



The FAST Detection of an H I Cloud around Supernova Remnant G116.6–26.1

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Abstract

G116.6–26.1 has been newly discovered as a supernova remnant (SNR) through the SRG/eROSITA X-ray survey, located in a high-latitude, low-density region. Its distance and progenitor nature remain uncertain. Our objective is to explore the surroundings of SNR G116.6–26.1 to determine its distance and surrounding environmental conditions. High-resolution and sensitive H I observations around G116.6–26.1 from the Five-hundred-meter Aperture Spherical radio Telescope, with an rms level of $1.0 \text{ mJy beam}^{-1}$, were utilized to study the distribution of cold gas in this SNR region. Furthermore, an extinction map for this area helps estimate the distance to G116.6–26.1. We identified four H I structures associated with G116.6–26.1 in the local standard of rest velocity range -133.9 to -63.9 km s^{-1} : clouds A1, B1, B2, and C1. Together with other components in the A-series and the C-series, they form a large cloud that exhibits a cavity in this SNR region. The A- and C-series share similar velocities, while B1 and B2, both in the SNR area, differ by $10\text{--}30 \text{ km s}^{-1}$. The X-ray morphology displays deformation features that align spatially with the H I structure C1 boundary interface. Using three-dimensional extinction data, we estimate the cloud's distance to be $2.7^{+3.18}_{-0.50} \text{ kpc}$, suggesting that G116.6–26.1 exploded within an H I cloud beyond the Galactic plane, about 2.7 kpc away.

Key words: ISM: clouds – ISM: supernova remnants – (ISM:) dust, extinction

1. Introduction

Churazov et al. (2021) discovered a new Galactic supernova remnant (SNR) candidate, designated G116.6–26.1 (hereafter G116), through the SRG/eROSITA all-sky X-ray survey. The identified source exhibits a nearly circular morphology, with a large angular diameter of approximately 4° . It is located at a high Galactic latitude of $b \approx -26.1$. Current Galactic surveys have identified approximately 310 SNRs. Observations reveal that over 91% of these objects are concentrated within 5° of the Galactic plane, while approximately 7% populate intermediate latitudes ($5^\circ < |b| < 15^\circ$). Only a small fraction of the remnants—merely 1.6%—reside at higher Galactic latitudes ($|b| > 15^\circ$) (Green 2025) (e.g., G70.0–21.5, G275.5+18.4, G249.7+24.7, G354.0–33.5; (Boumis et al. 2002; McCullough et al. 2002; Testori et al. 2008; Becker et al. 2021; Fesen et al. 2021)). Churazov et al. (2021) propose that G116 probably originated from a Type Ia supernova (SN) that exploded roughly 40,000 yr ago, located at an estimated distance of 3 kpc from the Sun (i.e., about 1 kpc out of the Galactic disk). They further propose that this SN event occurred within

the low-density (around 10^{-3} cm^{-3}) and hot (about $(1\text{--}2) \times 10^6 \text{ K}$) gas of the Milky Way halo. If the above hypothesis is confirmed, specifically its off-disk location and low-density environment, G116 would offer a unique opportunity to reveal properties of the hot gas (density, temperature, and metallicity) near the Galactic disk-halo interface and directly observe non-equilibrium dynamics of plasma heating and ionization (Churazov et al. 2021).

Recently, the LOFAR Two-meter Sky Survey (LoTTS-DR2; Shimwell et al. 2022) detected radio emission from G116 (Churazov et al. 2022). This emission exhibits a shell-like morphology that aligns with the X-ray boundary of G116. Using high-resolution, wide-field imaging combined with spectroscopic observations, Palaiologou et al. (2022) reported the first detection of optical emission from G116. The SNR nature of G116 is confirmed by the $[\text{S II}]/\text{H}\alpha$ line ratio of 0.56 ± 0.06 , exceeding the threshold of 0.4. Additionally, the $[\text{O III}]/\text{H}\beta$ ratio suggests a shock velocity ranging from 70 to 100 km s^{-1} .

