'Untersuchungen über das Sonnenspektrum und die Spektren der chemischen Elemente', *Abhandlungen der Königlichen Akademie der Wissenschaften Berlin* (1862), 63–95, plate 1.

[57] Fraunhofer Papers, Bayerische Akademie der Wissenschaften, archive, around 1817.

[58] H.-P. Sang (note 47), 91. See also Fraunhofer Papers (note 55), box 5. Also Thomas Young is cited by Fraunhofer. J. Fraunhofer, (note 50), 75 (footnote).

[59] D.C. Goodman, 'William Hyde Wollaston', in *Dictionary of Scientific Biography* (New York, 1970–80, 1990), vol. 14, 486–94. M.C. Usselmann, 'William Hyde Wollaston', in *New Dictionary of Scientific Biography* (New York, 2008), vol. 7, 342–5. There is no elaborate secondary literature about the optical work of Wollaston.

[60] W.H. Wollaston, 'A Method of Examining Refractive and Dispersive Powers, by Prismatic Reflection', *Philosophical Transactions of the Royal Society of London,* 92 (1802), 365–80.

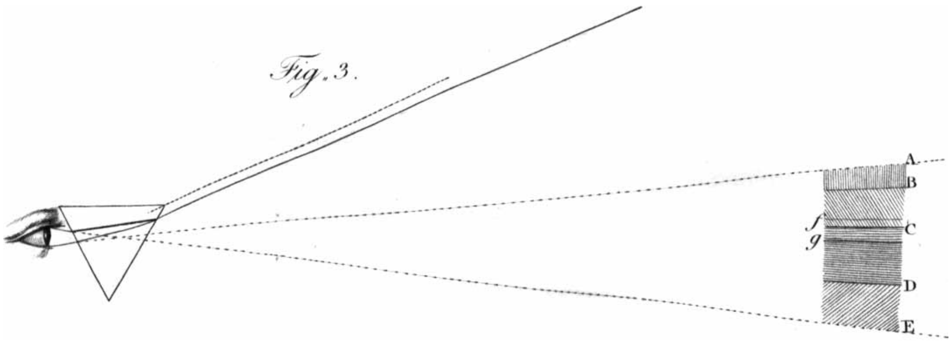

Figure 4. William Hyde Wollaston's dark solar lines as borders of his four basic colours (Philosophical Transactions 1802, note 60).

with a fluid, to split up the solar light. Only at the end of his publication does he change from this quantitative work to a principal topic of 18th century physics, namely to colour theory. An essential question at this time was connected to the number of basic colours in the solar spectrum. Newton had identified seven. Others, as Wollaston reported, found only three colours. Wollaston believed, contrary to Newton and others that he could see four, namely 'red, yellowish green, blue and violet'. For these observations he now used a glass prism 'free of veins', and a slit. Contrary to Fraunhofer later on he is observing with his naked eye. He is the first to find seven 'dark lines' in the spectrum, and interprets five of them as borders of his four colours (Figure 4). He concedes that there are two paler dark lines within the colours. This would in principle have weakened his thesis of the stronger ones constituting the borders. But he does not discuss this result. He draws the dark line C as a strong line, between yellowish green, despite the fact that in the text just mentioned he finds it 'not as clearly marked as the rest'.The two border lines A and E of the whole spectrum are the only ones so stippled (as part of the lines of the cone of view), despite the fact that in the text E is referred to as 'perfectly distinct', contrary to A. This demonstrates that he did not support his border thesis very profoundly. That matches with his drawing of what he saw as the less visible lines of f and g. It is possible that these lower-case characters mark a secondary effect.

In addition, he mentions that beyond the border of red there exists the region of invisible rays of heat (modern infrared radiation) and beyond violet the region of likewise invisible rays, which are detectable by chemical effects (modern ultraviolet radiation).[61]

We don't know of any coloured drawings by him. Also the existing black and white drawing has no prominent place within the other sketches of his article - not by its visual composition, nor by its magnitude. There is no other commentary contrary to the published black and white etching of Fraunhofer of 1817. Wollaston's drawing looks more neutral - seen from an aesthetic point of view. It does not gain a distinct life of its own within this article, and we find no further research work of Wollaston. In the following years, so far as optics is concerned, he turns more to physical/technical but also to physiological/technical topics.

[61] W.H. Wollaston (note 60), 379,380. Fraunhofer does not mention ultraviolet or infrared rays. Spectral lines in these parts of the spectrum were not examined before the 1840s. J.B. Hearnshaw (note 7), 34–5.

When discussing his discovery in 1802 he does not try to explain or describe the unknown side of this phenomenon, which could have suggested further research. For him it seems to be sufficient to order these few dark lines in a seemingly clear pattern of explanation, but only as a continuation of actual debates about colour theory. He also looks briefly at two other kinds of spectra. He observes that candle light does not appear in 'a series of lights of different hues contiguous' like the solar spectrum. It seems to be 'divided into five images, at a distance from each other'. This is the first detailed observation of an emission spectrum. The first image is red 'terminated by a bright line of yellow'. (Thomas Melvill, 1752, was the first scientist to see this yellow line. In addition, Fraunhofer later on found it and noted that his dark line D in the solar spectrum lies exactly at the same place.) The word 'terminated' reminds us of his dark border lines in the solar spectrum. Then he finds two green and two blue images. The last of these would 'correspond' to his 'division of blue and violet' in the solar spectrum. With 'electric light' he also finds several images but gives no further description or interpretation.

His thesis about the four basic colours in the solar light apparently was not made dubious by these observations. At the end of his article his resigned conclusion may be directly related to his electric light experiments:

> It is, however, needless, to describe minutely, appearances which vary according to the brilliancy of the light, and which I cannot undertake to explain.[62]

On the other hand, his spectrum is not a simple technical sketch, as were the other two sketches examined before (about the building up of his experiments to measure refractive indices). For example, the slit is missing. The naked eye of the observer - as the only instrument of registration - accentuates the emotional impression of all that and brings it near to the vision based on a relaxed view of a rainbow.

In contrast to Wollaston, Fraunhofer only referred indirectly to the human eye, by his measured curve of colour sensitivity, and approximately by the shading of colours (or of his black and white etchings) to the left and right.

Certainly, Wollaston would have coloured his sketch, if this had been easy and practicable for journals of that time. But he would have coloured his four basic colour blocks evenly, and not change in a continuous gradation, as direct observation would suggest. This can also be inferred from his constantly scratching out the uncoloured blocks. They are clearly meant to be separated from another. This missing gradation was criticized by John Herschel in 1828 (as already mentioned). The strict separation of these blocks emphasizes the function of his five dark lines as borders to the colours.

Wollaston does not present us with a new landscape that deserved to be explored. What he presents is more a conception - converted into an image - about the arrangement of colours in the solar spectrum by an innovative experimental physicist/chemist. Most scientists at this time did not argue for any continuous gradation of colours in the sun's spectrum.[63] Wollaston was convinced that he introduced by his experiment a more exact order that allowed for better observation. His etching illustrates this thesis. But it also suggests by its unique standing of a graphical description, including the non-border lines f and g, that Wollaston hid

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[62] W.H. Wollaston (note 60), 380.

