Bürgi, Jost

Born **Lichtensteig, St. Gallen, Switzerland, 28 February 1552**
Died **Kassel, Germany, 31 January 1632**

Jost Bürgi was a clock maker, astronomer, and applied mathematician. His father was probably a fitter. Very little seems to be known about his life before 1579. It is probable that Bürgi obtained much of his knowledge in Strassburg, one of his teachers being the Swiss mathematician Konrad Dasypodius. An indication that he did not get a systematic education is the fact that Bürgi did not know Latin, the scientific language of his time. Nevertheless, he made lasting scientific contributions that prompted some biographers to call him the "Swiss Archimedes." Bürgi was married first to the daughter of David Bramer, then in 1611, married Catharina Braun.

Bürgi developed a theory of logarithms independently of his Scottish contemporary **John Napier**. Napier's logarithms were published in 1614; Burgi' s were published in 1620. The objective of both approaches was to simplify mathematical calculations. While Napier's approach was algebraic, Bürgi's point of view was geometric. It is believed that Bürgi created a table of logarithms before Napier by several years, but did not publish it until later in his book *Tafeln arithmetischer und geometrischer Zahlenfolgen mit einer gründlichen Erlüterungen, wie sie zu verstehen sind und gebraucht werden können.* Indications that Bürgi knew about logarithms earlier in 1588 can be obtained from a letter of the astronomer **Nicholaus Bär** (Raimarus Ursus), who explains that Bürgi had a method to simplify his calculations using logarithms.

Logarithms paved the way for slide rules because the identity $\log(a \cdot b) = \log(a) + \log(b)$ allows one to compute the product of two numbers a and b as an addition. Bürgi also computed sintables. These tables, called *Canon Sinuum*, seem however to have been lost. The sintables were used in a method called *prosthaphaeresis*, known to many astronomers in the 16th century. In this method, trigonometric formulas like $\sin(x)\sin(y) = [\cos(x-y) - \cos(x+y)]/2$ are used to reduce multiplication to addition. Bürgi is considered as one of the inventors of that method; other identities were used by Ursus, **Johannes Werner**, and **Paul Wittich**.

Another indication that Bürgi's discovery of logarithms was independent of Napier's is the fact that **Johannes Kepler**, who admired Bürgi as a mathematician, states in the introduction to his *Rudolphine Tables* (1627): "… the accents in calculation led Justus Byrgius on the way to these very logarithms many years before Napier's system appeared; but being an indolent man, and very uncommunicative, instead of rearing up his child for the public benefit he deserted it in the birth." Although the two discoveries are today believed to be independent, Napier definitely enjoyed the right of priority in publication. Both methods were mainly computational. It seems that the first clear and theoretical exposition of the equation $\log(x\,y) = \log(x) + \log(y)$ can be found in Kepler's *Chilias logarithmorum*.

In 1579, Bürgi entered the employ of Landgrave **Wilhelm IV** of Hesse-Kassel, observing with the court-mathematician **Christoph Rothmann** at the excellent Kassel observatory. Some denote it as the first stationary observatory in Europe. Bürgi, who also knew **Tyge Brahe** and who was a friend of Kepler, made many instruments for the observatory. One of the instruments was the "reduction compass," another being the "triangularization instrument," both of which had military applications. Bürgi's famous celestial globe from 1594 can be seen on some Swiss stamps.

Bürgi is attributed to the invention of the minute hand on clocks in 1577. His invention was part of a clock he constructed for Brache, who needed precise time for observing. Bürgi is also known in the history of time measurement for a clock he made in 1585 that would run for 3 months. He introduced the idea of adding an independent system to the traditional wheel-train, which was wound in short periods by the mainspring, giving a more constant flow to the escapement. This was later perfected, leading eventually to an autonomy of several months. In 1604, Bürgi became court watchmaker to Emperor Rudolf II. He returned to Kassel the year before his death.

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Joost, Jobst

Bürgi, Jost

Schuster, Arthur

Born **Frankurt, Germany, 12 September 1852**
Died **Berkshire, England, 14 October 1934**

German-English theoretical astronomer Arthur Schuster is commemorated in the Schuster–Schwarzschild (or reversing layer) approximation for analyzing the spectra of stars to learn their chemical composition. The idea is that you can treat the situation as if there were a hot layer, the photosphere, emitting a blackbody continuum, and a cooler layer above which imposes the absorption lines. The opposite approximation, that the continuum source and absorbing atoms are uniformly mixed, is called the Milne–Eddington approximation, and real stars come somewhere in between. **Karl Schwarzschild**, **Edward Milne**, and **Arthur Eddington** appear elsewhere in this book.

