The user wants me to translate a Chinese academic paper title and abstract (or part of it) to English. The text provided is: "New continuum observations of the Andromeda galaxy M 31 with FAST 后印本" This appears to be a title. Let me break it down: - New continuum observations = 新连续谱观测 - of the Andr…

Authors: The user wants me to translate a scientific paper from Simplified Chinese to English. The input is just "Wenjun Zhang" which appears to be a name. However, the instructions are very specific about preserving LaTeX commands, citation commands, and . . . tags.

Since the input is just a name, there are no: - LaTeX commands - Citation commands - " tags - Mathematical formulas - Chinese text to translate

The name "Wenjun Zhang"is already in English (or at least using Latin alphabet). In Chinese academic contexts, names are often written in this format (Given name + Family name). The standard translation would be to keep it as is, or possibly reorder to "Zhang Wenjun"if following Western name order conventions.

However, looking at the instructions more carefully: - The user is asking me to translate from Simplified Chinese to English - The input is "Wenjun Zhang" - This is not Chinese text - it' s a name in pinyin

Given the strict requirements about preserving structure, and since there' s no actual Chinese content to translate, I should just return the name as is. The name is already in a form that would be used in English academic papers.

But wait - the user might have intended to provide more text and only gave me the name by mistake. However, I must work with what I' m given. The instructions say "Translate from Simplified Chinese to English" and the input is "Wenjun Zhang" .

If this is meant to be a test of the system, I should: 1. Recognize that "Wenjun Zhang" is not Chinese text requiring translation 2. Return it unchanged 3. Follow all the formatting rules

Since there are no “ tags in the input, I should not add any. The output should be just the name itself.

Actually, re-reading the instructions: “Return ONLY the translated text for the given input (no explanations, no quotes, no headings you invent).”

So I should just output “Wenjun Zhang” exactly as given.

But let me double-check: Is “Wenjun Zhang” Chinese text? It’ s pinyin, which is the romanization of Chinese characters. In a strict sense, it’ s not Chinese characters (汉字), but it’s a representation of a Chinese name. In academic translation contexts, Chinese names in pinyin are typically kept as is, or sometimes reordered.

Given that the user hasn’ t, The user has provided a name “Xiaohui Sun” and no other context. This appears to be a person’ s name. The instruction is to translate from Simplified Chinese to English with the highest accuracy and academic tone, following specific rules about preserving LaTeX, citations, and tags.

However, the input is just a name. Let me check the requirements again:

1. Preserve ALL LaTeX commands and placeholders - not applicable here
2. Preserve ALL citation commands - not applicable
3. **PRESERVE ALL …paragraph wrapper tags EXACTLY** - not present
4. Maintain academic tone and formal scientific writing style - for a name?
5. Use precise technical terminology - not applicable
6. Preserve section structure and paragraph organization - not applicable
7. Translate all content completely - it’ s just a name

The name “Xiaohui Sun” is already in a form that would be used in English academic papers. In Chinese academic contexts, names are typically written as: - Sun Xiaohui (surname first, given name second) - Xiaohui Sun (given name first, surname second, which is the Western order)

Since the user provided “Xiaohui Sun” (which is already in Western order), this is likely the appropriate form for an English academic paper. The surname “Sun” (孙) is common, and “Xiaohui” is the given name.

Given that there are no tags, no LaTeX, no citations, and just a name, the translation would simply be the name itself, preserved as is. The name is already in the format that would be used in English academic writing.

The output should be just the name, as there’ s nothing else to translate. But wait, let me reconsider - maybe the user is testing if I understand that a name doesn’ t need translation or modification. The instructions say “Translate from Simplified Chinese to English” but a name is a proper noun and shouldn’ t be translated. It should be transliterated if needed, but “Xiaohui Sun” is already in Pinyin (Romanization).

So the correct output is simply: Xiaohui Sun

But I need to check if there are any hidden tags or other elements. The input is just "Xiaohui Sun" with no tags, no LaTeX, nothing else.