[63] K. Hentschel (note 1), 579,580. See also O.F. Mosotti, 'Ueber die Fraunhofer'schen Gitterspectra und Analyse des Lichtes derselben', *Annalen der Physik,* 148 (1847), 509–29.

more in this etching. That is, it showed his astonishment having discovered a possible new world of knowledge. This we also may infer from his resignation to the plurality of phenomena of other spectra.

At the Deutsches Museum in Munich, one of the authors (J.T.) tried to reproduce Wollaston's results, but with a modern prism, which, surely, was too perfect. Different parameters were varied for the reproduction, also projection and direct observation by the naked eye. We also changed to a simple cheap pocket spectroscope. This way it was possible, in a limited way, to get a spectral impression, which allowed one to notice a few visible dark lines seen as borders for colours. The (almost) disappearance of yellow and Wollaston's clear blocks of red and yellowish green were clear to see, including a dark line perceivable as a border between these two colours. Two lines, left and right from the border between green and blue, look stronger than those Wollaston described in his article as the - apparently corresponding - lines f and g. They may correspond to the Fraunhofer line F and to the next stronger line within the colour blue. We saw no dark region as a separating line between green and blue. But Wollaston wanted to see his borders! The direct observation, with his naked eye immediately behind the prism, the relatively large width of the slit of 1.2 mm (1/20 inch), the bad quality of his glass prism, all facilitated his interpretation.

5. Johann Lamont and his observation of spectra of fixed stars, 1836

The sketches of Johann Lamont are the first drawings of spectra of fixed stars in history. They also remain the only successful observations in this field between Fraunhofer in 1821 and the beginning of astronomical spectral analysis in 1860, except for the short discussion of Amici in Humboldt's 'Kosmos' (see before) and some other short remarks.[64] Fraunhofer had already described spectra of fixed stars in his publication of 1817 (see before). However, these were only random notes. The main intention was to prove that the solar lines really were characteristic of solar light (also valid for the reflected planetary light). Indeed spectra of fixed stars clearly showed different lines. In 1819/20 he observed more carefully some fixed stars, together with Soldner, using a refractor of a larger aperture. He measured the lines of Sirius very exactly and found the localisation of four lines, the later so called Balmer series of hydrogen, relating to the place of his D line of the light from Venus. The maximum deviation was only 0.6% (in relation to the whole angle of reflection) compared to modern values.[65] Some short remarks, such as 'Betelgeuze may be similar to the solar light' prove that Fraunhofer began to be interested in a physics of stars.[66] He does not draw any sketches of star spectra, but gives detailed descriptions of his observations in his preserved manuscripts. He also published some of this observation in 1823 - but only in a short addendum. There he ends with the note that he considers these 'attempts . . . . . . only as a beginning'.[67]

[64] A.v. Humboldt (note 6), vol. 3, 63. H. Kayser (note 7),17. Kayser cites D. Brewster 1833, who only mentions lines in *'some of the fixed stars'* parallel to the *'deficient lines of Fraunhofer'* in the solar spectrum. J.B. Hearnshaw (note 7), 51, 52 about a short remark by Joseph Wilson Swan from the year 1856. Also William Henry Fox Talbot mentions spectra of fixed stars, in 1826. F.A.J.L. James 1981 (note 7), 37.

[65] R. Häfner and R. Riekher,(note 1),149. See also R. Riekher, 'Fraunhofer und der Beginn der Astrospektroskopie', *Sitzungsberichte der Leibniz-Sozietät der Wissenschaften, Berlin*, 103 (2009), 95–113, 102f.

[66] Fraunhofer papers (note 55). Box 2, *'Tagebuch für die physisch-optischen Versuche von Febr.1819 bis[April 1820]'*. Here March 30, 1820. Cited also by R. Häfner and R. Riekher (note 1), 148.

[67] J. Fraunhofer (note 51), 374–378.

John Lamont was born at Corriemulzie near Braemar, Aberdeenshire, Scotland. When he was only twelve years old he was sent to be educated at Regensburg, Bavaria and never saw Scotland again. In 1835 Johann Lamont was appointed director of the observatory of the Bavarian Academy of Sciences at Bogenhausen (today part of Munich), as successor to Soldner. Exactly in the same year the observatory acquired what was then the world's best telescope, a refractor, of which the (parallax) mounting was still the one Fraunhofer had designed. Also the glass from which the objective lenses of 28 cm aperture were ground and polished, had been melted under the supervision of Fraunhofer. The wealth of mechanical and optical ideas of Lamont is generally remarkable. To explore spectra of fixed stars, in addition to Fraunhofers cylindrical lens placed before the objective lenses, he installed a prism near the ocular. Fraunhofer in contrast had installed a prism before the objective lenses.

With his excellent apparatus he obtained spectra of fixed stars up to the 4th magnitude, and within five nights of observation in the year 1836. Fraunhofer's instruments from 1819/20 were able to find the spectra of only first magnitude stars. Lamont was fascinated by his new telescope, which allowed a comfortable 'hike through half the sky without leaving his seat'. He now starts to 'hike' using a new celestial landscape. And he denotes its topography of lines, intensity of colours and different brightness (of the spectral parts):

> I restrict myself to mentioning only that even for stars of the 4th magnitude I got a very intensive spectrum, in which several dark lines were identifiable with great clarity; in any way the exploration, which shall be continued, will embrace, in addition to the measuring of the dark lines, also the intensity of the different colours of the spectrum or the quantity of the colouring light.[68]

He wanted mainly to find out, if the difference in colours, which some components in double star systems present, were real or not. Perhaps Humboldt knew of these observations and confused Amici with Lamont, when mentioning in 1851 that, along with Fraunhofer and Amici, fixed stars possess different spectra?

It is a pity that Lamont did not continue with these observations, contrary to his announcement in 1838. Even the published remarks by him were only an appendix to an article about a different topic, namely planets. On the other hand, this article shows that Lamont at this time was strongly interested in the physical properties of celestial bodies. This interest forced him to explore light information more intensively using the reflected light by planets.

In his unpublished observatory notebooks we find richer and more accurate descriptions of his star observations, and some more exact measurements of line positions using a micrometer and sketches of spectra. These sketches and his remarks about them prove, more than his micrometer measurements, the unusual visual impression which hindered each orientation within this new pictorial world because of the wealth of details, which his instruments produced: 'very strange', 'lines clearly', 'totally uncertain', 'lines almost not visible', 'greenish blue, in the spectrum red almost not visible', 'a visible, b not' (Figure 5).[69]

[68] J. Lamont, 'Ueber die Anordnung und physische Beschaffenheit der Planeten', *Jahrbuch der Königlichen Sternwarte bei München,* 1 (1838), 175–202, footnote 190/191.

[69] R. Häfner and R. Riekher (note 1),155, 156. Lamont observed between July 14 and October 31, 1836.

