Chapter 1
A Brief Biography of Jost Bürgi (1552–1632)

Introduction

Several German- and French-language resources contain brief biographies of Jost Bürgi (e.g., Cantor 1900; Lutstorf 2005; Montucla 1758; Naux 1966; Wolf 1858). No substantial personal information on Jost Bürgi[1] exists in the English language, other than the short (just over one page) account by Nový (1970) in the *Dictionary of Scientific Biography*. We can, however, construct a decent timeline of Bürgi's life from German-language resources (see Appendix A), particularly when it is situated with respect to Bürgi's contemporaries who were engaged in or aided in the development of scientific work dependent upon the logarithmic relationship. Staudacher (2014) published (in German) a quite extensive account of Bürgi's life, which included content on his mathematical and scientific achievements and contributions, as well as accompanying obstacles, family relationships, and other personal attributes. Using translations of Staudacher's text, as well as more traditional sources of biographical information on Bürgi, the major aspects of Bürgi's professional life are highlighted in the brief biography presented here.

Lichtensteig and Surrounds: Bürgi's Early Life and Work (1552–1579)

Bürgi was born 28 February 1552, in Lichtensteig in the Toggenburg, a 70 km long alpine highland valley along the Thur River and southwest of Mount Säntis in the Canton of St. Gallen, Switzerland. Jost and his parents were Protestant, which was

[1] Bürgi's given name is sometimes given as Joost, Jobst, or Justus (when used with the Latinized version of his surname, Byrgius).

K. Clark, *Jost Bürgi's Aritmetische und Geometrische Progreß Tabulen (1620)*,
Science Networks. Historical Studies 53, DOI 10.1007/978-1-4939-3161-3_1

representative of the majority of Roman Catholic and Protestant families living in this small village of approximately 400 inhabitants (Figure 1.1). We do not know anything of substance about Bürgi's early learning (Waldvogel 2012, p. 3), except that he probably received an almost complete 6-year formal education that was typical of boys in Bürgi's time and until the beginning of the twentieth century (Staudacher 2014). In 1564, Bürgi finalized his formal education, but due to religious battles as a result of the Counter-Reformation in Switzerland, Lichtensteig was often left without a teacher. Consequently, Jost and his classmates may have lost 1 year of the 6-year formal education. Although the majority of people of the Toggenburg Valley supported and followed the Protestant teachings of Ulrich Zwingli (1483–1531), the citizens were almost always overruled by the duke-abbot of the St. Gallen monastery. According to Staudacher (2014), the lessons in public schools were composed of up to 50 % choral singing lessons, with the remainder in computing, reading, and writing. Bürgi did not know Latin (and certainly did not write or publish in Latin) and regarding his knowledge of scientific languages, Bürgi stated:

> Weil mir auß mangel der sprachen die thür zu den authoribus nit alzeitt offen gestanden, wie andern, hab jch etwas mehr, als etwa die glehrte vnd belesene meinen eigenen gedanckhen nachhengen vnd newe wege suechen müessen. (List and Bialas 1973, p. 7)[2]

After his early and brief education and beginning in 1565 (Staudacher 2014), Bürgi began training in various trades that later contributed to the craftsmanship necessary for instrument making by working with his father, who was a locksmith.[3] Bürgi possibly trained as a goldsmith between 1565 and 1567 with David Widiz (~1535–1596), when Widiz relocated to Lichtensteig from Augsburg (Staudacher, p. 52).

Bürgi most likely apprenticed with someone with experience in making technical instruments, such as clock- and watch-making. Faustmann (1997) and Naux (1966) noted that Bürgi possibly worked as a traveling apprentice in Straßburg, where he may have come in contact with the teachings of Conradus Dasypodius[4] (~1531 to ~1601). According to Sesiano (in the *Historical Dictionary of Switzerland*, 1986), Dasypodius was a mathematics professor at the Academy of Straßburg from 1562, where he also took care of Swiss fellows studying there. Dasypodius also continued the design and construction of the second version of the astronomical clock for the Straßburg Cathedral (built during 1570–1574), and Bürgi may have participated in the construction of this clock (Waldvogel 2014). Some experts still believe this hypothesis, put forth by Rudolf Wolf (1858), made sense at the time due to Bürgi's potential training trajectory.