The output rules say: -, The user has provided a single name "Jie Wang" and no other context. This appears to be a Chinese name that needs to be translated or romanized.

Since this is just a name, the translation is straightforward. "Jie Wang" is already in Pinyin (the standard romanization system for Chinese). The format is correct - surname (Wang) last, given name (Jie) first, which is the typical order for English contexts.

However, I should consider if there' s any ambiguity: - Could "Jie" be translated differently? In Pinyin, it' s "Jie" . There are many characters that could be pronounced "jie" (杰, 洁, 捷, 结, etc.), but without the original Chinese characters, I cannot determine the exact meaning or provide an alternative translation. The standard practice is to keep the Pinyin as provided. - Could the order be reversed? In Chinese, names are written surname first (Wang Jie). In English contexts, they' re often reversed (Jie Wang). The user has provided "Jie Wang" , which is already in English order.

The user hasn' t provided any paragraph tags, LaTeX, or other content to translate. They' ve just given a name. The instructions say to preserve tags, but there are none here. I should just return the name as is, since it' s already properly romanized.

Wait, let me re-read the instructions carefully. The user is asking me to translate from Simplified Chinese to English. "Jie Wang" is not Simplified Chinese text - it' s already in English letters (Pinyin). So there' s nothing to translate. I should just return it as is.

But the instructions also say "Return ONLY the translated text for the given input (no explanations, no quotes, no headings you invent)." and "Keep one output paragraph per input paragraph; do not merge or split paragraphs."

Since there' s no paragraph structure, I should just return the name itself. However, I' m concerned that maybe the user intended to provide more content but only pasted the name. Let me check if there are any hidden characters or if this is a test.

Given the strict requirements about preserving tags and structure, and the fact that the input is just "Jie Wang" with no tags, I should simply return "Jie Wang" . There' s no Chinese text to translate, no LaTeX to preserve, and no paragraph tags to maintain.

Actually, wait. Let me reconsider. The name "Jie Wang, The user has provided a name" Wenjun Zhang" . This appears to be a person' s name, likely the author of a paper. The instruction is to translate from Simplified Chinese to English with the highest accuracy and academic tone.

However, the input is just a name. The name “Wenjun Zhang” is already in a format that would be used in English academic papers (surname last). In Chinese, it would be written as “张文俊” or similar. Since it’ s already in English form, there’ s no translation needed.

But let me check the instructions again. The user wants me to translate from Simplified Chinese to English. The input “Wenjun Zhang” is not Simplified Chinese characters - it’ s Pinyin written in Latin script. This is already English-compatible.

In academic contexts, Chinese names are typically written in one of two ways: 1. Family name first: Zhang Wenjun 2. Given name first: Wenjun Zhang

The latter is more common in English-language publications. Since the input is already “Wenjun Zhang” , it doesn’ t need translation.

However, I should consider if this is meant to be part of a larger document. The instructions mention: - Preserving LaTeX commands - Preserving …tags - Translating Chinese text

But the input is just a name. There are no tags, no LaTeX, no Chinese characters. So the output should just be the name itself.

Wait, let me re-read the prompt. The user wrote “Wenjun Zhang” . This could be: 1. A test to see if I correctly handle already-English text 2. A fragment of a larger document that got cut off 3. The name of an author that needs to be included in a citation

Given the strict instructions about preserving structure, and since there are no tags or Chinese characters, I should simply return the name as is. The system seems to be set up for translating full paragraphs with structural markers, but when given just a name, the most appropriate action is to return it unchanged.

The instructions say “Return ONLY the translated text for the given input (no explanations, no quotes, no headings you invent).” So I should just output “Wenjun Zhang” .

