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Mapping the lunar shadow – the earliest solar eclipse maps

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The English astronomer Edmond Halley (1656–1742) is commonly credited as the first to draw and publish maps delineating the paths of totality for solar eclipses. Halley published such maps for the solar eclipses of 3 May 1715 and 22 May 1724, which were both visible from southern England. In this paper, the author presents examples of earlier maps depicting solar eclipse paths from Germany, the Netherlands and France. The earliest eclipse maps of this kind appear to be those showing the path of totality for the solar eclipses of 23 September 1699 and 12 May 1706.

Der englische Astronom Edmond Halley (1656–1742) gilt im allgemeinen als der erste, der Karten gezeichnet und publiziert hat, die die Totalitätspfade von Sonnenfinsternissen zeigen. Halley publizierte solche Karten für die Sonnenfinsternisse vom 3. Mai 1715 und vom 22. Mai 1724, die beide von Südengland aus beobachtbar waren. In dieser Arbeit werden Beispiele früherer Karten aus Deutschland, den Niederlanden und Frankreich gezeigt, die Sonnenfinsternispfade zeigen. Die frühesten derartigen Karten scheinen diejenigen für die Sonnenfinsternisse vom 23. September 1699 und vom 12. Mai 1706 zu sein.

1 Introduction

During the past few centuries astronomers have made frequent use of so-called 'eclipse maps' for predicting the local circumstances of solar eclipses.[1]

[1] Well known compilations of such maps include Th. Ritter von Oppolzer, *Canon der Finsternisse* (Kaiserlich-Königliche Hof- und Staatsdruckerei, Vienna, 1887 [= *Denkschriften der Kaiserlichen Akademie der Wissenschaften zu Wien*, Mathematisch-Naturwissenschaftliche Classe, Nr. 52]) – reprinted as *Canon of Eclipses* in 1962 by Dover Publications, New York – and J. Meeus, C.C. Grosjean & W. Vanderleen, *Canon of Solar Eclipses* (Pergamon Press, Oxford [etc.], 1966). These compilations (and those mentioned in the next footnote) are now largely superseded by Fred Espenak's Solar Eclipse Atlas, online at: `http://sunearth.gsfc.nasa.gov/eclipse/SEatlas/SEatlas.html`.

Historians of astronomy too have found these maps to be useful for studying and dating reports of ancient solar eclipses.[2] However, the origin of these maps is not well understood and the modern literature on this subject has largely depended on a very limited number of original sources.

Several recent publications claim that the first maps of this kind were published by the English astronomer Edmond Halley (1656–1742).[3] His maps depict the paths of totality across southern England for the solar eclipses of 3 May 1715 and 22 May 1724,[4] and give details on the visibility of these eclipses for locations on and near the path of totality.

In this paper several earlier eclipse maps will be discussed which delineate the regions of totality and partiality of solar eclipses on the terrestrial surface. It will be argued that these maps were developed with the intent of improving geographical longitudes rather than to increase astronomical knowledge of the sun or its distance.

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[2]Eclipse map compilations for historical periods include F.K. Ginzel, *Spezieller Kanon der Sonnen- und Mondfinsternisse für das Ländergebiet der klassischen Altertumswissenschaften und den Zeitraum von 900 vor Chr. bis 600 n.Chr.* (Mayer & Müller, Berlin, 1899); J.Fr. Schroeter, *Spezieller Kanon der Zentralen Sonnen- und Mondfinsternisse, welche innerhalb des Zeitraums von 600 bis 1800 n.Chr. in Europa sichtbar waren* (Jacob Dybwad, Kristiania, 1923); P.V. Neugebauer & R. Hiller, "Spezieller Kanon der Sonnenfinsternisse für Vorderasien und Ägypten für die Zeit von 900 v.Chr. bis 4200 v.Chr.", *Astronomische Abhandlungen: Ergänzungshefte zu den Astronomischen Nachrichten*, **8**, nr. 4 (1931); G. van den Bergh, *Eclipses in the Second Millennium B.C. (–1600 to –1207) and how to Compute them in a Few Minutes* (H.D. Tjeenk Willink & Zoon N.V., Haarlem, 1954); M. Kudlek & E.H. Mickler, *Solar and Lunar Eclipses of the Ancient Near East from 3000 B.C. to 0 with Maps* (Butzon & Bercker/Neukirchener Verlag des Erziehungsvereins, Kevelaer/Neukirchen-Vluyn, 1971 [= *Alter Orient und Altes Testament*, Sonderreihe, Band 1]) and F.R. Stephenson & M.A. Houlden, *Atlas of Historical Eclipse Maps: East Asia 1500 BC – AD 1900* (Cambridge University Press, Cambridge [etc.], 1986).

[3]Cf. G. Armitage, *The Shadow of the Moon: British Solar Eclipse Mapping in the Eighteenth Century* (Map Collector Publications, Tring, 1997), p. 7; A. Cook, *Edmond Halley: Charting the Heavens and the Seas* (Clarendon Press, Oxford, 1998), pp. 351–353; J.M. Pasachoff, "Halley and his Maps of the Total Eclipses of 1715 and 1724", *Astronomy & Geophysics (Royal Astronomical Society)*, **40** (1999), 18–22; J.M. Pasachoff, "Halley et ses cartes d'eclipses totales de 1715 et 1724", *Ciel et Terre*, **115** (1999), 51–56; J.M. Pasachoff, "Halley as an Eclipse Pioneer: His Maps and Observations of the Total Solar Eclipses of 1715 and 1724", *Journal of Astronomical History and Heritage*, **2** (1999), 39–54; B. Stephenson, M. Bolt & A.F. Friedman, *The Universe Unveiled: Instruments and Images through History* (Cambridge University Press/Adler Planetarium & Astronomy Museum, Cambridge/Chicago, 2000), pp. 82–83.

[4]On Halley's eclipse maps these dates were given as 22 April 1715 and 11 May 1724 as the Julian calendar was then still in force in Great Britain. Halley's eclipse maps are reproduced in the publications mentioned in the preceding footnote and also in E. Maor, "Mapping the Moon's Shadow", *Sky & Telescope*, **108** (2004), nr. 6, pp. 42–49.

2 The eclipse map ascribed to Cassini

According to the historian of science Otto E. Neugebauer, the earliest eclipse maps were probably made by the Italian-French astronomer Jean Dominique Cassini (1625–1712).[5] In his *History of Ancient Mathematical Astronomy*, Neugebauer wrote:

> "The idea of investigating the total path of a solar eclipse (instead of determining the magnitude and other circumstances for a given locality) is of modern origin – probably developed in the time of J. Cassini under the influence of the great theoretical interest of the Venus transits of 1761 and 1769. [...] According to Lalande (*Astron.* II, p. 358, No. 1799; *Bibl.*, p. 256, 1644) Dom. Cassini constructed in 1664 for the first time the path of a solar eclipse (visible in Ferrara) on a terrestrial map. But there was no total solar eclipse in 1664 and no publication of Cassini with the title quoted by Lalande seems to be known."[6]

Neugebauer identifies his source as the French astronomer Joseph Jérôme le Français de Lalande (1732–1807), who in his *Astronomie* wrote:[7]

> "Ce fut Domin. Cassini qui en donna l'idée et le model, à l'occasion de l'éclipse de 1664 (*Osservazione dell' eclisse solare fata in Ferrara*, 1664. *Ferraræ, in-fol.*)."

Neugebauer's second reference, "*Bibl.* p. 256, 1644" is obviously a typographical error for "1664". Under this year, we find in Lalande's *Bibliographie astronomique*:[8]

> "1664. *Ferraræ, in-fol.* Jo. Dominici Cassini Osservatione del eclisse solare fatta in Ferrara l'anno 1664, con una figura intagliata in rame, che rapresenta uno nuovo metodo di trovar l'apparenze varie che fa nel medesimo tempo in tutta la terra. *Weidler*, p. 527. = Astron. art. 1808.[9]"

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[5] For a recent biography, see A. Cassini, *Gio. Domenico Cassini: Uno scienziato del Seicento* (Comune di Perinaldo, 2003).

[6] O.E. Neugebauer, *A History of Ancient Mathematical Astronomy* (Springer Verlag, Berlin [etc.], 1975), vol. 3, p. 1093 & footnote 2.

[7] J.J. de Lalande, *Astronomie*, 3rd ed. (Veuve Desaint, Paris, 1792), vol. II, p. 358.

[8] J.J. de Lalande, *Bibliographie astronomique, avec l'histoire de l'astronomie depuis 1781 jusqu'à 1802* (Imprimerie de la République, Paris, 1803), p. 256.

[9] This refers to Johann Friedrich Weidler, *Bibliographia astronomia, temporis quo libri vel compositi vel editi sunt, ordine servato; ad supplemendam et illustrandam as-*

Of the three partial solar eclipses of 1664, only the first one on 28 January would have been visible from Ferrara.[10] However, according to the maps in Fred Espenak's solar eclipse atlas,[11] there was a very prominent solar eclipse visible from Ferrara on 30 March 1661.[12] The path of totality went over North Africa, the eastern Mediterranean Sea and the Black Sea before it ended in Central Asia. Possibly the year "1661" somehow got corrupted into "1664". Unfortunately, no copies of this publication (dated either to 1661 or 1664) appear to be known.[13]

3 Cassini's eclipse map for the solar eclipse of 23 September 1699

The earliest solar eclipse for which an eclipse map is known appears to be the annular-total solar eclipse of 23 September 1699. The path of totality passed through the northern tip of Scotland, Denmark, the German-Baltic coast, Poland and the Ukraine, continued into the Middle East and ended on the Indian subcontinent.

Observations of the eclipse were made at the Paris Observatory by Jean Dominique Cassini[14] and Philippe de la Hire.[15] The eclipse was also observed at Oxford by David Gregory[16] and at Nuremberg by Johann Philipp von Wurzelbau.[17]

In an addendum to his report in the memoirs of the Paris Academy, Cassini cited further observations of the eclipse from Marseilles, Parma

tronomiæ historiam digesta (Samuel Gottfried Zimmermann, Wittenberg, 1755), 2 vols. Of Weidler's earlier work *Historia astronomiæ, sive, de ortu et progressu astronomiæ liber singularis* (Gottlieb Heinrich Schwartz, Wittenberg, 1741), Lalande wrote: "Il s'est trompé sur plusieurs dates" (see footnote 8, Préf., p. vi).

[10] The maximum phase (0.20) occurred shortly after sunrise (solar altitude 3.6°).

[11] See footnote 1.

[12] Maximum phase (0.76) occurred in the morning (solar altitude 45.0°).

[13] A search on various large internet library catalogues did not produce any results. Anna Cassini, the author of a recent biography on Jean Dominique Cassini, has informed me that she has never seen this publication [pers. comm.].

[14] J.D. Cassini, "Observation de l'eclipse du soleil du 23. Septembre 1699. à l'Observatoire", *Histoire de l'Académie Royale des Sciences avec les mémoires de mathématique & de physique tirez des registres de cette Académie pour l'année MDCXCIX*, Mémoires, 163 [cited from the 3rd rev. Paris ed. of 1732].