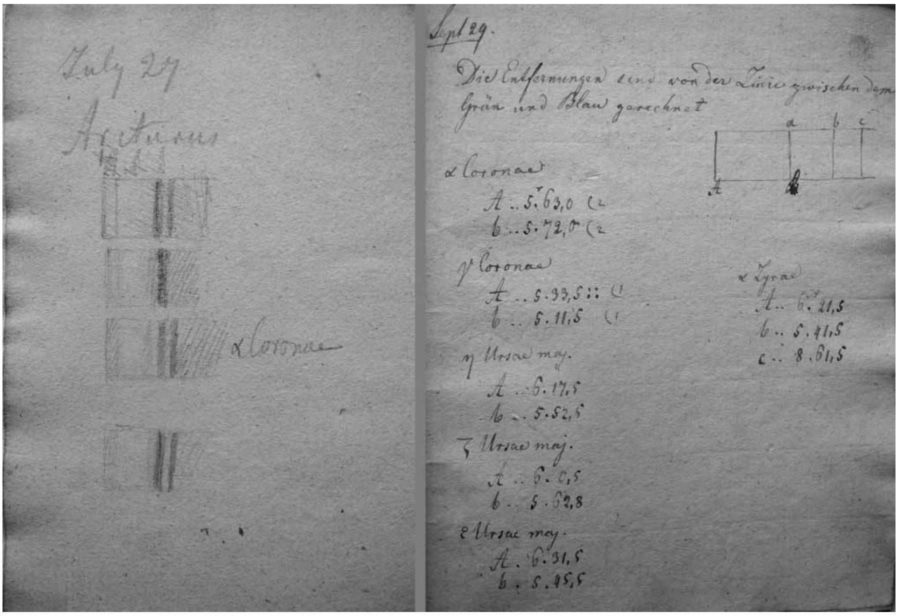

Figure 5. Sketches of star spectra by Johann Lamont (unpublished observatory note books 1836, note 69).

(The two lines a and b by Fraunhofer in 1817 are not the same ones as those Lamont here indicated.) We see in his description and in his sketches that Lamont alternates between being an exact astronomer (who works in positions, here positions of lines) and working in a new research perspective, which accepts individual pictorial constellations that cannot be explained any further. As far as this is concerned, his remarks, like 'very strange', remain unspecific. He doesn't go into details, such as giving descriptions of line groups. A comparison with Fraunhofer's solar spectrum would have stimulated such pictorial descriptions. On the other hand, his interest in 'measuring . . . the dark lines' and in exploring the 'intensity' of the different colours confirms that he had accepted lines, parallel to colours, as independent objects of research.

Why did he not continue these observations? Independent of any physical/chemical explanation they could have constituted a program of research, up to the first classification of stars. This program could have been pursued in parallel to programs of positional astronomy, which had just started to formulate the astronomy of the middle of 19th century.

Still, further research would have been possible. With his excellent refractor in Bogenhausen, Lamont could have discovered, in the 1830s, that cosmic nebulae (at first the so called planetary nebulae) don't emit continuous spectra with dark lines, but only a few bright lines, similar to flame spectra on earth. These few bright lines would have convinced all or most astronomers interested in nebulae that these objects are really extended and glowing material of gas and not clusters of stars, in spite of the confusion between dark and bright lines in spectra. This confusion was clarified much later, from 1859 on. Indeed, the question was one of the big riddles of astronomy since the 18th century: Did nebulae consist of extended gas material or of single stars?[70] Despite the primacy of positional astronomy, more and more scientists in the 19th century tried to answer this question. On the other hand, some few bright lines in spectra of nebulae would have very probably accelerated the development of spectral analysis, just because they offered such similarity to flame spectra on earth. The first to observe these bright lines was William Huggins, 1864, observing planetary nebulae with an 8 inch-refractor.[71] Lamont's telescope with slightly more than an 11 inch aperture was superior. And Lamont, with his large tacit knowledge in optical technology, would have also changed successfully the spectroscopic apparatus for such diffuse light information.

We know that Lamont conducted research on nebulae in the years 1835–37(and talked about it in a public lecture during a celebration of the Bavarian Academy of Sciences, on 25.8.1837).[72] But he was unable to bridge the gap between this research and the strange landscape of star spectra. He abandoned his nebulae observations, and declared more than 30 years later, 'because I was convinced, that we can consider all spots of nebulae as very distant clusters of stars, and we can only expect observable changes in very big spaces of time.'[73] From this we see that his actual interest had been to discover cosmic changes. But what he declares so much later could not be true. In the 1830ies he concluded, by accurate argumentation, that not all nebulae can be composed of stars. Does that suggest that he gave up his nebulae research, because of other reasons?

For a long time after Fraunhofer's death, Munich offered little motivation for innovative research. The successors of Fraunhofer at the optical institute had lost scientific interest. The relevant scientists at Munich University were not of first rank. (The University had been moved to Munich in 1826, from the small country town of Landshut)[74] The growing importance of positional astronomy made such a new pictorial world seem only of secondary importance. After the discovery of the planet Neptune in 1846, which was the most famous event in celestial mechanics and positional astronomy in the 19th century, Lamont became angry with himself for not having discovered the planet himself. He actually did observe this light point before 1846, but failed to notice that it moved among the fixed stars. A radical change of his research in the 1830s proves that external acceptance, chances of communication and absorption in broad basic research substantially decided the direction of his scientific life. He later remarked about this change that it is necessary to concentrate at any time on a specific object of research, so as not to splinter one's creative forces.

[70] W. Steinicke, *Nebel und Sternhaufen. Geschichte ihrer Entdeckung, Beobachtung und Katalogisierung - von Herschel bis Dreyers 'New General Catalogue'* (Norderstedt, 2009). R.F. Hirsh, 'The Riddle of the Gaseous Nebulae', *Isis,* 70 (1979), 197–212. Hirsh starts the story, but not before 1864.

[71] W. Huggins and W. H. Miller, 'On the spectra of some of the fixed stars', *Philosophical Transactions of the Royal Society of London,* 154 (1864), 413–435. B. Becker, *Unravelling starlight. William and Margaret Huggins and the rise of the new astronomy* (New York, 2011).

[72] J. Lamont, *Ueber die Nebelflecken* (München,1837). His observations of 32 nebulae were not published until 1869. See W. Steinicke (note 75),104. R. Häfner and H. Soffel (eds), *Johann von Lamont. Festschrift anlässlich seines 200. Geburtstages* (München, 2006), 34. There is no further secondary literature about the astronomical research of Lamont.

[73] W. Steinicke (note 70),109.

[74] W. Leibbrand, 'Gruithuisen,Franz von Paula', in: *Neue Deutsche Biographie,* 7 (1966), 210. H. Uebele: *Mathematiker und Physiker aus der ersten Zeit der Münchner Universität. Johann Leonhard Späth, Thaddäus Siber und ihre Fachkollegen* (unpublished PhD thesis, Ludwig-Maximilians-University of München, 1971).