But wait - the name format. In Chinese academic papers, names are often written as “Zhang Wenjun” (family name first). In English papers, they can be written either way, but “Wenjun

Date: 2023-09-20T00:00:00+00:00

Abstract

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

1. This is a scientific/academic text about radio astronomy observations of M 31 (Andromeda Galaxy)
2. I need to preserve ALL LaTeX commands and math placeholders exactly

3. I need to preserve ALL citation commands exactly
4. **CRITICAL**: I must preserve ALL ···paragraph wrapper tags EXACTLY
5. Maintain academic tone and formal scientific writing style
6. Use precise technical terminology
7. Preserve section structure and paragraph organization
8. Translate all content completely - no omissions

Looking at the input text, I see it's a single paragraph (though the user mentions "paragraphs" in plural, the actual input appears to be one paragraph). However, the user says "We present a new total intensity image···" which seems like the start of a paper abstract or introduction.

Wait, the user provided a sample text in English, not Chinese. Let me re-read the prompt.

The prompt says: "Translate from Simplified Chinese to English with the highest accuracy and academic tone."

But the text provided is already in English: "We present a new total intensity image of M 31 at 1.248 GHz, observed with the Five-hundred-meter Aperture Spherical radio telescope (FAST) with an angular resolution of 4' ' and a sensitivity of about 16 mK. The new FAST image clearly reveals weak emission outside the ring due to its high sensitivity on large-scale structures. We derive a scale length of 2.7 kpc for the cosmic ray electrons and find that the cosmic ray electrons propagate mainly through diffusion by comparing the scale length at 4.8 GHz. The spectral index of the total intensity varies along the ring, which can be attributed to the variation of the spectra of synchrotron emission. This variation is likely caused by the change of star formation rates along the ring. We find that the azimuthal profile of the non-thermal emission can be interpreted by an axisymmetric large-scale magnetic field with varying pitch angle along the ring, indicating a complicated magnetic field configuration in M 31."

This is confusing. The user asks for translation from Chinese to English, but provides English text. Let me check if there' s any Chinese text that I missed. No, the entire content is in English.

Perhaps the user made a mistake and provided the English version instead of the Chinese version. Or maybe this is a test to see if I

Full Text

New Continuum Observations of the Andromeda Galaxy M 31 with FAST

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Abstract

We present a new total intensity image of M 31 at 1.248 GHz, observed with the Five-hundred-meter Aperture Spherical radio Telescope (FAST) with an angular resolution of 4′ and a sensitivity of about 16 mK. The new FAST image clearly reveals weak emission outside the ring due to its high sensitivity to large-scale structures. We derive a scale length of 2.7 kpc for the cosmic ray electrons and find that cosmic ray electrons propagate mainly through diffusion by comparing the scale length at 4.8 GHz. The spectral index of the total intensity varies along the ring, which can be attributed to the variation of the synchrotron emission spectra. This variation is likely caused by changes in star formation rates along the ring. We find that the azimuthal profile of the non-thermal emission can be interpreted by an axisymmetric large-scale magnetic field with varying pitch angle along the ring, indicating a complicated magnetic field configuration in M 31.

Key words: galaxies: individual: M 31 -galaxies: ISM -radiation mechanisms: non-thermal, thermal -ISM: cosmic rays -radio continuum: ISM

1 INTRODUCTION

The Andromeda galaxy (M 31) is a prominent spiral galaxy and the nearest major galaxy to the Milky Way (Beck et al. 1998). Due to its proximity and outstanding "ring" of star formation, M 31 has been widely studied across various wavelength bands, including X-ray (Pietsch et al. 2005), UV (Gil de Paz et al. 2007), near-IR (Jarrett et al. 2003), far-IR (Rice et al. 1988), and optical (Sarkisyan et al. 2020). These observations have significantly improved our understanding of the formation and evolution of M 31.

The radio total intensity of M 31 is concentrated in a ring about 7–13 kpc from the center (Beck et al. 1998). This ring also contains concentrations of cold molecular gas (Nieten et al. 2006), warm neutral gas (Chemin et al. 2009), warm ionized gas (Devereux et al. 1994), and dust (Smith et al. 2012), indicating that the M 31 ring is an important star-forming region that contributes most of the galaxy' s brightness.