[15] Ph. de la Hire, "Eclipse du soleil arrivée le 23. Septembre au matin 1699. & observée dans la Tour Orientale de l'Observatoire à la hauteur de la grande Salle", *Histoire de l'Académie Royale des Sciences avec les mémoires de mathématique & de physique tirez des registres de cette Académie pour l'année MDCXCIX*, Mémoires, 164–165 [cited from the 3rd rev. Paris ed. of 1732].

[16] D. Gregory, "Part of a Letter from Dr. David Gregory, to Dr. Sloane, dated Oxford, October 12, 1699, containing his observations of the Eclipse of the Sun on the 13th of September last", *Philosophical Transactions of the Royal Society of London*, **21** (1699),

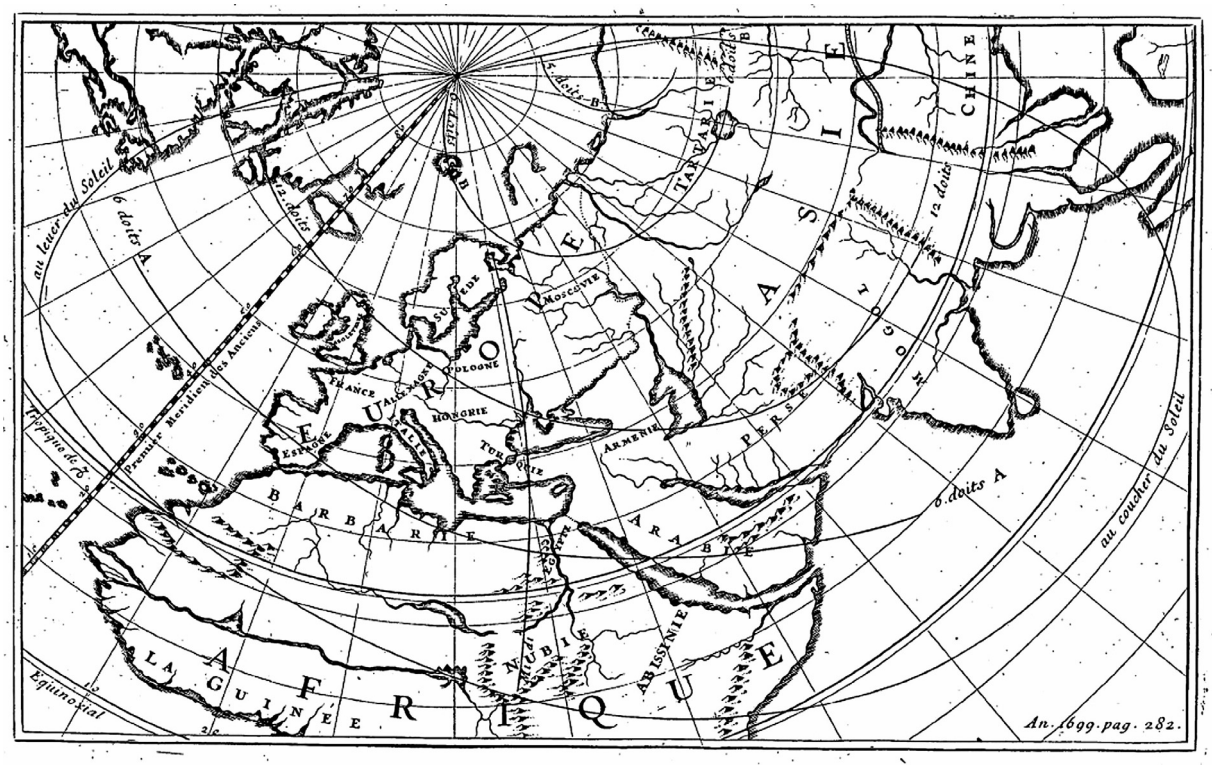

Fig. 1. Cassini's map depicting the region of visibility of the solar eclipse of 23 September 1699. The curves represent the northern and southern limits, the sunrise and sunset limits, the central line ('12 doits') and maximum eclipse magnitude lines of 6 digits (northern and southern curves) and 5 digits (northern curve only).

and Bologna, supplemented with a discussion on the geometry of the Sun, the Moon and the Earth during the eclipse.[18] In the same memoir Cassini also published a geographical map – apparently the earliest of its kind[19] – delineating the region of visibility from the Earth (Fig. 1). After plotting the path of totality over the Earth's surface, Cassini remarked that the speed of the lunar shadow exceeded that of a cannon ball travelling through the air.

At the conclusion of the same memoir, Cassini noted that careful timings

330–331.

[17] J.Ph. von Wurzelbau, "Eclipsis Solis, Anno MDCXCIX, d. 13./23. Sept. observata a Norimbergæ", *Acta Eruditorum, anno MDCXCIX publicata* (Leipzig, 1699), 544–548. An English translation of von Wurzelbau's paper was printed in the *Philosophical Transactions of the Royal Society of London*, **22** (1700/01), 619–624.

[18] J.D. Cassini, "Reflexions sur l'eclipse du 23. Septembre 1699. qui ont été omises dans leur place", *Histoire de l'Académie Royale des Sciences avec les mémoires de mathématique & de physique tirez des registres de cette Académie pour l'année MDCXCIX*, Mémoires, 274–282 [cited from the 3rd rev. Paris ed. of 1732].

[19] Cassini nowhere refers to earlier maps of this kind from his hand or from others.

of the phases of partial and total obscuration during a solar eclipse could be used to determine the geographical longitude of an observer when the latitude was assumed to be known. This problem was treated in more detail by Cassini in a memoir in the following year.[20] From several observations made in Germany, Cassini used his method to derive improved longitude differences for Nuremberg, Kiel and Greifswald from Paris. Several more longitude determinations were obtained from the same eclipse in a paper published by Cassini in 1701.[21] This was supplemented with a list of longitude determinations obtained from observations of the earlier solar eclipse of 12 July 1684.[22]

Cassini's son Jacques Cassini (1677–1756) further elaborated on this problem in a memoir published by the Paris Academy in 1705, describing a method in which observations of lunar occultations of bright stars and planets could be employed.[23]

Cassini's eclipse map of 1699 thus appears to be the direct result of his investigations in using astronomical observations for improving geographical longitudes.[24] The use of solar eclipses for longitude determinations had actually been suggested earlier by the German astronomer Johannes Kepler (1571–1630) in his *Rudolphine Tables*,[25] as the begin- and end phases

[20] J.D. Cassini, "Sur l'eclipse solaire du 23. Septembre 1699", *Histoire de l'Académie Royale des Sciences avec les mémoires de mathématique & de physique tirez des registres de cette Académie pour l'année MDCC*, Histoire, 105–108 [cited from the 2nd rev. Paris ed. of 1761].

[21] J.D. Cassini, "Comparaison de diverses Observations de l'Eclipse du Soleil du 23. Septembre 1699. faites en diverses Villes de l'Europe", *Histoire de l'Académie Royale des Sciences avec les mémoires de mathématique & de physique tirez des registres de cette Académie pour l'année MDCCI*, Mémoires, 80–87 [cited from the 2nd rev. Paris ed. of 1743].

[22] J.D. Cassini, "Voici encore les différences des Longitudes de plusieurs Villes de la France, tirées des Observations de l'Eclipse du Soleil du 12. Juillet 1684", *Histoire de l'Académie Royale des Sciences avec les mémoires de mathématique & de physique tirez des registres de cette Académie pour l'année MDCCI*, Mémoires, 87–89 [cited from the 2nd rev. Paris ed. of 1743].

[23] J. Cassini, "Methode de déterminer les longitudes des lieux de la terre par les eclipses des etoiles fixes & des planetes par la Lune, pratiquée en diverses observations", *Histoire de l'Académie Royale des Sciences avec les mémoires de mathématique & de physique tirez des registres de cette Académie pour l'année MDCCV*, Mémoires, 194–211 [cited from the Paris reprint of 1730].

[24] Up to then, astronomical methods for determining geographical longitudes had depended on observations of lunar eclipses, and more recently, on telescopically observed eclipses of Jupiter's inner satellites by the planet's disk. For a recent history of this problem, see the papers in W.J.H. Andrewes (ed.), *The Quest for Longitude: The Proceedings of the Longitude Symposium, Harvard University, Cambridge, Massachusetts, November 4–6, 1993* (Harvard University Press, Cambridge [Mass.], 1996).

[25] J. Kepler, *Tabulæ Rudolphinæ, quibus astronomicæ scientiæ restauratio continetur*

of a solar eclipse could be determined more accurately than that of a lunar eclipse, but in practice his method had been judged to be too difficult to use.[26] Cassini's method proved to be more practical and was in fact used by astronomers until the late 19$^{\text{th}}$ century.[27]

4 Eclipse maps delineating the solar eclipse of 12 May 1706

The next solar eclipse that was visible from most of Europe, the total eclipse of 12 May 1706, was depicted on several eclipse maps printed in Germany and in the Low Countries.

The solar eclipse of 12 May 1706 was one of the best observed eclipses in Europe during the 18$^{\text{th}}$ century and several observers on the central line noted a faint halo around the Sun during totality – now known to be the solar corona – that was then assumed to be caused by a tenuous lunar atmosphere. Published observations include those made at Marly-le-Roi (near Paris) by Jacques Cassini and Jean Dominique Maraldi in the presence of the French king Louis XIV and several court members,[28] at the Paris Observatory by Jean Dominique Cassini, Jacques Philippe Maraldi and Philippe de la Hire,[29] at Greenwich by John Flamsteed,[30] at

(Jonas Saur, Ulm, 1627), p. 36 [cap. XVI, præcep. 61] & p. 112 [cap. XXXII, præcep. 176].

[26] For a contemporary discussion, cf. J.B. Riccioli, *Geographiæ et hydrographiæ reformatæ, nuper recognitæ, & auctæ, libri duodecim* (Johannis la Noù, Venice, 1672), pp. 316–317 [lib. VIII, cap. III].

[27] The method was still treated in detail with a worked-out example in W. Chauvenet, *A Manual of Spherical and Practical Astronomy, embracing the General Problems of Spherical Astronomy, the Special Applications to Nautical Astronomy, and the Theory and Use of Fixed and Portable Astronomical Instruments. With an Appendix on the Method of Least Squares*, 5$^{\text{th}}$ ed. (Lippincott, Philadelphia, 1876), vol. I, pp. 518–542.

[28] J.D. Cassini & J.Ph. Maraldi, "Observation de l'eclipse du soleil faite à Marly le 12 May 1706, en presence du Roy, de Monseigneur, & de Monseigneur le Duc de Bourgogne", *Histoire de l'Académie Royale des Sciences avec les mémoires de mathématique & de physique tirez des registres de cette Académie pour l'année MDCCVI*, Mémoires, 165–168 [cited from the Paris reprint of 1731].

[29] J.D. Cassini & J.Ph. Maraldi, "Observation de l'eclipse de soleil faite le 12 May 1706 dans l'Appartement inferieur de l'Observatoire", *Histoire de l'Académie Royale des Sciences avec les mémoires de mathématique & de physique tirez des registres de cette Académie pour l'année MDCCVI*, Mémoires, 169–171 [cited from the Paris reprint of 1731]; Ph. de la Hire, "Observations de l'eclipse de soleil du 12 May 1706 au matin à l'Observatoire Royal dans la Tour orientale à la hauteur de la grande Salle", *Histoire de l'Académie Royale des Sciences avec les mémoires de mathématique & de physique tirez des registres de cette Académie pour l'année MDCCVI*, Mémoires, 172–177 [cited from the Paris reprint of 1731].

