Empirical study on the digital planetarium system for measuring visual perception of the night sky: Analysis of impact from light pollution and astrotourism

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This year, 2023, marks 100 years since the first planetarium projector was unveiled. Planetariums were developed to faithfully reproduce starry skies. Although many empirical studies have been conducted using planetariums, few have focused on how individuals perceive starry skies projected onto planetariums. To understand this point in the context of Japanese university students, the present study analysed subjects' perceptions of the starry sky, using the effects of light pollution and their experience of astrotourism as variables. This study projected the night sky onto a digital planetarium at six sequential intervals of the naked-eye limiting magnitude. Although there is a sample bias and some limitations, the results may imply that subjects living in areas more affected by light pollution are more likely to perceive night skies as authentic at a lower naked-eye limiting magnitude. Additionally, astrotourism experience may correlate with the perceived ability to qualitatively identify many stars. These results may impact light pollution awareness and abatement efforts.

Introduction

This year, 2023, marks 100 years since Carl Zeiss first developed the optical planetarium and unveiled it in Jena, Germany. Following the opening of the first public planetarium in 1925, planetariums have been an important tool in advancing the general public's understanding of astronomy. One of the objectives of planetariums is to reproduce authentic night skies and contribute to astronomical education (e.g., *Okyudo, 2012; Tanaka et al., 2021*), and the technology is continually being improved to achieve this goal. Since the 1980s, the development of digital planetarium equipment that combines optical projectors and computers to project starry skies onto dome screens has led to a dramatic worldwide increase in the number of installations (e.g., *Lantz, 2011*). Several systems that project images of various media, such as a canvas for real-time or pre-rendered computer animations and live-capture images onto a full dome, are currently in operation and used for entertainment facilities and astronomy education (e.g., *Schnall et al., 2012*).

Japan is considered a "Planetarium Country" (*Watanabe, 2001*). Planetariums were first introduced in Japan in 1937, and since then, 473 planetariums have been installed, of which 295 are currently operational (*Japan Planetarium Association, 2023*). Japan has the third-highest number of operational planetariums after the USA and China, although Japan has more planetariums per capita than either country (*Worldwide Planetariums Database, 2023*). After World War II, some Japanese manufacturers began producing planetariums, and many large planetariums were built in Japan.

The number of planetariums in Japan significantly increased between 1971 and 1995 (Figure 1). This coincided with a period of economic growth and urbanisation,

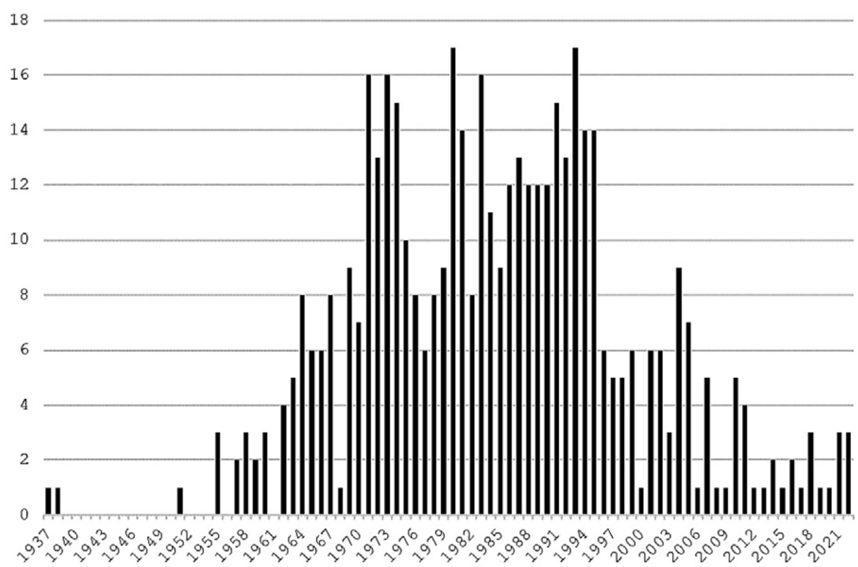

Figure 1: *The number of planetariums installed in Japan from 1937 to 2022. Image Credit: Data taken from Japan Planetarium Association (2023)*

implying that it overlapped with a period of significantly exacerbated light pollution, thus making it nearly impossible for many people in Japan to look up at the authentic night sky. Approximately 70% of Japanese residents no longer see the Milky Way near their homes (*Falchi et al., 2016*), which has an indirect influence on the increase in the number of planetariums installed in Japan (*Watanabe, 2001; Tanaka et al., 2017*). In fact, *Tanaka et al. (2017)* stated that the excessive amount of light pollution in our environment has led to the development of planetariums.

Japan is also considered a light-polluted country. Light pollution (LP) results from excess natural light levels at night caused by artificial light sources. It is one of the most prominent pollutants in modern society (e.g., *Cinzano et al., 2000*). LP is linked to human health disorders and impacts wildlife ecosystems (e.g., *Rich and Longcore, 2005*). Above all, stars and other celestial bodies are washed out by light that is either directed or reflected upward (e.g., *Longcore & Rich, 2004*). In other words, with more significant amounts of LP in an area, fewer residents can observe a dark night sky. *Cinzano et al. (2001)* identified Japan as a country with particularly serious LP, along with the USA and Europe. In a 2016 survey, Japan maintained its leading international position in the amount of artificial light radiation into space per unit area despite the significant development of neighbouring emerging countries (*Falchi et al., 2016*).

