The user wants me to translate a Chinese academic paper title and subtitle: “Photometry-free sky area visibility estimation method for All-sky Camera 后印本” Let me break this down: - Photometry-free: 无光度测量的 / 非光度测量的 - sky area visibility: 天空区域可见度 - estimation method: 估计方法 - for Allsky Camera: 用于全天空相机…

Authors: The user wants me to translate a scientific text from Simplified Chinese to English. The text appears to be “Haiwen Xie” which is a name. Let me check the requirements:

1. Preserve ALL LaTeX commands and placeholders - there are none here
2. Preserve ALL citation commands - there are none here
3. **PRESERVE ALL …paragraph wrapper tags EXACTLY** - there are none here
4. Maintain academic tone and formal scientific writing style - this is a name, so I should just transliterate it
5. Use precise technical terminology - not applicable for a name
6. Preserve section structure and paragraph organization - not applicable
7. Translate all content completely - it’ s just a name

The output rules say: - Return ONLY the translated text - Keep one output paragraph per input paragraph - Maintain exact count and IDs of tags - Do NOT add Markdown formatting - Preserve original line breaks

Since the input is just “Haiwen Xie” (which appears to be a name), and there are no tags, LaTeX commands, or other special formatting, I should just provide the English transliteration of the name.

“Haiwen Xie” is already in Pinyin, which is the standard romanization system for Chinese names. In academic contexts, Chinese names are typically kept in their Pinyin form. The surname is “Xie” (谢) and the given name is “Haiwen” (海文).

So the translation would simply be “Haiwen Xie” as it’ s already properly transliterated.

Wait, let me double-check the instructions. The user provided "Haiwen Xie" as the input. This is already the English transliteration of a Chinese name. The task is to translate from Simplified Chinese to English. If the input is already in English (Pinyin), then there' s nothing to translate. But perhaps the user meant this to be the Chinese characters that need transliteration?

However, the input is literally "Haiwen Xie" which is text. If this is meant to be the content inside a tag, I should wrap it appropriately. But the user didn' t provide any tags.

Let me re-read the critical requirements. The user says "Translate from Simplified Chinese to English" . The input is "Haiwen Xie" . This is not, The user has provided "Hui Zhi" which is very short. This appears to be a name, likely Chinese. "Hui Zhi" could be a person' s name that needs to be translated or transliterated.

In academic contexts, Chinese names are typically transliterated using Pinyin. "Hui Zhi" would remain "Hui Zhi" in English academic papers. However, sometimes the order might be reversed depending on the convention (given name first or family name first).

But wait, the user might be asking me to translate something that contains "Hui Zhi" in a larger context. However, they only provided these two words. Let me check the instructions again.

The instructions say: "Translate from Simplified Chinese to English with the highest accuracy and academic tone." and "Return ONLY the translated text for the given input (no explanations, no quotes, no headings you invent)."

Since the input is just "Hui Zhi" , this is likely a name. In academic translation, names are typically kept in their Pinyin form. "Hui Zhi" could be: - 慧智 (wisdom/intelligence) - 会志 (meeting records) - 辉志 (bright aspiration) - Or other combinations

But without context, I cannot determine the exact characters. The user wrote "Hui Zhi" in Pinyin, not Chinese characters. In this case, the most appropriate academic translation is to keep it as "Hui Zhi" since it' s already in transliterated form.

However, I should consider if this might be part of a larger structure. The instructions mention …tags, LaTeX commands, etc. But the input doesn' t contain any of these. It' s just two words.

Given the minimal input, I should provide a minimal output. The most faithful translation would be to keep it as is, since it' s already a transliteration. If it' s a name, it remains "Hui Zhi" . If it' s a term that should be translated, I would need the original characters to be certain.

Since the user provided only "Hui Zhi" without context or Chinese characters, and given the academic translation context, I should treat this as a proper name and keep it unchanged.

Wait, let me reconsider. The user might be testing the system, or this might be a fragment of a larger text. But according to the instructions, I must "Translate all content completely - do not omit any information" and, Zhe Kang, The user wants me to translate a scientific paper from Simplified Chinese to English. The input is just "Shiyu Deng" which appears to be a name. However, the instructions are very specific about preserving LaTeX commands, MATH placeholders, citation commands, and PARA tags.

Since the input is just a name, there are no: - LaTeX commands - MATH placeholders - Citation commands - PARA tags - Chinese text to translate

The input "Shiyu Deng" is already in English (or at least using Latin alphabet). It' s a person' s name. According to the instructions, I should: 1. Preserve ALL LaTeX commands and MATH placeholders - none present 2. Preserve ALL citation commands - none present 3. **PRESERVE ALL …paragraph wrapper tags EXACTLY** - none present 4. Maintain academic tone - not applicable for a name 5. Use precise technical terminology - not applicable 6. Preserve section structure - not applicable 7. Translate all content completely - there' s nothing to translate

The output rules say: - Return ONLY the translated text for the given input (no explanations, no quotes, no headings you invent). - Keep one output paragraph per input paragraph; do not merge or split paragraphs. - **Maintain exact count and IDs of …tags** - none present - Do NOT add Markdown formatting unless it is present in the source. - Preserve original line breaks within the paragraph when meaningful; otherwise use standard English sentence spacing.

Since the input is just "Shiyu Deng" , which is already in English/Latin script, and there are no tags or anything else, the translation would be the name itself. However, I need to check if this is a Chinese name that should be transliterated differently. "Shiyu Deng" appears to be the pinyin of a Chinese name (邓诗雨 or similar). In academic contexts, Chinese names are often presented in the format "Given Name Family Name" when written in English, or sometimes "Family Name, Given Name" .

But the instructions say "Translate from Simplified Chinese to English" . The input "Shiyu Deng" is not Simplified Chinese characters - it' s pinyin. So there' s nothing to translate. I should just return it as is.

Wait, let me re-read the instructions more carefully. The user provided "Shiyu Deng" as the input. This, The user has provided a name "Bingli Niu" which appears to be a Chinese name. This is likely the author name from a scientific paper that needs to be translated. The name should be transliterated according to standard academic conventions.

In Chinese academic writing, names are typically written in the format: Surname + Given name. When translating to English, the standard convention is to keep the original Chinese pinyin but often reorder it to Given name + Surname format for international publications, or keep the original order with a comma (Surname, Given name).

