

Chapter 2

The Development of Astronomy and Emergence of Astrophysics in Japan

Tsuko Nakamura

2.1 Introduction

The year 2008 was a very memorable one in the history of astronomy, and especially for Japanese astronomers. The reason is that 2008 was the 400th anniversary of the invention of the telescope in the Netherlands, and also the centenary of the foundation of the Astronomical Society of Japan. Hence, in taking advantage of this timely opportunity (these words are the ones used in Nakamura 2008), I would like to attempt to overview the emergence of modern astronomy and astrophysics in Japan, mainly before WWII. It is commonly recognized that the rise of the so-called ‘New Astronomy’ (astrophysics) is a major topic in the history of astronomy.

In order to clarify astronomical developments in Japan leading to the emergence of astrophysics, we describe in this chapter the history of Japanese astronomy by dividing it into four chronological stages as follows. The first stage was in the ruling era of the Tokugawa Shogunal Government, before the Meiji Restoration (1868),¹ during which the Japanese first learned about Western astronomy through books translated into Chinese, and then through books written in Dutch. The second stage was marked by the direct introduction of *modern* Western astronomy after 1868 through students who were educated in Europe or in the US. At the third stage, astrophysics emerged in the Japanese astronomical community for the first time. Thereafter, astrophysical research finally rivalled that of classical astronomy.

¹The Meiji Restoration (1868) was a sort of revolution, in which, after small-scale civil wars, political power moved from the Samurai’s hands to modern citizens. In Japanese history, the Meiji Restoration is generally regarded as the turning point from a feudal world to a modern society.

T. Nakamura (✉)
Institute for Oriental Studies, Daito-Bunka University,
Tokumaru 2-19-10, Itabashi, Tokyo 175-0083, Japan
e-mail: tsukonk@yahoo.co.jp

The Japanese version of this chapter can be found in Chaps. 1 and 2 of the book *One Hundred Years of Astronomy in Japan* (Nakamura 2008), although some new considerations and insight have been added here.

2.2 Encounters with Western Astronomy

2.2.1 Western Astronomy Learnt from Chinese Books

In ancient times from the seventh century through to the sixteenth century, the astronomy of Japan was under the exclusive influence of Chinese astronomy, and there was almost nothing original from a scientific viewpoint, except for very primitive and indigenous recognition of the heavens relating to animism. What the Japanese learned from China during that period was technical aspects of calendar-making, the institution of the court astronomical bureau (*Onmyo-ryo* in Japanese) and astrology (or celestial divination).

Japan's first encounter with Western astronomy took place through Chinese translations of astronomical books written or brought into China by Jesuit missionary priests² who served during the Ming or Qing Dynasties as court astronomers. Some of these books on astronomy began to be imported into Japan after 1720, when the eighth Shogun Tokugawa Yoshimune³ relaxed the import ban on Chinese books authored by Jesuit missionaries. As a result, the books on Western astronomy listed below arrived in Japan.

The first one that affected Japanese astronomy was *Lixiang kaocheng* (*Compendium of Calendrical Astronomy*, 1723). This book was compiled by the German Jesuit Ignatius Kögler (Dai Jinxian; 1680–1746) in collaboration with Chinese astronomers, and described the Tychonic planetary system, which was a compromise between the Copernican (heliocentric) and Ptolemaic (geocentric) systems. In the book, planetary motions were calculated using the epicycle-deferent technique.

The second book, *Lixiang kaocheng houbian* (*Revised Compendium of Calendrical Astronomy*, 1742) was the first one in Chinese that calculated motions of the Sun and Moon using Kepler's theory of elliptic orbits, so with this book Japanese astronomers learned about elliptic motion for the first time. Another influ-

² Actually in Japan, Christian evangelism had already begun soon after the landing of St. Francis Xavier in Japan in 1549. The Jesuit priests made full use of astronomy to demonstrate to the Japanese people the superiority of Christianity and the Western culture. They (mainly the Portuguese and Spanish) even attempted to build a few colleges in Japan to introduce the Christian doctrine to Japanese students, and elementary Western astronomy also was taught in these colleges—see Nakayama (1969), for the details.

³ In case of Japanese names, in the text of this chapter the first name indicates the surname, and the second name is the person's given name. Also, to distinguish persons with the same surname or to be in accordance with Japanese tradition, their given names are sometimes cited in the text and in references.

ential book, *Lingtai lixiangzhi* (*Astronomical Instruments*, 1674), compiled by Ferdinand Verbiest, (Nan Huai ren; 1623–1688; Coyne 2014), mainly discussed astronomical instruments that were based on Western astronomy, originally attributable to Tycho Brahe's instruments that were developed and used at his observatory on the island of Hven in Denmark.

From 1780s, civil astronomers such as Takahashi Yoshitoki and Hazama Shigetomi, led by Asada Goryu, the pioneer in this field who had taught astronomy at Osaka, started to learn from those three Chinese books. At a later date, because of their conspicuous ability, Takahashi and Hazama were ordered to become official astronomers by the Shogunal Government, so that they could be involved in calendar reform.

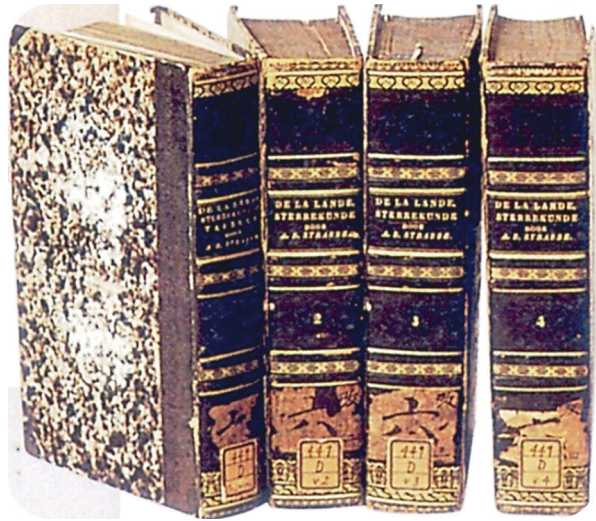
In addition to those three books—which were for professional astronomers—the book *Tienjing huowen* (*Queries on the Classics of Heaven*, 1681), written by You ziliu, also was imported and was popular with a wide cross-section of Japanese society, from the general public to professional astronomers. This book was repeatedly translated into Japanese with a variety of annotations, and contributed very much to help the Japanese understand elementary Western astronomy, meteorology and geography. Note that the Japanese had already been taught ‘the sphericity of the Earth’ by the Portuguese priests who had engaged in propagating Christianity in Japan during the period from the 1580s through to the 1630s when Japan introduced a strict ban on Christianity and the Christian priests were expelled.

2.2.2 Western Astronomy Learnt from Dutch Books

In 1803, Takahashi was required by the Shogunate to examine a Dutch translation of the French book on astronomy, *Astronomia of Sterrekunde* in five volumes (Fig. 2.1). The title of the original book was *Astronomie*, written by Joseph Jérôme Lalande (1773–1780; Boistel et al. 2010) who was once the Director of Paris Observatory (Lalande 1771).

When he examined this book Takahashi was deeply impressed by the elaborate contents, and he had never seen such high-level and exact astronomy presented in Chinese books. Therefore, without a dictionary or a book of Dutch grammar, and with only a poor knowledge of this language, Takahashi challenged himself to understand the book. After half a year of painstaking attempts to translate the book he died of pulmonary disease and overwork midway through this project, leaving eight notebooks that record his efforts. Although Takahashi could not grasp some of the concepts introduced, such as ‘aberration of light’, he was able to correctly understand most other parts of the book. His efforts then were continued by his two sons Takahashi Kageyasu and Shibukawa Kagesuke. This was the first Japanese encounter with a professional astronomical book written in a European language. As a Shogunal astronomer, Kagesuke later incorporated some results from his translation into a new calendar (the *Tenpo* calendar). It is worth noting, however, that the

Fig. 2.1 *Astronomia of Sterrekunde* (Second Edition, 1773–1780) by J.J.F. Lalande (Courtesy National Astronomical Observatory of Japan). These four books were all purchased at a later time of the Edo Era, since the original copies used by Takahashi et al. were lost in a fire in 1813. Note that for some unknown reason the first volume of the books preserved in the NAOJ Library is missing (Courtesy National Astronomical Observatory of Japan)



primary interest of the Shogunal astronomers was to apply knowledge of Western astronomy within the traditional framework of Chinese calendrical astronomy, and they had little interest in theoretical aspects of Western astronomy.