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[2] *Because I did not know other languages, the doors to the well-known scientists were not always open for me. So, opposite to the well-educated scholars, I had to think a little bit more by myself and find my own ways.*

[3] In the sixteenth century, the professions of locksmithing and making clocks were closely connected.

[4] Dasypodius' German surname was "Rauchfuss." Rauchfuss followed the practice of his time and grecianized his name to "Dasypodius."

Figure 1.1 Part of a stained glass coat of arms that mentions the grandparents of Bürgi (photo courtesy of Toggenburger Museum, Lichtensteig, Switzerland)

The construction of the second version of Straßburg Cathedral’s clock was carried out by the well-known clockmakers Isaac and Josias Habrecht (of the Canton of Thurgau, Switzerland). This version of the astronomical clock, which operated well into the eighteenth century, was well known for its complexity because of its numerous devices, including indicators for planets and eclipses, calendar dials, and the astrolabe. Wolf’s speculation that Bürgi apprenticed under the Habrechts during the construction of the cathedral’s clock in Straßburg has persisted for more than 150 years, but today it is denied by experts such as Roegel, Oechslin, and Oestermann. Waldvogel (2014) and Staudacher (2014) speculated that Bürgi might have acquired his skills in Schaffhausen, Switzerland, which is closer to Lichtensteig in eastern Switzerland and where the Habrecht family built clocks until at least 1572 before moving to Straßburg. The Habrechts designed and constructed the Bern, Solothurn, and Schaffhausen astronomical clocks, as well as clocks in many cities of southern Germany, including Heilbronn, Donaueschingen, Ulm, and Altdorf near Nürnberg (Staudacher 2014, pp. 55–56).

In 1570 or 1571, Bürgi most probably completed his professional trades training, and from about 1571 he worked as a clockmaker in various locations, possibly in Augsburg due to the many connections he held with people from there (e.g., Widiz), and later in Nürnberg. In 1576, Christoph Heiden (1526–1576), a famous mathematician and celestial-terrestrial globe inventor, died in Nürnberg, and Bürgi, who was in Nürnberg as well, finalized a celestial-terrestrial globe that was under construction in Heiden's workshop.[5] Heiden received orders directly from Emperor Maximilian II and also served as first president of Altdorf University in Nürnberg.

Also in 1576, Maximilian II died, and his son Rudolf II von Habsburg (1552–1612) was named successor and emperor of the Holy Roman Empire. Rudolf II was deeply interested in the arts and sciences, including alchemy. Since he was not as engaged in the political, ceremonial, and daily managerial duties of his position, he moved the seat of the Habsburg Empire from Vienna to Prague in 1583, to serve as better protection against the Ottoman Turks. In 1592 and upon the recommendation of Vice Chancellor Jacob Curtius (1554–1594), Rudolf II selected Nicolaus Reimers Baer, or Nicolaus Reimers Ursus[6] (1551–1600), as imperial mathematician. Then, in 1599 and after recommendation of his Imperial Physician Thaddäus Hagecius (1525–1601), he named Tycho Brahe (1546–1601) of Denmark as imperial astronomer to his court in Prague. Eventually, in 1601, Rudolf selected Johannes Kepler (1571–1630) as Brahe's successor, and, by following his own interest in goldsmithing and clockmaking, Rudolf selected Jost Bürgi as his imperial clockmaker in 1604.

However, before Bürgi worked in Nürnberg, close connections developed between Duke Wilhelm IV (1532–1592) and Georg Joachim Camerarius (1534–1598), as well as between Heiden, Camerarius, and Bürgi. In 1579, the duke invited Bürgi to court in Kassel to work as a clockmaker and also as a craftsman in his observatory (Staudacher 2014). To receive such an invitation from the duke would have meant that Bürgi was already established with most of the skills and knowledge to deserve such a prestigious appointment in the observatory in Kassel.