The growing worldwide awareness of and concern for LP is one of the factors behind the emergence of astrotourism (AT), in which individuals travel to search for authentic dark skies (e.g., *Collison & Poe, 2013; Soleimani et al., 2019*). *Pásková et al. (2021)* suggested that "the level of light pollution is not only monitored and predicted as a condition for astrotourism, but a new tourist attraction has also emerged — a destination of dark sky" (p. 6). In general, AT can be understood as a social practice of the general public, alienated from artificial light, seeking out the darkness that was the object of enlightenment in the past *(Edensor, 2017)*.

AT development has attracted the attention of local communities, amateur astronomers, tourism operators, and researchers because of its potential to meet sustainable development goals (e.g., *Rodrigues et al., 2014; Tapada et al., 2021; Sawada & Okyudo, 2022a*). AT could stimulate the economy in local communities (e.g., *Mitchell & Gallaway, 2019; Office of Astronomy for Development, 2023*), offer equal employment opportunities between women and men (e.g., *Dalgleish et al., 2021*), provide scientific astronomy communication for the general public (e.g., *Blundell et al., 2020*), and has potential for passing on star lore in local communities (e.g., *Sawada et al., 2023a*). In addition, AT encourages actions that preserve existing dark skies and restore them in areas where they have been lost to light pollution and other anthropogenic interferences (*Weaver, 2011*). DarkSky International (formerly the International Dark-Sky Association), an international organisation that promotes awareness of the issues of LP, also discusses AT as a solution to prevent LP (*DarkSky International, 2023*). As part of activities to promote AT, there has been some work done to host workshops on light pollution prevention for local communities (e.g., *Sawada & Okyudo, 2023*), in addition to advocating for regulations to protect dark skies (e.g., *Isobe & Sugihara, 1991*). In Japan, the rapid construction of planetariums and public observatories in the postwar period increased the popularity of visiting astronomy-related facilities. The 21st century saw increased astrotourists seeking authentic dark skies in the wilderness, mountains, and islands (*Sawada et al., 2023*).

While some researchers might argue that experiences in planetariums are not included within AT (e.g., *Weaver, 2011*), for people living in cities around the world, seeing the unobscured night sky is an extraordinary experience. Additionally, an increasing number of international studies refer to enjoying the night sky in a planetarium as AT (e.g., *Pásková et al., 2021*). This article will include AT as a factor in the perception of night skies.

This study aims to analyse how individuals perceive starry skies projected onto a planetarium, focusing on the impact of artificial light and AT experience.

Although there is a large accumulation of empirical studies using planetariums (e.g., *Plummer, 2009; Carsten-Conner et al., 2015*), few studies have focused on individuals' perceptions of starry skies projected onto a dome (*Tanaka et al., 2017*). Furthermore, few studies have focused on the internal factors of the respondents, particularly their AT experiences and the influence of artificial light (*Sawada et al., 2022b*). Empirical studies using planetariums, hemispheric domes, and full-dome projections include practical reports on recreating outer space through full-dome projection (e.g., *Wyatt, 2005*), a series of studies that incorporated planetariums into school education and measured the effects on astronomy and scientific learning (e.g., *Yu et al., 2016*), practical studies projecting a range of contents not related to astronomy (e.g., *Okyudo, 2012*), practical research for use in advanced occupational training simulations (*Blackham, 2000*), research for examining the applicability of VR technology in children with learning and cognitive disorders (e.g., *Adams et al., 2009*), studies examining the how immersive planetariums are and their effectiveness in comparison to other VR technologies (e.g., *Kuchelmeister et al., 2009*), and reports on the development of new projection systems (e.g., *Ott & Davis, 2007*). However, few studies analyse the subjects' perceptions towards starry skies projected onto the planetarium.

A series of studies by *Tanaka et al. (2017; 2019; 2021)* used the psychological method, in which data is collected from questionnaires to examine the factors that affect what is perceived as a faithful reproduction of stars in the planetarium, including the brightness of the projection and the size and colour of stars. The respondents evaluated their impression of a faithful reproduction of stars for each projection. However, this work does not sufficiently discuss participants' attributes that might impact their responses. We posit that people's ability to perceive starry skies differs depending on their living environment and the number of experiences of looking up at a true night sky. This study analyses individuals experiencing the night sky in a planetarium, considering the light pollution in respondents' neighbourhoods and their participation in AT. Specifically, this study empirically examines the relationship between respondents' attributes and their perception of the night sky as projected using a digital planetarium.

Experimental design and methodology

Hypothesis

To date, no empirical analysis has been found that examines the relationship between residential experience and perceptions of the night sky. However, in general terms, residing in areas affected by light pollution is likely to influence the perception of the night sky. For example, *Bogards (2013)* noted, though did not analyse empirically, that urban residents in the United States do not have a realistic understanding of a truly dark sky and might be satisfied even if they are not observing an authentic night sky.

The naked-eye limiting magnitude (NELM) is the apparent magnitude of the faintest object that is visible with the naked eye. It should be noted that Figure 2 shows the relationship between the NELM and other night sky brightness magnitudes and indicators. A high (~> 7) naked-eye limiting magnitude means that the faintest observable stars are very dim, indicating that the sky is dark with many visible stars.