Schuster was the son of a Frankfurt textile merchant and banker. In the wake of the 1866 "seven weeks war" when Frankfurt was annexed by Prussia, the family moved to Manchester, England. Schuster was educated privately and at the Frankfurt Gymnasium. He attended the Geneva Academy from 1868 until he joined his parents at Manchester in 1870. Schuster studied physics at the Owens College, Manchester, and the University of Heidelberg, where he obtained his doctorate in 1873.

After a few years at the Cavendish Laboratory in Cambridge (1875–1881), Schuster returned to Manchester to become professor of applied mathematics (1881–1888) and later professor of physics (1889–1907). After an early retirement at the age of 56, he spent his time with his own research and on the formation of the International Research Council. With his retirement, Schuster made way for **Ernest Rutherford**.

Schuster worked in following different areas, many of them related to astronomy:

Spectroscopy. In 1881, Schuster refuted the speculation of **George Stoney** that spectral lines could be regarded as harmonics of a fundamental vibration. He did this using a statistical analysis of spectral lines of five elements. Schuster concluded: "Most probably some law hitherto undiscovered exists which in special cases resolves itself into the law of harmonic ratios." In 1888, **Johann Balmer** took a fairly large step forward when he delivered a lecture to the Naturforschende Gesellschaft in Basel. He represented the wavelengths L of the spectral lines as $L = h \cdot m^2/ (m^2 - n^2)$, where m and n are integers. For the hydrogen atom, where n = 2, it would lead to wavelengths h·9/5, h·16/12,h·25/21 …, the Balmer Series which forms visible light. While Schuster had not yet seen this, his statistical analysis had refuted the speculation of a law L = hċm, which Stoney had speculated. The Balmer law $1/L = R \cdot (1/m^2 - 1/n^2)$ would later be derived by quantum mechanics.

Schuster's most notable paper, on the analysis of stellar absorption features, was not published until 1905.

Electricity in gases. Schuster was the first to show that an electric current is conducted by ions. He also showed that the current could be maintained by a small potential once ions were present. He was the first to indicate a path toward determining the charge–mass ratio e/m for cathode rays by using a magnetic field. This method would ultimately lead to the discovery of the electron.

Terrestrial magnetism. Schuster's study on terrestrial magnetism showed that there are two kinds of daily variations in the magnetic field of the Earth—atmospheric variations caused by electric currents in the upper atmosphere as well as internal variations due to induction currents in the Earth. The Schuster–Smith magnetometer is the standard instrument for measuring the Earth's magnetic field. Schuster's numerous articles examined and rejected many proposed theories of geomagnetism, usually because of shortcomings in their mathematics or physics.

X-rays. In 1896, Wilhelm Röntgen had sent copies of his manuscript to a small group of fellow scientists—Schuster in Manchester, Friedrich Kohlrauch in Göttingen, Lord Kelvin (**William Thomson**) in Glasgow, **Jules Poincare** in Paris, and Franz Exner in Wien. In the same year, Schuster proposed that the new x-rays of Röngten were, in fact, transverse vibration of the ether of very small wavelength, that is, a short-wavelength extension of the radiation (light) implied by Maxwell's equations.

Antimatter. Schuster published two letters on antimatter in *Nature* in 1898. In them, he surmised "if there is negative electricity, why not negative gold, as yellow as our own?" For 30 years, Schuster's conjecture gathered dust. Only in 1927, an equation by Paul Dirac predicted a new duality and underlined what Schuster had suggested in 1898.

Expeditions. Schuster, having been invited by **Norman Lockyer** to join an expedition to Siam in 1875, to observe a total eclipse, was then asked by **George Stokes** to take charge of the whole expedition on behalf of the Royal Society. In the 19th century, some, if not all, of the world's astronomers believed in a planet inside the orbit of Mercury. This speculative intra-Mercury planet was called Vulcan. Only a total solar eclipse would make possible seeing it.

The planet Vulcan had been a theoretical construct to solve a problem in planetary dynamics—the mystery of Mercury's orbit. This problem was only resolved in 1915 with **Albert Einstein**'s general theory of relativity, in which the orbital deviations could be explained due to relativistic effects of the Sun's huge mass bending space-time. Vulcan does not exist, and never did; the hunt for it was finally abandoned after the total solar eclipse of 1929.

No eclipse yielded an intra-Mercury planet. But Schuster photographed a comet during the total solar eclipse of 1882.