He had decided to switch to geomagnetic research. This kind of research quickly gained international reputation, especially when it was stimulated by Alexander von Humboldt, Carl Friedrich Gauss and others from 1834 on. Lamont joined this research in 1836 and secured for himself an important place in the history of geophysics.[75] Lamont once again mentioned the dark lines in star spectra, in 1851, but after 1859 we cannot find any more comments or references by him about his former spectral observations - with one exception. To the Italian astronomer Giovanni Battista Donati - successor to Amici - he sent a copy of the Yearbook of the Royal Observatory Munich for the year 1838, which included his appendix about star spectra. In his accompanying letter he noted that for these observations very fortunate conditions are necessary, which are seldom available in his 'climate'. Therefore he had decided to leave the research on this 'important object' to those, who are happier in this respect.[76] This looks more like an aperçu, if one reflects on his reasons for choosing geophysics as his main research topic. The 'climate' could not have been the sole reason for abandoning his spectral research. (Of course the weather conditions have more influence on star spectroscopy than on solar research.) Around 1850, Lamont allowed an outsider, the teacher of mathematics and physics, Karl Kuhn, to explore the solar spectrum at the Bogenhausen observatory. Occasionally, he cooperated with him and gave advice.[77] We know that in Great Britain after 1859, the rise of astrophysics was mainly influenced by outsiders. But in Germany there was no such culture of prosperous and independent non-professionals.[78]

6. Landscape and spectral landscape

In the work of Alexander von Humboldt we don't find any clear definition of the concept of landscape,[79] in spite of the fact that the modern geographical concept was attributed to him. He does, however, provide a short history of the concept of landscape in his "Kosmos". In Greek-Roman antiquity landscape painting was not an 'independent object of art'. Poetic description of scenery and landscape painting were only used as 'accessories'. What was attractive, was 'almost exclusively the agreeably habitable and not what we call the wild and romantic.'

'We first meet with a careful elaboration of the landscape portion of the picture' in the Netherlands, in the 15th century. But the 'greatest epoch' is the 17th century. Nevertheless, he believed that 'landscape painting may hereafter blossom with new and yet unknown beauty', if 'highly gifted artists' see the world by travelling.[80] 'Variety which is a chief merit in the natural landscape, must be sought . . . Symmetry is wearisome.'[81]

His words 'wild and romantic' point to a fundamental change of landscape painting that occurred after about 1800. We will talk more about this later.

[75] R. Häfner and H. Soffel (note 72), 65.
[76] G.B. Donati, 'Intorno alle strie degli spettri stellari', *Il Nuovo Cimento,* 15 (1862), 292–304, 295, 296 footnote.
[77] R. Häfner and H. Soffel (note 72), 7.
[78] Schaffer (note 10), 278, 279.
[79] See also http://www.zeno.org 'Landschaft'. R. Gruenter, 'Landschaft - Bemerkungen zur Wort- und Bedeutungsgeschichte', in A. Ritter (ed.), *Landschaft und Raum in der Erzählkunst* (Darmstadt, 1975), 192–207.
[80] Humboldt-Sabine, Cosmos (note 6), vol. 2, 74, 77, 78. On the history of the concept of landscape see also note 79.
[81] Humboldt-Sabine, Kosmos (note 6), vol. 2, 97.

Humboldt was strongly influenced by the philosophical ideas of the poet Friedrich Schiller, whom he met in 1794.[82] He thanked him for two things,[83]

- the historical and philosophical establishment of the high interest in sentiment (Gefühlsinteresse) of modern man in nature,
- a poetics of landscape as a specific modern genre, in which landscape will become 'the hero of the description'. Man in contrast will become only a marginal figure, whose subjective feeling, however, makes the objects of nature meaningful, which exist around him.

Landscape is essentially understood 'as a representation of subjective impression or a representation of ideas', be it through poetry or painting. The empirically observable part of nature offers only 'matter without soul', is only ordinary nature.

In this respect Schiller and Humboldt were still closely connected. Schiller, however, ultimately was not interested in the study of nature but in the study of man's soul. Here their world views drifted apart. Well known is Schiller's 1797 polemic verdict about Humboldt where he criticized him as possessing a 'naked and sharp cutting intellect'.[84]

Humboldt, with his attempt to integrate aesthetics and science moved nearer to the concepts of Goethe, integrating and embracing aesthetical treatment and detailed scientific observation. For Goethe a landscape painter had to be in addition to his talents a botanist.

Humboldt 1808, in his 'Aspects of Nature' (Ansichten der Natur)[85] still separated his broad poetically described 'painting of nature' (Naturgemälde) from his scientific explanations. This early 'aesthetical treatment of natural objects' is emphasized in Schiller's tradition. But the scientific explanations were developed and finalised in the third edition of 'Aspects' in 1849. In his Kosmos he tried to integrate these two ideas. This holistic ideal also came partly from the theories of the contemporary landscape painters. The 'total impression of a scenery' (Totaleindruck einer Gegend) became the decisive base for his description of nature. He argued that the physiognomy[86] of an area created the landscape. The observation and the contemplation of this entity set the 'aesthetically-seeing' natural philosopher apart from a 'botanic taxonomist'. This way he combined Schiller's radical asthetic requirements and Goethe's scientific conditions.

As we discussed at the beginning of this article, Humboldt's use of the concept of landscape does not clearly differentiate between an analogical transfer of morphological thinking into astronomy and geophysics and the metaphorical creation of images of sensory impressions.[87]

[82] B. Hey'l, *Das Ganze der Natur und die Differenzierung des Wissens. Alexander von Humboldt als Schriftsteller* (Berlin, 2007), 132.

[83] J. Robert, 'Weltgemälde und Totalansicht. Ästhetische Naturerkenntnis und Poetik der Landschaft bei Schiller und Alexander von Humboldt', in H. Feger, H.R. Brittnacher (eds), *Die Realität der Idealisten. Friedrich Schiller, Wilhelm von Humboldt, Alexander von Humboldt* (Köln, 2008), 35–52, 38f. The quotations are taken from W. Busch (ed.), Landschaftsmalerei (Berlin, 1997), 227–30. He cited Schillers review '*Ueber Matthissons Gedichte*' from 1794.

[84] I. Schwarz, ' "Ein beschränkter Verstandesmensch ohne Einbildungskraft." Anmerkungen zu Friedrich Schillers Urteil über Alexander von Humboldt' *HiN, Alexander von Humboldt im Netz - International Review for Humboldtian Studies*, IV, 6 (2003).

[85] A.v. Humboldt, *Ansichten der Natur* (Tübingen, 1808).

[86] A. Graczyk, *Das literarische Tableau zwischen Kunst und Wissenschaft* (München, 2004), 300–5.

[87] See also L. Daston, 'The Humboldtian gaze', in M. Epple, C. Zittel (eds), *Science as cultural practice* (Berlin, 2010), 45–60, 45. Humboldt used 'a way of seeing that was at once morphological and numerical, asthetic and scientific, local and global.'