In June 2007, a 200th-year memorial symposium after the death of Lalande was held at Paris Observatory, and it was reported there that Lalande's *Astronomie* had been translated into German, Italian, Russian, Turkish and Arabic, in addition to Dutch and Japanese, clearly showing that this book was widely welcomed by the international astronomical community.

2.3 The Introduction of Western Modern Astronomy

2.3.1 Foreign Teachers

In 1868, the Shogun Government surrendered to the new political power, and Japan finally abandoned its seclusion policy which had continued for 230 years and opened its gates to the world. On this occasion, many historical matters and traditions belonging to the 'ancien régime' were regarded as useless and were discarded. On the other hand, the new Meiji Government set the immediate introduction of Western science and technology as a top priority policy, in order to strengthen the country and catch up with European powers. Education was no exception either. In every field, foreign professors and teachers were invited to come and give lectures at newly-established universities and colleges. The first teacher of astronomy,

Émile-Jean Lépissier came from Paris Observatory in 1872 and taught at an astronomical school. However, since there were neither appropriate astronomy textbooks there nor instruments for astronomical education at the University of Tokyo, Lépissier's invitation was premature and not very fruitful (Nakamura 2016).

The next foreign astronomer to come to Japan was Thomas Corwin Mendenhall (1841–1924; Rubinger and Mendenhall 1989), the Professor of Physics at Ohio State University in the USA, who arrived in 1878. Since Mendenhall's autobiographical notes written during his 3-year stay in Japan were published by his grandson in 1989, we have a good idea of his educational experience in Japan. At the University of Tokyo he made precise measurements of the Fraunhofer lines in the solar spectrum, and he carried out meteorological observations. With assistance from some of his Japanese students, he also measured gravity at the top of Mt. Fuji, and from this he derived a figure for the mean density of the Earth. At the time, his value was believed to be the best one available.

Figure 2.2 is a photograph of Mendenhall taken together with his students and young staff at the University of Tokyo in 1881, just before he returned to the USA. Mendenhall had an enduring influence on Japanese society and on his students, some of whom later were promoted to important positions (including the President and the Dean of the University of Tokyo).



Fig. 2.2 T.C. Mendenhall (center, seated) with his students and the staff of University of Tokyo in 1881 (*Courtesy University of Hawaii Press, 1989*)



Fig. 2.3 The French expedition team for the transit of Venus (1874) to Japan. Seated are J. Janssen and F.F. Tisserand. To the left of Tisserand's shoulder is Janssen's 'Revolver camera' (after Launay and Hingley 2005; *Courtesy Anne Guigan-Léauté*)

The third foreign teacher, Henry M. Paul came from the US Naval Observatory and taught his students the fundamentals of positional astronomy using basic astronomical instruments.

However, it is worth emphasizing that the Japanese first learned professional techniques of astronomical observations *not* from those foreign teachers *but* from a spectacular cosmic event that also took place in the 1870s. This was the transit of Venus, which occurred on 9 December 1874 (Saito 1974). France (Débarbat and Launay 2006), the USA (Dick et al. 1998) and Mexico (Allen 2005) dispatched expeditions to Nagasaki, Kobe and Yokohama, respectively, on this occasion.

Figure 2.3 shows the French team photographed in France, probably at Marseille, before their embarkation (after Launay and Hingley 2005). The leader of the expedition, Jules Janssen (1824–1907; Launay 2012), is the person with the white hair seated in the center. He later became well known as the founder of modern astrophysics in France and Director of Meudon Observatory. The other seated man is François-Félix Tisserand (1845–1896; Débarbat 2014), who was then at Toulouse Observatory but later was appointed Director of Paris Observatory. He also is famous of his four-volume standard textbook on celestial mechanics, *Traité de Mécanique Céleste* (1889–1896). The short man standing immediately behind Janssen is Shimizu Makoto

Fig. 2.4 Portrait of Shimizu Makoto. After coming back from France, he devoted his life to the initiation and development of the domestic safety-matches industry (<http://www.match.or.jp/column/column02.html>)



(Fig. 2.4; 1845–1899), a Japanese who was then in France studying the French ship-building industry; he joined the French expedition as a photographic technician.

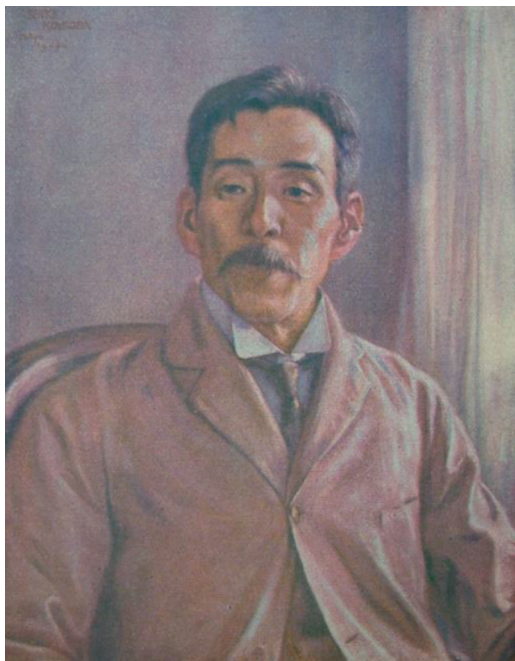
Through these overseas transit of Venus teams Japanese astronomers learned some of the professional techniques of Western astronomers for the first time, including (1) the use of geodesic and astronomical measurements to determine latitude and longitude; (2) how to establish time synchronization of clocks between remote sites using the telegraphic transfer of time signals; and (3) the application of photography to astronomy (Saito and Shinozawa 1972, 1973).

2.3.2 *The First Japanese Modern Astronomer*

The first Japanese modern astronomer was Terao Hisashi. He graduated from University of Tokyo in 1878, and went to Paris in 1879 to learn modern European astronomy, under the supervision of Professor Tisserand (Bartholomew 1989) and Jules Henri Poincaré (1854–1912; Trachet 2014). It is important to note that before going to Paris he had no knowledge of modern astronomy. Figure 2.5 shows a portrait of Terao painted by the famous Japanese artist Kuroda Seiki, who is now recognized as ‘the Father of Modern Oil-Painting in Japan’.

Terao was fortunate, because he could attend the Montsouris Astronomical School, which just happened to open in 1879, the year that Terao arrived in Paris. This school was established by Admiral Ernest Amédée Barthélemy Mouchez (1821–1892; Grillot 2014), the Director of Paris Observatory, with the purpose of training young astronomers in fundamental techniques of astronomical observa-

Fig. 2.5 An oil portrait of Terao Hisashi, the first Director of Tokyo Astronomical Observatory, painted by Kuroda Seiki in 1909. Terao, who had just returned from Paris, taught 18-year old Kuroda French conversation, as he was about to leave for France (Courtesy National Research Institute for Cultural Properties, Tokyo)



tions (Paris Observatory 1890); this indicated that French astronomers previously had a strong tendency towards theoretical astronomy rather than observations.

Figure 2.6 is a photograph of a small dome that was used by the Astronomical School and is now located in Montsouris Park in southern Paris. According to Mouchez (1890), in addition to Terao, students from China, Greece and Romania learnt modern astronomy at this School.

After finishing his 4-year study of astronomy in France, Terao joined the 1882 French transit of Venus expedition to Martinique Islands, off the shores of Venezuela, and he returned home via the USA in 1883 (Terao 1890). Then he was nominated as the successor to Paul's position, and promoted to a Chair in the Department of Astronomy at the University of Tokyo where he taught students astronomy and astrometric observations using meridian circles and the 15-cm equatorial refractor at the observatory that had been built on the University campus in 1878.