Cohen (1988) noted that general tourists, except experts in the area (e.g., curators at a museum), tend to be satisfied with broader and less rigorous standards of authenticity towards tourism. Further, *Mccartney & Osti (2007)* noticed a relationship between the number of prior experiences a person had with an event and how authentic it seemed to that person. Applied to this experiment, we might expect that people who are significantly affected by LP and are not amateur or professional astronomers may mistakenly think an authentic night sky does not have many stars. Therefore, this study developed the following hypotheses:

H1. There is a negative correlation between the amount of LP near a subject's residence and the NELM at which the subject perceives a planetarium projection as an authentic night sky.

H2. There is a negative correlation between the amount of LP near a subject's residence and the NELM at which the subject considers there to be a high number of stars.

In this study, we used the light pollution map (*Román et al., 2018*) to determine the amount of LP near a subject's residence.

Additionally, we assume that respondents with more AT experience, including planetariums, are more likely to understand authentic night skies. Based on this assumption, we developed the following additional hypotheses:

H3. AT-experienced subjects perceive night skies as more authentic in higher NELM than AT-inexperienced subjects.

H4. AT experience is related to the ability to qualitatively identify a large number of stars.

This article examines these four hypotheses using the methods detailed in the following pages.

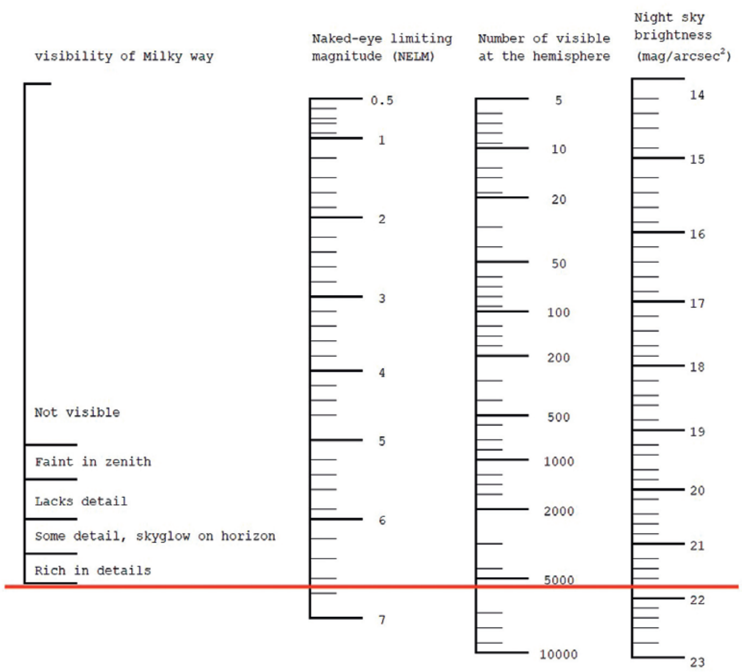

Figure 2: *A nomogram comparing different night sky brightness measurements. The red horizontal line indicates the natural night sky unobscured by light pollution. Image Credit: After IAU (n.d.)*

Experimental design and sample design

This empirical study was conducted in the digital planetarium at Wakayama University, Japan. The first planetarium with 2K resolution was installed in 2009 when the University opened its Faculty of Tourism. It has been used for academic research and educational practices, including live coverage of total solar eclipses, 360-degree video archives of traditional performing arts, and video projections of tourist destinations around Japan (*Yoshizumi & Okyudo, 2010; Okyudo, 2012*).

In 2020, much of the equipment was updated to enable projection at double the resolution. A fisheye lens (custom-ordered) and projector were used to achieve high resolution and contrast, in addition to sufficient brightness. The dome screen adopted a 5.0-metre decompression-type tilted dome at an angle of 15 degrees. A server with a dome content player was used as the projection system to project various images onto the dome screen. Figure 3 shows the digital dome system used in this study. Figure 4 shows the grid lines indicating the range of the video projector used in this system on the dome; the projection range on the dome screen is approximately 200 degrees horizontally and 120 degrees vertically. The system is intended for VR tourism studies and is not normally used as a planetarium. This means that the system does not have the function to project onto the entire hemisphere dome. However, the effective visual field of humans typically extends an elliptic range of around 30 degrees horizontally and 20 degrees vertically due to the spatial range of a visual field associated with particular perceptual and cognitive tasks. In addition, the supplementary visual field, the range which has no direct functional role in the perception of visual information, extends around 200 degrees horizontally and around 125 degrees vertically (*Hatada et al., 1980*). Therefore, the projection sufficiently covers the subjects' visual fields, taking into consideration head movements.

In this study, the night sky, reproduced by Stellarium (*Zotti et al., 2021*), was projected onto the digital planetarium. Stellarium is open-source software that allows a computer to use it as a planetarium. The software has a planetarium option, which can be exhibited in a 360-degree immersive environment in the dome. The realistic representation of a starry sky and its many customisable features makes it widely used in astronomy communication and education (*McCool, 2009*). Stellarium v0.22.0, released in March 2022, also added a switch from the Bortle scale to the NELM. This feature enables the test subjects to be provided with a variety of night-sky brightness magnitudes.