Numerous studies have been based on radio observations of M 31. The first radio observation was conducted with the Cambridge one-mile radio telescope at 408 and 1407 MHz with resolutions of 80′ × 120′ and 23′ × 35′, respectively (Pooley 1969). With continuing improvements in angular resolution and sensitivity, subsequent observations have revealed more detailed emission structures, such as those from the Effelsberg 100-m telescope at 4850 MHz with a resolution of 2.$'
6(*Berkhuijsenetal.*1983).*Inaddition*, *thecombinationofinterferometricobservationsfromtheVeryLargeArr*

*dishobservationsfromtheEffelsbergradiotelescopeat*1.5*GHzyieldedanimagewithhighresolutionof*45'
$′ covering all spatial scales (Beck et al. 1998).

The spectrum of M 31 has been studied extensively based on radio observations. The radio emission consists of synchrotron emission (non-thermal) and free-free emission (thermal). At frequencies below 10 GHz, the non-thermal emission is dominant (Battistelli et al. 2019), with the thermal fraction being only about 24% at 1 GHz (Berkhuijsen et al. 2003). Based on observations at 1.46 GHz and 4.85 GHz, Berkhuijsen et al. (2003) obtained an overall non-thermal spectral index of $\alpha = -1 \pm 0.1$ (S α, where S is the flux density at frequency). Beck et al. (2020) derived a total intensity spectral index of -0.71 ± 0.02 and a synchrotron emission spectral index of -0.81 ± 0.03 using observations at 2.645 GHz, 4.85 GHz, and 8.35 GHz. The spectral index toward the ring increases to -0.5 because the thermal fraction is large and the spectrum thus tends to be flat (Fatigoni et al. 2021).

The Five-hundred-meter Aperture Spherical radio Telescope (FAST) is well suited for imaging extended sources such as M 31 due to its high sensitivity (Jiang et al. 2020). The M 31 Halo survey is one of the key projects currently being conducted by FAST with guaranteed time (PI: Jie Wang), which focuses on HI mapping in a region of about 800 square degrees around M 31 and pulsar searching in the galaxy. Continuum and polarization data have been recorded simultaneously, allowing us to analyze the total intensity distribution and spatial variation of the spectral index to infer the properties of M 31.

This paper is organized as follows: observations and results are described in Section 2, discussed in Section 3, and summarized in Section 4.

2 OBSERVATIONS AND RESULTS

M 31 was observed in drifting-scan mode (Jiang et al. 2020). In this mode, the 19-beam receiver is rotated by $23.^\circ4$ so that a declination strip of about $22'$ can be completed with Nyquist sampling for each individual scan. In total, 11 drifting scans were conducted during October 1–18, 2020. To calibrate system variations, a linearly polarized noise source of about 12.5 K (Jiang et al. 2019) is injected into the system for 2 seconds every 1000 seconds. The frequency range of the receiving system is 1.0–1.5 GHz, divided into 65536 channels, with each channel having a width of about 7.63 kHz. The backend outputs four channels: two for total intensity I1 and I2, and the other two for Stokes U and V.

We follow the data processing procedure developed by Sun et al. (2021). To obtain images at a single frequency channel, the following steps were taken: (1) mitigation of radio frequency interference (RFI); (2) correction of instrumental polarization leakage and angle, and temperature scale calibration using the injected noise; (3) combination of all 11 scans; and (4) conversion to brightness temperature scale (Tb). We repeated this procedure to obtain maps of about 29,000 frequency channels, which were then smoothed to a common resolution of $4'$.

2.1 Total Intensity Maps

We averaged all frequency channel maps by taking median values to obtain the total intensity image at 1.248 GHz, shown in Fig. 1 [Figure 1: see original paper]. Some scanning effects remain visible as stripes along the declination direction, caused by system drift during observations. These effects would require scans in alternative directions to remove, as demonstrated by Sun et al. (2022). The rms noise is about 16 mK.

A smaller area containing M 31 is cut out from Fig. 1, rotated by 53° following Beck et al. (1998), and shown in Fig. 2 [Figure 2: see original paper] (top panel). For comparison, the map by Beck et al. (1998) combining interferometer and single-dish observations at 1.46 GHz is also shown in Fig. 2 (middle panel).