2.3.3 The Foundation of Tokyo Astronomical Observatory

In 1888 Tokyo Astronomical Observatory (TAO) was founded as an institute of the University of Tokyo in the central part of Tokyo (Fig. 2.7), with Terao as the Director. Since Terao's supervisor at Paris Observatory was Tisserand, who was a celestial



Fig. 2.6 The dome of the Montsouris Astronomical School established by Admiral Mouchez in 1879. Currently the dome is empty, and it seems to merely serve as a decorative pavilion in Montsouris Park (*Photograph* Tsuko Nakamura)

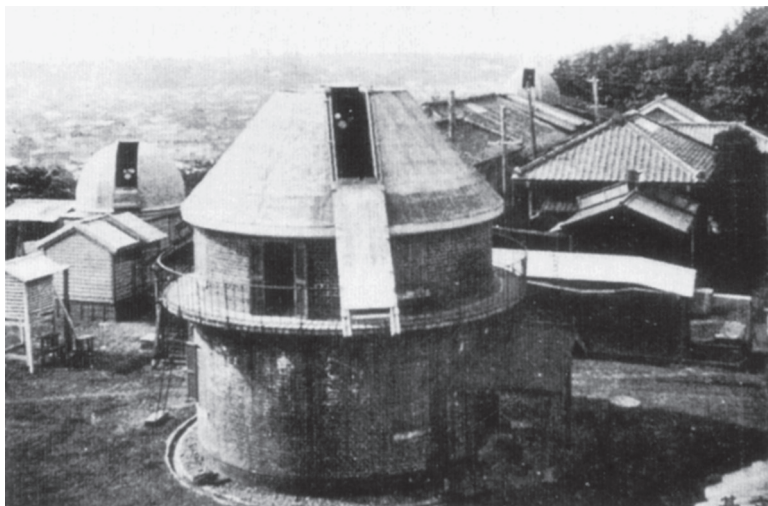


Fig. 2.7 Tokyo Astronomical Observatory, which was established at Azabu in downtown Tokyo in 1888 (*Courtesy* National Astronomical Observatory of Japan)

Fig. 2.8 A 20 s exposure of the 22 January 1898 total solar eclipse taken at Jeur, India, and clearly showing the corona (after Terao and Hirayama 1910: 4)

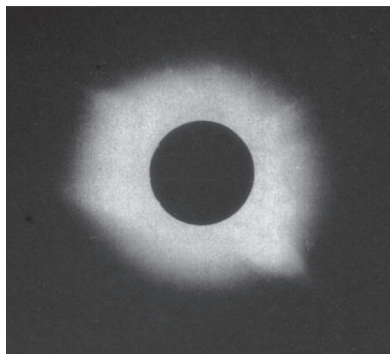
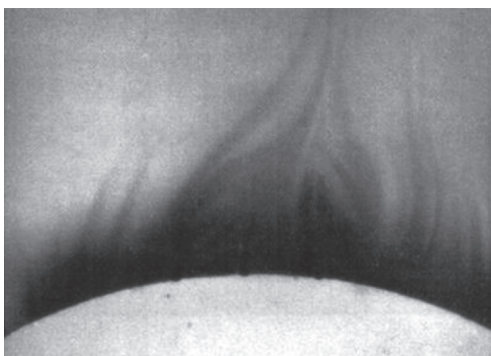


Fig. 2.9 A magnified image of prominences observed on the solar limb (after Terao and Hirayama 1910: 7)



mechanician, the astronomy that Terao mastered and taught his students was so-called ‘classical astronomy’. And for an extended period of time this characterized the type of astronomy studied at TAO. For almost two decades Terao had to contend with meager staff, poor instrumentation and a bad financial situation, and he also had to carry a laborious administrative load.

In 1898, the Japan Government for the first time dispatched a solar eclipse expedition to Jeur, near Bombay (now Mumbai), in India, where an American team also was based—see Chap. 26 in this book (Orchiston and Pearson 2017). The team was headed by Terao (see Terao and Hirayama 1910). Figure 2.8 is a copy of the first photograph of the solar corona taken by a Japanese astronomer outside of Japan, and Fig. 2.9 shows a magnified image of solar prominences on the limb of the solar disk. One can see the fine structure of prominences along the solar magnetic lines.

Figure 2.10 shows the prismatic camera that was used during the second Japanese solar eclipse expedition, to Padang (Sumatra) in 1901 (Hirayama et al. 1910; once again, a US Lick Observatory expedition also was sited in Padang—see Chap. 16 (Pearson and Orchiston 2017) in this book). On this occasion the solar spectra at

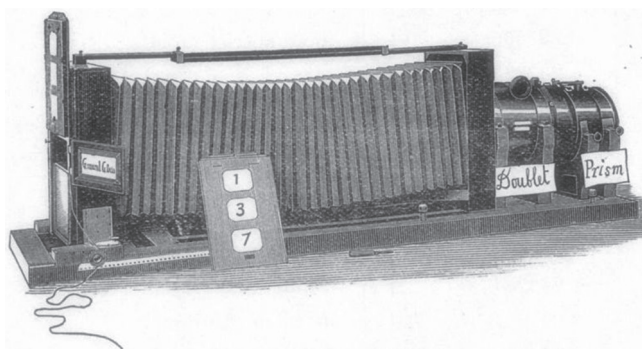


Fig. 2.10 Prismatic camera used to take flash spectra of the solar eclipse on 18 May 1901 at Padang, Sumatra (after Hirayama et al. 1910: 10)

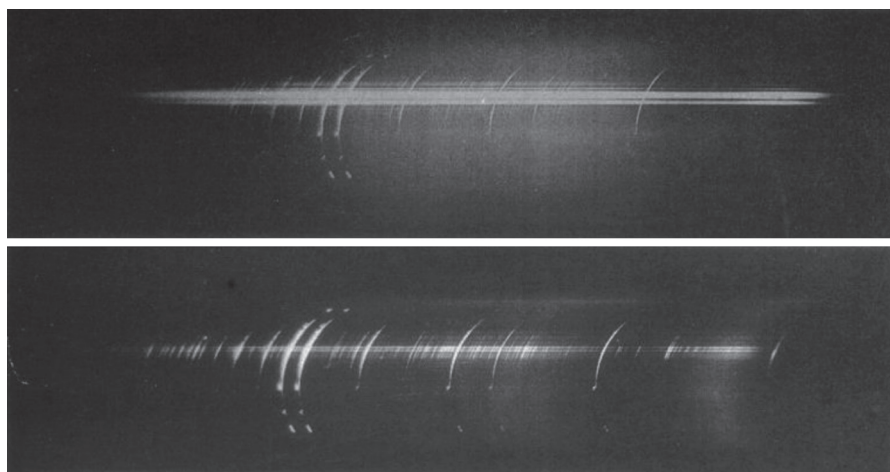


Fig. 2.11 Flash spectra photographed with the camera shown in Fig. 2.10 (Hirayama et al. 1910: 16)

totality were successfully observed by the Japanese astronomers for the first time, and Fig. 2.11 shows two flash spectra that they recorded. The wavelengths of emission lines associated with hydrogen (the Balmer series), helium, ionized metals, etc., were measured with a comparator. It was thought that the flash spectrum was caused by the chromosphere, a narrow atmospheric layer sandwiched between the photosphere and the corona.

Further overseas solar eclipse expeditions were mounted by Japan almost until the outbreak of WWII, but they did not produce any particularly important findings. Rather, they merely provided follow-up confirmation of new results obtained by Western solar physicists.

2.3.4 *The First Internationally Recognized Japanese Studies in Astronomy*

In a latter section, I shall show that the rise of astrophysics took place in Japan as late as in 1920s. This may be attributed at least partially to the nature of the ‘modern astronomy’ introduced by Terao. In particular, I would dare to say that discoveries made by Kimura Hisashi and Hirayama Kiyotsugu, which I will describe in the following subsections, would fail to stimulate young Japanese astronomers to be interested in astrophysics, rather than in classical astronomy. The works of Kimura and Hirayama were the first internationally recognized achievements in the field of classical astronomy since the Japanese had started to learn about Western modern astronomy.

2.3.4.1 Kimura Hisashi and the Z-Term in the Polar Motion of the Earth

Kimura Hisashi (1870–1943; Fukushima 2014) was one of Terao’s early students. Kimura (Fig. 2.12) graduated from the University of Tokyo in 1892. In 1888 a new phenomenon called ‘polar motion’ in the rotation of the Earth, which varied with latitude, was discovered by a German astronomer Karl Friedrich Küstner

Fig. 2.12 Kimura Hisashi at the Mizusawa Latitude Observatory. This photograph seems to have been taken soon after he was awarded the Gold Medal by the British Royal Astronomical Society. It is interesting to see in the background of his photograph the formula of Talcott’s method, the standard reduction technique of latitude observations (*Courtesy Mizusawa VLBI Observatory, National Astronomical Observatory of Japan*)



(1856–1936; Brosche 2000; Luzum 2014). Polar motion is a quasi-periodic motion of the instantaneous spin axis of the Earth, relative to the shape axis of the Earth as an ellipsoid. Such a type of rotation, like polar motion, had been theoretically predicted for the rigid-body Earth by the Swiss mathematician Leonhard Euler (1707–1783; Verdun 2014) more than 100 years prior to the actual discovery of polar motion.