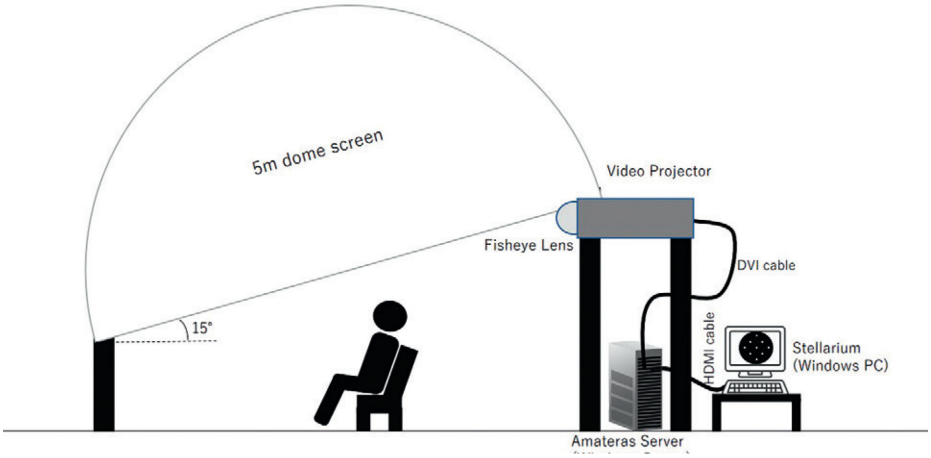

Figure 3: *A schematic of the digital planetarium system used in this study.*

We conducted the experiment intermittently between August and November 2022. The maximum capacity of the dome is 15 people. However, the view of the night sky differs depending on the seating position, so each subject sat on a chair at the centre of the dome with a sufficiently effective visual field (Figure 3). In addition, the reactions of others may influence subjects' perceptions of the night sky. Therefore, the experiments in this study were conducted individually.

The experimenter projected the night sky from the NELM of 3 to 8 onto the planetarium (six images) for 10 seconds each. The experimenter sequentially displayed NELM images but did not provide information about the total number of images or their order to the subjects in advance. The experiment began with the room dimmed, but the subjects were not given time to adapt to the darkness before the experiment began. However, in this study, the experimenters determined that dark adaptation did not need to be considered after consultation with the co-authors. As this study examined the subject's perception of a change in the number of projected stars, not the overall brightness of the sky, dark adaptation was deemed unnecessary.

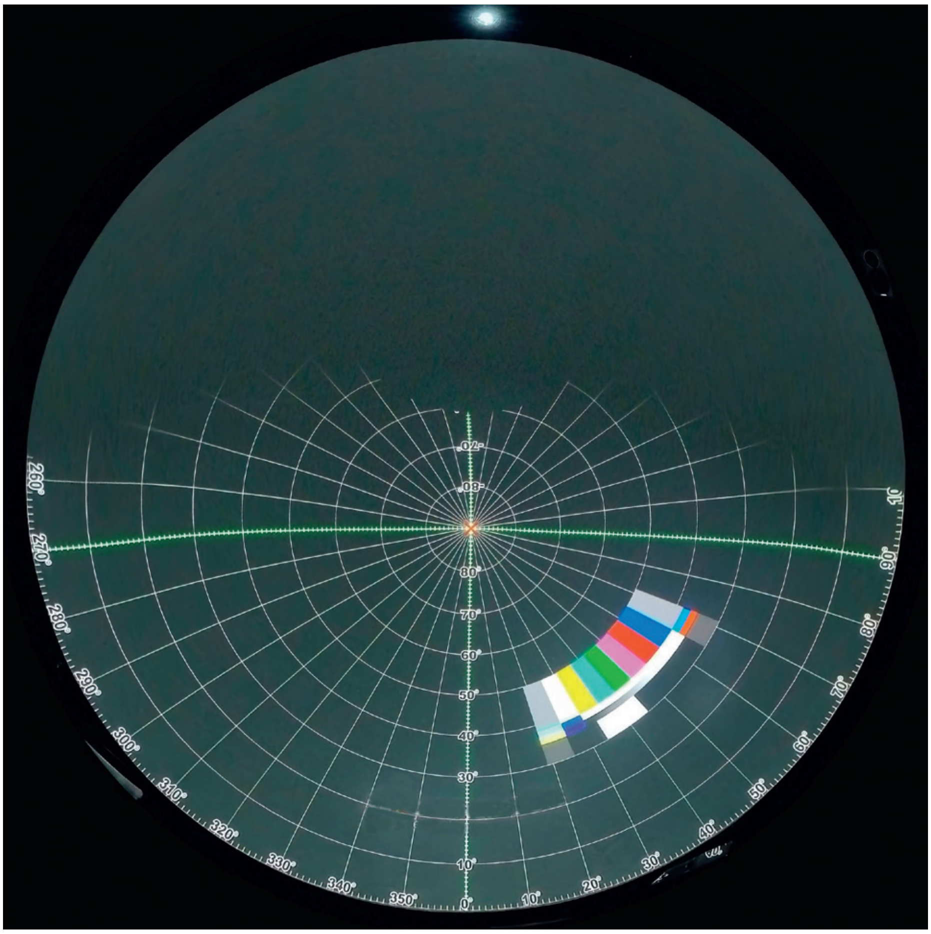

Figure 4: *Shown here is the omni-directional projection range of the video projector used in this study. The grid lines indicate the range of the video projector. The projection range on the dome screen is approximately 200 degrees along the horizon and 120 degrees in altitude.*

Due to the performance limitations of the projector, the NELM displayed in the software did not always match the NELM projected onto the dome screen. Since no significant visual differences were observed when night skies below a NELM of 2 were projected onto the screen, we decided to project the night sky above a NELM of 3 onto the screen. We set the projection to the night sky at 22:00 on 25 August 2022, when there was no moonlight influence, at the latitude and longitude of Wakayama University (34°15'56"N 135°9'5"E.). With this setting, the Milky Way was visible in front of the subject's field of view, and the Summer Triangle was near the zenith. The projected landscape was obtained from Wakayama University and originally processed in this study.