The study of the H I counterparts of SNRs is crucial as they provide valuable insights into the surrounding interstellar

Table 1
Observational Parameters of the H I Spectral Line Data

Parameter	Value
Survey strategy	3-pass drift scan
Number of beams	19
Beam size at 1420.4058 MHz	2.9
Frequency range	1050–1450 MHz
Channel width	1.6 km s ^{−1} at 1420.4058 MHz

medium (Kang et al. 2014; Kothés et al. 2014, 2017). H I observations can estimate the gas mass and the ambient density, enhancing our understanding of the SNR’s environmental conditions.

The H I emission associated with SNR G116 has not been previously reported in the literature. Five-hundred-meter Aperture Spherical radio Telescope (FAST), currently the largest single-dish radio telescope in the world, provides high resolution and sensitivity. In this work, we report the detection of H I emissions associated with G116 for the first time, using data from our FAST M31-centered wide-field H I emission survey.

This paper is organized as follows. Section 2 describes the observations and the data. In Section 3, we present the results of the H I emission associated with G116. Finally, Section 4 offers a summary of the work.

2. Observations and Data Reduction

We obtained H I survey data from FAST toward the M31 halo region. Our goal is to utilize FAST’s remarkable sensitivity and resolution to detect H I gas associated with G116 in this data set. Additionally, stellar reddening and distance measurements can help constrain the distance to G116. In the following subsections, we will describe the H I data and the 3D extinction data.

2.1. FAST H I Data

We carried out a wide-field H I emission survey using FAST. This survey is centered approximately on M31 and covers an area of $37^\circ \times 24^\circ$ along the direction of R.A. and decl. The G116 region is covered in the 21 cm spectral line data from this survey. Table 1 describes the observational parameters of the H I data. The beam size at 1420.4058 MHz of FAST is 2.9. The data were processed using the FAST H I data calibration and imaging pipeline, HiFAST (Jing et al. 2024; Liu et al. 2024; Xu et al. 2025). Following the spectral calibration and gridding process, we generated a FITS file with a grid size of $1'$ by combining data from three separate scans. The resulting rms noise level is 1.0 mJy beam^{−1}, with a velocity resolution of 1.6 km s^{−1} after velocity smoothing.

2.2. 3D Extinction Data

Our analysis uses a 3D interstellar dust map from Wang et al. (2025), which provides full-sky coverage of the reddening distribution. This map combines two components: reddening measurements from LAMOST low-resolution spectra (Luo et al. 2015) ($E(B - V)_{\text{LAMOST}}$) using the standard-pair method (Yuan et al. 2013; Zhang & Yuan 2023) and Gaia XP spectra ($E(B - V)_{\text{XP}}$) (Gaia Collaboration et al. 2016) through the forward modeling technique (Zhang et al. 2023), combined with Gaia’s revised distances. The $E(B - V)_{\text{LAMOST}}$ data set (Wang et al. 2025), containing 4.6 million stars, has a precision of about 0.01 mag per measurement. The $E(B - V)_{\text{XP}}$ catalog includes 150 million stellar sources with a median precision of approximately 0.03 mag.

Wang et al. (2025) adaptively partitioned the entire sky based on local stellar density. Using a novel parametric methodology, they derived reddening-distance relations for multiple sightlines. The map achieves an angular resolution of 3.4 – 6.6 in the studied region. The map reliably traces dust distribution to distances beyond 10 kpc.

3. Results

3.1. H I Structures Associated with G116

Figure 1 displays channel images of the FAST H I data with velocities between -140.9 and -56.9 km s^{−1}. Spatially smoothed to 4.9 resolution, the SRG/eROSITA X-ray data of G116 (Churazov et al. 2021, right panel of Figure 1) are represented by green contours. A significant H I structure, labeled A1, has an estimated angular size of $105'$ north of G116. It is situated at the boundary of the X-ray emission region of G116, with a morphology matching G116’s periphery, suggesting a possible connection. Filamentary structure C, located south of G116, exhibits a northern boundary spatially aligned with the X-ray boundary of G116, indicating a morphological coincidence/correlation. Notably, deformed X-ray features are observed at the interface between X-ray emission and H I structure C, evident in panels (c)–(f). Remarkably, an H I cavity is present within the SNR’s boundaries, except for two relatively faint H I clouds (B1 and B2). The positional and morphological consistency implies that structure A1, cloud B1, cloud B2, and C are likely associated with G116.