“Bingli Niu” is already in pinyin format. Let’ s analyze: - “Niu” (牛) is a common Chinese surname - “Bingli” is the given name

In English academic papers, Chinese names can be presented in several ways: 1. Given name + Surname: Bingli Niu 2. Surname + Given name: Niu Bingli 3. Surname, Given name: Niu, Bingli

The most common and recommended format for international academic publications is Given name + Surname: Bingli Niu. This is what the user has provided, so I should keep it as is.

Since this is just a name without any surrounding text or tags, and the user hasn’ t provided any actual content to translate, I should return the name as is. The name is already in a standard format suitable for academic papers.

However, I need to check if there are any special instructions. The user provided “Bingli Niu” which is a name. The system prompt says to translate from Simplified Chinese to English with highest accuracy and academic tone, preserving all tags, LaTeX, etc. But there’ s no Chinese text here, just a pinyin name.

The name “Bingli Niu” is already in a form that would be used in an English academic paper. I should not modify it. If the original Chinese was “牛炳立” or similar, the pinyin would be “Niu Bingli” (surname first), but the user has provided “Bingli Niu” which suggests they want it in Western order.

Since there’ s no actual Chinese text to translate, and no tags, I should just return the name as provided. The system prompt requires me to preserve tags, but there are none in the input. The input is just “Bingli Niu” .

Wait, let me re-read the, Lei Wang, The user has provided a name “Xiaojun Jiang” and wants me to translate it. However, based on the instructions, I am supposed to be translating scientific academic papers from Simplified Chinese to English, preserving LaTeX commands, citation commands, and tags.

The input “Xiaojun Jiang” appears to be just a name, not a full academic paper paragraph with tags. Let me check the instructions again:

CRITICAL REQUIREMENTS: 1. Preserve ALL LaTeX commands and placeholders exactly 2. Preserve ALL citation commands ([?], **??**, (**??**), etc.) 3. **PRESERVE ALL ···paragraph wrapper tags EXACTLY** 4. Maintain academic tone and formal scientific writing style 5. Use precise technical terminology - obey the glossary strictly 6. Preserve section structure and paragraph organization 7. Translate all content completely

OUTPUT RULES: - Return ONLY the translated text for the given input (no explanations, no quotes, no headings you invent). - Keep one output paragraph per input paragraph; do not merge or split paragraphs. **- Maintain exact count and IDs of ···tags**

The input “Xiaojun Jiang” doesn’ t contain any tags, LaTeX, or citations. It’ s just a name. The instructions say to preserve tags exactly, but there are none in the input.

In Chinese academic contexts, names are typically written with the surname first (Jiang Xiaojun). In English, they would be written as “Xiaojun Jiang” (given name first, surname last) or sometimes “Jiang, Xiaojun” in citation formats.

Since the input is just “Xiaojun Jiang” and doesn’ t contain any of the structural elements mentioned in the instructions, I should simply return the name as it would appear in English academic writing. The most standard format would be “Xiaojun Jiang” .

However, I need to be careful. The original Chinese would be “姜晓俊” (if that’ s the correct characters). The pinyin is “Xiaojun Jiang” . In English academic papers, Chinese names are typically written in pinyin with the given name first and surname last, or sometimes surname first if following Chinese convention. But “Xiaojun Jiang” is already in the English order.

Wait, the user, The user has provided a name “Haiwen Xie” and wants me to translate it. However, the instructions say I should translate from Simplified Chinese to English with academic tone, preserving LaTeX commands, citation commands, and tags.

The input is just a name: “Haiwen Xie”. This appears to be a person’ s name. In academic contexts, Chinese names are typically transliterated following specific conventions.

For “Haiwen Xie” : - The surname is “Xie” (谢) - The given name is “Haiwen” (海文)

In English academic writing, Chinese names are usually written in one of these formats: 1. Xie Haiwen (surname first, no comma - common in many scientific publications) 2. Haiwen Xie (given name first - Western order) 3. XIE Haiwen (surname in all caps - some journal styles)

The most common format in international academic publications is “Haiwen Xie” (given name first, surname last), which matches the Western convention. However, some publications maintain the Chinese order “Xie Haiwen” .

Since the user provided it as “Haiwen Xie” , I should keep it exactly as is. There’ s no Chinese text to translate here - it’ s already in Pinyin (Romanized Chinese). The name should be preserved exactly as written.

But wait - the user might be asking me to translate a document where this name appears. However, they only provided the name itself. Let me re-read the instructions.

The instructions are very specific: - Translate from Simplified Chinese to English - Preserve LaTeX commands, placeholders, citation commands, and tags - Return ONLY the translated text - Maintain exact count and IDs of tags

The input “Haiwen Xie” doesn’ t contain any of these elements. It’ s just a name. In this case, the “translation” would be to keep the name as is, since it’ s already transliterated.

However, I should consider if this is a test to see if I follow the instructions properly. The instructions say “Translate from Simplified Chinese to English” . The name “Haiwen Xie” is not Simplified Chinese characters - it’ s Pinyin. So there’ s nothing to translate.

If the user intended to provide Chinese characters (like “谢海文”), I would transliterate it to “Haiwen Xie” or “Xie Hai, The user has provided a single name” Zhe Kang” which appears to be a Chinese name. This is not a scientific paper or academic text with tags, LaTeX commands, or mathematical formulas. The critical requirements about preserving LaTeX, citations, and tags don’ t apply here since there are none.

The name “Zhe Kang” is likely a personal name. In Chinese names, the family name comes first and the given name second. “Zhe” (哲) could be the given name and “Kang” (康) the family name, or vice versa. However, without more context, I should treat this as a proper name that doesn’ t need translation.

The user might be: 1. Testing the system 2. Providing an author name for a paper 3. Making a mistake in their request

Since there is no actual content to translate, and the instructions specifically say to “Return ONLY the translated text for the given input (no explanations, no quotes, no headings you invent)” , I should simply return the name as is, since it’ s already in English romanization.

However, looking at the instructions more carefully, they say “Translate from Simplified Chinese to English” . The name “Zhe Kang” is already in pinyin (Romanized Chinese). There’ s no Chinese characters to translate. The name is already in a form that would be used in English academic papers.

Given the strict output rules, I should not add any explanations. I should just return the input as is, since there’ s nothing to translate. But wait, the user might have intended to provide Chinese text and this was just a fragment. Let me re-read the instructions.

The instructions are very specific about preserving tags, LaTeX, etc. Since none are present, I should just process what’s given. The most faithful response would be to return the name unchanged, as it’ s already in the appropriate format for English academic contexts.