Laboratory. Schuster raised funds to construct a new laboratory in 1897 and created new departments, including a department of meteorology in 1905.

Schuster was the first secretary of the International Research Council, established under the Treaty of Versailles (which abolished all pre-World-War-I international scientific collaborations) from 1919 to 1928, and was knighted in 1920.

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Wolf, Maximilian Franz Joseph Cornelius

Born **Heidelberg, Germany, 21 June 1863**
Died **Heidelberg, Germany, 3 October 1932**

Max Wolf, considered a pioneer in astrophotography, observed many new nebulae both within the Milky Way and outside our Galaxy. He discovered more than 200 asteroids along with three comets that now bear his name.

Wolf was born to Franz Wolf and Elise Helwerth in Heidelberg, where Max spent most of his life. As Wolf became interested in astronomy, his father, a physician, constructed a private observatory for him, which he used from 1885 until 1896. In 1884, when only 21 years old, he discovered comet 14P/Wolf. This discovery was remarkable because the object was first thought to be an asteroid.

Wolf received his Ph.D. from Heidelberg in 1888 working under Leo Königsberger. He then studied with **Hugo Gyldén** in Stockholm from 1888 to 1890. Wolf became *Privatdozent* in 1890 and served as professor of astrophysics and astronomy at the University of Heidelberg from 1893 to 1932. He prompted the building of a new observatory near Heidelberg at Königstuhl, and became its director. Wolf is now also known as the "Father of Heidelberg astronomy."

Wolf developed several new photographical methods for observational astronomy, and was the first astronomer to use time-lapse photography, useful, for example, in detecting asteroids. Wolf brought the "dry plate" technique to astronomy in 1880, and introduced the blink comparator in 1900 in conjunction with the Carl Zeiss optics company in Jena. Using a blink comparator, a microscope that optically superimposes two photographic plates onto the same viewing region by blinking between them so quickly that the two plates look like only one, an astronomer can compare two plates and easily find differences between them. The blink comparator turned out to be a valuable useful astronomical tool, used in the discovery of Pluto by **Clyde Tombaugh** in 1930. While Wolf himself did not contribute to this discovery, he was able to locate the new planet on his older plates.

Wolf discovered more than 200 asteroids using various photographic techniques. The first, discovered in 1891 during a search for the minor planets (10) Hygiea and (30) Urania, was (323) Brucia, named by Wolf in honor of Catherine Wolfe Bruce, who had contributed $10,000 for one of his telescopes. Already by 1892, while overcoming difficulties with the optics, Wolf had found 17 new asteroids. In 1906, Wolf discovered (588) Achilles, the first of the so-called Trojan minor planets, which orbit the Sun in low-eccentricity stable orbits with semi-major axes very close to that of Jupiter. These objects manifest the triangular three-body system analyzed and predicted theoretically by **Joseph Lagrange** in the 18th century.

Wolf was the first to observe comet 1P/Halley when it approached Earth in 1909. Halley's Comet produced much excitement the following year because it was so close to the Earth that some expected the earth would pass through its tail.

Wolf used wide-field photography to study the Milky Way. He discovered about 5,000 nebulae and galaxies and also found new stars, such as Wolf 359, an extremely faint star, the third closest to the Earth after Alpha Centauri 3 and Barnard's Star. Though Wolf 359 is much too dim to be visible to the naked eye, Wolf was able to discover it with photographic techniques.

Wolf used statistical star counts to prove the existence of dark nebulae. Independently of American astronomer **Edward Barnard**, Wolf discovered that the dark "voids" in the Milky Way are in fact nebulae obscured by vast quantities of dust. In studying their spectral characteristics and distribution, he was among the first astronomers to show that spiral nebulae have absorption spectra typical of stars and thus differ from gaseous nebulae like planetary nebulae.

Around 1905, Wolf suggested building an observatory in the Southern Hemisphere, though it was not until 1930 that such plans were realized by Berlin and Breslau astronomers in Windhoek (Namibia). Observations there were stopped by World War II. In the 1950s, the European Southern Observatory (ESO) tested two sites in South Africa and South America, with a new observatory opening eventually in 1969 in northern Chile.

Wolf was a codeveloper of the stereo comparator together with Carl Pulfrich from the Zeiss company. The stereo comparator consists of a pair of microscopes arranged so that one can see simultaneously two photographic plates of the same region taken at different times. Wolf seems to have experimented with such techniques as early as 1892, but without success. When Pulfrich approached him to adapt the technique from geodesy to astronomy, Wolf was delighted. A steady exchange of letters followed. Wolf and Pulfrich then worked together to analyze the rapidly growing accumulation of photographic plates. Tragically, Pulfrich lost one eye in 1906, preventing him from using the stereographic tool from then on.