In his 'Aspects' Humboldt transfers physiognomic methodology to the world of plants. In a similar way he sees the world of stars, which seems to exist as a static entity, as an analogy to a forest, where all the stages of growth take place. The crafting of the concept of 'Weltgarten', on the other hand, is to be understood in a metaphorical sense. But he used the principle of morphogenesis as an essential strategy for description. The concept of view of nature (Naturanblick) he uses synonymously with landscape, whether it is concerned with heavenly spaces or scenes on earth.

Humboldt's 'seeing' (Anschauung) is also influenced essentially by the 'landscape-aesthetical seeing and speaking of the books of artists (Malerbücher) and the theoretical literature of art of the late 18th and the middle of the 19th century'.[88] The term landscape was used in the literature of the 18th century mostly for the painted landscape, and seldom for the description of nature. In the latter case the term was rather understood in a metaphoric sense. For Humboldt landscape is still an 'aesthetic, pre-scientific phenomenon', in relation to 'sentiments'. But this is perhaps a too narrow an interpretation. Landscape is understood by Humboldt as an 'impetus to the study of nature'.[89] Humboldt's 'Aspects of Nature' (Ansichten der Natur) also demonstrates in its title the double meaning of objective scientific representation and subjective artistic design of landscape.[90] In his chapter about nebulae we see this double meaning is also valid for phenomena, which are only seen by telescope.[91]

Landscapes for Humboldt were generated in a twofold way: first, by the successive experience of an imaginary wanderer. In this form, we can say, Johann Lamont contemplated the sky. The second sight was generated by pausing for a moment at exceptionally touching impressions of nature. This way of looking at nature we can attribute mainly to Wollaston's and Fraunhofer's relation to a new pictorial world.

But the 'magic of the world of senses' (Zauber der Sinnenwelt), the 'Anschauung' of the landscape was only the first step towards knowledge for Humboldt. 'Sentiments' and 'ideas' were stimulated by this first step. But the more profound enjoyment of nature did not occur until rational thinking opened up the 'causal connection' of phenomena.

Humboldt was also educated in drawing. When travelling in foreign landscapes he made sketches, immediately after he visited them. However, he allowed landscape painters to transform them into high quality paintings. When he saw, in 1839, the presentation of the first daguerreotypes he was deeply impressed: These 'pictures [would have] the inimitable character of nature, which only nature itself [could] have impressed'.[92] We may conclude, this was the ideal of his landscape painting.

[88] G. Hard, 'Kosmos und Landschaft. Kosmologische und landschaftsphysiognomische Denkmotive bei Alexander von Humboldt und in der geographischen Humboldt-Auslegung des 20. Jahrhunderts', in H. Pfeiffer (ed.), *Alexander von Humboldt. Werk und Werkgeltung* (München, 1969),133–77, 165.

[89] Humboldt (note 6), vol. 2, title of part A.

[90] 'Ansicht' in German denotes at the same time the subjective seeing of something and the objective 'being seen'.

[91] He admires the discovery of a first spiral nebula by Lord Rosse in 1845. Rosse′s large telescope 'transformed . . . the whole image into what looked like a snake-like rope'. Humboldt talks about 'little light clouds', about 'puzzling natural appearances' but nevertheless displays soberly a new landscape.Humboldt (note 6), vol. 3, 310f.

[92] J. Robert (note 83), 49.

All these aspects of a geographical landscape were extended by Humboldt to his view of celestial space.[93] Not only the sky and the sun, planets and stars, visible to the naked eye, appear as a landscape, but everything we see by telescopic observation is included in the findings of a total 'Gestalt'. This becomes very clear, for example, when he describes the world of nebulae.

But sometimes the scientific taxonomist gets priority. When he describes the moon's surface we only find detailed factual topography.

If one tries to define an extended concept of landscape based on Humboldt's ideas, one can understand landscape as a visual area, in which typical attributes, patterns or structures repeat one another. Pictures of spectral lines then define a new branch of astronomy as unknown patterns, which were not related to any other visual experience. There was no immediate 'Anschauung' possible. Starting with spectral analysis after 1859 the arrangement of lines, in sequence or in groups, allowed a new mapping of the sky, analogous to the star maps of positional astronomy. Positional astronomy continued to be studied. It was in contrast to spectroscopic astrophysics technologically useful for geodetic, navigational and time measurement purposes.[94] Here scientific reputation was based on its relevance to celestial mechanics. Its objects of study, mainly star points, enabled a direct 'Anschauung'. This is also valid for nebulae research. Positional astronomy (of structures with clear borders) and nebulae research (of diffuse objects) differ from each other by the kind of objects involved. Astro-spectroscopy differs from both by the different kind of view when studying the same objects.

However, those aspects of landscape change with history. Humboldt reflects on the view of the concept of landscape in Greek culture, where Sea and Land are seen together, from other concepts in history, where Land and Sea are understood as landscapes, which were totally different in their character.[95]

Landscape for Humboldt (and Goethe) also contains an aesthetic view. The artist dissects the 'magic picture of nature' into 'a few simple streaks'.[96] Humboldt uses the expression of 'scenic loveliness' (landschaftliche Anmut) of the sky in many different ways. However, this does not separate celestial objects as specific landscapes in his total observation. It is not clear, if, for example, different landscapes exist at the southern sky, or if the total view of the firmament communicates this loveliness. The adjective 'landschaftliche' only served to increase the aesthetic characterisation of his impression.

In contrast to Humboldt, Fraunhofer and Wollaston as well as Lamont, discovered a new visual space of research, with the dark lines as a specific pattern. They were easily impressed by the aesthetic character of this new visual world. Despite this, Wollaston's interest was mainly concerned with his colour theory, limited to the observation of the solar spectrum. Fraunhofer and Lamont are the first researchers who see a new spectral landscape all over the sky, generated by a totally new view of the universe, communicated by new instruments that were attached to traditional telescopes. At the least, Humboldt approached this 'visual break'. This is shown by his commentary on spectroscopic observations of fixed stars, which was really singular at his time. He made no claim that his work was at the 'level of a

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[93] See also K. Barck (note 40).
[94] This William Huggins underlined 1890. A.J. Meadows (note 15), 70.
[95] A.v. Humboldt (note 6), vol. 2, 10/11.
[96] G. Hard (note 88), 136.

rational science of nature',[97] that is, a physical and astronomical science, which was quantified by mathematics. But, of course, he appreciated this kind of science. His engagement in a 'physical description of the world' (physische Weltbeschreibung) also brought forward his interest of astro-physical phenomena. This physical description of the world was meant to observe the empirical phenomena mainly as a 'total' (ganzheitliche) impression of nature. Because of this astro-physical interest he described the splitting of the light of 'coloured double stars' - and not only the movement of the components of these stars around each other (which was fundamental for the application of celestial mechanics). He often refers to the researches of his close friend François Arago, who was interested in the application of physics to astronomy. When Humboldt remarks that 'the observation of a phenomenon, which at the beginning stands isolated, often contains the seed of a big discovery', he refers to the applications of the theory of polarized light to the physical state of the sun and the comets, which Arago published in 1811.[98]

But an 'invisible' landscape does not exist for Humboldt. The Fraunhofer lines of course are visible for him. The polarization of light can be made visible by specific instruments.[99] The invisible rays of heat from the sun, the infrared radiation, are mentioned only very briefly. The 'chemical rays', the ultraviolet radiation, do not exist for him.