Within the velocity range of $-133.9 \lesssim v_{\text{LSR}} \lesssim -70.9$ km s^{−1}, both structures A1 and C are visible in panels (d)–(j). Moreover, A1 and the peak of C (C1) exhibit high intensity within $-112.9 \lesssim v_{\text{LSR}} \lesssim -91.9$ km s^{−1}. Additionally, they both display a distinct edge at the boundary of G116’s X-ray region. Notably, some faint structures (structures B1 and B2) appear at velocities exceeding -84.9 km s^{−1}; these may be considered the H I receding component of the cavity along the line of

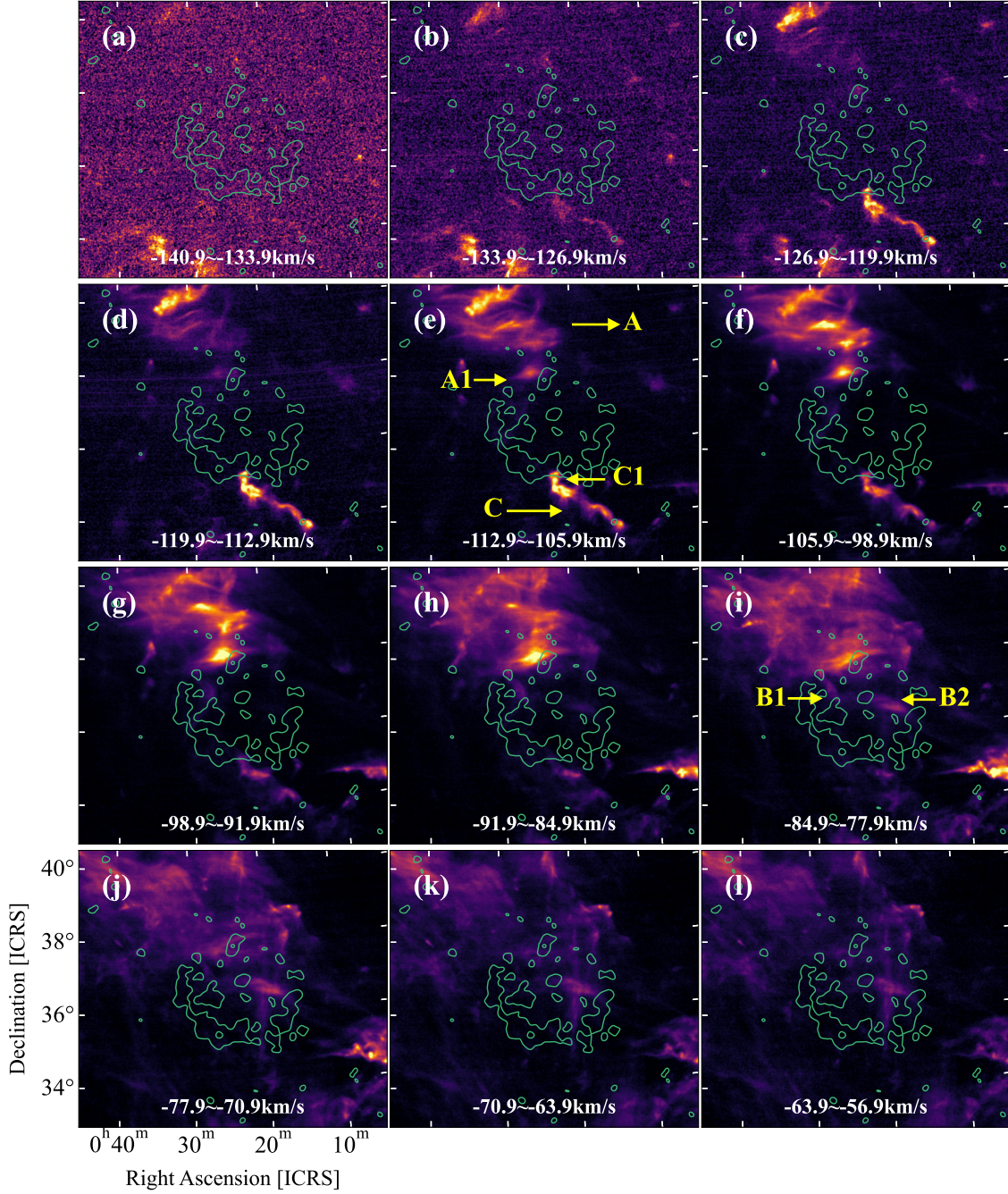


Figure 1. H I intensity channel images in the velocity range of -140.9 to -56.9 km s^{-1} . Each image is integrated over a velocity interval of 7 km s^{-1} . Green contours represent the SRG/eROSITA X-ray observations of G116 (Churazov et al. 2021, right panel of Figure 1), smoothed to a resolution of 4.9 . Yellow arrows mark the structures A1, A, B1, B2, C1, and C, with A1 and C1 representing substructures of A and C, respectively. The maximum and minimum values of the color scale in each panel are 99.9% and 2% of the respective image's value distribution.