Wolf also provided in 1912 suggestions for the idea of the modern planetarium, while advising on the new Deutsches Museum in Munich, Germany. Wolf was a gifted teacher who attracted students from all over the world. He was also highly esteemed by amateur astronomers, helping them out with pictures and slides. In 1930, Wolf became a Bruce Medalist, awarded each year by the directors of six observatories—three in the United States and three abroad. He received the Gold Medal of the Royal Astronomical Society in 1914.

Wolf was survived by his wife Gisela Wolf (born Merx), whom he married in 1897. She had assisted him often with his work at the blink comparator. In addition to the three comets, Wolf has a lunar crater, a star (Wolf 359), the minor planet (827) Wolfiana, and an irregular galaxy (Wolf–Lundmark–Melotte) named in his honor.

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Keywords

Asteroids; Astrophotography; Blink comparator; Comets; Heidelberg Observatory

Zwicky, Fritz

Born **Varna, Bulgaria, 14 February 1898**
Died **Pasadena, California, USA, 8 February 1974**

Swiss-American physicist and astrophysicist Fritz Zwicky is remembered as more or less the first (a) to point out the very large amounts of dark matter in rich clusters of galaxies, (b) to show that gravitational lensing of one galaxy by another is much more likely than star–star lensing, and (c) with **Walter Baade** to associate the supernova phenomenon with the formation of neutron stars and the acceleration of cosmic rays. Zwicky was born into a family of Swiss merchants working abroad, and returned with them to the village of Mollis, in the home canton of Glarus (where he was eventually buried) in 1904. Though employed for nearly his entire career in the United States, he remained a Swiss citizen his entire life, returning home to vote, and remarking that "a naturalized citizen is always a second-class citizen." Zwicky was educated at the Swiss Federal Institute of Technology (ETH), completing a diploma thesis (first degree) under mathematician **Herman Weyl** and a Ph.D. dissertation in theory of crystals under Peter Debye (winner of the 1936 Nobel Prize in Chemistry) and Paul Scherrer in 1922. Following a 3-year period as an assistant at ETH, Zwicky moved in 1925 to the California Institute of Technology, at the invitation of its president **Robert Millikan**, receiving a Rockefeller fellowship from the International Education Board to support 2 years' work there.

Zwicky remained at Caltech the rest of his professional career as assistant (1927–1929), associate professor of physics (1929–1942), and professor of astrophysics (1942–1968), the first person to hold such a title there. Millikan had expected Zwicky to work on quantum theory of solids and liquids, and he indeed published in these areas, but his primary interests gradually turned to astrophysics, beginning with cosmic rays and ideas for how they might arise. In 1929, very shortly after the announcement of the expansion of the Universe by **Edwin Hubble**, Zwicky suggested that the data (a linear correlation between distance and redshift) might equally well be explained by "tired light," that is, the idea that photons simply become less energetic after traveling very long distances. This alternative was finally ruled out only about 60 years later, with the discovery of supernovae in distant galaxies and their time-dilated light curves, showing that the expansion is real. Zwicky himself remained suspicious of large redshifts, and carefully referred to "symbolic velocities," although much of his work in fact assumed the standard redshift–distance relation.

In 1933, Zwicky measured redshifts for galaxies in the Coma cluster, and found that they were not all quite the same. Instead, there was a spread in velocities of the cluster members, which required a very large mass for the cluster to hold it together. The effect was confirmed in 1937 by the discovery of a similarly large velocity spread in the Virgo cluster by **Sinclair Smith**. Zwicky's paper was published in a German-Swiss journal, so he spoke of "dunkle materie" rather than dark matter, and suggested that it might consist of some combination of small, faint galaxies and diffuse gas (perhaps molecular hydrogen). Modern work has shown that both of these are present (though the gas is very hot and ionized rather than molecular), but that an even larger quantity of mass is some other form of dark matter. Zwicky's results implied that the average mass of a galaxy must be much larger than that advocated by Hubble, and he originally suggested that gravitational lensing of one galaxy by another would be a good way to decide which was right, and that it would also allow study of galaxies too distant and faint to be seen otherwise. These 1937 ideas both proved to be correct, but only with the first such lens identified in 1975 and mass measurements and "Zwicky telescopes" in the 1990s.