Connections in Kassel: 1579–1603

After arriving in Kassel in 1579, Bürgi was engaged in clock and instrument making, and later in astronomy and mathematics, as well. In 1580 he built his first Kassel celestial sphere, worked with astronomical instruments, and developed various metal sextants in brass, steel, and copper. In 1583, Bürgi invented his own type of proportional compass, and in 1584, he created the world's first clock precise to the second and which indicated seconds both visually and auditorily. As a prerequisite to this revolutionary observatory clock, Bürgi had to invent new methods and mechanical systems for smoothly and steadily distributing the initial forces of a weight or of a spring, which was realized by his inventions of the cross-beating escapement and of the rewound weight. Notably, both of these Bürgi inventions were in place 70 years before Huygens' and Newton's pendulum clocks and 120

[5] This is a newly discovered fact taken from the inventory list of Emperor Rudolf II's Kunstkammer (i.e., a "collector's cabinet," which contains a collection of curiosities and treasures) in Prague (Staudacher 2014, p. 76).

[6] Several variations exist for Reimers' name, some of which include Reimarus Ursus, Raimarus Ursus, and Nicolaus Reymers Baer. In this chapter, I will use Reimers.

years before John Harrison's chronometer (Staudacher 2014). It is not surprising then that in a letter to Brahe in 1586, Wilhelm IV said: "…unsers Uhrmachers M. Just [Bürgi], *qui quasi indagine alter Archimedes* ist."[7]

Most importantly for the time period 1584/1585, Bürgi, Christoph Rothmann (1551–1600), and Wilhelm IV—all as astronomers in Kassel—began a new measurement program of the stars in order to obtain better data for navigation, astronomy, and astrology. Two years after beginning their work, the *Grand Hessiae Register of Stars* (in the original German: *Grosses Hessisches Sternverzeichnis*) was completed and included 383 newly measured stars (Staudacher 2014, p. 134).

In 1584, Paul Wittich (~1546–1586) arrived in Kassel and stayed several months, and during the same time period, Bürgi began a search for ways in which to improve methods and formulae for prosthaphaeresis.[8] As a result of his extraordinary mathematical and technical talent and from his experience in calculating and formulating gearings, Bürgi was well positioned to contribute to innovations necessary to improve upon astronomical calculations. And, in order to improve upon such work at the time, Bürgi would have needed to be knowledgeable of the notion of prosthaphaeresis and computation involving sines.

Prosthaphaeresis, a process that converts more complicated multiplication (or division) into simpler addition (subtraction), was probably well known to Islamic scientists from at least the eleventh or twelfth century. Prosthaphaeretic formulas, in modern trigonometric notation, include the identities

$$\cos(a+b)=\cos(a)\cos(b)-\sin(a)\sin(b)$$

and

$$\cos(a-b)=\cos(a)\cos(b)+\sin(a)\sin(b)$$

To observe the "product to sum" transformation, we first subtract the second formula from the first

$$\cos(a-b)-\cos(a+b)=2\sin(a)\sin(b);$$

and isolating the product term yields

$$\sin(a)\sin(b)=\frac{1}{2}\left[\cos(a-b)-\cos(a+b)\right].$$

Thus, when two angle measures are known, an easier calculation is made when subtracting the cosine of their sum from the cosine of their difference and then dividing the result by 2, as opposed to multiplying two sine values.

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[7] "…*our clockmaker Jost Bürgi,* who is almost on the way of another [a second] Archimedes" (Roegel 2010a, p. 5).

[8] *Prosthaphaeresis*, from the Greek *prosthesis* (addition) and *aphaeiresis* (subtraction).