sight. These results collectively support the association between the H I structures A1, B1, B2, and C1 with G116.

Figure 2 shows the moment maps for the velocity range -133.9 to -69.4 km s^{-1} in this region. These maps provide distinct kinematic perspectives: moment 0 (M0) traces the

integrated H I intensity over the velocity range, moment 1 (M1) represents the intensity-weighted velocity field, and moment 2 (M2) quantifies the velocity dispersion. Black contours mark G116's X-ray emission (Churazov et al. 2021), and a dashed blue rectangle outlines the large H I cloud

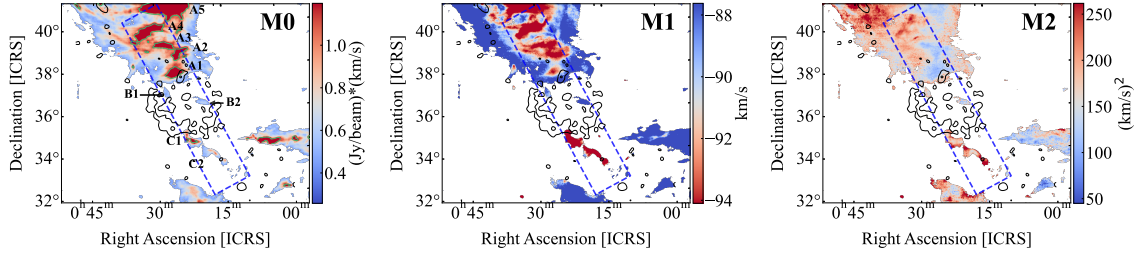


Figure 2. Moment 0 (left), moment 1 (middle), and moment 2 (right) of the cube in the velocity range of -133.9 and -69.4 km s^{-1} . Black contours show the G116’s X-ray observations (Churazov et al. 2021) displayed in Figure 1, and the dashed blue regions represent the extensive H I cloud structure. The labels A2 through A5 indicate the four structures to the north. Meanwhile, C1 and C2 refer to two subdivisions of C as depicted in Figure 1. The contour levels are 0.455 and 1.150 $\text{Jy beam}^{-1} \text{km s}^{-1}$ to show the structures A1–A5.