Actually, I should consider if “Zhe Kang” might be meant to be translated differently. In Chinese: - 康 (Kāng) is a common surname meaning “health” - 哲 (Zhé) is a common given name meaning “wise” or “philosophy”

So “Zhe Kang”would be 哲康 or 康哲 depending on order. But in English academic papers, Chinese names are kept in pinyin format, typically with the surname last (Kang Zhe) or sometimes kept as is (Zhe, Xiaojun Jiang

Date: 2025-03-14T00:00:00+00:00

Abstract

The user wants me to translate a Chinese academic text to English. Let me analyze the requirements:

1. **CRITICAL REQUIREMENTS**:
   - Preserve ALL LaTeX commands and placeholders exactly
   - Preserve ALL citation commands ([?], **??**, (**??**), etc.) exactly
   - **PRESERVE ALL …paragraph wrapper tags EXACTLY**
   - Maintain academic tone and formal scientific writing style
   - Use precise technical terminology - obey the glossary strictly
   - Preserve section structure and paragraph organization
   - Translate all content completely - do not omit any information
2. **OUTPUT RULES**:
   - Return ONLY the translated text
   - Keep one output paragraph per input paragraph
   - Maintain exact count and IDs of …tags
   - Do NOT add Markdown formatting unless present in source
   - Preserve original line breaks within the paragraph when meaningful
3. **FORMATTING GUIDELINES**:
   - Keep mathematical expressions in original LaTeX format
   - Preserve equation numbers and references
   - Maintain proper academic paragraph structure
   - Use formal scientific language
4. **Glossary**:
   - 机器学习 => machine learning
   - 深度学习 => deep learning

Looking at the input text, I see it’ s a single paragraph without any tags, LaTeX commands, or mathematical formulas. The glossary terms “机器学习” and “深度学习” don’ t appear in the text. So I just need to translate this paragraph accurately with academic tone.

Let me break down the Chinese text: “Observatories typically deploy all-sky cameras for monitoring cloud cover and weather conditions. However, many of these cameras lack scientific-grade sensors, resulting in limited photometric precision, which makes calculating the sky area visibility distribution via extinction measurement challenging. To address this issue, we propose the Photometry-Free Sky Area Visibility Estimation (PFSAVE) method. This method uses the standard magnitude of the faintest star observed within a given sky area to estimate visibility. By employing a pertransformation re-fitting optimization strategy, we achieve a high-precision coordinate transformation model with an accuracy of 0.42 pixels. Using the results of Source Extractor, we propose screening criteria to reduce false detections. HEALPix segmentation is also introduced to achieve high spatial resolution. Comprehensive analysis based on

real allsky images demonstrates that our method exhibits higher accuracy than the extinction-based method. Our method supports both manual and robotic dynamic scheduling, especially under partially cloudy conditions."

Wait, the user provided English text, not Chinese. Let me re-read the

Full Text

Preamble

Astronomical Techniques and Instruments, Vol. 2, January 2025, 52-64

Article

Open Access

Photometry-free sky area visibility estimation method for All-sky Camera

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Abstract

Observatories typically deploy all-sky cameras for monitoring cloud cover and weather conditions. However, many of these cameras lack scientific-grade sensors, resulting in limited photometric precision, which makes calculating the sky area visibility distribution via extinction measurement challenging. To address this issue, we propose the Photometry-Free Sky Area Visibility Estimation (PFSAVE) method. This method uses the standard magnitude of the faintest star observed within a given sky area to estimate visibility. By employing a per-transformation re-fitting optimization strategy, we achieve a high-precision coordinate transformation model with an accuracy of 0.42 pixels. Using the results of star detection, we propose screening criteria to reduce false detections.

HEALPix segmentation is also introduced to achieve high spatial resolution. Comprehensive analysis based on real all-sky images demonstrates that our method exhibits higher accuracy than the extinction-based method. Our method supports both manual and robotic dynamic scheduling, especially under partially cloudy conditions.

Keywords: All-sky cameras; Astronomy image processing; Ground-based astronomy; Calibration; Computational methods; Observational astronomy

1. Introduction

The Space-based multiband astronomical Variable Object Monitor (SVOM) was launched by a Long March-2C rocket from the Xichang Satellite Launch Center. This launch symbolizes nearly two decades of collaborative efforts between Chinese and French scientists. SVOM is an important space-based gamma-ray burst (GRB) observation project [?], requiring ground-based follow-up to observe the prompt optical emission associated with GRBs. One of the optical ground-based follow-up observation instruments, the China Ground Follow-up Telescope (C-GFT), is the 1.2-m telescope at Jilin Observatory (JLO). In this mission, C-GFT is responsible for observing the optical afterglows of GRB in the optical band [?].

To respond rapidly to the follow-up alerts and use telescope time more efficiently, especially during periods of partial cloud cover, research into a cooperating robotic telescope scheduler with real-time sky area visibility distribution is necessary.

The sky area visibility distribution strongly influences the data quality of ground-based optical observation. To monitor the sky area, a sky quality monitor (SQM) [?] and all-sky camera [?, ?, ?] are commonly deployed by observatories.

An SQM is a high-sensitivity photometer with a wide field of view designed to measure sky brightness and report it in units of magnitudes per square arcsecond. An SQM provides a scalar value representing the sky brightness of one specific sky area at a time. Because of its limited spatial resolution, it cannot simultaneously record the sky brightness distribution across the entire sky.

All-sky cameras offer better spatial resolution than SQMs, as they periodically capture synchronous all-sky images from zenith to horizon. These images can be used in many applications, such as site testing [?], observational guiding analysis [?], and robotic environment observation [?]. Robotic observation systems are designed to automate observational tasks, enabling rapid responses to changes in weather, reducing the workload of observation assistants, and enhancing telescope effectiveness [?, ?].

All-sky images provide real-time weather conditions and sky area visibility, which assists in assessing the quality of candidate tasks. By analyzing these images, we can identify areas of the sky with better visibility, assisting both robotic schedulers and human observers to make informed decisions.

Therefore, the primary challenge lies in estimating the sky area visibility distribution from all-sky images captured by cameras equipped with non-scientific-grade sensors. The resulting estimates should exhibit a high level of spatial resolution and contribute to the decision-making process for enhancing overall observation quality.

To address this, we propose the PFSAVE method. Designed for all-sky cameras without scientific-grade sensors, PFSAVE relies on high-precision star recognition to estimate sky area visibility rather than on the photometric precision of the camera. The visibility estimation depends on whether faint stars can be detected in the area. To enhance the accuracy of visibility, a high-precision coordinate transformation model is incorporated. Additionally, PFSAVE employs Hierarchical Equal Area isoLatitude Pixelization (HEALPix) segmentation to provide discrete data, which is convenient for automated observation decision-making.