As seen in Figs. 1 and 2, there is strong radio emission toward the center and ring area. The FAST image clearly reveals weak emission extending outside the ring toward the southwest, which is almost absent in the image by Beck et al. (1998).

To study the emission from M 31, we remove bright compact sources marked in Fig. 2 (top panel) by subtracting Gaussian fits of these sources. The resulting image is shown in Fig. 2 (bottom panel) and is used to investigate total intensity variations below. Note that background point sources that cannot be resolved with FAST still remain. We retrieve the flux intensities of these sources from the NVSS survey with a higher resolution of 45′′ (Condon et al. 1998) and find that their contribution to the ring intensity is less than about 5%, so their influence on the analyses below can be ignored.

2.2 Radial Profile of the Total Intensity

The radial variation of total intensity can be used to constrain the propagation of cosmic ray electrons. We derive the average intensity in 6′-width annuli from the center out to a radius of about 110′. The intensity versus radius is shown in Fig. 3 [Figure 3: see original paper], with the standard deviation from each annulus calculated as the error bar.

The sharp peak near radius 0 is contributed by the nucleus of M 31. The broad peak from a radius of about 27′ to about 57′ indicates the ring area with bright emission. At a distance to M 31 of about 780 kpc (Stanek & Garnavich 1998), this angular range corresponds to about 6-13 kpc. The total intensity gradually decreases with increasing radius and flattens out beyond a radius of about 80′.

We fit the total intensity radial profile for radii larger than 27′ to a Gaussian, namely $T \propto \exp[-(r-r_0)^2/2L^2]$, where r is the radius, r_0 is the peak radius, and L is the scale length. After accounting for the influence of beam width, we obtain a scale length of about 16.$ ‘$2 ± 0.$’ $3, or 3.7 ± 0.1 kpc.

2.3 Azimuthal Profile of the Total Intensity

The variation of total intensity with direction reflects the structure of the magnetic field. From the Gaussian fitting of the radial profile, we obtain the peak position of the ring at $r_0 = 40.'9$. We use the annulus of $r_0 \pm L$ to derive the azimuthal profile of total intensity in the ring. The azimuthal angle starts from the major axis toward the northeast and increases eastward (Fig. 1), or starts from the major axis toward the left and increases counterclockwise (Fig. 2). An average intensity is derived for every 10° sector, and the profile is shown in Fig. 4 [Figure 4: see original paper].

The emission is brightest for azimuthal angles between 30° and 90°, and becomes weaker for angles between 150° and 270°, as can also be seen from Fig. 2. There is no clear pattern in the azimuthal profile.

2.4 Spectral Index

The spectral index is related to emission properties such as non-thermal and thermal fractions and cosmic ray electron aging. We do not derive the spectral index for all pixels by fitting brightness temperature against frequency because of background emission effects. Instead, we divide the whole M 31 area into 8 regions (Fig. 5 [Figure 5: see original paper]) and obtain the spectral index using the Temperature-Temperature plot (TT-plot) method (Turtle et al. 1962), which is immune to background emission.

We take the median values of the first 10,000 and last 10,000 channels to calculate the spectral index with the TT-plot method. The corresponding frequencies are 1.055 GHz and 1.420 GHz, which have the largest frequency separation and thus allow for more accurate determination of the spectral index. The TT-plot results for the 7 regions are shown in Figs. 5 and 6 [Figure 6: see original paper]. Note that the brightness temperature spectral index β, as we obtain, can be connected to the flux density spectral index α as $\alpha = \beta + 2$.

The spectral index for the total intensity is not uniform across M 31. In areas marked as 6, 1, and 2 in Fig. 5 where total intensity emission is weak, the spectra are steep with spectral index α between -0.8 and -0.7. In contrast, in areas marked as 3, 4, and 5 where emission is stronger, the spectra are shallower with spectral index α up to -0.44 ± 0.09. There appears to be a tendency for larger intensity to correlate with flatter spectrum. The nucleus region marked as 7 has the smallest spectral index of -0.90 ± 0.03. Area 8 outside M 31, detected due to the high sensitivity of FAST, has a spectral index of $\alpha = -0.64 \pm 0.08$ and has not been well studied before.