[30] J. Flamsteed, "Observations of the Solar Eclipse, May 1/12, 1706, at the Royal Observatory at Greenwich, &c.", *Philosophical Transactions of the Royal Society of*

Geneva by Jean Christophe Fatio de Duillier,[31] at Zürich by Johann Jakob Scheuchzer,[32] at Nuremberg by Johann Philipp von Wurzelbau,[33] at the residence of Baron Bernhard Friedrich von Krosigk (near Berlin) by Johann Heinrich Hoffmann,[34] at Zeitz by Gottfried Teuber[35] and at Arkhangelsk by Martin(?) Michaëlis.[36]

Additional observations were reported by Christian Wolff[37] and Jean Dominique Cassini.[38] In the latter publication, Cassini gave a detailed verbal description of an apparently unpublished eclipse map prepared by his son Jacques and by Maraldi, depicting the path of the eclipse across the terrestrial surface, similar to the eclipse map of 1699.

The observations of the 1706 eclipse were subsequently used by Jacques Cassini to obtain improved longitudes for various European locations.[39]

London, **25** (1706/07), 2237–2241. Flamsteed's report also includes the observations of Stephen Gray at Canterbury, Abraham Sharp at Horton and Capt. Stannyan (a kinsman of the diplomat Abraham Stanyan) at Bern (Switzerland).

[31] J.Chr. Fatio de Duillier, "An Abstract of a Letter written from Geneva, May the 31th, 1706. N.S. by Monsieur J.Chr. Facio Duillier, R.S.S. to his Brother Mr Nic. Facio, R.S.S. containing some Observations of the Sun's Eclipse, on the 12th of May, 1706. N.S.", *Philosophical Transactions of the Royal Society of London*, **25** (1706/07), 2241–2246. De Duillier's report also included observations made at Marseilles.

[32] J.J. Scheuchzer, "Pars Epistolæ á Cl. D. Jh. Jac. Scheuchzer, M.D. Tigur. & Societat. Reg. Lond. Soc. ad D. Jacobum Petiver, dictæ Societ. Soc. de Eclipsi Solis totali Die 12°. Maij Tiguri observatâ", *Philosophical Transactions of the Royal Society of London*, **25** (1706/07), 2246.

[33] J.Ph. von Wurzelbau, "Observatio Eclipseos Solis totalis cum mora, Anno 1706. die 12. Maji horis antemeridd. habita Norimbergæ", *Miscellanea Berolinensia ad incrementum scientiarum, ex scriptis Societati Regiæ Scientiarum exhibitis edita*, **1** (1710), 219–226.

[34] J.H. Hoffmann, "Observatio magnæ Eclipseos Solaris, quæ anno 1706. die 12. Maji antemeridiem accidit", *Miscellanea Berolinensia ad incrementum scientiarum, ex scriptis Societati Regiæ Scientiarum exhibitis edita*, **1** (1710), 227–240.

[35] G. Teuber, "Observatio Ecclipsis Solaris totalis Cizæ 12 Maji 1706. cœlo summe sereno habita", *Miscellanea Berolinensia ad incrementum scientiarum, ex scriptis Societati Regiæ Scientiarum exhibitis edita*, **1** (1710), 241.

[36] J.W. Wagner, "De Eclipsi Solis, A. 1706. Archangelopoli Moscoviæ observata", *Miscellanea Berolinensia ad incrementum scientiarum, ex scriptis Societati Regiæ Scientiarum exhibitis edita*, **2** (1723), 140.

[37] [Chr. Wolff], "Eclipsis solis, d. XII. maii MDCCVI in diversis Germaniae locis observata", *Acta Eruditorum, anno MDCCVI publicata* (Leipzig, 1706), 335–336.

[38] J.D. Cassini, "Reflexions sur l'eclipse du soleil du 12 May 1706", *Histoire de l'Académie Royale des Sciences avec les mémoires de mathématique & de physique tirez des registres de cette Académie pour l'année MDCCVI*, Mémoires, 249–260 [cited from the Paris reprint of 1731].

[39] J. Cassini, "Comparaison de diverses Observations de l'Eclipse du Soleil du 12 May 1706 faites en diverses Villes de l'Europe", *Histoire de l'Académie Royale des Sciences avec les mémoires de mathématique & de physique tirez des registres de cette Académie pour l'année MDCCVI*, Mémoires, 462–471 [cited from the Paris reprint of 1731].

4.1 The eclipse maps of Symon van de Moolen and Andreas van Lugtenburg

The earliest maps delineating the local circumstances of the solar eclipse of 12 May 1706 appear to be those published in the Low Countries by the Amsterdam mathematician Symon van de Moolen (year of birth & death unknown)[40] and Andreas van Lugtenburg (16??–1709),[41] a teacher of mathematics and navigation at various schools in Rotterdam, Willemstad and Amsterdam.

The earliest of both maps was published in 1705 by Symon van de Moolen, whose interest and expertise in solar and lunar eclipse calculations is attested by a device (*Maan en Eclips-Wyser*) to predict the times of the lunar phases and the approximate circumstances of luni-solar eclipses with an explanatory booklet published in 1698,[42] a book-length treatise published in 1702,[43] a 16-page booklet on the solar eclipse of 12 May 1706[44]

[40] On van de Moolen, see R.H. Vermij, *The Calvinist Copernicans: The Reception of the New Astronomy in the Dutch Republic, 1575–1750* (Koninklijke Nederlandse Akademie van Wetenschappen, Amsterdam, 2002), pp. 199–200.

[41] On van Lugtenburg, see C.A. Davids, *Zeewezen en wetenschap: De wetenschap en de ontwikkeling van de navigatietechniek in Nederland tussen 1585 en 1815* (Bataafsche Leeuw, Amsterdam, 1985), pp. 133–135; H.J. Zuidervaart, *Van 'konstgenoten' en hemelse fenomenen: Nederlandse sterrenkunde in de achttiende eeuw* (Erasmus Publishing, Rotterdam, 1999), pp. 60–62.

[42] S. van de Moolen, *Beschryvingh over de nieuw bedachte Maan en Eclips-Wyser, op welke tot alle tyden met groote vaardigheyt kan gevonden worden de tyd der Nieuwe, Volle en Quartier Manen, overeen komende met de ware rekening, als mede de verduysteringh in de Son en Maan, mitsgaders de hoegrootheyt derselve, vertoonende die in de Maan sijn grootheyt der verduysteringh, soo als die sal konnen werden gesien, en die in de Son, soo als die sijn verduysterngh op sijne grootste op der aarde sal gevallen. Vertoonende ook over welke zyde dat de Maan sal verduysteren* (Johannes Loots, Amsterdam, 1698). Copies of this booklet are preserved in the Leiden University Library, Museum Boerhaave (Leiden), Utrecht University Library, the Amsterdam University Library and the Dutch Maritime Museum (Amsterdam).

[43] S. van de Moolen, *Astronomia of Hemel-Loop-Kunde, leerende de hoedanigheden der beweginge van alle zigbaare Hemel-ligten, als Zon, Maan, Dwaalders en vaste Sterren, het berekenen haarder zigbaare plaatsen, de verduysteringe van Zon en Maan, midsgaders het berekenen der Tafelen die hier toe nodig zijn [...] Met een Byvoegsel om een Maan, Eclips en Planeet-wyzer te berijden, na een nieuwe uitvinding, en van een zeer dienstelijk gebruyk* (Johannes Loots, Amsterdam, 1702). Copies of this treatise are preserved in the Leiden University Library, Museum Boerhaave (Leiden), Utrecht University Library, the Zeeuwse Bibliotheek (Middelburg), the Amsterdam University Library and the Dutch Maritime Museum (Amsterdam).

[44] S. van de Moolen, *Meet-Konstig Afbeeldsel van een Verduystering in de Zon, die wesen zal den 12 May, 1706. In welke oogenschynlyk werd vertoont, alle de Plaatsen in 't algemeen op den Aardkloot, daar dees' Verduystering zal konnen gezien werden, en ook in 't bezonder, hoe die alhier te Amsterdam, zig zal vertoonen, de tyd van 't begin, midden, eynde, &c. Midsgaders een naaukeurige Aanmerking op de wetenschap van*

and a 31-page booklet on the solar eclipse of 3 May 1715.[45]

The map is found on a fold-out in van de Moolen's 1705 booklet,[46] together with a diagram depicting how the eclipse would be observed from Amsterdam (Fig. 2). Van de Moolen's booklet thus appears to contain the earliest known 'predictive' eclipse map (i.e. was published before rather than after the event).

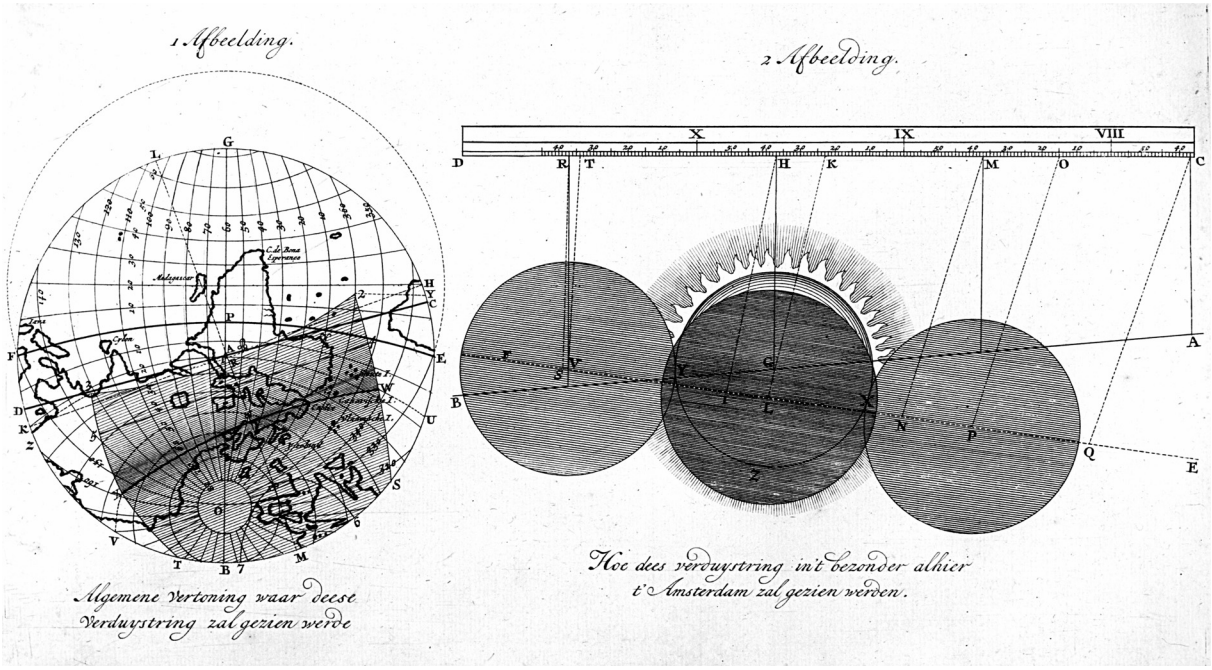

Fig. 2. Map and diagram from Symon van de Moolen's booklet on the solar eclipse of 12 May 1706. The lines on van de Moolen's map are explained as follows: WNX indicates the central line, SW2 eclipse begins at sunset, TX3 eclipse ends at sunset, SMT northern limit of the eclipse, 2R3 southern limit of the eclipse. Maximum eclipse magnitude of 50% (6 digits) is indicated by the curves labelled 4,5 and 6,8,7. (Collection Bodel Nijenhuis, Leiden University Library)

Andreas van Lugtenburgs Konst, in de Loop des Hemels, en vinding van Oost en West, en wat van zyn gedane Prognosticatien is te geloven (Johannes Loots, Amsterdam, 1705). Copies of this booklet are preserved in the Royal Library (The Hague), the library of the Free University of Amsterdam and the Dutch Maritime Museum (Amsterdam).