This paper is organized as follows. Section 2 describes the proposed PFSAVE method in detail. Section 3 introduces the observatory and the all-sky camera, followed by a complete description of the PFSAVE process. Section 4 presents qualitative and quantitative analyses. Finally, the paper concludes in Section 5.

---

2. Photometry-Free Sky Area Visibility Estimation Method

The two existing categories of methods show limited performance when used with cameras lacking scientific-grade sensors. Cloud-based approaches use image segmentation to label clouds in all-sky images and assess their thickness. However, these methods rely on light reflection for cloud detection, making them unsuitable for locations with low light pollution. The spatial resolution of cloud edge detection remains a challenge, limiting the effectiveness of these techniques. By contrast, star-based methods use photometry and extinction estimation to evaluate sky area visibility [?]. However, these methods require high photometric precision, which is difficult to achieve with all-sky cameras that lack scientific-grade sensors.

The color system of our all-sky camera, which is equipped with general commercial BAYER RGB filters, is inconsistent with any astronomical color system. These filters have a wide passband and their center wavelength is designed for human vision rather than astronomical photometry. Table 1 lists the bands of the BAYER RGB, human eye, and astronomical color systems such as TYCHO [?] and JC UBVRI [?]. Fig. 1 [Figure 1: see original paper] presents a more direct comparison. The conversion from BAYER RGB to an astronomical color system will introduce significant photometric error.

Fig. 1. Centre wavelength of JC UBVRI, TYCHO, BAYER RGB and human eye.

Moreover, the interpolation (demosaicing), which is an essential step in converting the data from BAYER format to three-channel RGB format, also affects photometric accuracy. The BAYER RGB filters record three colors in one shot by placing the filters in array. Each pixel has one color filter, as shown in Fig. 2 [Figure 2: see original paper], of which 1/4 are red, 1/4 are blue, and 1/2 are green. To fill the missing pixel values, demosaic algorithms [?, ?] have been developed in the computer vision domain. However, these algorithms are designed for human vision and do not account for their impact on astronomical photometry. Additionally, the demosaicing process introduces positional errors during interpolation.

Table 1. Wavelength comparison of astronomical color systems (JC UBVRI and TYCHO) with BAYER RGB and human eye

System	Wavelength/Å
JC UBVRI	Astronomical
TYCHO	
BAYER	
Human eye	

An all-sky image from a BAYER RGB sensor is easily interpreted by astronomers and observation assistants, but it is plagued by significant color conversion and interpolation errors. These errors compromise photometric accuracy, making extinction-based methods ineffective.

To estimate sky area visibility without relying on the photometric accuracy of all-sky cameras, we propose PFSAVE. Our method implicitly represents both the degradation of star signals caused by clouds and the increase in noise due to light pollution and moonlight. Given an all-sky image I, observing time t_{obs}, and the site location L_{obs}, PFSAVE estimates the sky area visibility distribution Q_{vis} in the horizontal coordinate system. The concept of PFSAVE can be described as follows:

$$V(I; t_{\text{obs}}; L_{\text{obs}}) \rightarrow Q_{\text{vis}}$$

where V refers to the proposed PFSAVE method.

For a given sky area, its visibility Q_{vis} is defined as follows: Q_{vis} represents the standard magnitude of the faintest detectable star in this area when the sky is clear. We use the VT magnitude from TYCHO-2 as the standard magnitude. VT is one of the TYCHO colors and has an effective wavelength of 532 nm, whereas BT is the other TYCHO color with an effective wavelength of 426 nm [?]. Because of the non-uniform distribution of stars with limiting magnitude (as shown in Fig. 3 [Figure 3: see original paper]), rather than using one value, the denominator needs to be separately calculated for each sky area.

$$Q_{\mathrm{vis}} = \frac{\max(m_{\mathrm{obs}}) - \min(m)}{\max(m_{\mathrm{cat}}) - \min(m)}$$

where $\min(m)$ is the minimum VT magnitude of TYCHO-2 stars in an area. This extra term ensures Q_{vis} remains positive in all conditions, and ranges from 0 to 1.

When the sky area is clear, $\max(m_{\mathrm{obs}})$ will be equal to $\max(m_{\mathrm{cat}})$, and Q_{vis} will be equal to 1. When the sky area is covered by clouds or influenced by moonlight or light pollution, $\max(m_{\mathrm{obs}})$ will be smaller than $\max(m_{\mathrm{cat}})$, and Q_{vis} will be smaller than 1. Additionally, we define that if no star is observed in a sky area, i.e., $m_{\mathrm{obs}} = 0$, then Q_{vis} will be set to 0.

Fig. 3. Distribution of the stars with limiting magnitudes in the equatorial coordinate system, ranging from 7.95 mag to 8 mag.

Q_{vis} reflects two factors uniformly. One factor is the degradation in the signal, and the other is the increase in noise. Clouds and large airmass cause extinction, causing the signal to degrade, whereas moonlight and light pollution result in stronger skylight, increasing noise. Both of these factors decrease the accuracy of faint star detection.

Sky area visibility is different from the visibility defined in Reference [?], which refers to the minimum brightness threshold at which a target is distinguishable using given equipment under specific sky brightness conditions. In contrast, our visibility metric describes the observing conditions of a given sky area. Unlike star-based methods, our approach does not rely on photometric precision; thus, it is suitable for all-sky cameras. Furthermore, in contrast to cloud-based methods, our technique provides a higher spatial resolution, facilitating improved robotic observation.

---

3. Method

In this section, we introduce the detailed process by which we analyze all-sky images to estimate the sky area visibility distribution. Initially, we provide a brief overview of the observatory and the specifications of our all-sky camera. Subsequently, we describe the processing pipeline, which includes image preprocessing (Section 3.2), coordinate transformation (Section 3.3), star matching and recognition (Section 3.4), sky area segmentation (Section 3.5), and sky area visibility estimation (Section 3.6). The entire pipeline is illustrated in Fig. 4 [Figure 4: see original paper].

Fig. 4. The pipeline of PFSAVE.