The concept of 'invisible' we borrowed from positional astronomy. But we tried to thwart its definition.

On the one hand, there was the spectral landscape, which Fraunhofer and Lamont first realised. It was invisible in the same sense, as the infrared or the ultraviolet rays were invisible. To see these rays it was necessary to use instruments, which originated from outside of astronomy. It should be mentioned that thermometers for IR and layers of silver chloride for UV were even stranger to astronomy than observation slits and the theodolite.

On the other hand, this spectral landscape was invisible because it was not possible to interpret it in relatively simple ways as an enlargement of the normal space of seeing (as it was possible, in wave theory of light, with IR and UV). All early trials failed to organize the lines, at least by mathematical rules or by combining them with phenomena on earth, for example, to the bright lines of luminous gases. Moreover, the latter seemed to be a mere chemical problem, far away from astronomical research.

If one compares the visual impression, the graphic execution, the immediate effect on contemporaries and the independence of contexts of interpretation of the spectral illustrations by Wollaston, Fraunhofer and Lamont, we can ascribe to Fraunhofer's spectrum a much stronger notion of 'life of its own'. Of course it was embedded in a context of a new research technology, which was not directly astronomical. But his etching with more than 350 lines, partly very fine, is already in its black and white

[97] A.v. Humboldt (note 6), vol. 1, 52, 31.

[98] A.v. Humboldt (note 6), vol. 1, 35.

[99] But Humboldt constructed patterns, which were invisible in nature, e.g. his isotherm maps. He really experimented with line diagrams. Daston (note 87), 46. See also A.M.C. Godlewsky,'Von der Vision der Aufklärung zur modernen Wissenschaft? Humboldts visuelles Denken', in O. Ette, W.L. Bernecker (eds), *Ansichten Amerikas, Neuere Studien zu Alexander von Humboldt* (Frankfurt a.M., 2001), 157–94. N. Rupke, 'Humboldtian distribution maps: the spatial ordering of scientific knowledge', in T. Frängsmyr (ed.), *The structure of knowledge: classifications of science and learning since the Renaissance* (Berkeley, 2001), 93–116.

versions and more in its coloured copies, an enigmatic and also highly aesthetic new landscape of the invisible. At least the few clear-sighted scientists among his contemporaries understood it that way.

This way of understanding, of course, is valid for Fraunhofer's scientific mentor, the astronomer and geodesist Georg Soldner. He declared in 1820, that the lines were to be considered the most important discovery in the field of light and colours since the time of Newton.[100] However, he mainly emphasized that it was now possible to provide an exact treatment of the sequence of colours in the solar spectrum. This, too, provided a reason for Fraunhofer to be elected as a regular member of the Bavarian Academy of Sciences. Soldner, as noted above, together with Fraunhofer, made further spectral observations of fixed stars in his observatory. But he did not play an active part in this cooperation. After Fraunhofer's death, he did not continue with this kind of work in his last active years, 1826–28.

It should also be mentioned that Thomas Sömmering did not show his admiration for Fraunhofer's lines by doing active research. Granted, he had no intimate contacts with astronomy or astronomers. His use of the Chladni sound figures, as a metaphor, in his theory of the brain and his correspondence with Goethe shows that he was very open to new visual patterns.

The physicist Chladni only offered some prophetic predictions. He said in 1818:

> The discovery of Mr. Fraunhofer from Benediktbeuern that there are different systems of streaks in the light spectrum of the sun and of other stars . . . seems to me to be one of the most important ones, that recently appeared. The brave discoverer himself seems not to suspect, which broad field will be opened up, not only for researches about the different refraction of light, but also for the enlargement of our physical-astronomical knowledge. If the system of light and streaks of the many fixed stars would be observed exactly, with a very good apparatus, and if (like it was done with the solar spectrum), would be presented in drawings, by measuring the angles, then this would give us information about the qualitative variation of some fixed stars – it may not be for centuries, that we could observe variations in these systems of light.[101]

Chladni was interested, as Lamont and Humboldt[102] were, to know more about variations in the heavens. But the 'enlargement' of 'physical-astronomical knowledge' had to wait until after 1859. The prophetic interest of Chladni in the 'drawings' of Fraunhofer's lines, was clearly inspired, or at least amplified, by his own sound figures. On the other hand, he was very interested in the matter of the cosmos, that is, in a physical astronomy, because of his own research on meteorites.[103]

The colouring of Fraunhofer's solar spectrum should not only be seen as a decoration of his landscape of lines. As already mentioned, it amplified the aesthetics considerably, but it also set a precedent contrary to 'uncoloured' light points in the sky, in favour of a more physical observation of the universe. Even though coloured spectra in general were not distributed as reproduced pictures, before 1860, they were

[100] J. Fraunhofer (note 57), 4. (April 1820). M.W. Jackson (note 8), 93.

[101] E.F.F. Chladni, 'Verschiedene physikalische Bemerkungen', *Annalen der Physik,* 59 (1818), 1–11, 1–3.

[102] A.v. Humboldt (note 6), vol.1, 22, 86.

[103] E.F.F. Chladni, *Über den kosmischen Ursprung der Meteorite und Feuerkugeln* (Leipzig, 1971. 1st edition 1794).

present as impressions and known by a few interested scientists by direct observation with a spectroscope. John Herschel explained in 1828: If there is a good prism (he warns that 'with glass prisms of our manufacture it would be quite useless to attempt the experiment', and recommends 'prisms of highly refractive liquids', an achromatic telescope and a narrow slit), then the 'fixed lines are beautifully exhibited'. A projection on a screen would offer the lines in 'a peculiarly elegant and satisfactory method . . . to several persons at once'.[104]

Even after 1859, or even today, no common reproduction of Fraunhofer's hand coloured spectrum can give the impression of this fine drawing of the painted original. The raw reproductions may be another reason, why this broadly distributed almost mythical picture did not find a popular echo as an aesthetic symbol of the scientific revolution of astrophysics. On the other hand, rough hand-drawn and coloured absorption spectra of the sun and different stars, and also emission spectra of flames of different chemical elements, became common in the late 19th century in scientific and popular publications.[105]

As far as Wollaston is concerned, the few lines he saw are a kind of 'scientific' decoration of his theory of colours: border lines of colour blocks, interesting but inexplicable and not essentially seen as a new phenomenon.

Lamont's observatory note books and his publication of 1838 show that he saw new picture codes, more than Wollaston had but still not such independent landscapes of spectral lines as those of Fraunhofer. He was interested substantially in the different nuances of colours in starlight, in its 'intensity' or 'quantity'. He did not consider that it was not so much nuances of colours but just the dark lines, their discontinuity and irregularity that would mainly produce a new astrophysics.

Conversely it is astonishing, that by comparing pictures of terrestrial and celestial light, a long time before any useful atomic physics emerged, new celestial physics became possible. This happened from 1859 on, but it would have been possible even earlier.