Zwicky did live to see the confirmation of another of his seminal ideas. Baade had come to Mount Wilson Observatory in the early 1930s. He was interested in novae, and Zwicky had begun to think that these stars might be sources of cosmic rays. Together in 1933/1934 they put forward the ideas that a small subset of novae were actually much brighter supernovae—**Knut Lundmark** had said the same thing a year or two earlier, that the energy source was the collapse of a normal star to a neutron star, that some of the energy would go into accelerating cosmic rays, and that the Crab Nebula was an example of the remnant of such an event and that one should look for a neutron star in it. Because the neutron had been discovered only in 1932, these were remarkably prescient ideas, which were confirmed by the discovery of pulsars in 1968 and a pulsar in the Crab Nebula in 1969. The Russian theoretical physicist **Lev Landau** also conceived the neutron star idea, probably independently, but somewhat later, and the first serious calculations were done by **J. Robert Oppenheimer** and **George Volkoff** in 1939. Zwicky was never convinced that an object too massive to form a stable neutron star would collapse to a black hole (as implied by work by Oppenheimer and **Hartland Snyder** the same year), and advocated a hierarchy of more compact objects, beginning with pygmy stars and object Hades beyond neutron stars.

Zwicky had begun deliberate searches for supernovae using a small camera mounted atop Robinson Laboratory at Caltech in 1934, soon after his 1932 marriage to Dorothy Vernon Gates, daughter of a wealthy

California family. The marriage ended in divorce, but not before Gates had paid a large fraction of the cost of the first telescope erected on Palomar Mountain, an 18-in. Schmidt in 1936, with which Zwicky began finding new supernovae for systematic study. Both supernova searches and a desire for a wide field of view to study clusters of galaxies motivated Zwicky to be a strong supporter of the 48-in. Schmidt, which began operation at Palomar in 1948. He personally discovered 122 supernovae (more than half of those known at the time of his death). Images from the Palomar Observatory Schmidt Survey also yielded a six-volume catalog of clusters of galaxies, completed by Zwicky and several collaborators in 1968 and still very much in use. He also compiled, in the wake of the 1963 discovery of quasars, a catalog of compact galaxies and compact parts of galaxies, and noted their connection with Seyfert galaxies. His catalog, with **Milton Humason**, of high-latitude B stars (HZ objects) turned out to include both a variety of highly evolved stars and some quasars.

During and after World War II, Zwicky worked on rocketry and propulsion systems with Aerojet (later Aerojet General) Corporation, for which he received a high civilian award, the United States Medal of Freedom in 1949. He was for many years vice president of the International Academy of Astronautics, and many of his more than 50 patents were in rocketry, although his 1957 attempt to put a small mass into cislunar space (with a secondary firing of a projective off a rocket as it ascended) was probably a failure.

Zwicky was, in fact, a very hands-on scientist, who developed not only telescopes but ways of handling photographs, for instance the subtraction of a negative of one image from a positive of another (in another color, taken at a different time, or in a different polarization) to reveal aspects of galaxies and nebulae that would otherwise have been missed. Others of his ideas were extremely theoretical, for instance the possibility of estimating the mass of the particle that carries the gravitational force (the graviton) from the nonexistence of structures in the Universe larger than, perhaps, 100 megaparsecs on the distance scale then in use. The absence of larger structure turns out to be correct, the finite mass of the graviton probably not.

Zwicky had a number of nonastronomical interests, including Alpine climbing, the rebuilding of ravished European libraries after World War II, and the housing of war orphans, through the Pestalozzi Foundation, whose board of trustees he chaired for a number of years. Reminiscences of Zwicky invariably attempting to reproduce his Swiss-German accent—he is said to have spoken seven languages, all badly; point out that, late in life, he became inclined to point out that he had been working on some astronomical problems for many decades; and quote one or more of his uncomplimentary remarks about colleagues, most often "spherical bastards" (meaning from which ever way you look at them). On the other hand, his claim that a particular Mount Wilson colleague was color blind in his description of stars turned out, upon application of the Ishihara test, to be literally true. This irascibility (though he could be very kind as well) is probably responsible for the paucity of honors Zwicky received, despite his enormous accomplishments. Apart from the Medal of Freedom, these were limited to the 1948 Halley Lecture (in which he presented the concept of morphological astronomy) and the 1972 Gold Medal of the Royal Astronomical Society.

Zwicky was survived by his second wife, Margrit Zurcher, whom he met and married in Switzerland, and their three daughters.

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Keywords

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