In order to study the newly-discovered polar motion in more detail the international astronomical community proposed to establish a special series of astronomical stations along a nearly-equal-latitude circle of the Earth, so that the latitude change could simultaneously and systematically be observed at different places. Accordingly, a latitude observatory was built at Mizusawa, a village in the northern part of Japan, and Kimura was appointed as the Director. Although Kimura and his international colleagues continued careful and persistent latitude observations for several years, the Central Bureau of Latitude Variation in Germany judged that only Mizusawa's data deviated markedly from those obtained at other stations and were far from reliable. Shocked by this unexpected judgment, Kimura and his colleagues again and again rechecked both their meridian transit instruments and the data reduction method, but they could not pin-point any mistakes or problems. As a result, Kimura gradually became confident that he had detected something new in the polar motion.

The relationship between latitude variation ($\Delta\phi$) and the coordinates (x, y) of the instantaneous spin axis with respect to a certain origin on the surface of the Earth near the north pole is given by the equation:

$$\Delta\phi = x \cos \lambda - y \sin \lambda \quad (2.1)$$

where λ is the longitude of an observing station.

Kimura demonstrated that, if the third term, the 'Z-term', which is independent of longitude, is introduced anew in the right-hand side of the above equation, all the observed latitude data, including Mizusawa's values, could satisfactorily be fitted without mutual contradiction. Kimura published his discovery in 1902 (Kimura 1902).

The discovery of the Z-term was reasonably quickly approved and was welcomed by the world-wide astronomical community. As a result, Kimura was awarded the Gold Medal of the British Royal Astronomical Society, in addition to some domestic prizes.

Currently, we know that the Z-term was eventually no more than a result of an incomplete nutation correction of star positions used in the reduction of the latitude data (Wako 1970). And this correction has recently been shown to have been caused by the motion of the liquid core of the Earth. However, it still deserves to be appreciated that Kimura's finding motivated geophysicists to pursue physical connections of the latitude variation with the inner core motion of the Earth. In a sense then, the Z-term could be regarded as a tracer to sound the interior of the Earth.

2.3.4.2 Hirayama Kiyotsugu and Asteroid Families

Another internationally recognized project carried out by one of Terao's former students was the discovery of 'asteroid families' by Hirayama Kiyotsugu (1874–1943; Fig. 2.13; Kozai 2014b), and this subject is discussed in detail by Yoshida and Nakamura (2017) in Chap. 3 in this book. Hirayama graduated from the University of Tokyo 5 years after Kimura did, also majoring in classical astronomy. Before going to the USA, he was involved in studies of the latitude observations. He also surveyed accounts of ancient eclipses and comets that appeared in the historical records of Japan and China, and therefore should be regarded as a pioneer in this field.

In 1915 Hirayama went to the USA where he studied there celestial mechanics under Professor Ernest William Brown of Yale University (1866–1938; Baum 2014), an authority on the lunar motion. Brown suggested that Hirayama study the dynamics of the asteroids, and upon following this advice Hirayama began statistical and dynamical research on asteroids. However, Hirayama seems to have been interested in the behavior of asteroids as a group, not in the dynamics of individual asteroids.

By applying secular perturbation theory of planets to the motions of asteroids, Hirayama calculated so-called 'proper eccentricity and inclinations' of those objects that were free from the gravitational effects of Jupiter, the dominant disturber of asteroidal orbits. In his analysis, Hirayama recognized several groups of asteroids, each of which shared common values of proper elements. This fact suggested that asteroids belonging to a group were produced from a single parent body. Hence Hirayama called those groupings 'families', and each one was identified by the name of a particular asteroid belonging to that family, such as the Koronis Family. Hirayama (1918) published his discovery in 1918.

After WWII, Dirk Brouwer (1902–1966; Fosmire 2014), another US highly-regarded celestial mechanician, recognized the importance of Hirayama's discovery, and Brouwer soon added several new families. It is now understood that asteroid

Fig. 2.13 A portrait of Hirayama Kiyotsugu (Courtesy National Astronomical Observatory of Japan)



families are dynamical evidence of mutual collisions between asteroids. In addition, impact events between celestial objects are now regarded one of the basic processes in the evolutionary history of the Solar System. However, Hirayama himself was reluctant to admit that asteroid families were collisional products, and he adhered to the idea that they resulted from autonomous explosions of individual asteroids.

The following are some relatively recent developments relating to asteroid families:

1. In 1993 there was an international symposium in Tokyo that celebrated the 75th anniversary of Hirayama's discovery of asteroid families (Kozai et al. 1993).
2. In 2001 a large conference was held in Palermo, Sicily, to memorialize the 200th Anniversary of the discovery of the first asteroid, Ceres, by Giuseppe Piazzi. Out of 228 papers presented at that conference, 74 (~30%) discussed asteroid families.
3. In 2004 the Karin asteroid family was dynamically identified using a theory of family-formation (Nesvorný et al. 2002), and it also was shown that the spectroscopic nature of each of the member asteroids is consistent with the idea that this group has a common origin. This is a very young family, with an age of only 5.8 My.
4. Families have recently been detected among Trojan asteroids (e.g. see Beaugé and Roig 2001) and among Kuiper-belt objects orbiting the Sun beyond Pluto's orbit (Ragozzine and Brown 2007).

In the near future, therefore, it is very likely that the concept of asteroid families will become even more important in Solar System studies.

2.3.5 *Studies of Variable Stars*

As explained above, during the late nineteenth and early twentieth century the Japanese astronomical community of Japan was almost totally committed to research in classical astronomy. However, there was a unique individual who chose instead to explore astrophysics (Nakayama 1989). His name was Ichinohe Naozo (1872–1920; Sakuma 2002).

After studying (classical) astronomy at the University of Tokyo Ichinohe (Fig. 2.14) joined the staff of TAO, and then spent 1905–1907 in the USA, where the recent construction or refurbishing of large reflecting telescopes had led to a rapid rise in the popularity of astrophysics. Thus, Ichinohe was the first Japanese astronomer to make observations with these large telescopes, and his favorite targets were variable stars. Between 1906 and 1911 he published 25 research papers in the *Astronomical Journal*, the *Astrophysical Journal* and in *Astronomische Nachrichten*.

Table 2.1 provides a chronological list of the different variable stars that Ichinohe studied. As we can see, the first object that he observed was RY Cassiopeiae in 1906, while in the USA, and the last one was 27.1911 Cygni, in 1911, several years after he had returned to Japan.

The majority of Ichinohe's papers are reports on light curve measurements and period determination of these variable stars, but some papers that he wrote while in the USA included spectroscopic observations, and the discovery of a few new vari-

Fig. 2.14 A portrait of Ichinohe Naozo (after Nakayama 1989)



Table 2.1 Variable stars studied by Ichinohe

Year	Names of variable stars
1906	RY Cassiopeiae
1907	κ Cancri, μ Sagittarii, η Virginis, 120.1906 Persei, 24.1907 Monocerotis, RZ Draconis, 87.1906 Draconis, o Ceti (Mira)
1908	122.1906 Ceti, RU Camelopardalis
1909	S Sextantis, 43.1906 Crateris, μ Herculis
1910	26.1910 Scuti, 62.1907 Scuti, SZ Aquilae, Y Scuti
1911	TT Aquilae, 27.1911 Cygni

able stars. Back in Japan, he noticed that RT Scuti was variable in 1909, and this object was regarded as the first variable star discovered by a Japanese astronomer (although later confirmation negated Ichinohe’s discovery).

After returning to Japan Ichinohe eagerly promoted the importance of astrophysical studies among his TAO colleagues. Around that time, there was active discussion about moving TAO outside central Tokyo, because of the increasingly-intolerable light pollution. Most TAO staff followed Terao’s lead and supported the movement of the Observatory to Mitaka in the suburbs of Tokyo as a realistic plan, whereas Ichinohe vehemently believed that TAO should transfer to a remote high mountain site in northern Japan. After continuing conflict, Ichinohe eventually was forced to leave TAO and the astrophysical research activities that he had initiated ceased. This clearly indicates that the inertia of the times was so strong that Ichinohe’s enthusiasm and research efforts were unable to affect any change in direction.