Kirchhoff and Bunsen stated explicitly in 1860, that to detect single chemical elements it was not necessary to measure exactly the (emission-)lines: 'Their colour, their relative location, their specific form and shading, the gradations of their brilliance are signs, which even for the untrained suffices to show a definite orientation.'[106]

And Kirchhoff pointed out directly in 1861, with the example of his very detailed solar spectrum, the metaphor of a new celestial landscape. He used an astro-poetical comparison. Referring to groups of (absorption-) lines, 'which are so characteristic that they can be easily perceived and easily recognized. These are groups of lines, which can be compared justifiably with the groups of stars, which make us perceive single star constellations so easily.'[107]

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[104] J.F.W. Herschel (note 46), 409–10.

[105] K. Hentschel (note 1), 47–48. H. Helmholtz, *Handbuch der physiologischen Optik* (Leipzig, 1867) plate IV, fig.1. Detailed solar spectra were only published in black and white. E.g. G. Kirchhoff, 'Untersuchungen über das Sonnenspectrum und die Spectren der chemischen Elemente', *Abhandlungen der Königlichen Preußischen Akademie der Wissenschaften zu Berlin* (1861), 63–95.

[106] G. Kirchhoff and R. Bunsen, 'Chemische Analyse durch Spectralbeobachtungen', *Annalen der Physik,* 186 (1860), 163–89 (184).

[107] G. Kirchhoff (note 105), 63. This was adopted by H.E. Roscoe, *Spectrum Analysis. Six Lectures* (London, 1870), 145. See also K. Hentschel (note 1), 458f.

Kirchhoff himself observed no spectra of fixed stars, so far as we know. But he mentioned the possible use of such a research. Indeed, for these observations a specific optical-astronomical apparatus was necessary, and a specific know-how to handle it. This was a big problem for the whole prehistory of astronomic spectral analysis. David Brewster and John Hall Gladstone also attested to this problem, in 1860, when they could not see any decisive result in their observations of fixed stars. They believed that all solar lines were produced in the atmosphere of the earth. Different spectra of fixed stars therefore could not exist![108]

Are we actually allowed to describe spectra as 'pictures' and compare them with the paintings of landscapes?

Astrophysicists of the late 19th century accepted spectra to be pictures as the cited comparison shows, made by Kirchhoff of groups of lines with star constellations, or as based on the cited judgement of Henry Draper of one of his photographs of star spectra.[109] He uses the term 'picture' as well as the term 'map.'

On the other hand, spectra do not represent an object that one can directly see by way of enlargement or by getting closer to it. However, also objects that are observed microscopically and fixed in drawings or photographs cannot be considered to represent reality clearly. The classical definition, that pictures are two-digit representations, that is, direct reflections of independently existing objects, has been criticized more and more in the last decades of the 20th century. The necessity of a resemblance between the picture and the thing that it was supposed to represent was already criticized in the 1960s. 'Realistic representation, in brief depends not upon imitation or illusion or information but upon inculcation . . . realism is a matter of habit.'[110]

What we see, after all, depends on our conventions. We need to be practically involved in order to learn to see something in the first place.[111] A picture is a reference to other references, as a process of construction or staging.[112] It is not necessary anymore, as Nelson Goodman demanded, that pictorial symbol systems have to be syntactically and semantically dense and relatively replete.

Pictures produce their essence by way of colours, contrasts, forms, lines, figures. That is, aesthetics is fundamentally contained in every picture.

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[108] D. Brewster and J.H. Gladstone, 'On the Lines of the Solar Spectrum', *Proceedings of the Royal Society,* 10 (1860), 339–41 (341). See also J.F.W. Herschel, *A Treatise on Astronomy* (1834), 202, 203. W. Huggins confirmed in 1864 the observations of fixed stars by J. Fraunhofer. H. Kayser,(note 7), 52,107.

[109] Draper (note 41). The 'new astronomy' in general defined new astronomical landscapes. Lockyer for example compared, almost ecstatically, the sun's chromosphere with the landscape of a tropical forest. Schaffer (note 10), 282. The chaotic picture of Fraunhofer lines now was seen as an aesthetic mystery. Hentschel (note 1), 456f.

[110] N. Goodman, *Languages of art* (Indianapolis, 2nd ed., 1976), 38. German edition (Frankfurt, 1995), 17. I. Hacking, *Einführung in die Philosophie der Naturwissenschaften* (Stuttgart, 1996), 316, 344. This is a German translation from *Representing and Intervening* (Cambridge, 1983). There were only a few philosophers, who once again tried to defend the model of resemblance, for example F. Schier, *Deeper into pictures: An essay on pictorial representation* (Cambridge, MA, 1986).

[111] Hacking (note 110), 315.

[112] M. Hessler, 'BilderWissen. Bild- und wissenschaftstheoretische Überlegungen', in R. Adelmann et al. (eds), *Datenbilder. Zur digitalen Bildpraxis in den Naturwissenschaften* (Bielfeld, 2009), 133–61. M. Hessler, D. Mersch, *Logik des Bildlichen.Zur Kritik der ikonischen Vernunft* (Bielefeld, 2009). See also A. Soojung-Kim Pang, 'Visual representation and post-constructivist history of science', *Historical Studies in the Physical and Biological Sciences*, 28 (1997), 139–71,142: 'A visual representation (expresses) a relationship between an instrument or observer and nature, between instruments or between other representations.'

In the theory of semiotics, pictures are signs, which are only approximations of perception. The phenomenological theory of pictures, on the other hand, stresses the intrinsic value of them. What we see on pictures, is an imaginary object, a 'picture-object', which cannot be reduced to a pure sign character.[113]

A mediating view would be a scientific picture denoting both sign and picture tools and independent objects. Since the 19th century and especially the beginning of the 20th century in astronomy we are able to speak of 'data-pictures'. As far as their sign character is understood, depends on the knowledge of the observer.[114] In this respect the pictures of spectra (before 1859) are to be seen as an independent parallel world. Humboldt saw this world with an individual physiognomy.

Throughout the 1860s and following decades the term 'maps' has been used for representations of spectra.[115] They are placed in the same category as star maps or geographic maps. The use of the term 'thematic map' was enlarged by Humboldt already before 1850.[116] He also inserted sketches of layers of typical vegetation into vertical profiles of mountains.

All this was not a simple representation of empirical data but was the result of picture design, as were Fraunhofer's coloured and also his black and white spectra. In the extended sense of Humboldt's understanding they also represented new patterns and landscapes of the heavens.

7. Conclusion

With Wollaston, Fraunhofer and Lamont a visual break in astronomy began, which changed the content and the methodology of existing research in a radical way. The landscape of star points was no longer the starting point of all research. Now it was the 'stippled' (durchstrichelte) spectra, as Goethe called them.

We could compare this development to the change that occurred with painting in art, which took place at about the same time. Landscape painting now was understood as a new field in the practice of painting and in art theory.