[45] S. van de Moolen, *Generale en Particuliere Uytrekening van een groote Zon-Eclips, op den 3 May, A°. 1715. Nevens een meetkonstige vertoning waar die op den Aardkloot zal konnen gezien werden, en ook in 't bezonder hoe die alhier zig zal vertoonen de grootheyt, de tyd van het begin, midden en eynde. Alles op een geheele uytvoerlyke wyze berekent en uytgewerkt, mitsgaders het berekenen van 't verscheen-zigts verschil in de Top-bogen, zonder Tafelen hier toe te gebruyken, en wanneer de Maan in haar hoogste boog komt* (Johannes Loots, Amsterdam, 1715). Copies of this booklet are preserved in the Leiden University Library and Museum Boerhaave (Leiden).

[46] A copy of the fold-out (without the booklet) is preserved in the collection Bodel Nijenhuis in the Leiden University Library (cat. nr. BN 144, nr. 180).

The second map, van Lugtenburg's *Nieuwe Wereld Kaart*[47] (Fig. 3), was dedicated to the burgomasters of Rotterdam and was published either in 1705 or in early 1706.[48] It consists of a world map with an explanatory section giving detailed predictions for the circumstances of the eclipse as it would be visible from various places in Europe.

The path of totality is only roughly indicated on van Lugtenburg's world map by two straight lines, running in north-easterly direction from the mid-Atlantic Ocean to a point north of Moscow and then in south-easterly direction to China (Fig. 4).

4.2 The eclipse maps published by Johann Baptist Homann

In Germany, the solar eclipse of 12 May 1706 was depicted on several retrospective eclipse maps issued by the Nuremberg publisher Johann Baptist Homann (1664–1724).[49] The maps were all based upon the calculations of the Nuremberg astronomer-mathematician Johann Gabriel Doppelmayr (1677–1750),[50] and the observations published by various European astronomers. Two maps were published shortly after the event (probably in the first months of 1707), while two more were published many years later.

The first map (Fig. 5), bearing the elaborate title cartouche *EUROPA Christiani Orbis Domina in sua Imperia, Regna, et Status exactè divisa per IOHAN BAPT. HOMANN Norimbergæ*, appears at first sight to be an ordinary map of Europe and its adjacent regions and waters.[51] However, a closer inspection reveals that it is a very sophisticated and accurate eclipse map.

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[47] The only known copy of this world map is preserved in the collection Bodel Nijenhuis in the Leiden University Library (cat. nr. BN 144, nr. 178). A French-language version of the same world map is preserved in the Rotterdam Maritime Museum (cat. nr. K 180).

[48] Van Lugtenburg's eclipse map was published after van de Moolen's eclipse map, as van Lugtenburg refers to van de Moolen's calculations in the explanatory section, but it too was published before the event.

[49] On Homann's publishing firm, see M. Diefenbacher, M. Heinz & R. Bach-Damaskinos (eds.), *"auserlesene und allerneueste Landkarten": Der Verlag Homann in Nürnberg 1702–1848* (Stadtarchiv Nürnberg/Stadtmuseum Fembohaus, Nuremberg, 2002).

[50] On Doppelmayr, see H. Gaab, "Johann Gabriel Doppelmayr (1677–1750)", in: W.R. Dick & J. Hamel (eds.), *Beiträge zur Astronomiegeschichte: Band 4* (Harri Deutsch, Frankfurt am Main, 2001 [= *Acta Historica Astronomiae*, nr. 13]), pp. 46–99.

[51] Reproduced in H. Wolff (ed.), *Vierhundert Jahre Mercator – Vierhundert Jahre Atlas: "Die ganze Welt zwischen zwei Buchdeckeln": Eine Geschichte der Atlanten* (Anton H. Konrad Verlag, Munich, 1995), p. 86 [fig. 55]. A detail from this map is also reproduced in Diefenbacher *et al.* [ref. 49], p. 124 [fig. 63]. Cf. also V. Hähnel, "Die Sonnenfinsternis am 12. Mai 1706", *Sterne und Weltraum*, **38** (1999), 422–423.

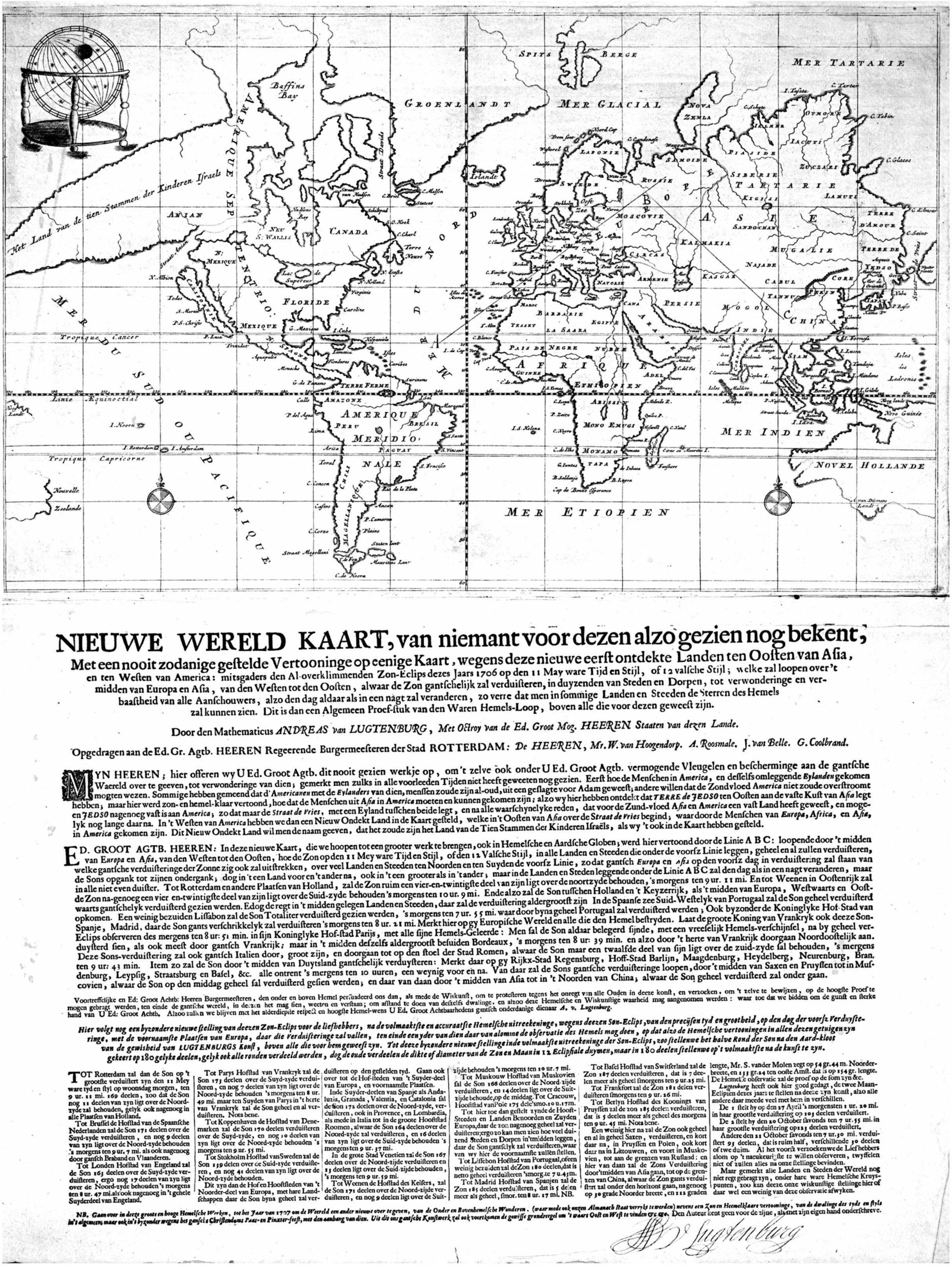

Fig. 3. Andreas van Lugtenburg's world map with predictions for the solar eclipse of 12 May 1706. (Collection Bodel Nijenhuis, Leiden University Library)

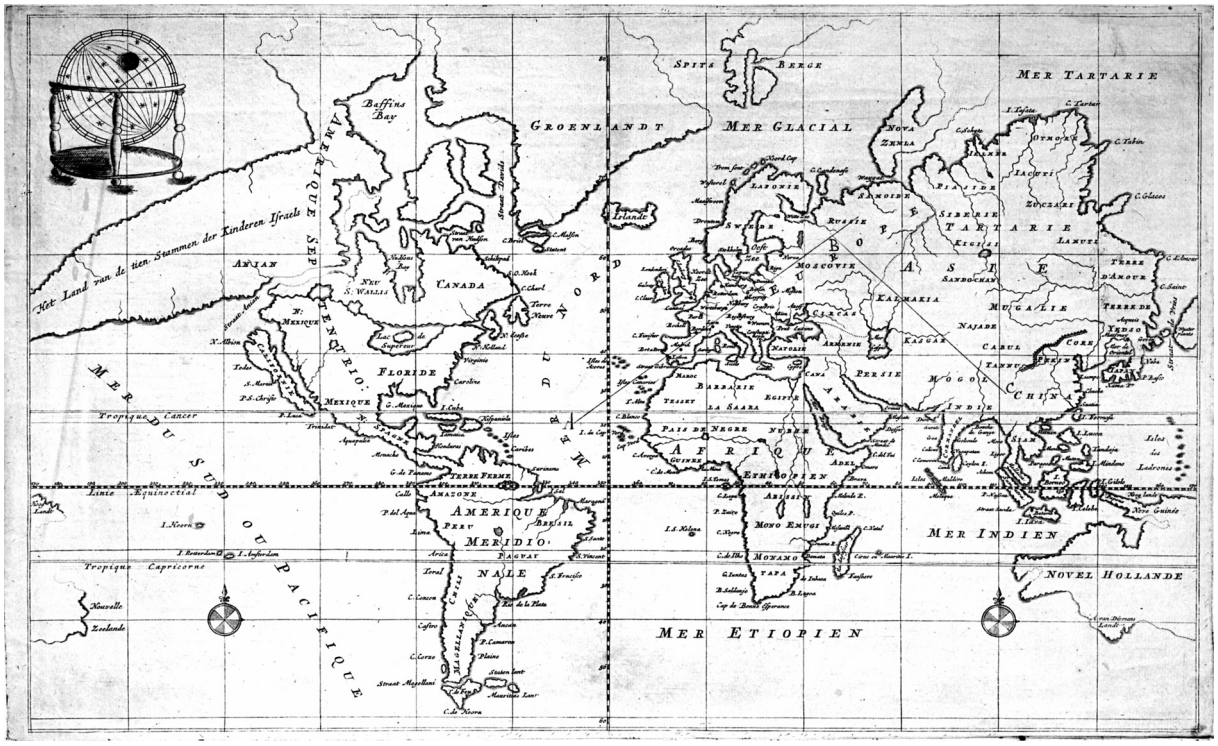

Fig. 4. Detail from van Lugtenburg's world map (Fig. 3). The central line of the solar eclipse of 12 May 1706 is indicated by the linear segments AB and BC. Note the greatly overestimated extent of northwest America, believed by van Lugtenburg to be the abode of the Ten Lost Tribes of Israel. The poor representation of the coasts of the Pacific Ocean and Australia is typical for maps from that period. (Collection Bodel Nijenhuis, Leiden University Library)