The experimenter asked the subjects two questions:

Q1. Please raise your hand when you feel the night sky is authentic.

Q2. Please raise your hand when you feel there are a lot of stars.

The experimenter ended the projection when the subjects answered both questions. Subjects were also allowed to raise their hands for both questions simultaneously. While the experimenter changed the night-sky brightness, the subject was covered by light shielding and could not see the dome screen. In this experiment, the light shielding was a cardboard box (30cm long, 40cm wide and 25cm deep) that the subjects put over their head to shield their vision.

The experimental sample comprised 30 undergraduate and postgraduate students from Wakayama University. Ten members of the sample were part of the Astrotourism Laboratory. All subjects attended basic astronomy lectures at the University; however, they were humanities and social sciences students and did not specialise in astronomy. Of the 30 original sample, 25 answered validly in both *Q1* and *Q2*; five respondents answered only one of the questions, and so their contribution was considered invalid. The valid samples may be biased, which could have significant effects on the data analysis and discussion. Before and after participating in the experiment, the subjects were asked to complete a questionnaire in Japanese using Google Forms, which is presented in more detail in the next section. The experiment took approximately 45 minutes per subject, including the time spent answering the questionnaire.

Questionnaire design

The post-experimental questionnaire was composed of three sections: demographics, AT experiences, and push motives for AT.

The first section involved the respondents' basic demographic and background data. This section consisted of seven questions and collected data on the subject's gender, age, visual acuity in both eyes and postcode of their current residence. "Residence" was operationally defined as staying in the same geographical space continuously for at least one year (*National Tax Agency Japan, 2022*). This section also collected information on how the participants moved over the past ten years, excluding studying abroad for less than one year. Visual acuity was self-reported, and some subjects responded using the "370 method", a qualitative measure of visual acuity that did not meet our quantitative standards. As a result, this item was not used in the analysis.

The second section collected the respondents' AT experiences. This section consisted of five questions. In this study, AT was operationally defined as participation in paid stargazing tours, including viewing educational planetariums implemented under compulsory education. Subjects' experiences were recorded as the number of times they participated in AT, ranging from zero to five or more times. The survey also collected information regarding with whom and when the respondents participated in AT.

The third section involved a list of 16 push motives for AT; however, a discussion of push motivations is out of the scope of this article.

Measurement and data analysis for LP in the subjects' residence

In our questionnaire, we asked subjects where they lived (that is, their current and previous postcodes) over the last ten years. We chose this time frame to align with the beginning of the Day-Night Band (DNB) data: the visible and near-infrared spectral imagery of the Earth under illumination conditions from full sunlight to night illumination with the half-illuminated lunar disk (*Liao et al., 2013*). The VIIRS-DNB is provided by the Suomi National Polar-Orbiting Partnership spacecraft(e.g., *Liao et al., 2013*). Of the 25 valid respondents, four reported an invalid postcode. This study used 21 samples to analyse *H1* and *H2*, which investigate potential correlations with geographical residence.

The postcodes were processed by the Geocoding Service provided on Google Maps to derive the geographical coordinates of a point corresponding to that postcode. These geographical coordinates were input into the VIIRS-DNB from the light pollution map (*Román et al., 2018*). In this study, geographical coordinates were input into the service to extract LP conditions in residential areas over the past decade. The analysis included four variables: mean, maximum, minimum, and latest values over the last ten years. Higher values from the VIIRS-DNB indicated worse LP.

Limitations of the sample

We would like to note that the sample size was very small, and the participants were likely biased. As noted above, due to issues with the sample, we had 21 valid contributions to test *H1* and *H2*, and 25 valid contributions to test *H3* and *H4*. In addition, ten individuals were part of the Astrotourism Laboratory at Wakayama University, and the others attended basic astronomy lectures at the University; both experiences are likely to impact respondents' answers to the experimental questions. Specifically, students who attend basic lectures may perceive more authenticity in higher NELM than those who do not. These biases may be important for determining the generalisability of the data. Future studies should consider using a larger sample size with demographics representative of the general public.

Data analysis and findings

As stated above, the experimental questions are:

Q1. Please raise your hand when you feel the night sky is authentic.

Q2. Please raise your hand when you feel there are a lot of stars.

Analysis of differences in background data

Of the final sample of 25 individuals, there were 23 Japanese students and two Chinese students, 17 of whom identified as women and eight as men. The mean age was 24.4 (SD = 11.4, *range* = 18 – 63). Results from *Q1* and *Q2* as a function of basic demographic and background data are provided in Table 1. The T-values in Table 1 (and also Tables 2 and 3) are derived from the Welch's T-test, a two-sample location test used to test the (null) hypothesis that two populations have equal means. These values are used to indicate the relative difference in the variation of the sample data. In other words, the greater the T-value, the greater evidence that there is a significant difference between the means of the two samples.