There has been much speculation about Bürgi's contribution to the improvement of prosthaphaeresis, as well as his construction of a table of sines. For example, Thoren (1988) discussed Bürgi's role in the evolution and publication of the trigonometric formulas that reduce a more complicated operation (multiplication) into a simpler one (subtraction), as in the formula above. In his account, Thoren traced the first publication of the method of prosthaphaeresis to Reimers, who first mentioned Bürgi's calculations in 1588. Attributing this "first" to Reimers is questionable, according to Thoren, and he discussed the potential contribution of Tycho Brahe, Paul Wittich, and Jost Bürgi to the use, publication, and geometrical proof of prosthaphaeretic formulas (e.g., for computing sin(a)sin(b)). Moreover, Thoren stated that:

> Ursus…issued a disclaimer in 1597…. According to him, Wittich…brought the *method* to the astronomical observatory of the Landgrave [Landgraf] of Hessen-Cassel in 1584; but what he brought was only one prosthaphaeretic equation (for sin A sin B), and no *proof* for it! It had been the Landgrave's [Duke's] clock-maker, Joost Bürgi, Ursus said, who devised a geometrical proof for that identity. (Emphasis in the original, p. 33)

In approximately 1586 or 1587, Bürgi designed and constructed a three-dimensional planetarium (i.e., a planetary model) for Reimers, of his "Tychonian" world model (Staudacher 2014, p. 119). The Tychonian model of the universe was a hybrid model of Ptolemy's geocentric model, where the sun and planets orbit around the Earth, and of Copernicus' heliocentric world model, which places the sun at the center. The hybrid model had the support of the Jesuits and also had two inventors, Reimers and Tycho Brahe, each of whom fought hard for his own priority until the death of Reimers in 1600. The hybrid world model shows the Earth in the center, surrounded by the moon and the sun. The other planets revolve about the sun, and all together they revolve around the Earth. Bürgi then constructed a second version of the planetary model at the request of Wilhelm IV and which incorporated feedback from Rothmann. In 1587, Reimers translated Copernicus' *De revolutionibus orbium coelestium* into German for Bürgi. Despite Bürgi's lack of Latin ability, his friend Reimers—imperial mathematician to Emperor Rudolf II—also likened Bürgi's abilities to those of Euclid an Archimedes (Gaulke 2015).

Afterwards (from 1587 until 1591), Bürgi began new work on the measurement of celestial bodies in order to define better orbital paths of the sun, Earth, and moon. And, in December 1590 until 1597, "Bürgi…regularly determined the angular distances of the planets and the Moon from those of the fixed stars recorded in the [*Grand Hessiae Register of Stars*] catalogue of 1587" (Gaulke 2015, p. 45). He needed these data for computations and to design a mechanically working device of Copernicus' moon theory to be integrated in the equation clock (or solar and lunar anomalies clock) of 1591.[9] This small table clock showed the mean moon and sun positions, as well as the highly accurate relative positions of the sun, the moon, (including eclipses), and the fixed stars (astrolabium dial) through the creation of elliptic movements of epicyclical and differential-epicyclical gearings. To integrate

[9] For a detailed discussion of this clock, see Gaulke (2015).

various paths, Bürgi selected the form of an elliptical movement, which is the same progression of the planets that Kepler discovered 15 years later. Thus, Bürgi's measurements and calculations would have required precision, and consequently, Bürgi needed methods for which he could carry out the computations. As an already skilled instrument maker, he needed mathematical tools to complete the work.

In 1588, Reimers published part of Bürgi's new mathematical methods in *Fundamentum Astronomicum*; however, Reimers published perhaps more than Bürgi would have actually agreed to—leading to a slightly strained relationship between the two men—and an unwritten or unspoken publication agreement of sorts was part of the problem. To prevent this undesirable outcome from happening again, Bürgi asked his friend and colleague Reimers to swear to keep quiet all of Bürgi's developments and innovations in future.[10] This misunderstanding (about what could and could not be published by Reimers) between Bürgi and Reimers in 1588 may have led to Bürgi being overly cautious about writing down his mathematical innovations and sharing them with others. For example, Bürgi's "Kunstweg" was a method that dealt with interpolation, and it was included in *Arithmetica Bürgii*, which was edited by Kepler in 1603.[11] Staudacher (2014), in following Ludwig Oechslin, is of the opinion that Bürgi had already prepared his *Aritmetische und Geometrische Progreß Tabulen* by this time, as he would have been able to create the tables and methods using his "Kunstweg," which included methods of interpolation.