Running over the map is a parallel grid of dotted lines indicating the degree of obscuration of the solar diameter at maximum eclipse in 1-digit steps.[52] Between the northern and southern borders of the central line, the map furthermore has an explanatory text near to Strait of Gibraltar that reads:

> *Via centralis Eclipseos, ubi plena Nox fulgentibus stellis accidit cum mora 1. 2. 3. vel 4 minut. Anno 1706 die 12 May.*

Between Iceland and the Norwegian coast there is a short table (Fig. 6) with the caption:

> Geographica Repræsentatio EUROPÆ die 12. Maji 1706 ECLIPSATÆ *qua phasium Solis (in 12 digitos divisi) magnitudines quævis, suis locis apparentis, cum via totalis Umbræ, ex multis*

[52] Until the late 19th century, eclipse magnitudes were usually measured on a duodecimal scale with 12 indicating totality.

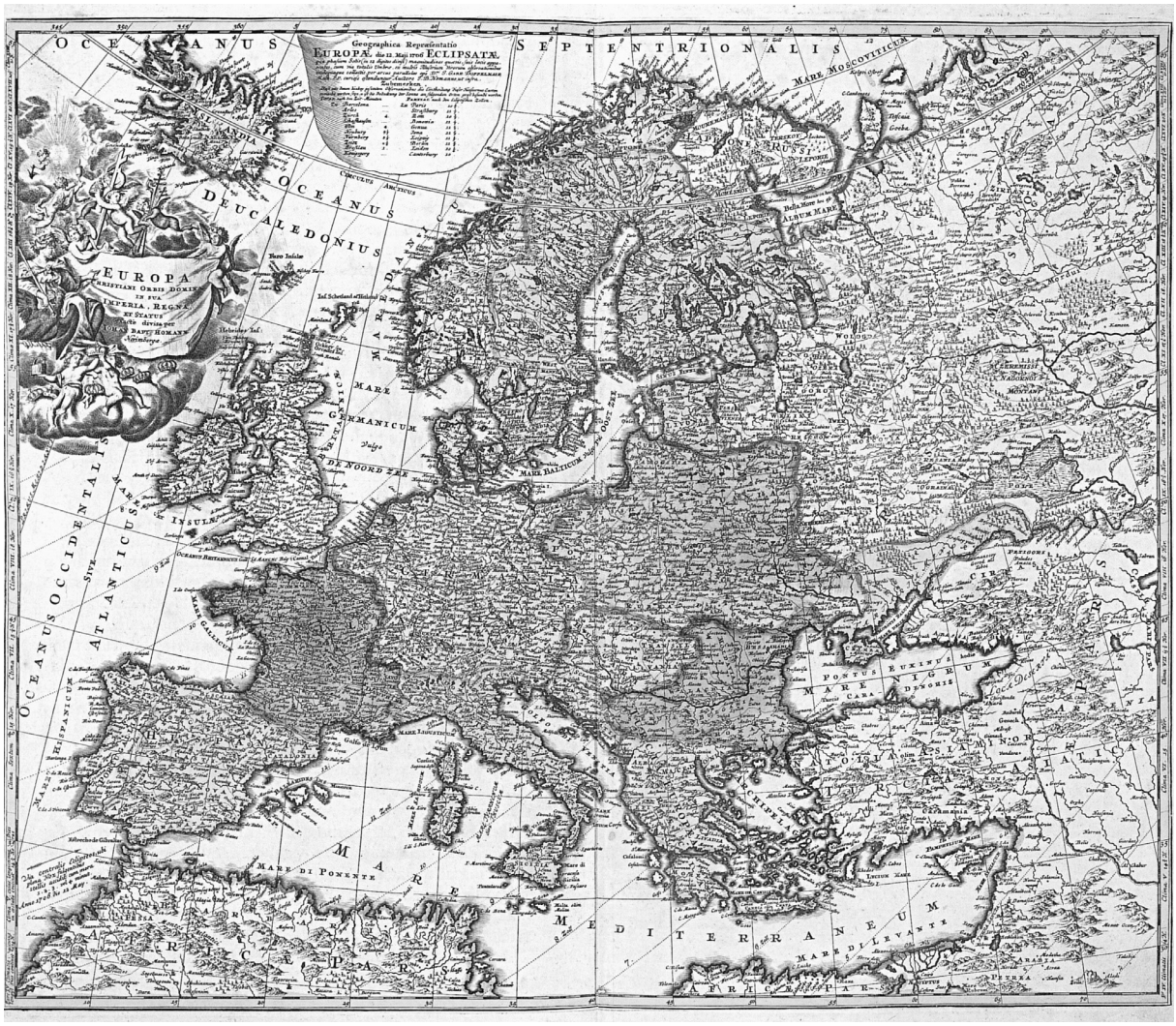

Fig. 5. Map of Europe published in 1707 on the solar eclipse of 12 May 1706 by the Nuremberg printer Johann Baptist Homann, based on the calculations of the Nuremberg astronomer Johann Gabriel Doppelmayr.

> *Illustrium Virorum observationibus undequaque collectis, per arcus parallelos ope D^ni. J. GABR. DOPPELMAYR Math. P.P. curiose ostenduntur Auctore J.B. Homanno, ut infra.*

This is followed by a table with the caption:

> Zu bemerken, *Daß aus denen hierbey gesetzten Observationibus die Eintheilung dieser Finsternus-Carten gemacht werden seyn, u. ist die Bedeckung der Sonne am folgenden Orten groß befundê worden*

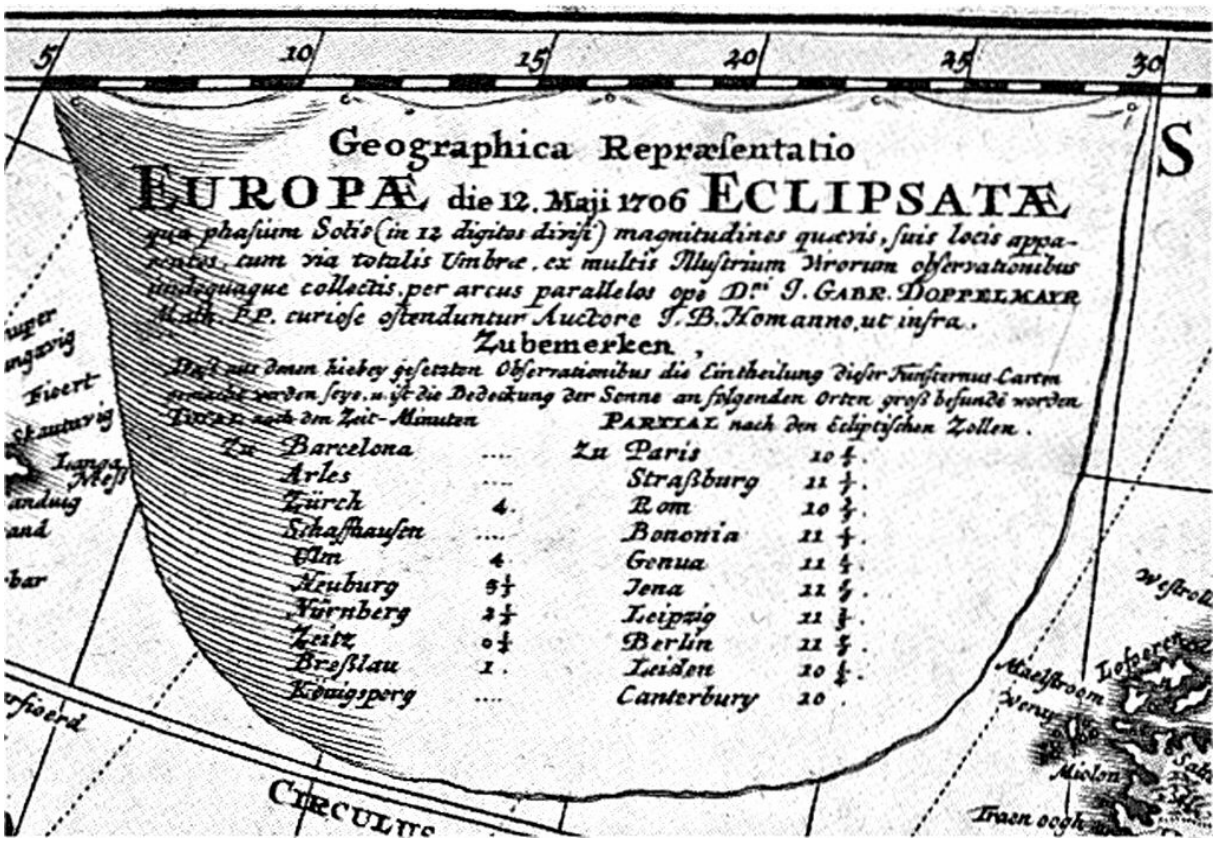

Fig. 6. Detail of Homann's map of Europe (Fig. 5), tabulating the duration of totality and the maximum eclipse magnitude as observed from various towns and cities in Europe.

TOTAL nach den Zeit-Minuten			*PARTIAL nach den Ecliptischen Zollen*		
Zu	*Barcelona*	...	*Zu*	*Paris*	10 5/6
	Arles	...		*Straßburg*	11 3/5
	Zürch	4.		*Rom*	10 3/5
	Schaffhausen	...		*Bononia*	11 1/3
	Ulm	4.		*Genua*	11 1/2
	Neuburg	3 1/3		*Jena*	11 5/6
	Nûrnberg	2 1/2		*Leipzig*	11 2/3
	Zeitz	0 1/2		*Berlin*	11 7/8
	Breßlau	1.		*Leiden*	10 1/2
	Königsperg	...		*Canterbury*	10.

The table lists the duration of totality (in minutes) and the eclipse magnitude as it was recorded by various observers. For certain cities in the path of totality (Barcelona, Arles, Schaffhausen and Königsberg), the duration of totality was left blank in the table. As will be explained further on, this was done on purpose and was not an error of the engraver.