The results summarised in Table 1 indicate that most of the respondents evaluated *Q2*

Variables. n = 25	Q1.		T-value	Q2.		T-value
	M	*SD*		*M*	*SD*	
1. Total	3.00	1.00	-	4.40	0.82	-5.42***
2. Gender						
Female (68%)	2.94	0.90	-0.37	4.24	0.90	-1.88
Male (32%)	3.13	1.25		4.75	0.46	
3. Age						
18 – 29 (88%)	3.13	0.99	5.38***	4.50	0.80	2.22
over 30 (12%)	2.00	0.00		3.67	0.58	
4. Nationality						
Japanese (92%)	3.13	0.92	3.04	4.39	0.84	-0.21
Chinese (8%)	1.50	0.71		4.50	0.71	

*** $p < .001$

Table 1: *Descriptive analysis of respondents' characteristics. The table shows the mean score, standard deviation and T-value for each respondent's characteristics (gender, age and nationality for a total of 25 valid entries) for* Q1 *and* Q2*. "M" shows the mean value, "SD" shows the standard deviation, and "p" shows the p-values. Higher mean scores indicate higher NELM and a dimmer night sky.*

as higher (dimmer) than *Q1*. That is, most respondents indicated an authentic night sky at a dimmer NELM than the NELM where they felt there were a lot of stars. By aggregating the totals, the mean for *Q1* was 3.00 ($SD = 1.00$), and that of *Q2* was 4.40 ($SD = 0.82$), with a statistically significant difference between the two ($p < .001$). There were no statistically significant differences between men and women for either question. Students in their teens and twenties (22 respondents) rated both questions higher than students in their thirties and above (3 respondents), with a statistically significant difference between those age groups in *Q1*. Though the sample size is far from ideal, this may indicate that older individuals may perceive authentic night skies to be at a lower NELM (brighter sky with fewer stars).

Analysis of correlations in geographical residence

We determined the Pearson correlation coefficient between the respondents' decade LP measurements at their residences, in addition to the results of their answers to *Q1* and *Q2* using the method detailed above and reported in Table 2.

We obtained 21 valid responses for respondents' postcodes, as some responses were invalid. Table 2 summarises responses to *Q1* and *Q2* as a function of mean, minimum, maximum and latest LP values over the course of their previous 10 years' reported residences. The results for *Q1* indicate that there was a moderate negative correlation for all items except the lowest LP measurement, which was statistically significant in all cases ($p < .05$). It should be noted that we carried out the Smirnov-Grubbs test (used to identify outliers in a univariate dataset), which led to the rejection of the null hypothesis for all items ($p > .05$). However, we noticed that the strong correlation coefficient might have been driven by three data points at the high LP end (e.g., Figure 5, which is shown to demonstrate the spread of the data), and as such, we removed them to test the robustness of the correlation. In doing so, we found that the correlation coefficient in this smaller sample was much less strong than in the original sample. We want to emphasise that it is very difficult to draw conclusive statements about correlation or outliers given such a small amount of data.

In addition, we did not find any correlation between the respondents' residence and *Q2*. Our data does not suggest a correlation between *Q2* and each variable in LP, which measures the subject's perception of the number of star results and the amount of LP. Figure 6 shows a scatter plot relating the latest LP measurements to respondents' answers to *Q2*.

Variables.	Q1.		Q2.	
	Correlation coefficient	T-value	Correlation coefficient	T-value
Mean LP	-.46 (-.23)	-2.26* (-0.63)	.19 (-.28)	0.82. (-0.66)
Minimum LP	-.30 (-.29)	-1.39 (-0.67)	.10 (-.10)	0.42. (-0.54)
Maximum LP	-.50 (-.28)	-2.50* (-0.66)	.21 (-.22)	0.96. (-0.63)
Latest LP	-.52 (-.22)	-2.64* (-0.62)	.10 (-.02)	0.46. (-0.48)

* $p < .05$

Table 2: *The Pearson correlation between the respondents' LP measurements and their answers (Q1 & Q2). The analysis included four variables: mean, maximum, minimum, and latest values of LP for respondents' residences over the last ten years; higher values of VIIRS-DNB indicate higher levels of LP. For each entry, we report these values for the 21 sample data set on the top row and the 18 sample data set (removing the three highest LP samples) on the bottom row in parentheses. T-value indicates the significance of the correlation coefficient.*

Analysis of differences in AT experience

Table 3 presents the T-test results of the differences in AT experiences. Of the original sample, 25 individuals answered both *Q1* and *Q2*. In this analysis, subjects with two or more AT experiences were considered "experienced", and those with one or less were considered "inexperienced". Assuming that subjects who experienced AT more than five times had experienced AT five times, the mean number of experiences for all subjects was 1.92 (SD = 1.85); as such, this is a lower limit for the average number of AT experiences. It is noted that the number of AT experiences may be higher than in the general public due to the bias in this sample.