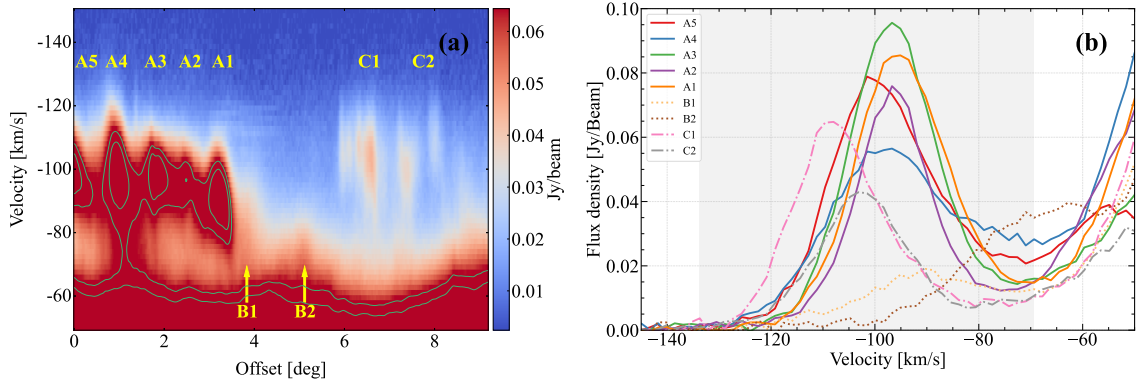


Figure 3. (a) PV diagram of H I gas across G116 and surrounding areas. The data is selected along the dashed blue rectangle in Figure 2 (direction: from northeast to southwest). The width of the diagram cut is 1.86 . (b) Spectra of the localized peak points of structure A1–A5, B1–B2, and C1–C2. The dashed area indicates the integrated velocity range depicted in the left panel of Figure 2.

complex. A2–A5 represent the H I gas north of A1, while C1–C2 refer to subdivisions of structure C. A1 shares similar velocities with A2–A5, hinting at a physical connection. Figure 1 further illustrates tenuous H I gas connection between A1 and A2–A5, indicating these components constitute a unified structure termed the A-series (A1–A5). In the M1 map, it is apparent that the A-series and C-series structures have similar values around -98 to -92 km s^{-1} . Although other H I structures are present along the western and southern edges of the C-series, their velocities differ from those of the A-series. In the M2 map, the A-series and C-series reveal similar values of approximately 150 – 210 $\text{km}^2 \text{s}^{-2}$. The observational data indicate that the A-, B-, and C-series likely originated as a unified H I gas complex before. This interpretation probably implies the pre-existing presence of connecting H I gas within the G116 region.

Moreover, the M0 map provides a mass estimate of approximately $\sim 215.6d^2 M_{\odot}$ for the H I gas in components A1, cloud B1, cloud B2, and structure C, where d is the distance to G116 in units of kpc. The peak column density ($N_{\text{HI,peak}}$) reaches $\sim 7.5 \times 10^{19} \text{cm}^{-2}$, while the average column

density is about $\sim 2.6 \times 10^{19} \text{cm}^{-2}$. It is noteworthy that the H I column density does not contradict the value of $N_{\text{H}} \sim (6.9 \pm 2.3) \times 10^{20} \text{cm}^{-2}$ reported in Table 2 by Churazov et al. (2021). The latter represents the foreground hydrogen column density along the sightline between G116 and the Earth, derived through X-ray absorption modeling (using the `tbabs*(v) apec` model). Conversely, the H I column density in this work exclusively traces kinematically associated H I structures linked to G116.

The left panel of Figure 3 illustrates the position–velocity (PV) diagram for the dashed blue region in Figure 2 (direction: from northeast to southwest). The A- and C-series are lined up around a velocity of -100 km s^{-1} . A notable “signal void” is present between the A- and C-series, with the B-series clouds (B1 and B2) located in the lower velocity part of this gap (~ -70 km s^{-1}). This pattern is similar to the observations in Figure 1.