German mathematics historian Menso Folkerts further supported this claim. Folkerts located a handwritten (allegedly by Bürgi himself) document titled *Fundamentum Astronomiae*—a document very similar to Reimers' *Fundamentum Astronomicum*—in the Biblioteka Uniwersytecka we Wrocławiu (Wroclaw University Library, Poland). The manuscript was personally given to Emperor Rudolf II as a gift 10 days after Bürgi's first audience with the emperor in June 1592.[12] The analysis and publication on the results of this Bürgi text on trigonometry, which includes algorithms for building sine tables and his "Kunstweg" method of interpolation, was published in 2015 (Folkerts, Launert, and Thom). The sine tables included in this document could be the same as shown to Brahe, which also took place in 1592.

Prior to Bürgi's first trip to Prague, he remained busy in Kassel, continuing to work on a system to measure planets, and he collects measurement data until 1597

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[10] Reimers must have kept his promise; he refused to divulge information about Bürgi's "Kunstweg" (meaning artful (or skillful) method), because he had promised Bürgi to keep all of his (Bürgi's) information confidential (Staudacher 2014, p. 181).

[11] This work came to be known as Bürgi's *Coss*. The *Coss* manuscript was never delivered to a printer for publishing; it was finally edited and published in 1973 by List and Bialas. In 1604, Kepler wrote a letter to Fabricius, stating that he now had an understanding of the "Kunstweg" after having edited the *Coss* manuscript (Staudacher 2014, p. 181). However, Kepler did not mention his *Coss* editing work for Bürgi and therefore did not compromise the secrecy agreement he held with Bürgi.

[12] In the forward for *Fundamentum Astronomiae*, Bürgi gives the date "Prag, am Tage Mariae Magdalenae, Anno Christi 1592" (Folkerts 2015, p. 109), which corresponds to 22 July 1592.

on more than 1000 planet positions.[13] Bürgi built a silver and gold planetary globe in 1591–1592, which is considered one of the most highly developed automated models ever built. It is this planetary globe that Rudolf II asked Bürgi (through Wilhelm IV) to bring to Prague and which Bürgi personally delivered to Rudolf II in 1592. The construction of the globe required precise astronomical values for planetary positions, which Bürgi was able to compute in his own work as an astronomer and also as a mathematics expert (Staudacher 2014, p. 147). Bürgi returned to Prague in 1596, most likely for the purpose of checking and servicing the planetary globe and observatory clocks. Bürgi also met and spoke with Rudolf II during this visit regarding distances to planets and other astronomical interests. They also spoke about Bürgis' work in trigonometry, including the trigonometry document (*Fundamentum Astronomiae*) that he left with the Emperor during his last audience with him in 1592.

In addition to Bürgi's extensive work on celestial measurements and the design and construction of intricate instruments, he also worked to finalize a table of sines, *Canon Sinuum*, during this time. The table was probably completed at the end of the sixteenth century (Roegel 2010a), with List and Bialas (1973) and Staudacher (2014) giving the year 1598. However, as with every other mathematical endeavor of Bürgi's, coupled with his fear of others publishing without his permission, Bürgi most likely carried a copy of the *Canon Sinuum* on his person and used the tables for his own and Kepler's purposes and calculations.[14] Bürgi's *Canon Sinuum* contained sines calculated to eight (8) places, at intervals of 2″ (2 s).