The artists and art theorists now were interested to see nature as more and more 'wild und romantic', as Humboldt later on formulated it in his 'Kosmos'. Now landscape by an exact observation of processes in nature, like moonlight or sunrise, should activate sentiments and produce a state of deeper contemplation.

The earliest writing about the so called realistic 'open air painting' (Freilicht-malerei) in Germany originated in 1807 and refers to Humboldt's 'Aspects of Nature'. Landscape painting is seen related to landscape morphology: the 'visual' (anschauliche) richness of nature must not be idealized, as it had been done so far.

[113] All together the analytical theory of picture(following N. Goodman), the semiotic theory of picture(in part following M. Foucault), and the phenomenological theory (based on E. Husserl) are distinguishable.
There are good summaries in K. Sachs-Hombach (ed.), *Bildtheorien. Anthropologische und kulturelle Grundlagen des Visualistic Turn* (Frankfurt, 2009), part 2: *Theoriegeschichte*. Regarding the phenomenological theory see also L. Wiesing, *Artifizielle Präsenz. Studien zur Philosophie des Bildes* (Frankfurt a.M., 3rd ed. 2010).

[114] Adelmann (note 112).

[115] e.g. Hentschel (note 1).

[116] See note 99.

The controversial painting of Caspar David Friedrich 'Cross in the Mountains' elicited the following comment in 1809:

> Those who believe it is impossible to express ideas and feelings with landscape (painting) have probably never been touched by nature.[117]

The officer, writer and friend of the poet Heinrich von Kleist, Otto August Rühle von Lilienstern demanded in 1810: The painter of landscapes 'is allowed to do all, what he is able to do'. Ideal landscape, morphological landscape and the exposition of atmospheric phenomena with its 'music of shadows and colours' (by this he probably refers to the paintings of Caspar David Friedrich) are especially striking variations of a new activity by artists, which will open up many unexpected possibilities.[118] This sounds now almost like the paean of praise of Sömmering or Chladni about Fraunhofer's line spectrum. The painter, poet and doctor Carl Gustav Carus, who also was a friend of Humboldt, stressed in 1826 the dynamical aspect of seeing nature (Naturanschauung) and propagated an 'earth-living-picture-art' (Erdlebenbildkunst).[119]

Painters began to deal with the interactions of light, space and natural powers. For example, we can see this in the intensive use of colours in paintings of J.M.W. Turner. Here the pictorial qualities of colours, spots, lines play a more and more substantial role.[120] In the paintings of Caspar David Friedrich the metaphor of distance and the loneliness of the observer became essential; for example, in his 'monk at the sea' in 1810, which caused severe disputes among critics.[121] The vast, empty, almost chaotic landscape, with an overwhelmingly unfriendly sky and with large regions of dark water, all of this pictured in spots and dashes, looked very revolutionary. Despite this seeming chaos it contains a very exact observation of nature. But it differs from a simple realistic imitation of nature.

Friedrich was a loner among the artists of his time - he had no pupils, he never visited Italy. Fraunhofer was a loner among the scientists of his time - he had no academic education and was only regarded as an optician. Not unlike Friedrich's 'monk at the sea' in relation to art, Fraunhofer's 'stippled ' (durchstricheltes) solar spectrum demonstrated an alternative to the methodology of astronomical science as well as suggested the need for a new style of seeing. The spectrum also looked chaotic, a combination of colour spots and dark lines. These also could be understood as symbols, but coming from an unknown reality. On the other hand, the romantic painters used new poetic and partly mystical symbols for their visual language. But this visual language also included, for example with Friedrich, very exact geometric construction.[122] Finally, in romantic landscape painting there exist, for example, with Turner, early playful attempts towards more abstraction.[123]

Though the spectral landscape had little historical impact until about 1860, in contrast to romantic painting, it owes its beginning to the same foundations of this

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[117] M. Bertsch, R. Wegner (eds), *Landschaft am "Scheidepunkt" - Evolution einer Gattung in Kunsttheorie, Kunstschaffen und Literatur um 1800* (Göttingen, 2010), 58.

[118] Bertsch (note 117), 60.

[119] Bertsch (note 117), 53.

[120] R. Rosenberg and M. Hollein, *Turner-Hugo-Moreau. Entdeckung der Abstraktion* (München, 2007), 112–57. J. Gage, *Colour and meaning. Art, science and symbolism* (London, 2000), 162–8.

[121] Bertsch (note 117), 297. J.E. Howoldt and U.M. Sneede (eds), *Expedition Kunst. Die Entdeckung der Natur von C.D. Friedrich bis Humboldt* (Hamburg, München, 2002), 17f.

[122] Werner Busch in J.E. Howoldt and U.M. Sneede (note 121), 17f.

[123] Rosenberg (note 120).

epoch. Different cultural changes in the same epoch may be subject to different determining factors in its further development.[124]

Neither for physicists nor for astronomers did the new spectral landscape count as relevant knowledge. Despite this, we can relate the metaphor of Maedler (a new astronomy of the invisible) to these researches. There was more and more awareness that phenomena in the universe, which could not be reduced to simple observations, in the sense of Comte, would still become important for scientific research. So the rays of heat and chemical rays in sunlight outside the visible solar spectrum appeared more and more in the researcher's field of view. The same is valid for polarized light of the sun and of comets and for research about meteors. On the whole, more and more interest, at least in physics, inspired the exploration of matter in the cosmos.[125]

The most impressive development - even within astronomical research - to understand more about matter in the cosmos, was research in understanding nebulae. Nebulae, in their subtlety, lying at the border between the visible and invisible, gained more and more interest. It was also a by-product of positional astronomy, as in the example of Friedrich Georg Wilhelm Struve, the German director of the Russian state observatory at Pulkowo (and father of the earlier mentioned Otto Struve).[126] Also, this landscape was not easily observed. Its form, colour and structure therefore became interpreted in very subjective ways. Charles Piazzi Smyth declared, in 1841, referring to nebulae: The task of drawing in astronomy 'is, or ought to be, not the mere imitation, but the *rivalship* of nature'. John Herschel described the Orion nebula with an emotional picture: '. . . the brightest portion offers a resemblance to the head and yawning jaws of some monstrous animal, with a sort of proboscis running out from the snout'.[127]

On the other hand, the incomprehensible bar code of spectra was a reality much more abstract, still farther away from immediate visual objects and still more difficult to verify in detail.

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[124] The historian Reinhart Koselleck named this epoch 'Sattelzeit', in comparison to a mountain saddle - a lower horizontal part of a mountain - (in German: 'Bergsattel'), as a transition time between 1750 and 1850. R. Koselleck, 'Einleitung', in: O. Brunner, W. Conze, R. Koselleck (eds), *Geschichtliche Grundbegriffe* (Stuttgart, 1979), vol.1, S. XV.

[125] A.v. Humboldt (note 6), vol 1, 35.

[126] W. Steinicke (note 70).

[127] S. Schaffer, 'On Astronomical Drawing', in: C.A. Jones and P. Galison (eds), *Picturing Science, Producing Art* (New York, London, 1998), 441–74, 441, 454.