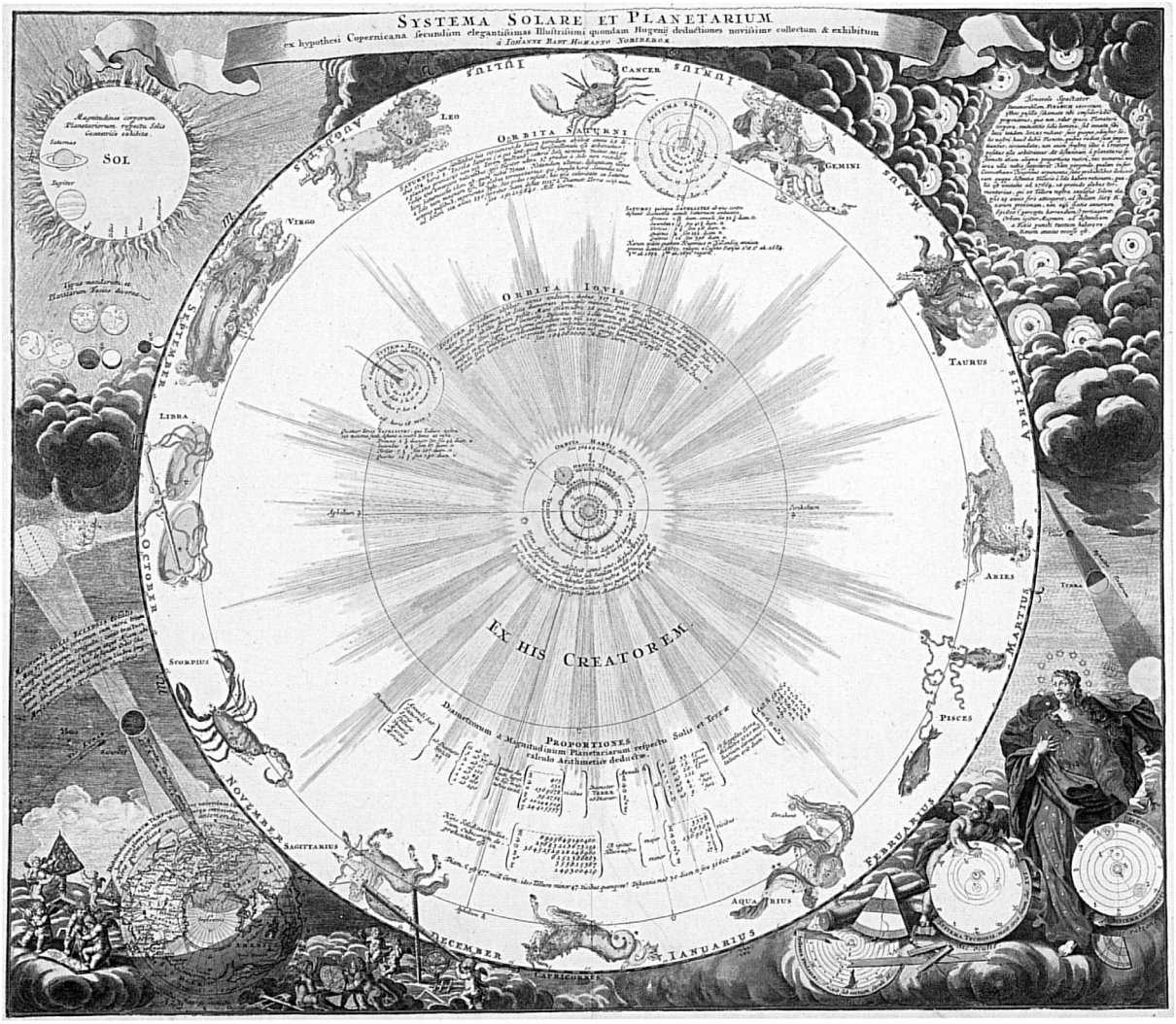

Fig. 7. Diagram of the Copernican world system designed by Johann Gabriel Doppelmayr, published in 1707 by the Nuremberg printer Johann Baptist Homann.

The second map, entitled *SYSTEMA SOLARE ET PLANETARIVM ex hypothesi Copernicana secundum elegantissimas Illustrissimi quondam Hugenii deductiones novissime collectum & exhibitum* (Fig. 7), features an inset in the left on the geometry of the solar eclipse of 12 May 1706. The map was also included in Homann's *Neuer Atlas* (1707), the *Atlas von hundert Charten* (1712), the *Grossen Atlas* (1716) and in Doppelmayr's *Atlas Coelestis* (1742).

On the left side of the map, a large inset gives particulars of the eclipse (Fig. 8). The explanatory text in the diagram reads:

> *Memoranda solis Eclipsis totalis 12 May 1706 alicubi terrarum cum mora trium et amplius minutorum conspecta, cuius tractum integram per universam Europam, atque Asiam, ubi plena*

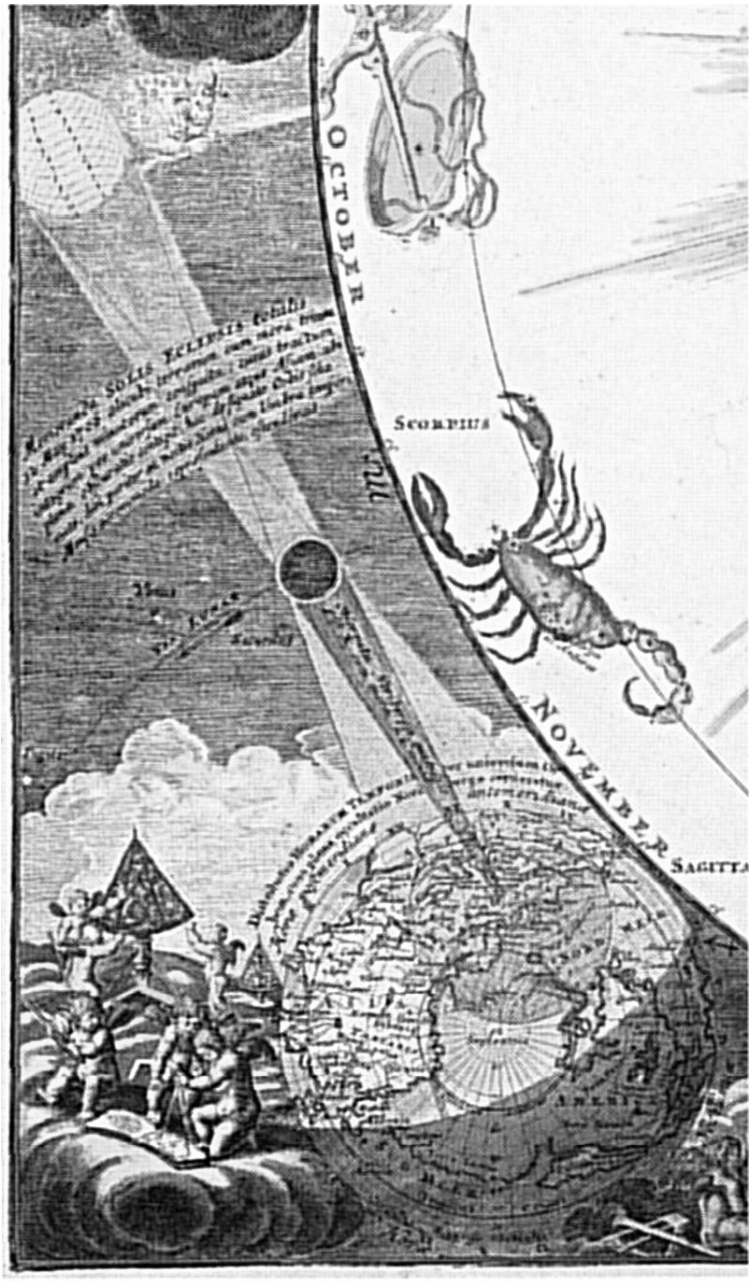

Fig. 8. Detail from the Homann/Doppelmayr diagram of the Copernican world system (see Fig. 7), explaining the geometry of the solar eclipse of 12 May 1706.

> *obscuratio contigit, hoc designato orbis schemate, diei pariter ac noctis Horas cum Umbra tempori Mensis accomoda repræsentente ostendimus.*

The solar disk is depicted on the top, with the lunar disk at one-digit intervals indicating the ingress and the egress of the eclipse. As indicated in the diagram the eclipsed sun was in the constellation of Taurus attended

by the planets Saturn, Venus and Jupiter.[53]

Inside the shadow cone of the Moon, the text reads:

Observati Noribergæ quidrante post X cum mora $2\frac{1}{2}$ *minut.*

Both maps were described in detail in a 55-page booklet published by Doppelmayr.[54] In the booklet, Doppelmayr refers to an approaching lunar eclipse (on 16/17 April) and transit of Mercury across the Sun's disk (on 5/6 May), thus indicating that the booklet and the maps that it describes were published during the first months of 1707.[55] From the booklet we also learn the reason why for certain cities listed in the table on the map of Europe the duration of totality had been left blank. The observed duration of totality had been too long compared with that obtained from calculation and had probably been based on subjective estimates rather than on actual measurements.[56]

4.3 Further eclipse maps published by Doppelmayr

As scientific advisor to the cartographic publisher Homann, it is easily to understand why Doppelmayr had a great interest in solar eclipses and their application to the determination of geographical longitudes. This interest is also evident from two plates published by Doppelmayr in 1742 in his *Atlas Coelestis*,[57] on the topic of eclipses in general and on the knowledge

[53] Modern calculations, such as with the PC astronomy program RedShift, show that the diagram is in error here as the last mentioned planet should be Mercury, not Jupiter.

[54] J.G. Doppelmayr, *Ausführliche Erklärung über Zwey neue Homännische Charten, als über das SYSTEMA SOLARE ET PLANETARIUM Copernico-Hugenianum, und EUROPAM ECLIPSATAM, in welcher alles was in besagten Charten angemercket worden, absonderlich die leßte, sowol universal in dem Systemate Planetario, als particular und besonders in dem Europa Eclipsata vorgestellte grosse Sonnen-Finsternuß vom 12ten May des vergangenen 1706ten Jahrs, samt einer Astronomia comparativa, oder wie die Beschaffenheit der Stern aus der Sonne und einen jeden Planeten seyn mögte* (J.B. Homann, Nuremberg, 1707). I am grateful to Hans Gaab (Nuremberg) for providing me with a photocopy of this booklet.

[55] Doppelmayr [ref. 54, pp. 25 & 28].

[56] According to Doppelmayr [ref. 54, pp. 22–23], totality had been estimated to last 7 minutes in Schaffhausen, 6 minutes in Barcelona and 5 minutes in Arles, while his calculations indicated that the eclipse had nowhere lasted more than 4 minutes.

[57] J.G. Doppelmayr, *Atlas Coelestis in quo Mundus Spectabilis et in eodem Stellarum omnium Phoenomena notabilia, circa ipsarum Lumen, Figuram, Faciem, Motum, Eclipses, Occultationes, Transitus, Magnitudines, Distantias, aliaque secundum Nic. Copernici et ex parte Tychonis de Brahe Hipothesin. Nostri intuitu, specialiter, respectu vero ad apparentias planetarum indagatu possibiles e planetis primariis, et e luna habito, generaliter celeberrimorum astronomorum observationibus graphice descripta exhibentur, cum tabulis majoribus XXX* (Haeredis Homanni, Nuremberg, 1742).