The right panel of Figure 3 presents the spectra for the A-, B-, and C-series of structures, with solid, dotted, and dashed lines representing the A-, B-, and C-series, respectively. A1 exhibits spectral line widths similar to A2–A5, with velocity

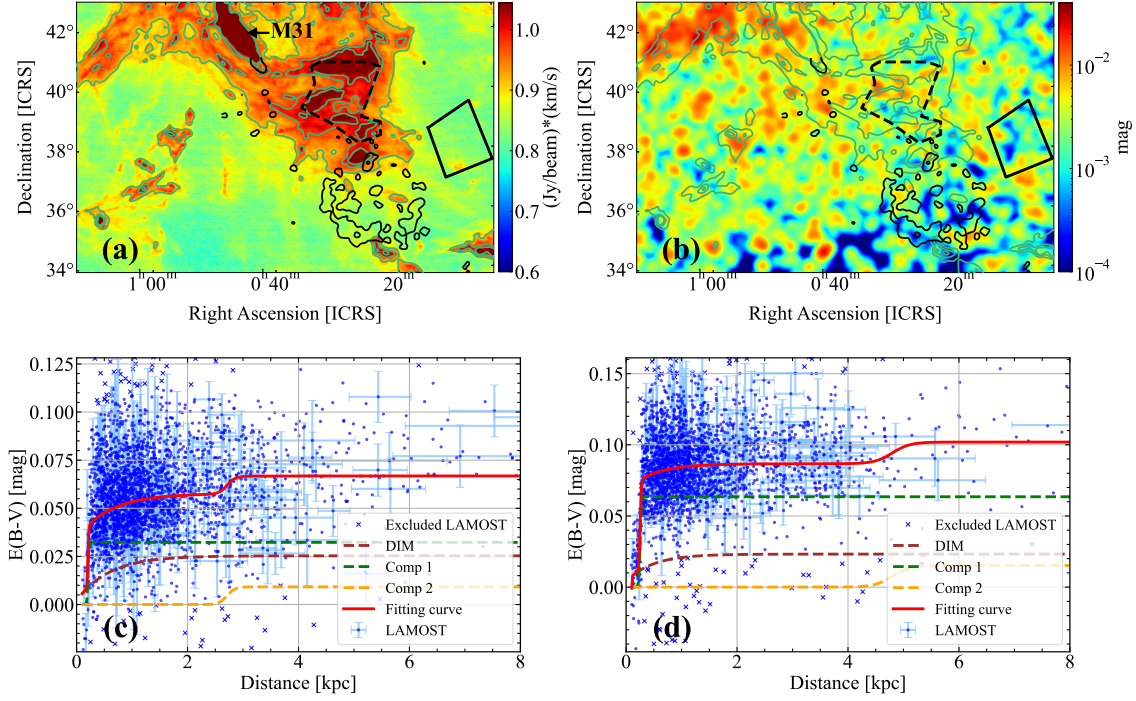


Figure 4. (a) Integrated H I image in the velocity range of -133.9 to -69.4 km s^{-1} , with green contour levels at 0.46 , 0.83 , and 1.15 $\text{Jy beam}^{-1} \text{ km s}^{-1}$. Black contours show the X-ray observations of G116 (Churazov et al. 2021) displayed in Figure 1. The dashed and solid black polygons mark regions A2–A5 and a control region, respectively. The black arrows indicate the northern M31 disk, which contains kinematic components within this velocity range. (b) Dust map within $d = 1.4$ – 2.3 kpc, overlaid with H I counterparts and G116 X-ray contours from panel (a). (c) The LAMOST star color excess $E(B - V)$ values as a function of distance toward regions A2–A5 (dashed black polygon) in panel (a). Blue dots correspond to LAMOST stellar measurements employed to model the extinction–distance relation. To avoid overlap of error bars, only 10% of the blue points are displayed with error bars. Blue crosses mark $>3\sigma$ outliers excluded during initial LAMOST data fitting to minimize outlier influence. The solid red line displays the best-fitting model to the LAMOST data (blue points). Brown dashed line traces the diffuse dust component, whereas yellow and green dashed lines correspond to two high-extinction regions. (d) Identical extinction–distance relation as in panel (c), but analyzed for the control region (solid black polygon) marked in panel (a).

variations fewer than 6 km s^{-1} . Furthermore, the A- and C-series show comparable line widths, with velocity differences of 2 – 12 km s^{-1} . In contrast, the B-series shows spectral profiles and center velocities distinct from the A- and C-series, likely corresponding to the receding H I cavity component. The collective outcomes suggest that the A-series, B-series, and C-series likely originated from a unified H I gas cloud.