Also at this time (1597–1599), Bürgi was completing the manuscript for the previously mentioned mathematical work, *Arithmetica Bürgii* (Staudacher 2014, pp. 185–186). Bürgi certainly felt at a disadvantage due to his poor knowledge of languages and his need to work more intently to read and understand the solutions of mathematical authorities. Thus, he searched for someone to improve and edit his draft of his *Arithmetica*. Bürgi's relationship with Reimers made him a candidate as editor of the manuscript; however, Reimers was himself writing a new book on mathematics and algebra. Also at this time, Reimers, Brahe, and Kepler's paths were converging, and strained relations in Prague were due to the priority fight between Reimers and Brahe (regarding their model of the universe), in which Brahe already asked Kepler to write a study of the subject. Brahe would eventually hire Kepler as an assistant at the observatory in Prague to help with analyzing data on Mars, although Kepler held ill feelings toward Brahe's dealings with Reimers (particularly since Kepler had only favorable dealings with Reimers). Eventually, Reimers handed Bürgi's draft of the *Arithmetica* over to Kepler for editing.

Soon after, in August 1600, Reimers died of tuberculosis while awaiting trial in a case that Brahe brought against him for allegedly stealing Brahe's idea for a hybrid model of the universe. Brahe had the support of Rudolf II, and Brahe expected

[13] The data was accessible to Kepler from 1603 until 1612, when both Kepler and Bürgi were in Prague.

[14] The *Canon Sinuum* was never published and most likely remains lost. However, it makes sense that if Bürgi kept it on his person, others would have seen it and stated that it did exist.

Reimers to be found guilty, the punishment for which would have entailed being "publicly beheaded, drawn, and quartered" (Staudacher 2014, p. 210).

Prague: 1603–1631

Upon arriving in Prague, Bürgi continued to produce specialized mathematical instruments and Kepler finalized his edited draft of Bürgi's *Coss*. Additionally, Bürgi's astronomical data, which had been recorded over a period of 12 years in Kassel, became available to his friend (and now Imperial Court Astronomer) Kepler in Prague from 1603 until 1612. Bürgi's strong need for secrecy (as agreed upon between Kepler, Bürgi, and Bürgi's brother-in-law, Benjamin Bramer (1588–1652)) was a major factor for his work and name as an astronomer to be all but forgotten and eliminated from any mention by Brahe's successors. However, as Staudacher (2014) claimed, without Bürgi it would have been difficult or nearly impossible for Kepler to define and to verify the small elliptical deviation of an only eight (8) arc minutes from a circular path in his calculation of planetary motion. Bürgi provided to Kepler not only the most precise instruments for time-second and angle-minute part measurements but also the mathematical methods necessary to accommodate this mass of spherical data.

In December 1604, Bürgi was officially named imperial clockmaker. There he maintained a clock- and watch-making workshop, with two employees, in the same building as Rudolf II's alchemy laboratory and artist Adriaen de Vries' atelier with metal casting equipment. Beginning in 1608, Bürgi owned a private house in the downtown area close to the Powder Tower, and with a monthly salary of 60 guilders, he was the third-highest paid employee of Rudolf II. For the next dozen years or so, Bürgi continued to develop instruments, clocks, and watches in his workshop and to support Kepler as an astronomical observer. Furthermore, others applied Bürgi's mathematical methods in their own work. For example, in the 1608 edition of *Trigonometria*, Bartholomaeus Pitiscus (1561–1613) published brief excerpts of Bürgi's new algebraic methods, including how to determine the direction and magnitude of eccentricity of the Earth's orbit and finding the sine of half-angle from the sine of an angle. In this edition of his *Trigonometria* (a book with examples from Bürgi), Pitiscus called Bürgi an "ingeniosissimus Mathematicus," or "ingenious mathematician" (Staudacher 2014, p. 187). One of the main reasons for the publication of Bürgi's mathematical examples in Pitiscus' books is the secrecy agreement between Bürgi and Kepler. That is, Kepler could publish Bürgi inventions in his own publications only after Bürgi had previously presented it himself in another publication. Therefore, it was necessary for Bürgi to hand over an example or excerpt for publication before a Kepler example was shown in *Astronomia Nova*.