3.1 Observatory and All-sky Camera

Jilin Observatory (JLO, IAU code P61) is operated by Changchun Observatory (CHO), National Astronomical Observatories, Chinese Academy of Sciences. JLO is situated in Jilin, China, with geographical coordinates of 126.33°E, 43.82°N. The observatory houses many ground-based optical telescopes, including the C-GFT, making it a significant site for ground-based follow-up observations of gamma-ray bursts, particularly in response to alerts from SVOM [?]. The CHO Optoelectronic Observation Research Laboratory installed an all-sky camera (as shown in Fig. 5 [Figure 5: see original paper]) to monitor and record sky conditions.

The specifications of the all-sky camera (ALCOR OMEA 3C, France) are detailed in Table 2 . It is equipped with a SONY IMX178LQJ-C CMOS sensor, which is sensitive to low-light conditions and suitable for nighttime observations. The exposure time for each capture of the camera is determined by ALCOR SKYWATCH, which is software developed by the all-sky camera manufacturer ALCOR.

Table 2. The specifications of the all-sky camera installed at JLO

Parameter	Model
Camera	ALCOR OMEA 3C
Sensor	ZWO ASI 178MC Sony IMX178LQJ-C
Focal length	1.8 mm
f-number	f/1.6
Pixel size	7.4 m
Image size	
Sensor size	
Sensor frame	
Field of view	

3.2 Image Preprocessing

We decide to use all-sky images saved in the FITS format rather than the JPEG format. The all-sky camera saves images in both JPEG and FITS formats [?]; however, the JPEG format includes auto white balance (AWB), which enhances the visual effect for human perception. AWB alters the color distribution, affecting the pixel amplitude distribution. Additionally, the JPEG format is stored in 8 bits, which compresses the image' s dynamic range. These factors complicate the extraction of faint stars from JPEG images. In contrast, the FITS format preserves the raw image data in 14 bits without additional processing, making it more suitable for the extraction of faint stars.

Fig. 5. The all-sky camera deployed at JLO.

To convert a color image to grayscale, we use the following formula:

$$\mathrm{GRAY} = \frac{1}{3}(R + G + B)$$

The arithmetic average avoids introducing additional color bias into the pixel amplitude distribution, thereby enhancing the accuracy of star extraction.

3.3 Coordinate Transformation

PFSAVE depends on accurate star recognition. Therefore, a high-precision coordinate transformation is required to convert the horizontal coordinate system onto the photographic coordinate system.

3.3.1 Dataset building The coordinate dataset is constructed using pairs of horizontal coordinates and their corresponding photographic coordinates, indicating the mapping relationship between the two coordinate systems. To generate this dataset, we selected a clear-night all-sky image, plotted the catalog stars, and extracted the source centers. The image used to construct the dataset is displayed in Fig. 6 [Figure 6: see original paper]. In the figure, the white number indicates the extraction star ID, the fuchsia circle is its location, the red number is the star index in the catalog, and the olive round object indicates its position.

To mark catalog stars in the all-sky image, we use `astroplan` to calculate the horizontal coordinates (azimuth, altitude) of catalog stars based on the observatory location and observation time. Then, with the initial camera model parameters (zenith coordinates, field of view radius, and north offset) provided by ALCOR SKYWATCH, we compute the positions of the catalog stars in the image coordinate system according to Algorithm 1.

Star extraction on the all-sky image was performed using `SEP` [?]. Since the extraction accuracy is higher for bright stars and their central positions are more precise, we retained the brighter point sources. `SEP` is a Python wrapper for the SourceExtractor library [?].

Using the image in Fig. 6 [Figure 6: see original paper], we constructed the coordinate dataset by recording the data pairs of the horizontal coordinates and the photographic coordinates. Table 3 shows the first 10 records of the dataset, in which the columns "calculated x" and "calculated y" represent the photographic coordinates calculated by Algorithm 1, and the columns "extracted x" and "extracted y" represent the source centers extracted by SEP.

Table 3. The coordinate dataset for the coordinate transformation model

TYCHO ID	alt/(°)	az/(°)	Calculated x/pix	Calculated y/pix	Extracted x/pix	Extracted y/pix

3.3.2 Coordinate transformation model A camera model describes the relationship between real-world coordinates and those in the photograph. Our coordinate transformation model is based on the classic fish-eye camera model [?]. This model comprises three concatenated transformations: the rotation and translation transformation, the projection transformation, and the radial and tangential distortion transformation. For a given point $P(az, alt)$ in the horizontal coordinate system, the photographic coordinate $P(x, y)$ are calculated as follows:

1. Use the initial camera parameters to transform $P(az, alt)$ into polar coordinates $P(\theta, \phi)$:
$$\theta = s(1 - \frac{2 \cdot alt}{\pi})$$
$$\phi = az - \phi_{\text{north}}$$
where s is the distance between the zenith and the horizon in pixels, and ϕ_{north} is the north offset.
2. Use the projection transformation to correct θ to radial distance radius r:
$$r = k_0\theta + k_1\theta^3 + k_2\theta^5 + k_3\theta^7 + k_4\theta^9$$
where k_0, k_1, k_2, k_3, k_4 are the projection coefficients. Only odd power terms are included based on Kannala and Brandt' s conclusion [?].
3. Correct the radial and tangential distortions to obtain $P(r', \phi')$ using:
$$r' = r + \Delta r(\theta, \phi)$$
$$\phi' = \phi + \Delta\phi(\theta, \phi)$$
where the radial distortion term $\Delta r(\theta, \phi)$ and the tangential distortion term $\Delta\phi(\theta, \phi)$ are given by:
$$\Delta r(\theta, \phi) = (\delta_{r1}\theta + \delta_{r2}\theta^3 + \delta_{r3}\theta^5)(\delta_{r4}\cos\phi + \delta_{r5}\sin\phi + \delta_{r6}\cos 2\phi + \delta_{r7}\sin 2\phi)$$
$$\Delta\phi(\theta, \phi) = (\delta_{\phi1}\theta + \delta_{\phi2}\theta^3 + \delta_{\phi3}\theta^5)(\delta_{\phi4}\cos\phi + \delta_{\phi5}\sin\phi + \delta_{\phi6}\cos 2\phi + \delta_{\phi7}\sin 2\phi)$$

4. Transform $P(r', \phi')$ to Cartesian coordinates $P(x, y)$:

$$x = r' \cos \phi'$$

$$y = r' \sin \phi'$$

5. Transform $P(x, y)$ to photographic coordinates $P(u, v)$, moving the origin to the top-left of the image as follows:

$$u = x + x_c$$

$$v = y + y_c$$

where $P_c(x_c, y_c)$ is the zenith position in photographic coordinate system.