2.4 The Move to Mitaka and the Dawn of Astrophysical Studies

In 1923 the Tokyo district experienced the Great Kanto Earthquake and more than 100,000 people were killed or disappeared. TAO located in the central part of Tokyo also was heavily damaged, but for several years prior this earthquake the move of TAO to the Mitaka campus—about 20 km from central Tokyo—had been under way. The destruction of TAO facilities in central Tokyo by the earthquake accelerated the move to Mitaka.

2.4.1 *The Introduction of Large Instruments*

The movement to Mitaka had been almost completed by the end of 1924.⁴ At this new site, the land area was widened by as much as 50 times than at the old TAO, and the sky was dark enough to observe faint celestial objects. Because of those reasons, two large telescopes were installed for the first time; such instruments would have been of no use at the light-polluted old campus.

2.4.1.1 The 65-cm Equatorial Refractor

One of these telescopes was a 65-cm equatorial refractor made by the famous Carl Zeiss Co. of Jena (Fig. 2.15), which was completed in 1929. It has generally been believed that Japan acquired this telescope from Germany as ‘reparations’ following WWI.

Scientific ‘first-light’ of this telescope was dedicated to the international observation campaign of a near-Earth asteroid Eros, because a close encounter with an asteroid of this kind was very time-critical. The purpose of the observations was to try and determine a precise value for the solar parallax (or the astronomical unit).

In spite of the expectations of TAO astronomers, this large telescope did not generate any important scientific results. The reasons of this failure are considered to be due to the large chromatic aberration of the telescope objective and the worldwide shift to 1 m-class reflectors for astrophysical research—a 65-cm refractor was simply too small for most up-to-date astrophysical observations.

Nevertheless, some useful observations were made with this telescope. Figure 2.16 shows stellar spectra of some early-type bright stars obtained with a prismatic spectrograph by Sekiguchi et al. (1939). We also see below two spectra through optical wedges exposed on the same plate for calibrations. These observations of nearly 30 objects were conducted to make quantitative analyses of hydrogen absorption lines for A-B type stars, and spectral profiles such as those of the H β -line shown in Fig. 2.16 were measured with a photo-densitometer.

⁴The Mitaka campus is the same place where the present-day National Astronomical Observatory of Japan (NAOJ) is located.

Fig. 2.15 The 65 cm equatorial refractor installed at Mitaka campus in 1929. The main telescope is mounted in parallel with a 38 cm guiding telescope, having the same focal length of 10 m. Currently, the 65 cm telescope is on display at the NAOJ campus as an historic instrument (Courtesy National Astronomical Observatory of Japan)

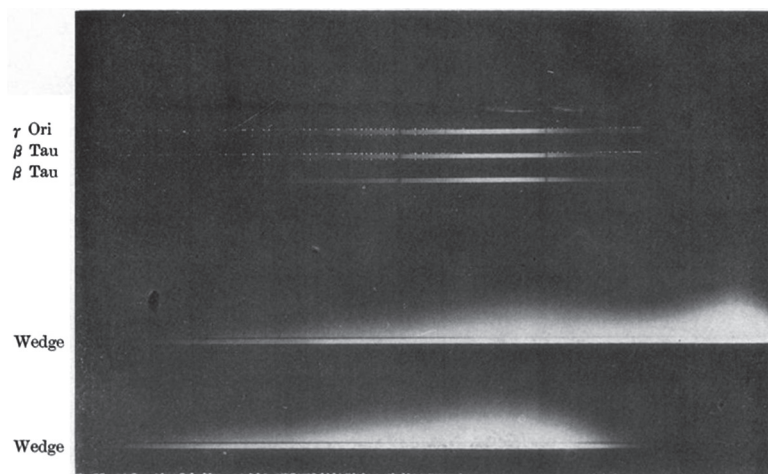


Fig. 2.16 Spectra of some of bright early-type stars taken in 1939 with a prismatic spectrograph attached to the 65 cm refractor (after Sekiguchi et al. 1939: 482)

2.4.1.2 The Einstein Tower

Another large telescope that soon was built at Mitaka was the so-called “Einstein Tower” (or the Solar Tower), which was completed around 1930 (see Fig. 2.17). This instrument was inspired by the Einstein Tower at the Potsdam Astrophysical Observatory at Babelsberg in Germany. This type of the solar telescope was constructed to prove observationally the gravitational red-shift of the light from the Sun, theoretically predicted by Einstein’s General Theory of Relativity. A coelostat in the dome on the top of the tower directed the solar light down the tower to an underground darkroom where high-dispersion spectrographs were located for precise measurements. Although the solar telescope at Mitaka was never used to study the General Theory of Relativity, it provided post-WWII Japanese astronomers with good opportunities to gain experience in high-dispersion spectroscopy.

2.4.2 Einstein’s Visit to Japan

Responding to the invitation from a certain Japanese publishing company, Albert Einstein came to Japan in 1922 (Kaneko 1981). The construction of the Einstein Tower at Mitaka may have had something to do with his visit to Japan, and the Japanese



Fig. 2.17 The Einstein Tower (Solar Tower) at Mitaka (*left*; *photograph* Tsuko Nakamura), and its ‘twin’ (*right*; Wikipedia Commons), build in 1924 at the Potsdam Astrophysical Observatory in Germany



Fig. 2.18 Einstein's visit to the University of Tokyo in 1922. He is seated in the middle of the front row (*Courtesy University of Tokyo*)

Einstein Tower also was actively promoted by Hirayama Shin, the second Director of TAO.⁵ Erwin Freundlich (1885–1964; Kragh 2014) had built the Germany solar tower telescope at the Potsdam astrophysical observatory in 1924, and he succeeded in detecting the spectral red-shift predicted by Einstein (Freundlich 1924, 1925, 1930; Yokoo 1999). Figure 2.18 is a group photograph with Einstein in the center, taken at the campus of the University of Tokyo after a series of lectures that he gave.

Although the main purpose of Einstein's visit to Japan was to give lectures on his General Theory of Relativity to both professional scientists and the general public in various cities, he also discussed his relativistic theories with some Japanese physicists during his 40-day stay in Japan. According to Einstein's diary (Kaneko 1981), on his journey he made calculations of the electromagnetic energy tensor with Ishiwara Atsusi of Tohoku University, who was Einstein's colleague in Zürich back in 1913. Furthermore, in regards to proof of his General Theory of Relativity Einstein also showed strong interest in laboratory spectroscopic experiments relating to the Stark Effect that were being conducted by Kimura Masamichi of Kyoto University and his collaborators.

Excitement brought about by the Einstein's visit later stimulated Hagihara Yusuke, who was a student at the University of Tokyo at that time, to be involved in studies of relativistic celestial mechanics. Later, in 1960, he was awarded the James

⁵Probably this was because after graduating from the University of Tokyo Hirayama Shin went to the Potsdam Astrophysical Observatory, where he studied astrophysics and particularly solar physics.

Craig Watson Medal. In the 1970s, Hagihara published nine books in five volumes overviewing the field of theoretical celestial mechanics (Hagihara 1970–1972, 1974–1976)

2.4.3 *The Founding of the Astronomical Society of Japan*

The founding of the Astronomical Society of Japan (ASJ) took place in 1908, more than 100 years ago. The initial purpose of launching the ASJ was heavily biased towards promotion and education of astronomy among ordinary people, rather than astronomical research. But this situation is understandable because at that time the number of professional astronomers in Japan was only about ten while the total membership of the ASJ was ~650.

Terao became the first President of the ASJ. It issued a monthly journal in Japanese titled *Tenmon Geppo* (*The Astronomical Herald*). On the other hand, the official English journal *Publication of Astronomical Society of Japan* (PASJ) started in 1949, and now counts more than 60 volumes, with 6 issues per year. The membership breakdown, as of 2008, was about ~2000 professional astronomers and ~1000 amateur astronomers.

2.4.4 *The Science Data Book Rika Nenpyo*

Here it may be worth mentioning the unique scientific data book called *Rika Nenpyo* (*Chronological Scientific Tables*), which has been published by TAO and the NAOJ every year (see Fig. 2.19). The first volume was issued in 1925 as a concise ephemeris book. It included up-to-date numerical data and tables from a range of scientific disciplines, such as astronomy, planetary sciences, meteorology, geosciences, physics, chemistry and biology. In 2005, a new chapter on the terrestrial environment was added, in response to the increased concern about global warming and chemical pollution.

The *Rika Nenpyo* seems to have originated from the *Annual Book* that was issued by the Bureau des Longitudes, Paris Observatory, because the book size and the item contents are very similar and the library at the University of Tokyo had continued to purchase the French book from around the time when the University was founded.