A great deal has been written about when Bürgi began his work to construct the tables of the *Aritmetische und Geometrische Progreß Tabulen*, and a brief step back is in order. Nový (1970) speculated that Bürgi began computing his tables of logarithms as early as 1584. Grattan-Guinness placed Bürgi's computation of tables of logarithms as early as 1590 (1997, pp. 180–181). Many sources, however, quote Bürgi's brother-in-law, Benjamin Bramer, for a firsthand account of when Bürgi must have computed his tables of logarithms (actually, tables of antilogarithms). In his testimony, Bramer stated in a book published in 1630 that:

> [It] is on these principles that my dear brother and master Jost Bürgi, calculated, twenty years ago and more, a beautiful table of progressions, …, calculated to nine digits, [and] he did not print the [tables] until 1620 in Prague, so the invention of logarithms is not by Napier, but was made by Jost Bürgi long before." (translated from Montucla 1758, p. 10)

This passage has influenced some to place Bürgi's construction of tables as a result of his invention around the year 1610 (Roegel 2010a).

Refining the time frame for which Bürgi completed the construction of his tables of logarithms may be possible with Folkerts' forthcoming analysis of Bürgi's *Fundamentum Astronomiae* (which is dated to 1592). In particular, the first of the two books of the *Fundamentum Astronomiae* includes an explanation of the four basic arithmetic operations and root extraction using sexagesimal (base 60) numbers, a 12-page multiplication table (again, with sexagesimal numbers), a chapter dealing with prosthaphaeresis, and the calculation of the sine value for each angle, in increments of 1 min and to six places. The sheer amount of calculation work in the *Fundamentum Astronomiae*, coupled with the underlying similarity among the various calculation techniques required to construct tables of sines and to make the accurate calculations required to construct the astronomical models, could place Bürgi's construction of his tables of logarithms prior to 1592. That is, his method for simplifying all manners of calculations using logarithms (like those eventually needed in the *Fundamentum Astronomiae*) may have been the precursor to Bürgi's more complex mathematical texts.

Kepler, as his friend and colleague, urged Bürgi to print and disseminate his tables and instructions for their use as "an efficient method to carry out multiplications and divisions" (Waldvogel 2012, p. 13). Some time between 1600 and 1603 and in an effort to avoid a similar situation that Bürgi experienced with Reimers publishing his work without first establishing a proper agreement with Kepler, Bürgi arranged a secrecy agreement with him. Consequently, along with handing over of Bürgi's *Coss* draft to Kepler, Kepler and Bürgi swore to not betray each other and to keep the methods and innovations in mathematics of the other secret until he published them himself (Staudacher 2014).

Yet Kepler knew and worked with Bürgi's *Aritmetische und Geometrische Progreß Tabulen* while editing Bürgi's *Coss*, and from 1603 onward, Kepler worked in silence with both of Bürgi's innovative tables, the *Canon Sinuum* and the *Aritmetische und Geometrische Progreß Tabulen*, in order to calculate with a vast amount of observation data collected by Tycho Brahe. Then, in 1609 both Kepler and Bramer were convinced that Bürgi would bring both manuscripts to the printer. Unfortunately, Bürgi's first wife (Bramer's sister) died in 1609, and this, along with the growing trouble in Prague between Catholic League soldiers and of the people of Old Town Prague, made the eventual printing of Bürgi's manuscripts difficult. Bürgi would not start publication until 1620, and even then only the actual tables were printed as proofs and in small quantity and without the instructions necessary for their use. Whatever copies of the tables existed in 1620 were most likely lost during the Thirty Years' War. One battle—the Battle of the White Mountain—was fought just outside of Prague in November 1620 and 7000 men lost their lives there (González-Velasco 2011, p. 101).

The subject of assigning a timeframe or year to Bürgi's construction of his tables of logarithms is often due to the question of priority with regard to the invention of logarithms. In 1614, John Napier (1550–1617) published his *Mirifici Logarithmorum Canonis Descriptio* (or the *Descriptio*), officially earning publication priority with regard to the invention of logarithms. However, for some, the priority issue is about more than the moment of publication. González-Velasco (2011) stated that "for the sake of fairness that the earliest discoverer of logarithms was Joost, or Jobst, Bürgi (1552–1632), a Swiss clockmaker, about 1588" (p. 100).