3.3.3 Model solving Our coordinate transformation model involves 23 undetermined coefficients: the distance between the zenith and the horizon in pixels (s), the north offset (ϕ_{north}), the zenith position in photographic coordinates $P_c(x_c, y_c)$, five projection coefficients k_0, k_1, k_2, k_3, k_4, seven radial distortion coefficients $\delta_{r1}, \delta_{r2}, \delta_{r3}, \delta_{r4}, \delta_{r5}, \delta_{r6}, \delta_{r7}$, and seven tangential distortion coefficients $\delta_{\phi 1}, \delta_{\phi 2}, \delta_{\phi 3}, \delta_{\phi 4}, \delta_{\phi 5}, \delta_{\phi 6}, \delta_{\phi 7}$. Table 4 summarizes these coefficients.

ALCOR SKYWATCH provides the initial camera parameters, including the zenith distance $s = 983$ pixels, north offset $\phi_{\text{north}} = 155.6°$, and zenith position $P_c = (1053, 1063)$. These parameters serve as initial values throughout the process until the final step. We solve these three parameters along with the other 20 coefficients.

Table 4. Coordinate transformation model coefficients

Coefficients	Count	Description
Zenith distance in pixel	1	s
North offset in degree	1	ϕ_{north}
Zenith position in photographic coordinate system	2	$P_c(x_c, y_c)$
Projection coefficients	5	k_0, k_1, k_2, k_3, k_4
Radial distortion coefficients	7	$\delta_{r1}, \delta_{r2}, \delta_{r3}, \delta_{r4}, \delta_{r5}, \delta_{r6}, \delta_{r7}$
Tangential distortion coefficients	7	$\delta_{\phi 1}, \delta_{\phi 2}, \delta_{\phi 3}, \delta_{\phi 4}, \delta_{\phi 5}, \delta_{\phi 6}, \delta_{\phi 7}$
TOTAL	**23**	

We propose a per-transformation re-fitting procedure, illustrated in Fig. 7 [Figure 7: see original paper], to solve the model. This process consists of the following five steps:

Step 1: Solve the projection coefficients k_i by minimizing the error in the polar coordinate system. We use the initial parameters s, ϕ_{north}, and $P_c(x_c, y_c)$ to transform the horizontal coordinates into the polar coordinates as the fitting objects.

Step 2: Solve the radial distortion coefficients δ_r and the tangential distortion coefficients δ_ϕ by minimizing the error in the polar coordinate system.

Step 3: Use the results of Steps 1 and 2 as the initial values to solve these coefficients again by minimizing the error in the polar coordinate system. At this stage, we have all the transformation coefficients in the polar coordinate system.

Step 4: Solve the zenith distance s, north offset ϕ_{north}, and zenith position $P_c(x_c, y_c)$ by minimizing the error in the photographic coordinate system.

Step 5: Use the results of Step 3 and Step 4 as the initial values and handle the transformations as a whole to solve all 23 coefficients by minimizing the error in the photographic coordinate system.

The fitting errors decrease step-by-step as shown in Fig. 8 [Figure 8: see original paper]. Although the model is fitted in the polar coordinate system from Step 1 to Step 3, the error distribution graphs in Fig. 8 are plotted in the photographic coordinate system for consistent comparison of errors. Despite changes in error distribution during the initial three steps of fitting, there was not a pronounced overall trend of error reduction. However, after re-fitting the coefficients in Step 4, the error significantly decreased to 0.83 pixels. Subsequently, using the results from Step 3 and Step 4 as initial values and re-fitting all 23 undetermined coefficients in Step 5 led to a significant reduction in the fitting error to 0.49 pixels. This represents a 40.96% decrease over independent fitting (Step 4), with a corresponding 30.77% decrease in the standard deviation, indicating a substantial improvement in fitting accuracy.

Table 5 provides an overview of the changes in these errors throughout the process.

Fig. 7. Process for solving the coordinate transformation model. The numbers indicate the order of the coefficients solved.

Fig. 8. Distribution of fitting error in the photographic coordinate system during the solving procedure.

Table 5. Fitting error of each step in the solving procedure

Step	Mean/pixel	Standard deviation/pixel	Median/pixel

To demonstrate the overall performance of our coordinate transformation model, we plotted the altitude distribution in the photographic coordinate system in Fig. 9 [Figure 9: see original paper]. The color of each pixel corresponds to its altitude. A perfectly circular distribution of colors indicates the high quality of the transformation.

Fig. 9. Distribution of altitude in the photographic coordinate system after coordinate transformation.

3.4 Star Matching and Recognition

We use the high-precision coordinate transformation model presented in Section 3.3 to obtain the photographic coordinates of catalog stars. Then, we match the catalog stars with the extracted stars to recognize the stars in the all-sky images. After recognition, we determine the standard VT magnitude of the recognized stars.

We extract the star points (extracted stars) from the all-sky images using SEP. Since SEP is not specifically designed for all-sky images, the extracted stars may contain some errors. To eliminate these errors, we implement three screening criteria: the Signal-to-noise ratio (R_{SN}), T-metric, and semi-major axis (a).

R_{SN}: The R_{SN} is defined as the ratio of the peak value of the star to the background noise. A higher R_{SN} of a star indicates it is more reliable. Generally, reliable stars have an R_{SN} greater than 3.0. Therefore, we retain sources with R_{SN} values greater than 3.0.

T-metric: The T-metric is the ratio of the number of object pixels (npix) and R_{SN}. We found that some false detections extracted by Source Extractor have a high R_{SN} because they have a large npix caused by the texture of the clouds. Because of the angular resolution of the all-sky camera, npix should not be too large. Therefore, we designed the T-metric to use R_{SN} and npix. The T-metric is defined as:

$$T = \frac{\text{npix}}{R_{SN}}$$

In our case, we keep the sources with T values less than 7.2.

Semi-major axis (a): The semi-major axis (a) is given by SourceExtractor and represents the size of the source. According to the angular resolution of the all-sky camera, the size of the star should not be too large. After analyzing the size distribution of the correct points, sources larger than 10 are lower confidence. Therefore, we keep the sources whose semi-major axis is less than 10.

The thresholds for the screening criteria are specific to the data being analyzed. These thresholds have been established through a rigorous analysis of the data captured by our all-sky camera. It is important to note that when applying these criteria to other sets of all-sky images, corresponding adjustments to the thresholds may be necessary to ensure accurate and reliable results.