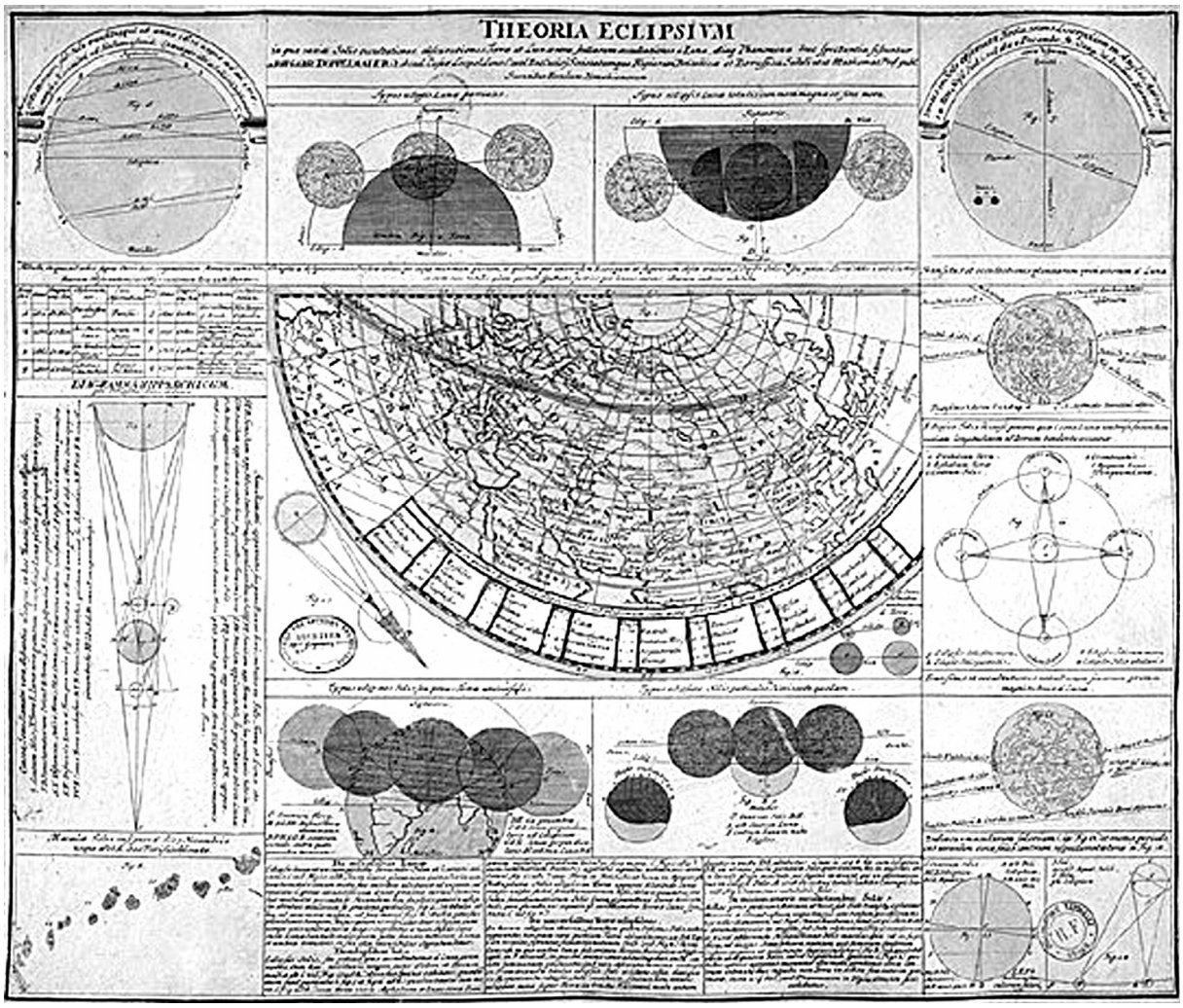

Fig. 9. Doppelmayr's plate on the general theory of eclipses. The centre features a map of Europe and Asia with the path of the solar eclipse of 12 May 1706 (*Atlas Coelestis*, Nuremberg, 1742).

of astronomically determined geographic longitudes and latitudes in his time.

In the *THEORIA ECLIPSIVM in qua variæ Solis occultationes, obscurationes Terræ et Lunæ veræ, stellorum occultationes a Luna, aliiq. Phænomena huc spectantia sistuntur* (plate 13 in the *Atlas Coelestis*), in which Doppelmayr explained the various kinds of eclipses of the Sun, the Moon and the fixed stars by the Moon, the central part is filled by a map of Europe and Asia with the path of the solar eclipse of 12 May 1706 (Fig. 9).

In his *BASIS GEOGRAPHIÆ RECENTIORIS ASTRONOMICA in qua situs locorum insigniorum geographici ea exactitudine, qua celeberrimi Astronomi eosdem per observationes è plurimis luminarium et circumjovialium Eclipsibus nobis hactenus suppeditarunt pro certiori Geographiæ stabilimento positi designantur* (plate 15 in the *Atlas Coelestis*), Doppelmayr

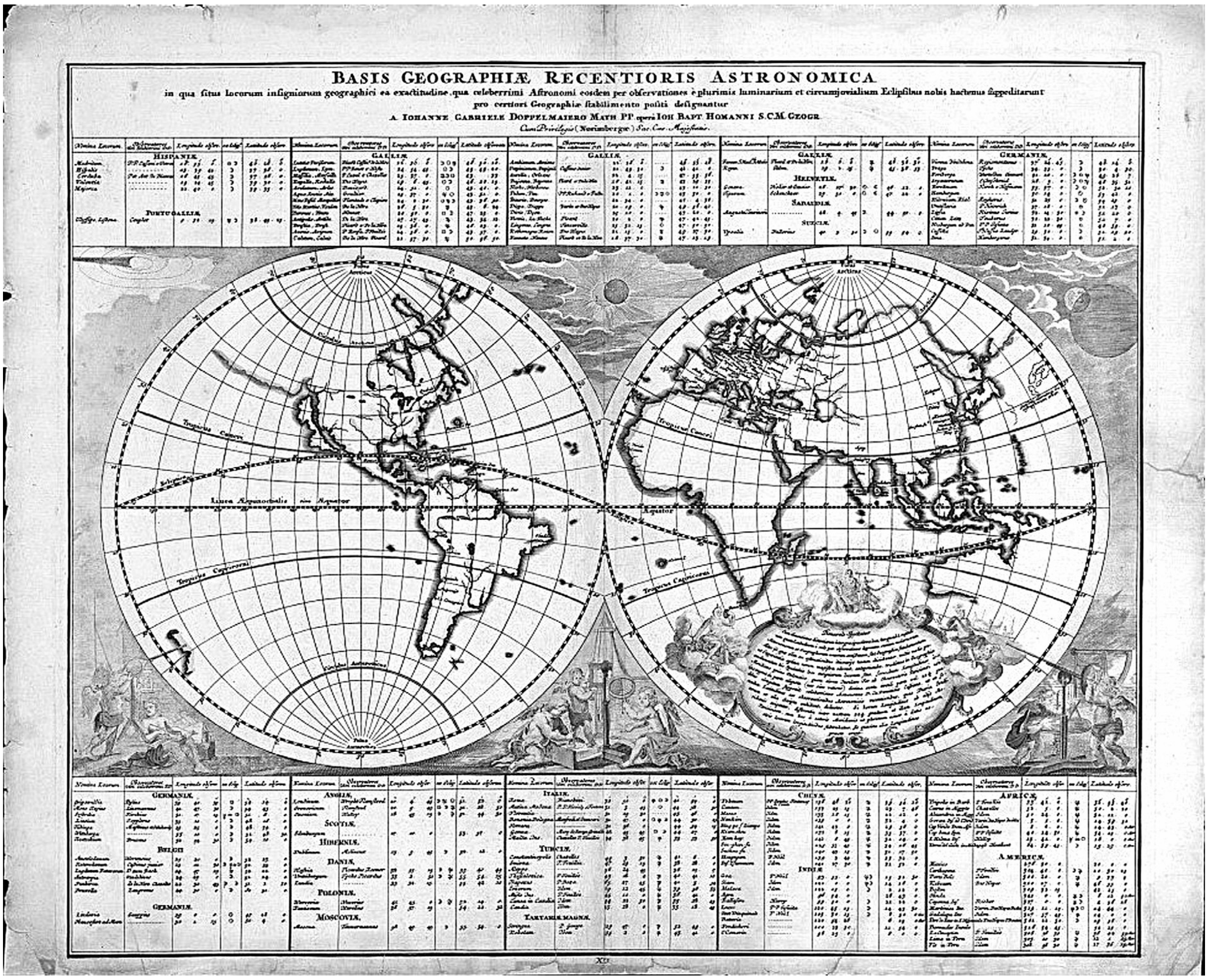

Fig. 10. Doppelmayr's world map *Basis Geographiæ Recentioris Astronomica*, based on the astronomically determined positions of various locations on the globe (*Atlas Coelestis*, Nuremberg, 1742).

presented a world map based on the astronomically determined positions of some 140 towns and cities derived from observations of lunar and solar eclipses and eclipses of the Jovian satellites (Fig. 10).[58]

4.4 The celestial planisphere published by Abraham Allard

Several maps in Dutch cartographic collections provide graphic proof that the Homann/Doppelmayr publications on the solar eclipse of 12 May 1706 had a great influence on Dutch cartographers.

In early May 1708, the Amsterdam map seller Abraham Allard (*c.* 1675–*c.* 1730) published a pair of celestial planispheres that were clearly influenced by the work of Homann and Doppelmayr.[59]

[58]Doppelmayr's world map is discussed in detail in A. Hanle & O. Mittelstaedt, "Basis