It is also likely that when the first TAO Director, Terao, was at Paris Observatory in the 1880s he was impressed by the *Annual Book* and later he imitated the style of that book when he launched the *Rika Nenpyo*. Incidentally, Paris Observatory largely changed the style of publication of the *Annual Book* during the 1970s. Therefore, the *Rika Nenpyo* may be regarded as a successor of the historic French *Annual Book*.



Fig. 2.19 (Top left) *Annuaire pour l'Anne 1880* (*Annual Book for 1880*), issued by the Bureau des Longitude, Paris Observatory. (Top right) The first *Rika Nenpyo*, issued in 1925 from TAO. (Bottom) The *Rika Nenpyo* of 2008 (the 81st volume, 998 pages), published by the NAOJ

2.5 The Rise of Astrophysics in Japan

In the modern history of astronomy, it is a common recognition that the emergence of astrophysics⁶ is a major theme (e.g., Herrmann 1984; Hoskin 1997), so that I believe that the problem of when the rise of astrophysics took place in each country deserves serious consideration.

In general, it is said that the world-wide rise of astrophysics happened in the second half of nineteenth century. In fact, according to the *Oxford English Dictionary*, the first use of the term ‘astrophysics’ is found in the book *The Midnight Sky*, which Edwin Dunkin (1821–1898) published in 1869. Thus one can understand that the concept of astrophysics was established around the middle of the nineteenth century.

2.5.1 A Quantitative Analysis of the Development of Astrophysics at the University of Tokyo

In this subsection, a statistical analysis is attempted to examine when activities of astrophysical research caught up with those of classical astronomy in Japan, by taking the University of Tokyo as a typical example. Accordingly, I surveyed papers published in Japan before WWII. From the book *Gakujutsu Taikan (Research Overview at the University of Tokyo)* published in 1942, I compiled a list which included ~580 papers published during 1880–1940, whose authors were mainly from the Department of Astronomy and TAO.

Then, in order to make my analysis quantitatively tractable and simple I adopt an approach of dichotomic analysis. Namely, each paper was classified into one of two groups, classical astronomy or astrophysics. The former included positional astronomy, astrometry, celestial mechanics, geodesy, and applied astronomy, etc. On the other hand, we refer to stellar spectroscopy and photometry, stellar structure and evolution, solar physics and relativistic astronomy as ‘astrophysics’. Papers belonging to the two groups were assigned to 3-year bins and were counted.

Figure 2.20 shows a plot of the paper numbers per 3 year intervals as a function of the Christian year, where the filled circles (the CA curve) refer to classical astronomy, and the open squares (the AP curve) to astrophysics. The number ratio of astrophysics papers relative to the total number of papers, i.e. $AP/(CA + AP)$, is shown by the open triangles, and the percentage values are given in the right-hand ordinate. This ratio can be regarded as a measure of activities in astrophysical research.

⁶Astrophysics was referred to as the ‘New Astronomy’ at that time. According to Herrmann (1984) it was Johann Karl Friedrich Zöllner, the German physicist and a pioneer of astronomical photometry, who first suggested the use of the term ‘astrophysics’.

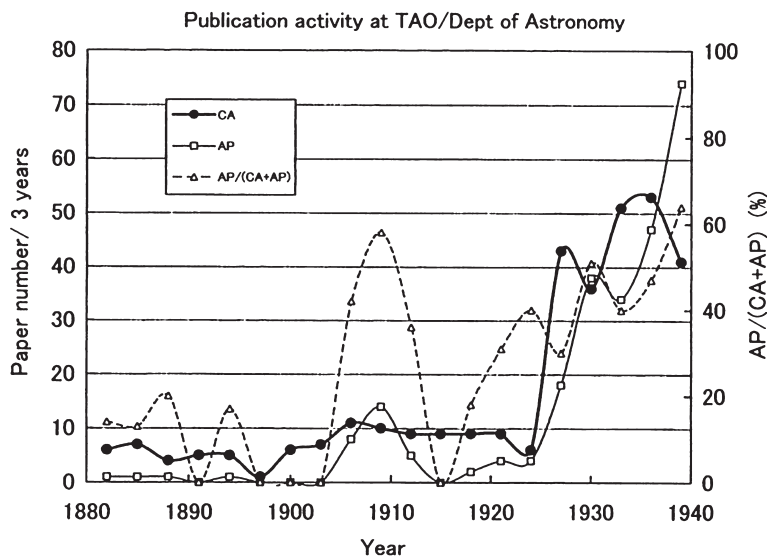


Fig. 2.20 A plot showing the chronological evolution of research publications by staff in the Department of Astronomy at the University of Tokyo. The CA and AP curves respectively show the numbers of papers in classical astronomy and astrophysics (after Nakamura 2008)

From Fig. 2.20 it can be seen that research activities were a fairly low level for both classical astronomy and astrophysics until the 1920s. This period corresponds to the time when the first TAO Director, Terao, struggled with few staff and little funding. The temporary rise in astrophysical output for several years from around 1910 was due to the papers on variable stars by Ichinohe (as described in Sect. 2.3.5). Then after 1930, one can see that both the total number of papers and astrophysical activities increased rapidly and by the mid-1930s the number of papers on astrophysics almost rivalled those on classical astronomy. From this analysis, therefore, we may conclude that most astrophysical developments in Japan took place after 1930.

The rapid rise in the total number of papers after 1930 can be interpreted as follows: one reason is the increase in the number of research staff at the University of Tokyo. But another important reason was the emergence of nationalism in Japan. Because of the prevailing militarism among the Japanese before WWII, Japan gradually became isolated from the international community, and as a result both the Government and individual scientists—including astronomers—strongly encouraged original research and stimulated autonomous studies. I suppose that this is a major reason for the rapid increase in the papers published and for the rise of astrophysics in Japan during the 1940s; such a situation seems to be unique to Japan.

It is therefore interesting to compare the situation in Japan with the world trend. The diagram in Fig. 2.21 shows the changing number of active professional astronomers in the world, given in the book by Struve and Zeberg (1962).

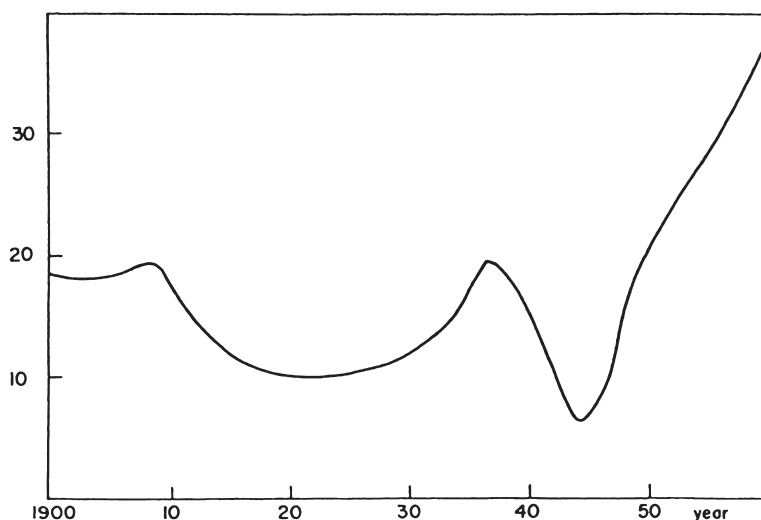


Fig. 2.21 Number evolution of active astronomers; the ordinate is expressed by the unit of 100 astronomers (after Struve and Zeberg 1962)

The ordinate expresses the number of astronomers per one hundred persons. Since the number of astronomers is approximately proportional to the number of papers published, we may compare Fig. 2.20 for Japan with Fig. 2.21, at least in a qualitative sense. The wide dip of the curve centered around 1920 shown in Fig. 2.21 was caused by WWI (1914–1918). In this war, both the defeated countries and the victorious allies suffered from a long-term depression. On the other hand, WWI had little effect on Japan. I suppose that this difference in the situation between Japan and other countries is reflected in the different curves shown in Figs. 2.20 and 2.21.

Finally, I must admit that the analysis presented in this section is obviously a one-sided view and may be somewhat oversimplified. Thus, it may be unfair for us to compare—with equal weighting—the monumental paper by Hirayama announcing the discovery of asteroid families with a paper reporting, say, astrometric measurements of known comets. Nevertheless, I believe that the analysis presented here at least indicates the overall chronological trend of astrophysical research in Japan.