After the screening process, a set of stars extracted with high confidence is obtained. To identify these stars, we compare them with the catalog stars in the photographic coordinate system using the Euclidean distance. Before matching, the catalog stars are sorted in ascending order based on their VT magnitude.

The matching process follows this sorted order, prioritizing brighter stars for matching first. If the distance between a catalog star and an extracted star is less than 5 pixels, the extracted star is considered a match with the catalog star. This approach is based on the assumption that within a small area, only the brightest star can be detected by all-sky cameras because of their limited angular resolution.

Fig. 10 [Figure 10: see original paper] presents the performance of star matching and recognition in different sky conditions. When the sky is clear, a high number of stars are recognized across all sky areas. When it is cloudy, stars obstructed by clouds are not recognized. When it is overcast, all sky areas are covered by clouds, and only a few false recognitions exist.

Fig. 10. Performance of star matching and recognition when it is clear (A), cloudy (B) and overcast (C). Purple circles mark the recognized stars.

3.5 Sky Area Segmentation

Sky area segmentation is required to provide astronomers and observation assistants with sky area visibility at a high spatial resolution. The segmentation must divide the sky into equal areas to ensure comparability. Therefore, we introduce HEALPix to divide the sky into equal-area grids within the horizontal coordinate system. This approach achieves discrete spatial resolution, which is beneficial for robotic observation.

HEALPix was proposed by Górski et al. [?] to divide the sphere into equal-area pixels (grids). It provides a segmentation, or pixelization, of the sphere at a fixed resolution.

When using HEALPix to segment the sky area, the parameter N_{side} defines the resolution of the segmentation. Fig. 11 [Figure 11: see original paper] illustrates the segmentation with different N_{side} values. A higher N_{side} provides higher spatial resolution; however, if the segmentation is too fine, the number of stars in some grids may be too small to effectively estimate the sky area visibility. Therefore, based on the specifications of our all-sky camera and balancing performance with spatial resolution, N_{side} was set to 8, resulting in 384 grids covering the entire sky area from zenith to horizon. The number of grids is calculated by:

$$N = \frac{1}{2} \times (12 \times N_{\text{side}}^2) = \frac{1}{2} \times (12 \times 8^2) = 384$$

where the factor $\frac{1}{2}$ is used because only half of the sphere is visible in the horizontal coordinate system.

The official HEALPix library can only run on Unix-like systems, such as Linux or Mac OS. Fortunately, `astropy-healpix` [?, ?, ?] has been released, providing a cross-platform implementation of the basic HEALPix functionality. Therefore, we use `astropy-healpix` to segment the sky.

Fig. 11. The sky area segmentation with different N_{side} in the horizontal coordinate system. The color represents the grid ID. (A) $N_{\text{side}} = 1$, (B) $N_{\text{side}} = 2$, (C) $N_{\text{side}} = 4$, (D) $N_{\text{side}} = 8$.

3.6 Sky Area Visibility Estimation

To estimate the sky area visibility of a sky area, we require the observed stars and catalog stars within this area. The observed stars are identified using the method described in Section 3.4. Let S_{obs} be the set of observed stars, which includes the TYCHO ID, VT magnitude, and horizontal coordinates. Let S_{cat} be the set of catalog stars above the horizon at the corresponding time. The horizontal coordinates are calculated using `astroplan`. According to the segmentation described in Section 3.5, we assign the HEALPix index to the observed stars and catalog stars. Let $S_{\text{obs}}^{(i)}$ and $S_{\text{cat}}^{(i)}$ be the sets of observed stars and catalog stars in the i-th grid, respectively.

For the i-th sky area (the i-th grid), the faintest observed magnitude is $\max(m_{\text{obs}}^{(i)})$ and the faintest catalog magnitude is $\max(m_{\text{cat}}^{(i)})$. Based on Equation (2), the visibility of the i-th sky area is calculated by:

$$Q_{\text{vis}}^{(i)} = \frac{\max(m_{\text{obs}}^{(i)}) - \min(m)}{\max(m_{\text{cat}}^{(i)}) - \min(m)}$$

where $\min(m)$ is the minimum VT magnitude of the catalog stars in the sky area. If $S_{\text{obs}}^{(i)} = \emptyset$, the visibility of the i-th sky area is set to 0. Additionally, a further correction is applied to mitigate the impact of potential misrecognition. If the number of observed stars in the sky area is insufficient ($N_{\text{obs}} = N_{\text{cat}} < 1\%$) and the observed brightest star is notably fainter than the catalog brightest star ($\min(m_{\text{obs}}) - \min(m_{\text{cat}}) > 1$), the visibility of the sky area is set to 0.

Fig. 12 [Figure 12: see original paper] shows the sky area visibility distribution when the sky is clear. The orange circle indicates the altitude of 25°. Objects are typically not observed when they are below this altitude, and thus those areas are ignored. When plotting, these grids are set to 0. These sky areas have high airmass and are not assigned for observation, and hence they are not included in the visibility estimation.

Fig. 12. Visibility of all sky areas when clear.

4. Results and Analysis

In this section, we present results of comparison experiments with the extinction-based method [?] to demonstrate the effectiveness of PFSAVE.

4.1 Benchmark Method

The benchmark method in the comparison experiments is the extinction-based method, which measures the observation condition using the overall extinction of the sky area. To obtain the extinction, the overall standard flux is required. As we discussed in Section 2, the filters of the all-sky camera are not consistent with any astronomical color system. Despite this, we use the VT magnitude from the TYCHO catalog as the standard magnitude to calculate the overall standard extinction, since the comprehensive passbands of the RGB filters are close to the VT passband. An all-sky image taken on a clear night was used to determine the zero point z, which was estimated to be approximately 18 mag. The overall standard flux of the i-th sky area was defined as:

$$F_{\text{cat}}^{(i)} = \sum_{j=1}^{N_i} 10^{-0.4[m_{\text{cat}}^{(j)} - z]}$$

where i is the HEALPix index of the sky area, j is the index of the catalogue star in the sky area, and $m_{\text{cat}}^{(j)}$ is the VT magnitude of the j-th catalog star.

The overall observed flux of i-th sky area is defined as:

$$F_{\text{obs}}^{(i)} = \sum_{j=1}^{N_i} f^{(j)}$$

where $f^{(j)}$ is the flux of the j-th observed star given by SourceExtractor. As our method uses a uniform format to estimate sky area visibility, the impact of airmass was not corrected for a fair comparison.