3.2. Distance Estimation from Extinction Map

As (Churazov et al. 2021) noted, G116 is likely in proximity to us, only a few kpc away. In this study, we believe that G116 is probably situated within a large nearby H I cloud. This suggests that by determining the distance to the H I cloud, or the dust within it, we might estimate the distance to G116.

Figure 4 presents the H I and dust distributions in the G116 vicinity. Panel (a) displays the integrated H I image in the velocity range of -133.9 to -69.4 km s^{-1} , with green contours at 0.46 , 0.83 , and $1.15 \text{ Jy beam}^{-1} \text{ km s}^{-1}$. Black contours mark the X-ray observations of G116 (Churazov et al. 2021). The dashed and solid black polygons outline regions A2–A5 and a control region, respectively. Black arrow indicates the northern

M31 disk, which contains kinematic components within this velocity range. The A-series appears kinematically connected to the northeastern H I structure, forming a coherent large-scale complex.

Distance was estimated from the 3D dust map in Wang et al. (2025). We applied 2D Gaussian smoothing with $\sigma = 6'$ to the 3D map to reduce noise and enhance the signal-to-noise ratio. The dust distribution within 1.4 – 2.3 kpc (panel (b)) exhibits morphological agreement with H I emission contours. Although the A-series region exhibits reduced signal-to-noise ratio, the H I–dust correlation remains statistically significant. Dust signatures are identified throughout the extended H I complex field, yet we find no compelling evidence for spatial alignment between dust and the A-series features. This result implies that A-series dust clouds are indistinguishable from noise in the 3D map, motivating our subsequent extinction analysis.

For the A-series region, we derived the reddening–distance relation through multi-component logistic function fitting, using the high signal-to-noise LAMOST extinction measurements from Wang et al. (2025). This data set prioritizes

photometric precision over spatial resolution, making it ideal for identifying low-contrast extinction features.

Panel (c) shows the stellar color excess $E(B - V)$ as a function of distance for structures within the dashed black polygon outlined in panel (a) (including A2–A5). Blue dots represent LAMOST stellar measurements. To prevent overlap of error bars, only 10% of the blue points are shown. Blue crosses mark $>3\sigma$ outliers excluded during initial LAMOST data fitting to minimize outlier influence. The solid red line is the best-fit model to the LAMOST data (blue points). The brown dashed line represents the diffuse dust contribution, while the yellow and green dashed lines correspond to two high-extinction regions. Significant $E(B - V)$ spikes appear at $d = 0.2$ kpc and $d = 2.7$ kpc. The 0.2 kpc signal likely originates from Galactic plane structures, leading us to adopt 2.7 kpc as the probable distance for A2–A5. In contrast, panel (d) exhibits no $E(B - V)$ spike at $d = 2.7$ kpc for the control region (solid black polygon in panel (a)), thereby substantiating the reliability of the 2.7 kpc extinction feature in regions A2–A5. Using 1000 bootstrap resampling analyses, we obtained a 95% confidence interval for the distance parameter of $2.7^{+3.18}_{-0.50}$ kpc, with a statistical significance of 2.87σ . We attempted to estimate distances for the B- and C-series, but the limited number of background stars at higher latitudes makes their distance harder to determine. Given the A2–A5 results, we propose that the entire H I complex (A-, B-, and C-series) and SNR G116 likely share this distance of roughly $2.7^{+3.18}_{-0.50}$ kpc. This finding is consistent with the proposed few kpc distance to G116 by Churazov et al. (2021), while further substantiating the physical association between H I structures A1, B1, B2, C, and SNR G116. In addition, we estimate the H I mass associated with G116 (A1, B1, B2, C1) as $1571.6M_{\odot}$.

4. Discussion and Conclusions

We conducted an exploration of the area surrounding G116 and identified a large H I cloud in the vicinity using FAST. Our findings indicate that this cloud is physically linked to the X-ray region of G116. The key outcomes of this study are outlined below.