2.5.2 *The Riken Institute and Spectroscopy*

The Riken was established in 1917 as a non-government Institute of physics and chemistry, with abundant research funding, thanks largely to studies of nuclear physics and the cyclotron. The laboratory of spectroscopy at the Riken Institute was

headed by the physicist Takamine Toshio (1885–1959), who played a leading role in high precision spectroscopy of the Stark Effect, and also studied infrared and ultraviolet spectra. Takamine also collaborated with TAO astronomers by applying the results of laboratory spectroscopy to astrophysical observations (DeVorkin 2002). This helped TAO astronomers conduct serious stellar spectroscopy with large telescopes after WWII.

2.5.3 *Astronomy at Kyoto and Tohoku Universities*

Prior to 1920 the University of Tokyo was the only one in Japan that had a Department of Astronomy dedicated to astronomical education and research. Then in 1921 another Department for Astronomy was founded, at Kyoto University, and led by Shinjo Shinzo (Kogure 2008).

After studying physics at the University of Tokyo, Shinjo (1873–1938; Fig. 2.22) got a position in the Department of Physics at Kyoto University. He then spent 1905–1907 at the University of Göttingen in Germany where, under the expert supervision of Karl Schwarzschild (1873–1916; Habison 2014), he studied the theory of stellar atmospheres and Einstein’s General Theory of Relativity as applied to the internal structure of stars. In 1921 the Ministry of Education approved the establishment of a new Department of Astronomy at Kyoto University, and Shinjo was nominated as the founding Professor. Just like

Fig. 2.22 An undated photograph of Shinjo Shinzo (*Courtesy Kyoto University*)



Terao in Tokyo (Sect. 3.2), Shinjo also was so busy with administrative duties and educating students in astronomy that he failed to publish any significant research on modern astronomy. However, his works on the history of the ancient calendars of China (Shinjo 1928) are cited, often now. Fortunately, the astrophysics that Shinjo had learnt in Germany later was developed by his disciples, such as Araki Toshima (1897–1978) and Miyamoto Shotaro (1912–1992). The Department of Astronomy at Kyoto University is unique in that some of its graduates later became eminent specialists in the history of astronomy, as perhaps best represented by Yabuuchi Kiyoshi (e.g., see Yabuuchi 1969). In 1968 Kyoto University opened the Hida Observatory on a high mountain in Japan's main island, Honshu. This Observatory is equipped with a 65-cm refractor, which was used mainly for research on Martian meteorology.

Although Tohoku University was founded in 1911, it was only in 1934 that this University acquired a Department of Astronomy (Takeuchi and Seki 2008). The early staff in astronomy at this University, just like those at Kyoto University, were mainly graduates from the Department of Physics and Astronomy at the University of Tokyo. Matsukuma Takehiko (1890–1950) was the first Professor of Astronomy at Tohoku University, and it seems that because of insufficient funding and limited staff the astronomers at this University have concentrated on theoretical astronomy, such as celestial mechanics, the internal structure of stars, fundamental processes in the interstellar medium and galactic dynamics. However, Matsukuma's equation (a special class of non-linear differential equations) that he proposed in 1930 as a means to calculate the gravitational potential to explain motions of member stars in a globular cluster, is now being seriously reconsidered.

Nowadays, the University of Tokyo, the NAOJ, Kyoto University, Tohoku University and Departments of Astronomy and Physics at other universities and institutes in Japan have good collaborative working relations in regards to personnel and the funding of major national astronomy projects.

2.5.4 Post-WWII Developments led by Hagihara Yusuke

Astronomical research from the outbreak of WWII to the surrender of Japan is summarized in the book *Nihon Tenmongaku-no Gaikan 1940–1945 (Overview of Japanese Astronomy during 1940–1945)* (Astronomical Society of Japan 1951). In 1946, Hagihara Yusuke (1897–1979; Fig. 2.23; Kozai 2014a) was nominated to be the Director of TAO. Under his strong leadership, TAO was able to recover rapidly from the damage suffered during WWII. Although Hagihara (1970–1972, 1974–1976) was an eminent celestial mechanician, he concentrated on developing astrophysical studies in Japan (Nakamura et al. 2008). His efforts resulted in the construction of a 74-in. reflector in 1960, the

Fig. 2.23 Hagihara Yusuke, the Fifth Director of Tokyo Astronomical Observatory (Courtesy National Astronomical Observatory of Japan)



first large telescope erected in Japan for astrophysical observations, and in fostering radio astronomical research at TAO—see the next two chapters in this book (Tajima 2017; Orchiston and Ishiguro 2017). In 1961 he was elected the Vice-President of the International Astronomical Union (Kozai 1979).

Acknowledgements My thanks are due to Suzanne Débarbat of Paris Observatory, who informed me of the location of the remaining buildings of the Montsouris Astronomical School. I also thank Sakuma Seichi and the late Yokoo Hiromitsu for providing me with some valuable information and literature.

References

- Allen, C. (2005). The Mexican expedition to observe the 8 December 1874 transit of Venus in Japan. In D.W. Kurtz (Ed.), *Transits of Venus: New Views of the Solar System and Galaxy* pp. 111–123. Cambridge: Cambridge University Press.
- Astronomical Society of Japan (1951). *Nihon Tenmongaku-no Gaikan (Overview of Japanese Astronomy during 1940–1945)*. Tokyo: Japan Society of Promotion of Science. (in Japanese).
- Astronomical Society of Japan (2008). *One Hundred Years of Astronomy in Japan*. Tokyo: Astronomical Society of Japan. (in Japanese).
- Bartholomew, J.R. (1989). *The Formation of Science in Japan*. New Haven: Yale University Press.
- Baum, R. (2014). Brown, Ernest William. In T. Hockey et al., pp. 321–322.
- Beaugé, C., & Roig, F. (2001). A semianalytical model for the motion of the Trojan asteroids: proper elements and families. *Icarus*, 153, 391–415.
- Boistel, G., Lamy, J., & Le Lay, C. (Eds.) (2010). *Jérôme Lalande (1732–1807). Une Trajectoire Scientifique*. Rennes, Presses Universitaires de Rennes. (in French).
- Brosche, P. (2000). Küstner's observations of 1884–5: the turning point in the empirical establishment of polar motion. In S. Dick, D. McCarthy, & B. Luzum (Eds.), *Polar Motion: Historical and Scientific Problems*, pp. 101–108. San Francisco: Astronomical Society of the Pacific.
- Coyne, G.V. (2014). Verbiest, Ferdinand. In T. Hockey et al., pp. 2227–2229.
- Débarbat, S. (2014). Tisserand, François-Félix. In T. Hockey et al., pp. 2160–2162.