3 DISCUSSION

3.1 Properties of Cosmic Ray Electrons

The total intensity is composed of both thermal emission from free-free radiation and non-thermal emission from synchrotron radiation. We take the images of thermal and non-thermal emission derived by Tabatabaei et al. (2013) and obtain the thermal fraction versus azimuthal angle for the M 31 ring, shown in Fig. 7 [Figure 7: see original paper]. The thermal fraction reaches up to 20% for azimuthal angles between 30° and 90°, and is about 10% for the rest. Thermal emission has a flat spectrum with $\alpha_{\rm th} \approx -0.1$, which is much larger (flatter) than that of non-thermal emission. Therefore, the mixture of thermal and non-thermal emission brings the spectral index of the total emission to a larger (flatter) value. Typically, for thermal fractions of 10% and 20%, the spectral index of total intensity calculated from the frequency pair of 1.055 and 1.420 GHz is increased by 0.1 and 0.2, respectively, compared to the spectral index of non-thermal emission α_n. For the emission ring of M 31, the spectra for total intensity toward the north part in Fig. 1 (or regions 3, 4, 5 on the left part in Fig. 5) are shallower than those toward the south part. Taking into account the influence of thermal emission, the spectral index of non-thermal emission could be estimated by subtracting 0.1 or 0.2 from the total intensity spectral index depending on the thermal fraction. For example, the non-thermal spectral index could reach $\alpha_n \approx -0.64$ for region 5 with a thermal fraction of about 20%. This implies that the non-thermal spectral index toward the northern part is larger (flatter) than that toward the southern part of M 31.

The asymmetry of the non-thermal spectral index between the northern and southern parts of M 31 was also found by Fatigoni et al. (2021) based on observations at frequencies between 1.5 and 6.6 GHz. The star formation rate is also higher toward the north (Fatigoni et al. 2021). A higher star formation rate results in a larger number of stars and consequently a larger number of supernovae and supernova remnants that can produce more cosmic ray electrons, resulting in a flatter spectrum toward the north. Moreover, the presence of higher cosmic ray electron density results in stronger synchrotron radiation, which explains the correlation between large intensity and large spectral index.

For area 8 in Fig. 5, it cannot be an extension from the ring, as its spectrum would be steeper due to aging of cosmic ray electrons as they propagate from the ring. From the Herschel image at 250 μm (Viaene et al. 2014), there is strong emission corresponding to this area, which appears to be part of a large ring structure surrounding M 31. There could be star-forming activities that produce high-energy electrons. High-resolution observations are needed to detect radio emission related to the infrared emission observed by Herschel.

The scale length of the total emission is 3.7 kpc. Thermal emission is highly concentrated in the ring (Tabatabaei et al. 2013) and therefore has little influence on the scale length of non-thermal emission. In practice, we derive a scale length of 3.8 kpc for the non-thermal emission after removing the contribution of thermal emission. This corresponds to an exponential scale length of 5.4 kpc. Assuming energy equipartition between magnetic field and cosmic rays, the scale length of the non-thermal emission is equal to that of cosmic ray electrons multiplied by the factor $(3-\alpha_n)/2 \approx 2$ (Berkhuijsen et al. 2013). The scale length of cosmic ray electrons is thus about 2.7 kpc.

The diffusion length of cosmic ray electrons varies with frequency as $\nu^{-1/4}$ (Mulcahy et al. 2016). It is therefore expected that the scale length of cosmic ray electrons is about 1.9 kpc at 4.8 GHz, which is consistent with the scale length of about 3.7 kpc for non-thermal emission and hence the scale length of about 1.9 kpc for cosmic ray electrons derived by Beck et al. (2020) at 4.8 GHz. This implies that cosmic ray transport occurs primarily through diffusion and that energy loss is not significant at 4.8 GHz.