As was the case with Bürgi, Napier began working on his conception of logarithms some years before his first publication in 1614. Napier stated in his *Descriptio* that he worked some 20 years on the tables he presented within it, which would place the beginning of his work on logarithms in 1594. Interestingly and perhaps out of respect for his colleague and friend, Kepler did not show an official interest in Napier's logarithms since he had been urging Bürgi to publish the *Aritmetische und Geometrische Progreß Tabulen* for many years. In 1619, Kepler would have known that Bürgi's tables were being typeset for publication, and since they would soon be printed and distributed, Kepler no longer felt he was bound to secrecy. And his reaction was to not maintain allegiance to Bürgi but to align with Napier's (and, consequently, Briggs') tables of logarithms and, eventually, his own. In 1627 Kepler famously wrote in the foreword to *Tabulae Rudolphinae*: "Der zaudernde Geheimniskrämer liess sein Kind im Stich, anstatt es zum allgemeinen Nutzen grosszuziehen"[15] (Staudacher 2014, p. 206).

The discussion about assigning the title of inventor of logarithms to Bürgi or Napier is now over 400 years old. If we only consider publication date as the defining metric for priority, then Napier is the clear winner. Another dimension to the discussion, however, is to recognize that the parallel insights of both Napier and Bürgi occurred at approximately the same time. In the late sixteenth century and early seventeenth century, both Bürgi and Napier, in two different locations and engaged in very similar life's work (the need to perform a vast amount of difficult calculations, particularly with respect to astronomical computation applications), came to develop a mathematical method that enabled them to improve their own work and the work of others. Whereas Napier's original conception of the logarithmic relationship was dependent upon a kinematic argument (Appendix B), and which required complex calculations to construct his table of logarithms, Bürgi's original conception was algebraic in nature and much simpler in construction. It is unfortunate that because of Bürgi's need for secrecy to protect his innovations and methods until he believed them to be ready for publication and the events of the time (e.g., the worsening political conditions in Prague and the start of the Thirty Years' War),

[15] "*The hesitant secretive [man] abandoned his child instead of raising it for the general benefit.*"

the *Aritmetische und Geometrische Progreß Tabulen* would not be published and enter into mainstream use as Napier's conception of logarithms did.

There are several resources that describe Napier's conception of the logarithmic relationship, as well as the method used to construct his tables, including Havil (2014), Katz (2009), and Roegel (2010b).

Return to Kassel: 1631–1632

In 1631, just before his death, Bürgi left Prague for the last time to return to Kassel. He died just 4 weeks shy of his 80th birthday on 31 January 1632, and without children of his own, his legacy died there as well. Although the grave no longer exists, a plaque was placed to commemorate his contributions:

> Auf diesem Friedhof liegt begraben
> der landgräflich- hessische und
> kaiserliche Uhrmacher sowie Mathematiker
> Jost Bürgi
> geb. 28.2.1552 in Lichtensteig, Schweiz
> gest. 31.1.1632 in Kassel.
> 1579–1604 und in späteren Jahren tätig in Kassel
> als genialer Konstrukteur von Messinstrumenten
> und Himmelsgloben, Erbauer der
> genauesten Uhren des 16. Jahrhunderts,
> Erfinder der Logarithmen. (Volk 2009)[16]

[16] *On this cemetery lies buried/the Landgrave of Hessen and/the Emperor's watchmaker and mathematician/Jost Bürgi/born February 28th, 1552 in Lichtensteig, Switzerland/died January 31st, 1632 in Kassel/ingenious designer of measuring instruments/and celestial globes, builder of the/most precise clocks of the 16th century,/inventor of the logarithms.*

http://www.springer.com/978-1-4939-3160-6

Jost Bürgi's Aritmetische und Geometrische Progreß
Tabulen (1620)
Edition and Commentary
Clark, K.M.
2015, XIII, 258 p. 97 illus., 93 illus. in color., Hardcover
ISBN: 978-1-4939-3160-6
A product of Birkhäuser Basel