- Débarbat, S., & Launay, F. (2006). The 1874 transit of Venus observed in Japan by the French, and associated relics. *Journal of Astronomical History and Heritage*, 9, 167–171.
- DeVorkin, D. (2002). Toshio Takanime's contact with Western astrophysics. In S.M.R. Ansari (Ed.), *History of Oriental Astronomy*, pp. 145–157. Dordrecht: Kluwer.
- Dick, S.J., Orchiston, W., & Love, T. (1998). Simon Newcomb, William Harkness and the nineteenth century American transit of Venus expeditions. *Journal for the History of Astronomy*, 29, 221–255.
- Fosmire, M. (2014). Brouwer, Dirk. In T. Hockey et al., pp. 320–321.
- Freundlich, E. (1924). Das neue Einstein-observatorium in Potsdam. *Die Sterne*, 5, 33–41. (in German).
- Freundlich, E. (1925). Das neue Einstein-observatorium. *Zeitschrift für Physik*, 26, 102–105. (in German).
- Freundlich, E. (1930). Über den Verlauf der Wellenlängen der Fraunhoferschen Linien längs der Sonnenoberfläche. *Zeitschrift für Astrophysik*, 1, 43–57. (in German).
- Fukushima, N. 2014. Kimura, Hisashi. In T. Hockey et al., pp. 1204–1205.
- Grillot, S. (2014). Mouchez, Ernest Amédée Barthélemy. In T. Hockey et al., pp. 1528–1529.
- Habison, P. (2014). Schwarzschild, Karl. In T. Hockey et al., pp. 1960–1963.
- Hagihara, Y. (1970–1972). *Celestial Mechanics. Volumes 1, 2(I), and 2(II)* (revision of the 1947 edition). Cambridge, MA: MIT Press.
- Hagihara, Y. (1974–1976). *Celestial Mechanics. Volumes 3(I), 3(II), 4(I), 4(II), 5(I), 5(II)*. Tokyo: Japan Society for the Promotion of Science.
- Herrmann, D.T. (1984). *The History of Astronomy from Herschel to Hertzsprung*. Cambridge: Cambridge University Press.
- Hirayama, K. (1918). Groups of asteroids probably of common origin. *Astronomical Journal*, 31, 185–188.
- Hirayama, S., Hirayama, K., & Sotome, K. (1910). Report on the total eclipse of the Sun observed at Padang, Sumatra on May 18, 1901. *Annales de l'Observatoire Astronomique de Tokyo*, IV, 1–26.
- Hockey, T. et al. (Eds.), (2014). *Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.
- Hoskin, M. (Ed.), (1997). *The Cambridge Illustrated History of Astronomy*. Cambridge: Cambridge University Press.
- Kaneko, T. (1981). *Einstein Shock to Taisho Era* (2 Vols). Tokyo: Kawade-shobo Shinsha Publishing Co.. (in Japanese).
- Kimura, H. (1902). A new annual term in the variation of latitude independent of the components of the pole's motion. *Astronomical Journal*, 22, 107–108. (Also see) *Astronomische Nachrichten*, 158, 234–240.
- Kogure, T. (2008). Origin and tradition at Kyoto University. In *One Hundred Years of Astronomy in Japan*, pp. 27–35. Tokyo: Astronomical Society of Japan. (in Japanese).
- Kozai, Y. (1979). Yusuke Hagihara. *Quarterly Journal of the Royal Astronomical Society*, 20(3), 325–328.
- Kozai, Y. (2014a). Hagihara, Yusuke. In T. Hockey et al., pp. 880–882.
- Kozai, Y. (2014b). Hirayama, Kiyotsuga. In T. Hockey et al., pp. 986–987.
- Kozai, Y., et al. (1993). *Seventy-five Years of Hirayama Asteroid Families: The Role of Collisions in the Solar System History*. San Francisco: Astronomical Society of the Pacific (PASP Conf. Series, No.63).
- Kragh, H. (2014). Freundlich, Erwin. In T. Hockey et al., pp. 757–758.
- Lalande, J.J. (1771). *Astronomie*. Paris: la Veuve Desaint. (in French).
- Launay, F. (2012). *The Astronomer Jules Janssen: A Globetrotter of Celestial Physics*. New York: Springer.
- Launay, F., & Hingley, P.D. (2005). Jules Janssen's 'Revolver Photographique' and its British derivative, 'The Janssen Slide'. *Journal for the History of Astronomy*, 36, 57–79.
- Luzum, B. (2014). Küstner, Karl Friedrich. In T. Hockey et al., pp. 1257–1258.
- Mouchez, E.A.B. (1890). *Rapport annuel sur l'Etat de l'Observatoire de Paris, 1890–91*, Paris: l'Observatoire de Paris.

- Nakamura, T. (2008). The dawn of Japanese modern astronomy. In *One Hundred Years of Astronomy in Japan*, pp. 3–12. Tokyo: Astronomical Society of Japan. (in Japanese).
- Nakamura, T. (2016). A French astronomer of multiple misfortune, Émile Lépassier (1826–1874) and Japan. *Tenmon Geppo*, 109, 799–810 (in Japanese, with English abstract).
- Nakamura, T., & Orchiston W. (Eds.), (2017). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.
- Nakamura, T., Yokoo, H., & Unno, W. (2008). The first-half century of astronomy in Tokyo. In *One Hundred Years of Astronomy in Japan*, pp. 3–12, 13–20. Tokyo: Astronomical Society of Japan (in Japanese).
- Nakayama, S. (1969). *A History of Japanese Astronomy*. Cambridge (Mass.): Harvard University Press.
- Nakayama, S. (1989). *Biography of Astronomer Ichonohe Naozo*. Tokyo: Libro-port Co.. (in Japanese).
- Nesvorny, D., Bottke, W.F., Dones, L., & Levison, H.F. (2002). The recent breakup of an asteroid in the main-belt region. *Nature*, 417, 720–721.
- Orchiston, W., & Ishiguro, M. (2017). The early development of Japanese radio astronomy. In T. Nakamura, & W. Orchiston (2017).
- Orchiston, W., & Pearson, J. (2017). American observations of the 22 February 1898 total solar eclipse from Jeur, India. In T. Nakamura, & W. Orchiston.
- Paris Observatory (1890). Rapport annuel sur l'État de l'Observatoire de Paris pour l'année 1890/1891. Paris: l'Observatoire de Paris. (in French).
- Pearson, J., & Orchiston, W. (2017). American observations of the 16 May 1901 total solar eclipse from Padang, Dutch East Indies. In T. Nakamura, & W. Orchiston.
- Ragozzine, D., & Brown, M.E. (2007). Candidate members and age estimate of the Family of Kuiper Belt Object 2003 EL61. *Astronomical Journal*, 134, 2160–2167.
- Rubinger, R., & Mendenhall, T.C. II (1989). *An American Scientist in Early Meiji Japan: The Autobiographical Notes of Thomas C. Mendenhall*. Honolulu: University of Hawaii Press (Asian Studies at Hawaii, No. 35).
- Saito, K. (1974). The “Black Ship” of science: the transit of Venus a hundred years ago. *Tenmon Geppou*, 67, 50–56. (in Japanese).
- Saito, K., & Shinozawa, S. (1972). On the transit of Venus observations of 1874 in Japan: Part I. *Tokyo Tenmondai-Ho*, 16, 72–162. (in Japanese).
- Saito, K., & Shinozawa, S. (1973). On the transit of Venus observations of 1874 in Japan: Part II. *Tokyo Tenmondai-ho*, 16, 259–385. (in Japanese).
- Sakuma, S. (2002). Japan's first variable star observer, Dr. Naozo Ichinohe, *Journal of the American Association of Variable Star Observers*, 31, 63–64.
- Sekiguchi, R., Okuda, T., & Shimizu T. (1939). Note on the spectrophotometric study of hydrogen line in early type stars. *Tokyo Astronomical Bulletin*, No. 481–483.
- Shinjo, S. (1928). *Toyo Tenmongaku-shi Kenkyo (Studies on the History of Oriental Astronomy)*. Kyoto: Kobundo Publishing Company. (in Japanese).
- Struve, O., & Zeberg, V. (1962). *Astronomy of the 20th Century*. New York: MacMillan.
- Tajima, T. (2017). The National Astronomical Observatory of Japan and post-war Japanese optical astronomy. In T. Nakamura, & W. Orchiston.
- Takeuchi, M., & Seki, M. (2008). Foundation of the Department of Astronomy at Tohoku University. In *One Hundred Years of Astronomy in Japan*, pp. 37–42. Tokyo: Astronomical Society of Japan. (in Japanese).
- Terao, H. (1890). Communication sur les travaux géodésiques au Japon. *Proceedings of the International Geodetic Congress*. Berlin: von Georg Reimer (Annex B-XXII) (in French).
- Terao, H., & Hirayama, S. (1910). Report on the total eclipse of the Sun observed at Jeur, in western India on January 22, 1898. *Annales de l'Observatoire Astronomique de Tokyo*, III, 1–12.
- Trachet, T. (2014). Poincaré, Jules-Henri. In T. Hockey et al., pp. 1741–1742.
- University of Tokyo (1942). *Gakujutsu Taikan (Research Overview of the University of Tokyo)*. Tokyo: University of Tokyo. (in Japanese).

- Verdun, A. (2014). Euler, Leonhard. In T. Hockey et al., pp. 676–680.
- Wako, Y. (1970). Interpretation of Kimura's annual Z-term. *Publications of the Astronomical Society of Japan*, 22, 525–544.
- Yabuuchi, K. (1969). *Chugoku no Tenmon Rekihou (Chinese Calendrical Sciences)*. Tokyo: Heibon-sha. (in Japanese).
- Yokoo H. (1999). E.F. Freundlich and his Einstein Tower. *Tenmon-Geppou*, 92, 452–453 (in Japanese, with English abstract).
- Yoshida, S., & Nakamura, T. (2017). Hirayama Kiyotsugu: discoverer of asteroid families. In T. Nakamura, & W. Orchiston.

The Emergence of Astrophysics in Asia

Opening a New Window on the Universe

Nakamura, T.; Orchiston, W. (Eds.)

2017, XV, 878 p. 578 illus., 212 illus. in color.,

Hardcover

ISBN: 978-3-319-62080-0