1. Within the velocity range of $-133.9 \lesssim v_{\text{LSR}} \lesssim -70.9$ km s $^{-1}$, two H I structures A- and C-series are detected north and south of G116's X-ray region. Especially, two structures A1 and C1 at the G116's X-ray boundary, show a sharp cut in the direction of G116. Significantly, the X-ray morphology exhibits deformation signatures that coincide with the H I structure C boundary interface. Also, moment maps indicate similar density, velocity, and velocity dispersion between structures A- and C-series. Between A- and C-series, no H I emission is detected at comparable velocities, except for two low-density regions (B1 and B2) at a velocity of -70 km s $^{-1}$, which may be the receding H I gas of G116. These

observations may suggest the A-, B-, and C-series share origin in a unified H I cloud.

2. We estimate a total mass of $\sim 215.6d^2M_{\odot}$ for the associated H I gas. The peak and average column density are $\sim 7.5 \times 10^{19}$ cm $^{-2}$ and $\sim 2.6 \times 10^{19}$ cm $^{-2}$, respectively.
3. Based on the 3D distinction map and the reddening-distance relation in this region, we estimate the distance of the A-series structure to be roughly $2.7^{+3.18}_{-0.50}$ kpc. If G116 is physically related to this H I cloud as we noted in this paper, it is expected that the distance of G116 is also $2.7^{+3.18}_{-0.50}$ kpc, which agrees well with what Churazov et al. (2021) proposed. This consistency strengthens the association between H I structures A1, B1, B2, C, and SNR G116. The mass of the H I gas associated with G116 is estimated to be $1571.6M_{\odot}$.

We also found H I gas only in the north and south areas around G116, not in a full expanding shell. This happens because the H I cloud likely comes from the Galactic disk. The cloud thins out and weakens as it moves away from the disk, and G116 is located at the southern edge of this cloud. Several incomplete H I shells around SNRs are also reported, such as GSH 91.5+2–114 (Cichowolski & Pineault 2011), FVW 190.2+1.1 (Koo et al. 2006), and FVW 172.8+1.5 (Kang et al. 2012). This also indicates that the environment around SNRs is complicated.

Although H I gas associated with SNR G116 has been observed, the formation mechanism of the H I cavity in the G116 region remains unresolved. We suggest that the H I structure was not swept up by the SNR, given the nearly spherical SNR morphology in the X-ray, radio, and optical bands (Churazov et al. 2021, 2022; Palaiologou et al. 2022). A deformation feature is observed at the southern interface between structure C and the X-ray boundary, which may suggest potential interaction between the SNR and the H I gas. However, we detect neither interaction signatures in X-ray spectral line diagnostics nor associated H α emission signals at the deformed X-ray region. In other words, no conclusive evidence for direct interaction between SNR G116 and H I gas has been identified. Therefore, we hypothesize that the progenitor star/system of G116 likely expelled powerful stellar winds that evacuated the surrounding H I gas. This process disrupted the originally continuous H I structure observed in the region. Subsequently, the progenitor star underwent an SN explosion within this pre-existing low-density cavity, with the remnant evolving within the cavity environment. Similar cases of SNRs evolving within cavities blown by progenitor stellar winds have been previously observed, whether for Type Ia SNRs or core-collapse SNRs (Zhou et al. 2016; Arias et al. 2019; Zhang et al. 2023).

G116 is located at a high Galactic latitude ($l \approx 116.6^\circ$ and $b \approx -26.1^\circ$). Combining Churazov et al. (2021)'s results with

our analysis, we constrain the distance to $2.7^{+3.18}_{-0.50}$ kpc, indicating a vertical distance of about 1.19 kpc from the Galactic plane. Located far away from the Galactic disk, this region exhibits a significantly lower gas density compared to the interstellar medium within the disk (Marasco & Fraternali 2011; HI4PI Collaboration et al. 2016). Churazov et al. (2021) further suggest that G116 developed in a low-density medium ($n = 10^{-3} \text{ cm}^{-3}$). The occurrence of such an SN explosion in such conditions remains uncertain. Our discovery of a large HI cloud surrounding G116 may provide insights into the surrounding environments of an SNR located far away from the Galactic plane.

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