The analysis results indicated that "experienced" subjects rated both *Q1* and *Q2* higher than "inexperienced" subjects. In particular, there was a statistically significant difference between these two populations for *Q2* (p <.05), implying that subjects with more AT experience had a better perception of the number of stars, in support of *H4*. However, we did not find any statistically significant differences for *Q1*, leading to the rejection of *H3*. The details of AT experience, such as when and where it was experienced, reach beyond the scope of this work.

Discussion and Conclusions

This study aims to analyse how subjects perceive starry skies projected onto a planetarium, with a particular focus on internal factors. This study tested four hypotheses. The analysis may suggest that *H1* and *H4* were supported, whereas *H2* and *H3* were rejected.

Discussion

H1. there is a negative correlation between the amount of LP near a subject's residence and the NELM at which the subject perceives a planetarium projection as an authentic night sky.

We found a negative correlation between the amount of LP in subjects' residences and the NELM at which they perceive an authentic night sky projected onto a planetarium. That is, our results may suggest that subjects living in areas more affected by LP are more likely to perceive night skies as authentic at a lower NELM

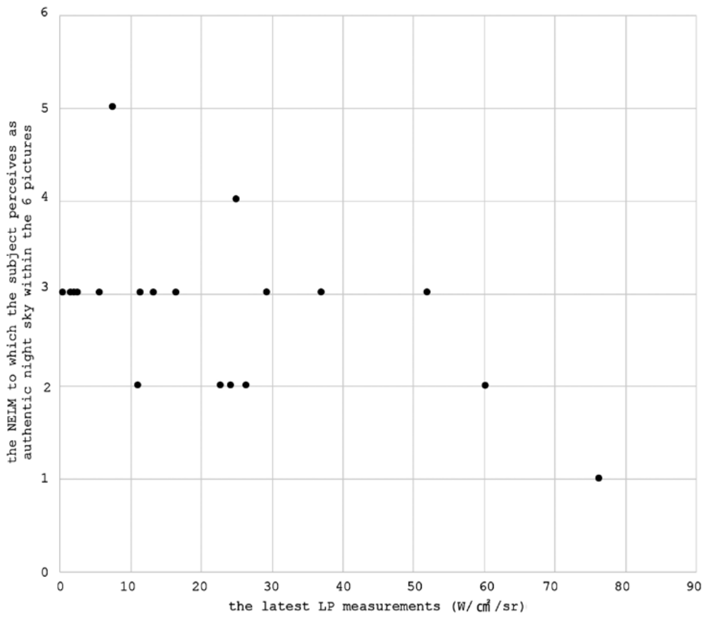

Figure 5: *Scatter plot showing the latest LP measurements and respondents' answers for the question,* Please raise your hand when you feel the night sky is authentic *(Q1; n = 21).*

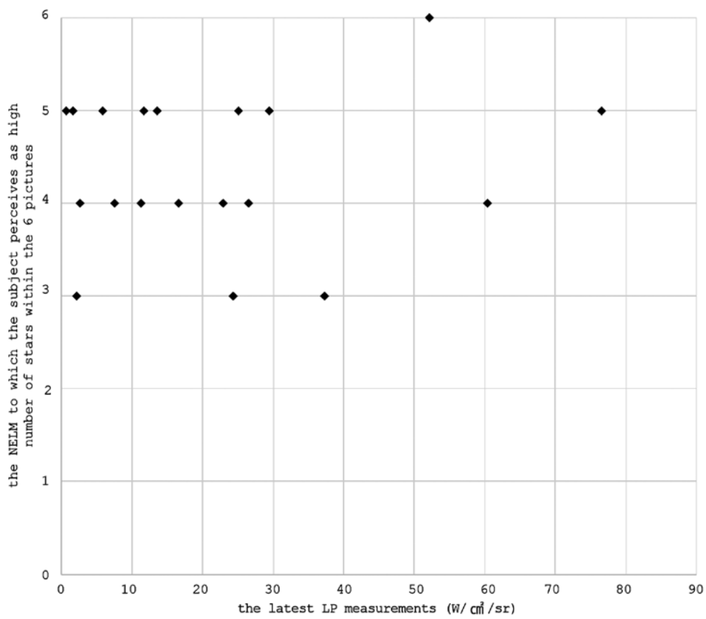

Figure 6: *Scatter plot showing the latest LP measurements and respondents' answers to the question,* Please raise your hand when you feel there are a lot of stars *(Q2; n = 21).*

Variables. n = 25	Q1. M	Q1. SD	T-value	Q2. M	Q2. SD	T-value
Experienced (48%) (Twice or more)	3.33	1.15	1.63	4.75	0.75	2.22*
Inexperienced (52%) (0 or 1 time)	2.69	0.75		4.08	0.76	

* p <.05

Table 3. *Descriptive analysis of participant responses to Q1 and Q2 as a function of differences in AT experience.*

(translating into fewer visible stars, consistent with their lived experience). The correlation coefficient between *Q1* and the Latest LP, which indicated the relationship between the subject's perception of authentic night skies and the latest LP, had the lowest correlation value (r = -.52; Table 2) compared to the other items. There is a possibility that the subjects more affected by the most recent LP impact are more likely to identify an authentic night sky at a lower NELM. However, to reiterate, it is difficult to draw conclusive statements about correlation or outliers given such a small amount of data.

H2. there is a negative correlation between the amount of LP near a subject's residence and the NELM at which the subject considers there to be a high number of stars.