The extinction of the given i-th sky area is defined as:

$$Q_{\text{ext}}^{(i)} = \frac{F_{\text{cat}}^{(i)} - F_{\text{obs}}^{(i)}}{F_{\text{cat}}^{(i)}}$$

We note that because of the limited photometric accuracy of the all-sky camera, the following statement is not always true: $\forall i, F_{\text{cat}}^{(i)} \geq F_{\text{obs}}^{(i)}$. $Q_{\text{ext}}^{(i)}$ may be negative in some sky areas. Negative extinction is irrational; therefore, these values are truncated to 0 in practice.

4.2 Qualitative Analysis

Figs. 13, 14, and 15 show the visibility Q_{vis} and extinction Q_{ext} of all sky areas when the sky is clear, cloudy, and overcast, respectively. As shown in Fig. 13 [Figure 13: see original paper], the visibility of all sky areas is close to 1, while the extinction of those area ranges from 0.3 to 0.6. The visibility estimation more closely aligns with the actual observation conditions. As shown in Fig. 14 [Figure 14: see original paper], our method successfully distinguishes sky areas with clouds from those without and accurately represents the degree of visibility reduction caused by clouds. In contrast, the extinction-based method performs poorly, as it deems most of the sky area to be not observable. As shown in Fig. 15 [Figure 15: see original paper], our star recognition method (Section 3.4) has few errors, with the visibility of all sky areas being 0 and the extinction being 1.

Qualitative analysis indicates that the proposed method can effectively estimate the sky area visibility under various sky conditions and measure the decrease in visibility caused by clouds. Compared with the extinction-based method, the PFSAVE method is more accurate.

Fig. 13. Visibility and extinction of all sky areas when clear.

Fig. 14. Visibility and extinction of all sky areas when cloudy.

Fig. 15. Visibility and extinction of all sky areas when overcast.

4.3 Quantitative Analysis

To quantitatively analyze the performance of the proposed method, we compared the visibility with manual scores. The scores are discrete and consist of $\{0, 1, 2\}$. Here, "0" means the area is fully covered by cloud or affected by moonlight; "1" means the area is partially covered by cloud or affected by moonlight; "2" means the area has no clouds nor moonlight. To ensure a comprehensive and fair comparison, we selected five all-sky images taken on a cloudy night. Table 6 lists examples of different manual scores. The quantitative analysis was conducted using Spearman' s correlation efficiency and the Jaccard similarity coefficient.

The Spearman correlation is a non-parametric measure of rank correlation, which is defined as:

$$\rho = 1 - \frac{6 \sum d_i^2}{N(N^2 - 1)}$$

where d_i is the rank difference, and N is the number of sky areas. The Spearman correlation ranges from -1 to 1. A value of -1 indicates a perfectly negative correlation, 1 indicates a perfectly positive correlation, and 0 indicates no correlation between the two variables. To compute the Spearman correlation, we use the Python package `SciPy` [?]. Ideally, the Spearman correlation between the visibility and the manual score should be 1, and that between the extinction and the manual score should be -1. The results are presented in Table 7 .

The Spearman correlation between the visibility and the manual score is 0.30, indicating a positive correlation. Conversely, the Spearman correlation between the extinction and the manual score is 0.29, which contradicts the expected negative correlation. These results suggest that the proposed method is more accurate in terms of rank-order correlation than the extinction-based method.

The Jaccard similarity is another classical metric used for evaluating the accuracy of a classification method. It is defined as the ratio of the intersection of correctly classified categories to the union of all categories. Let categories $c \in \{0, 1, 2\}$ represent the three levels of the manual score, GT_c represent the set of manual scores, and Q_c represent the classification derived from either the visibility or extinction. The Jaccard similarity J is defined as:

$$J = \frac{1}{C} \sum_{c=0}^{C-1} \frac{|Q_c \cap GT_c|}{|Q_c \cup GT_c|}$$

where C is the number of categories.

Quantitative analysis using the Spearman correlation and Jaccard similarity shows that PFSAVE is more closely aligned with human judgment than the extinction-based method.

Table 6. Sky area samples and their manual scores

Image	Grid ID	Grid image	Manual
2024_{{{05}}*{{14}}}*{{{20}}*{{52}}}*{51}	4		2
2024_{{{05}}*{{14}}}*{{{20}}*{{52}}}*{51}	6		1
2024_{{{05}}*{{14}}}*{{{20}}*{{52}}}*{51}	98		0

Table 7. Accuracy of the visibility and extinction results. The values in parentheses are the ideal values

Metric	Visibility	Extinction
Spearman correlation	0.30 (1)	0.29 (-1)
Jaccard similarity		

5. Conclusion

In this paper, we proposed the PFSAVE method to achieve high spatial resolution sky area visibility using all-sky cameras without scientific-grade sensors. This method estimates sky area visibility without relying on photometric precision, making it particularly suitable for all-sky cameras with limited photometric accuracy. Visibility is assessed based on the magnitude of the faintest star observed within each specific sky area. High spatial resolution is achieved through the segmentation of the sky using HEALPix. The cornerstone of PFSAVE is a high-precision coordinate transformation model, and we introduce a per-transformation re-fitting technique to solve this model, achieving an accuracy of 0.42 pixels.

Qualitative and quantitative analyses demonstrate that our method is effective under various sky conditions and more accurate than extinction-based methods. The approach generates a sky area visibility distribution in HEALPix format, which is both discrete and searchable, making it suitable for robotic observation software. Based on this distribution, astronomers and observation assistants can select sky areas with high visibility to conduct observations, thereby obtaining higher quality observational data.

For the model fitting, our method depends on a pre-established dataset that maps horizontal coordinates to photograph coordinates. Low-resolution all-sky images have serious signal aliasing, and our method has limited performance on such images.

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Author Contributions

Haiwen Xie conceived the ideas. Haiwen Xie and Xiaojun Jiang drafted the initial manuscript. Haiwen Xie, Hui Zhi, Zhe Kang, Shiyu Deng, and Bingli Niu developed the methodology. Zhe Kang managed and maintained research data and provided study resources. Xiaojun Jiang and Zhe Kang acquired the fundings and administered the project. Xiaojun Jiang supervised the research. Haiwen Xie, Hui Zhi, Zhe Kang, Shiyu Deng, Lei Wang, and Xiaojun Jiang reviewed and edited the manuscript. All authors read and approved the final manuscript.

Declaration of Interests

The authors declare no competing interests.

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27. (Note: Reference 27 appears to be missing from the original text, but was cited in the quantitative analysis section)

Note: Figure translations are in progress. See original paper for figures.

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