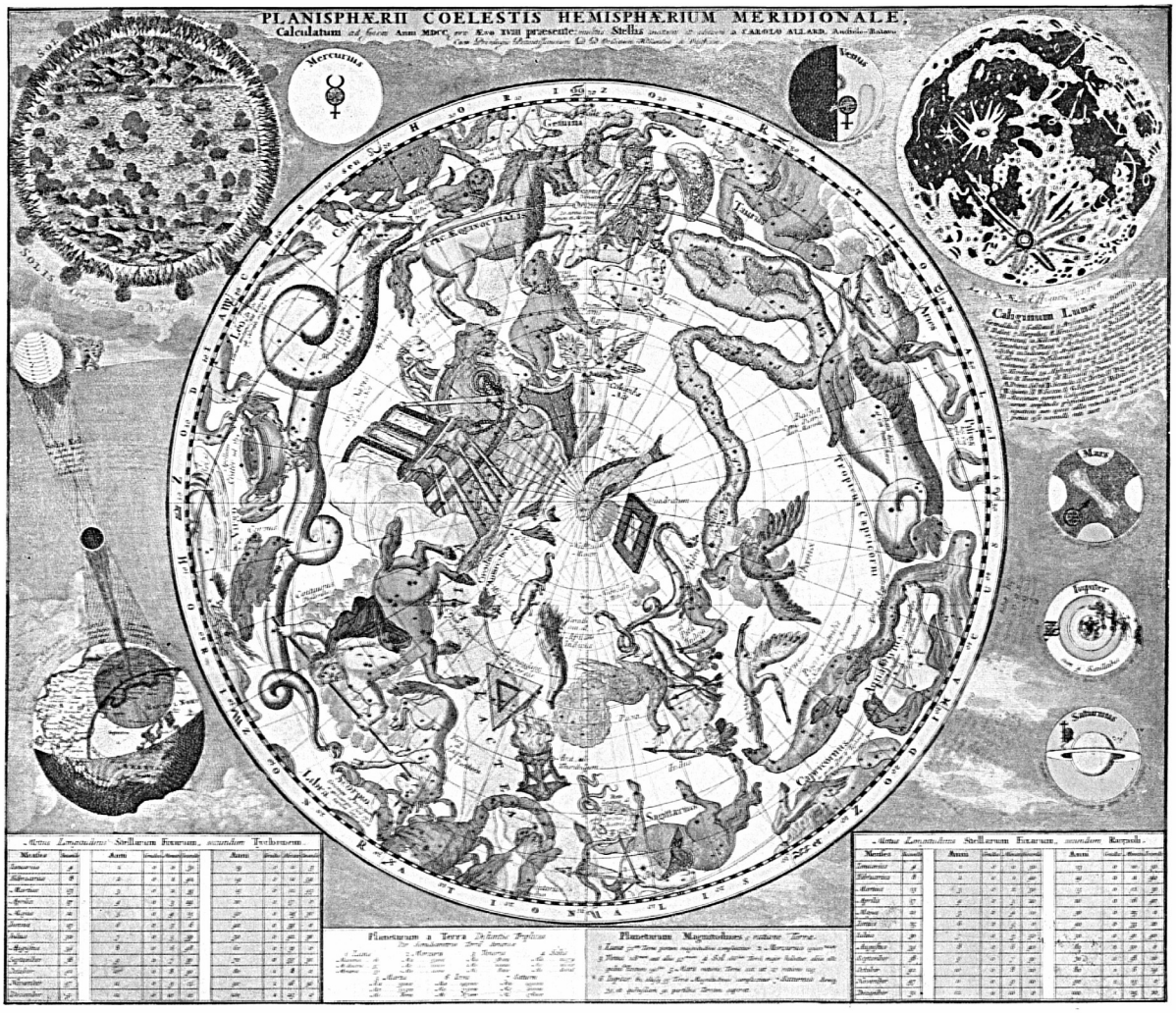

Fig. 11. Celestial planisphere depicting the southern constellations published in 1708 by the Amsterdam map seller Abraham Allard. The diagram in the left was copied from the Homann/Doppelmayr plate on the Copernican world system (see Fig. 7).

Allard's planisphere (Fig. 11),[60] entitled *PLANISPHÆRII COELESTIS HEMISPHÆRIUM MERIDIONALE, Calculatum ad finem Anni MDCC, pro ÆVI XVIII præsente multis Stellis auctum et editum* and depicting the southern constellations for the equator and equinox of 1701.0, includes a solar eclipse diagram that was copied from the Homann/Doppelmayr plate

Geographiæ Recentioris Astronomica", *Sterne und Weltraum*, **19** (1980), 407–410.

[59] The publication was announced in an advertisement in the *Amsterdamse Courant* of 8 May 1708. Cf. P.C.J. van der Krogt, *Advertenties voor kaarten, atlassen, globes e.d. in Amsterdamse kranten 1621–1811* (HES Uitgevers, Utrecht, 1985), p. 70 [nr. 301]. The map title attributes the planisphere to Abraham's father, Carel Allard (1648–1706), under whose name Abraham appears to have published his products.

[60] The planisphere is poorly reproduced in R.A. Skelton, *Decorative Printed Maps from the 15th to 18th Centuries*, 2nd ed. (Spring Books, London, 1965), p. 66 & plate 72.

Fig. 12. Copy of the Homann/Doppelmayr map of Europe with the path of the solar eclipse of 12 May 1706 published around 1715 by the Amsterdam map seller Petrus Schenk jr. (Collection Bodel Nijenhuis, Leiden University Library)

explaining the Copernican world system.[61]

4.5 The eclipse maps published by Petrus Schenk sr. and Petrus Schenk jr.

Shortly after 1707 the Homann/Doppelmayr map of Europe with the path of the solar eclipse of 12 May 1706 was reprinted by the Amsterdam publisher Petrus Schenk sr. (1661–1711) with the title *ECLIPSEOS SOLIS*

[61] According to D.J. Warner, *The Sky Explored: Celestial Cartography 1500–1800* (Alan R. Liss/Theatrum Orbis Terrarum, New York/Amsterdam, 1979), pp. 2–3, Allard's planispheres were later included in Nicholas Visscher's *Atlas minor sive geographia compendiosa* (Amsterdam, *c.* 1717) and were reprinted again by Covens & Mortier in their *Nieuwe Atlas* (Amsterdam, *c.* 1759 and later editions).

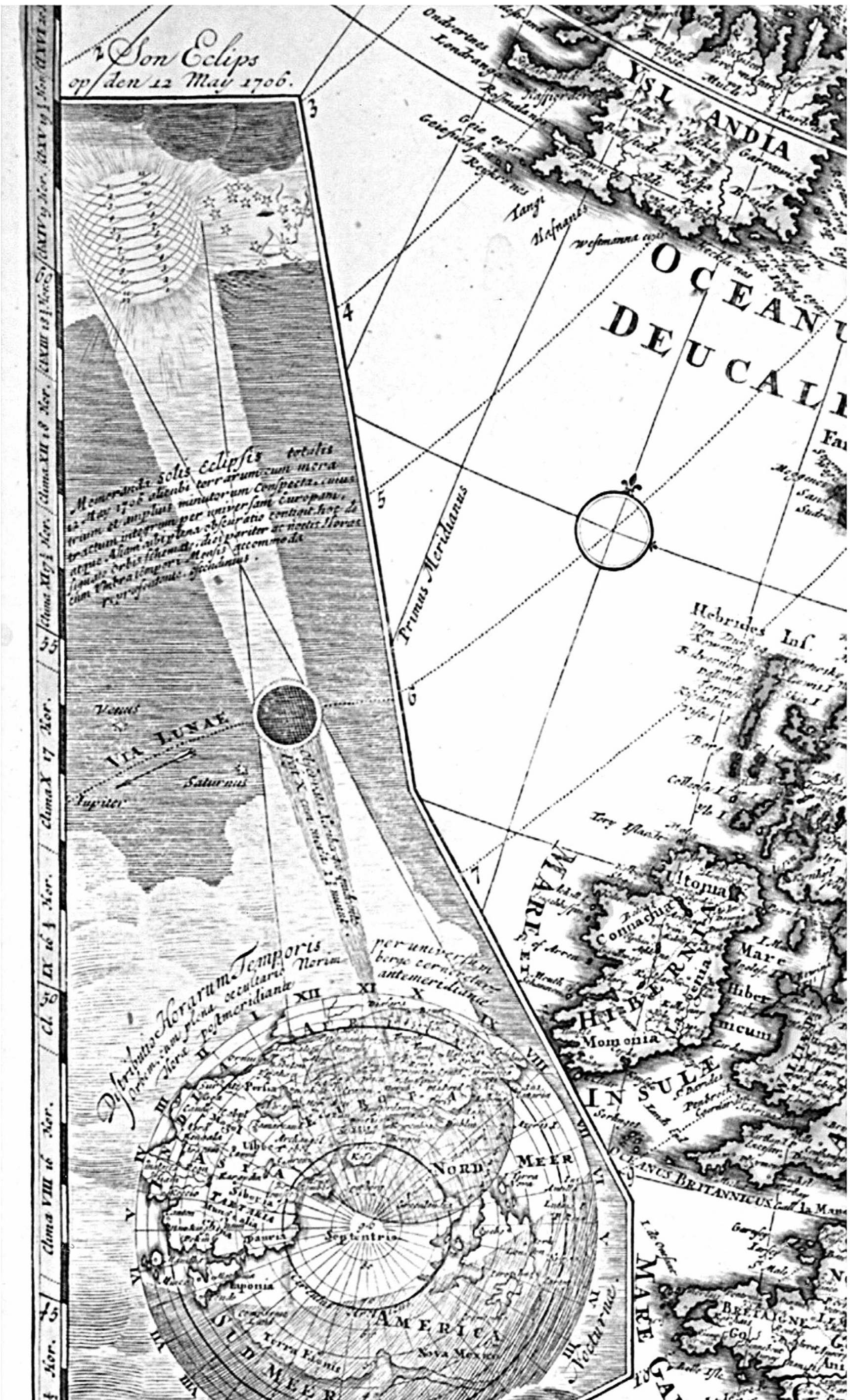

Fig. 13. Detail of the Petrus Schenk jr. map of Europe depicting the relative positions of the Sun and the Moon during the solar eclipse of 12 May 1706. (Collection Bodel Nijenhuis, Leiden University Library)

Fig. 14. Detail of the Petrus Schenk jr. map of Europe depicting the global circumstances of the solar eclipse of 3 May 1715 as predicted by Symon van de Moolen. (Collection Bodel Nijenhuis, Leiden University Library)

TOTALIS cum mora, d. 12 Maji 1706, horis autem: in EUROPA celebratæ, Geographica Repræsentatio, in: qua CENTRALIS UMBRÆ TRACTUS ac reliquæ Magnitudines suis locis competentes, ex Illustrium Virorum observationibus deductæ, per arcus parallelos, ceu digitorum singulorum indices, ope D^ni. J. Gabr. Doppelmayr Math. P.P. et Simon à Moolen Mathematici.[62] The map was printed again by Petrus Schenk jr. (1693–1775) in, or around, 1715 (Fig. 12).[63]

Both maps appear to be exact copies of the 1707 Homann/Doppelmayr map of Europe but they differ in two respects. In the place of the elab-

[62] Two copies of this map are preserved in the collection Bodel Nijenhuis in the Leiden University Library (cat. nrs. BN 207, nr. 43 [coloured] & BN 212, nr. 13 [uncoloured]).

[63] Two copies of this map are preserved in the collection Bodel Nijenhuis in the Leiden University Library (cat. nrs. BN 169, nr. 25 & BN 212, nr. 14 [both coloured]). Further copies of this map (either the first or the 1715 edition) are preserved in the Stadsarchief en Athenaeumbibliotheek (Deventer), the Staatsbibliothek zu Berlin (Preußischer Kulturbesitz) and in the Bayerische Staatsbibliothek (Munich).

orate title cartouche on the Homann/Doppelmayr map, the Schenk maps insert the solar eclipse diagram from the Homann/Doppelmayr plate on the Copernican world system (Fig. 13). And in the space between Iceland and the Norwegian coast, where the Homann/Doppelmayr map places Doppelmayr's table of observed eclipse durations and magnitudes, the map of Schenk sr. inserts the eclipse diagram from Symon van de Moolen's booklet on the solar eclipse of 1706 (cf. section 4.1 and Fig. 2). In Schenk jr.'s reprint of his father's map, the diagram of the solar eclipse of 1706 is replaced by van de Moolen's diagram of the solar eclipse of 1715 (Fig. 14).

In Schenk sr.'s map, both insets carry no captions, but in the map of Schenk jr. Dutch captions were added to distinguish between the solar eclipses of 1706 (*Son Eclips op den 12 May 1706*) and 1715 (*Son Eclips op den 3 May 1715*).

5 Conclusions

The cartographic material discussed in this paper clearly proves that the commonly held claim that the earliest solar eclipse maps were made by Edmond Halley is unfounded. So far, several earlier examples have been found which were printed in France, Germany and in the Low Countries. The earliest eclipse maps appear to have originated around 1700 as the result of Jean Dominique Cassini's investigations in the use of solar eclipses for determining geographical longitudes.

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