Our data does not suggest a correlation between *Q2* and each variable in LP, which measures the subject's perception of the number of star results and the amount of LP. Therefore, it was suggested that the ability to recognise many stars was nearly the same regardless of where respondents live or have lived. In other words, this result may imply that people know that the sky should have more stars even if they live in a place with a bright sky. *Sawada et al. (2021)* indicated that the most sought push motive for Japanese astrotourists was "seeing beautiful starry skies". Though how "beautiful" is defined is subjective, it may be that providing a sufficient number of stars in AT activities, including planetariums and star parties, may improve satisfaction with AT experiences. Additional research into the relationship between the perceived beauty of the night sky and the number of stars, along with a comparison of outcomes from experiments both in a planetarium and outdoors, would enhance our comprehension of tourists' perceptions of the sky.

H3. AT-experienced subjects perceive night skies as more authentic in higher NELM than AT-inexperienced subjects.

Though our sample is biased toward those more familiar with astrotourism, our data does not suggest a correlation between the perception of authenticity of the night sky and AT experiences. The *H1* hypothesis was adopted, which means that subjects' perceptions of the authenticity of a night sky may be more influenced by their living environment than by their AT experience. A larger sample size is required to confidently adopt one hypothesis over another.

H4. AT experience is related to the ability to qualitatively identify a large number of stars.

Related to *H2*, we found that AT experience correlates with the ability to qualitatively identify many stars. *Tanaka et al. (2021)* found no relationship between personal data, such as astronomical observation experience, and the subject's perception of faithfulness as projected onto the planetarium. However, in contrast to these findings, this study revealed a relationship between AT experience and subjects' ability to perceive the number of stars. As we mentioned above, the data presented in Table 2 might indicate that people know, even if they live in a place with a bright sky, that the sky should have more stars. The ability to perceive the number of stars may be more likely affected by the number of observation experiences than their living environment. However, our study could not analyse when the subjects experienced AT. There may be changes in the perception of the number of stars depending on when the subjects participated in AT. It is also necessary to understand which AT experiences subjects experienced: a planetarium, a visit to an observatory, or some other dark-sky experience. It should be noted again that all subjects had attended a basic astronomy lecture, which may have been a major bias.

Limitations

This study had some limitations. First, the planetarium system used in this study was digital, which meant that the faithfulness of the night skies was insufficient. The absolute and relative star brightness and size of stars in our digital planetarium differ from those of real stars (*Okyudo, 2012*). Some researchers also implied that star images are more faithfully replicated in optical planetariums than digital planetariums (*Tanaka et al., 2017*). In particular, we did not measure the brightness ratio of the stars in this study; we simply projected the PC monitor input Stellarium onto the dome. Additionally, the resolution of the planetarium used in this study was 4K, which is slightly out of focus for human vision (*Okyudo, 2012*). Therefore, subjects' responses regarding their perceived NELM are not necessarily accurate. Future experiments using an optical planetarium should be conducted and compared with the night sky outside (*Sawada et al., 2022b*).

In addition, allowing the subjects to adapt to dark sky conditions may affect their perceptions of the sky under the dome. In this study, the experimenters determined that dark adaptation did not need to be considered, but further analyses may be required to get more correct data.

An additional limitation was that the participant sample was biased, as stated above. The study sample consisted predominantly of university students in their 20s, making generalisability impossible. This study also asked subjects to evaluate their willingness to participate in AT on a 5-point scale, most of whom rated it as 4 or higher (M = 4.50, SD = 0.63), likely skewed by the ten members of the sample who are part of the Astrotourism Laboratory at Wakayama University. In another survey conducted among 2,000 Japanese residents, 50.0% of the sample expressed interest in participating in AT, while the remaining 50.0% stated they would not (*Sawada et al., 2023b*). Though these two studies are not necessarily directly comparable, we expect the present study's participants are not representative of the general public. Beyond the biases of our participants, the sample size was very small. The results stated in this study should be carefully considered against our sample size. It is possible that with a larger group of participants who are more representative of the general public, we would garner considerably different results. Further analyses with larger sample sizes are required.

Conclusions and Suggestions for Future Work

The results of this study may have implications for suppliers of AT services, such as planetarians and organisers of star parties. This study may indicate a relationship between the level of light pollution in participants' neighbourhoods and their AT experience, influencing their perception of the night sky. Therefore, suppliers can vary their approach to AT based on their location and the individual astrotourists. Specifically, when AT occurs under the beautiful night sky (e.g., space with NELM 6th magnitude or higher) or in a planetarium, tourists may be satisfied simply by looking up at the starry sky. On the other hand, service providers may need to make more effort to entertain tourists in spaces with fewer visible stars. Although there is a sample bias and some limitations, this study implies that tourists from areas with low light pollution and those who are AT-experienced may not be visually satisfied if the night sky lacks sufficient stars. Therefore, in spaces where the night sky cannot be enjoyed visually, it may be necessary to improve tourist satisfaction by combining efforts such as enhanced astronomical explanations and utilising telescopes for observing celestial objects.

Although the main sample in this study consisted of Japanese participants, it is possible that results may differ for other cultural samples (e.g., *Ito et al., 2020*). However, the suggestion of a relationship between subjects' internal factors and their perception of the night sky should interest the readers of this issue.

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