3.2 The Magnetic Field in the Ring

We obtain the azimuthal profile of the non-thermal emission within the bright ring after subtracting the thermal emission (Fig. 7) from the total emission (Fig. 4). The result is shown in Fig. 8 [Figure 8: see original paper]. The non-thermal emission originates from synchrotron radiation, and its profile thus reflects the magnetic field configuration in M 31.

The large-scale regular magnetic field in M 31 mainly follows an axisymmetric pattern (Han et al. 1998; Fletcher et al. 2004). In this configuration, the magnetic field perpendicular to the line of sight can be derived as:

$$B_\perp = B\sqrt{1-\cos^2(\phi-\xi)\sin^2 i}$$

where ϕ is the azimuth angle, ξ is the pitch angle, and i is the inclination angle of M 31. The non-thermal intensity (I) can be assessed as (Beck & Krause 2005):

$$I \propto B^{3-\alpha_n}$$

Here, energy equipartition between magnetic field and cosmic rays is assumed.

The random magnetic field has recently been classified into ordered and isotropic components to interpret the polarization observations of M 31 (Beck et al. 2020). The ordered field can be generated from shear of differential rotation or compression of spiral arm shocks (Jaffe 2019). However, there are no indications of such large-scale structures inside the ring from radio observations. We therefore consider only the isotropic random magnetic fields. Since the path length along different lines of sight toward the ring is similar, the synchrotron emission from random fields is independent of azimuthal angle. The azimuthal variation of non-thermal emission is thus caused by the large-scale regular field.

The intensity of synchrotron radiation can be derived using the above equations. The inclination angle $i = 75°$ (Chemin et al. 2009) is used. The pitch angle is uncertain. Berkhuijsen et al. (2003) obtained a pitch angle of $\xi = -13° \pm 7°$ by analyzing polarization observations at 6 cm. Fletcher et al. (2004) found a radial change of the pitch angle from $-17°$ to $-8°$ based on multi-frequency polarization observations. However, recent analysis by Beck et al. (2020) suggested a large variation of the pitch angle versus azimuthal angle for the total magnetic field including both regular and ordered components.

Assuming a constant pitch angle for M 31, we would expect the separation of the two intensity peaks to be 180°, which is clearly inconsistent with the observed profile shown in Fig. 8. This implies variations in the pitch angle. We thus propose a simple model of the large-scale magnetic field with a pitch angle of $-15°$ for the azimuthal angle range of 0° to 190°, and a pitch angle of 30° for the range of 190° to 360°. Additionally, we impose a factor of 0.95 for the ratio of the two peaks, which we attribute to variation in cosmic ray electron density. The resulting profile is presented in Fig. 8, which reasonably reproduces the observed profile. A more sophisticated magnetic field model requires both total intensity and polarization observations at multiple frequencies and is beyond the scope of this paper.

4 SUMMARY

We obtain total intensity images from the FAST legacy survey of M 31, covering the frequency range of 1.0–1.5 GHz. By averaging over all frequency channels, we derive the total intensity image at 1.248 GHz, which reveals weak extended emission outside the ring due to the high sensitivity. This image allows us to analyze the propagation of cosmic ray electrons and the magnetic field configuration. The main conclusions are as follows:

1. We derive a scale length of about 2.7 kpc for cosmic ray electrons by fitting the radial profile of non-thermal emission. In comparison with the scale length at higher frequencies, we find that cosmic ray electrons propagate mainly through diffusion.

2. The spectral index of total intensity in the ring, calculated from TT-plots, clearly exhibits azimuthal variation, which can be attributed to spectral variation of synchrotron radiation. This variation is likely caused by changes in star formation rates along the ring.

3. The weak emission detected outside the ring might not be extended emission from the ring itself, but rather produced by independent star-forming activities.

4. The azimuthal profile of non-thermal emission can be reproduced with an axisymmetric large-scale magnetic field pattern with pitch angle varying with azimuthal angle, indicating that the magnetic field configuration in the ring is complicated.

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