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Low-Metallicity Star Formation Survey of Sh2-284 (LZ-STAR): The Core Mass Function

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Abstract

We present an Atacama Large Millimeter/submillimeter Array 1.3 mm dust continuum study of the dense core mass function (CMF) in Sh2-284, a low-metallicity outer Galaxy star-forming complex with $Z \sim 1/3\text{--}1/2 Z_{\odot}$. The observations cover six far-infrared bright subregions at $\sim 0''.65$ (3000 au) resolution. We identify a total of 91 candidate dense cores and define a robust catalog of 68 cores with Gaussian fitting. The high-mass CMF above $2.5 M_{\odot}$ is well described by a Salpeter-like slope, with a fiducial forward-modeled value of $\alpha = 1.22^{+0.24}_{-0.22}$ for $dN/d \log M \propto M^{-\alpha}$. Together with existing constraints on the initial mass function (IMF) of Sh2-284, the Salpeter-like CMF is consistent with a resemblance between the CMF and IMF shapes in the outer Galaxy environments, suggesting that moderately low metallicity alone does not strongly reshape the high-mass CMF/IMF slope.

Unified Astronomy Thesaurus concepts: Star formation (1569); Initial mass function (796); Metallicity (1031)

Materials only available in the online version of record: machine-readable table

1. Introduction

The stellar initial mass function (IMF) is a fundamental distribution that links star formation and galaxy evolution. Observations of the Galactic field and nearby young clusters have revealed broadly similar IMFs, characterized by a Salpeter-like power-law slope above $\sim 1 M_{\odot}$ and a turnover near $\sim 0.2\text{--}0.3 M_{\odot}$ (P. Kroupa 2001; G. Chabrier 2003; N. Bastian et al. 2010), yet variations have been reported in other Galactic and extragalactic environments (e.g., F. R. N. Schneider et al. 2018; M. W. Hosek et al. 2019). Metallicity is a key parameter in this context, as low-metallicity conditions are common in the early universe. Spatially resolved studies of nearby subsolar-metallicity regions do not show a simple metallicity-dependent IMF trend. Several Magellanic Cloud associations appear broadly consistent with Galactic IMFs (e.g., M. Schmalzl et al. 2008; M. Andersen et al. 2009; N. Da Rio et al. 2009), whereas the massive star IMF over $15\text{--}200 M_{\odot}$ is shallower than the Salpeter IMF in 30 Doradus (F. R. N. Schneider et al. 2018), and recent JWST studies of the outer Galaxy clusters suggest a lower turnover mass than the field IMF (C. Yasui et al. 2024; M. Andersen et al. 2026).

The IMF is commonly hypothesized to be at least partly inherited from the core mass function (CMF), the mass

distribution of dense cores before they form stars (S. S. R. Offner et al. 2014). In solar neighborhood clouds, the CMF resembles the IMF and is shifted toward higher masses (e.g., J. Alves et al. 2007). Over the past decade, extensive measurements with the Atacama Large Millimeter/submillimeter Array (ALMA) have been made in diverse Galactic environments, revealing high-mass slopes ranging from a shallower index of ~ 1 to the Salpeter-like index of ~ 1.35 (e.g., F. Motte et al. 2018). Recent ALMA-IMF and ALMAGAL studies indicate that the CMF is not static, showing systematic differences between prestellar and protostellar core populations and shifting toward higher masses and shallower slopes as clumps evolve, favoring a clump-fed scenario in which cores continue to accrete material from their surroundings (e.g., T. Nony et al. 2023; M. Armante et al. 2024; A. Coletta et al. 2025). However, the CMF measurements in low-metallicity regions remain rare (e.g., A. Traficante et al. 2026). While it is now clear that interpreting the CMF-IMF connection also requires accounting for processes such as fragmentation and core growth, observations at earlier stages of stellar mass assembly remain essential for testing whether possible IMF variations are already imprinted during cloud fragmentation, where metallicity may have a more direct influence.

Here we present an ALMA 1.3 mm dust-continuum measurement of the CMF in the outer Galaxy region Sh2-284. As one of the most metal-poor star-forming environments known in the Milky Way ($1/3\text{--}1/2$ solar, I. Negueruela et al. 2015), Sh2-284 is located at a favorable distance of 4.5 kpc



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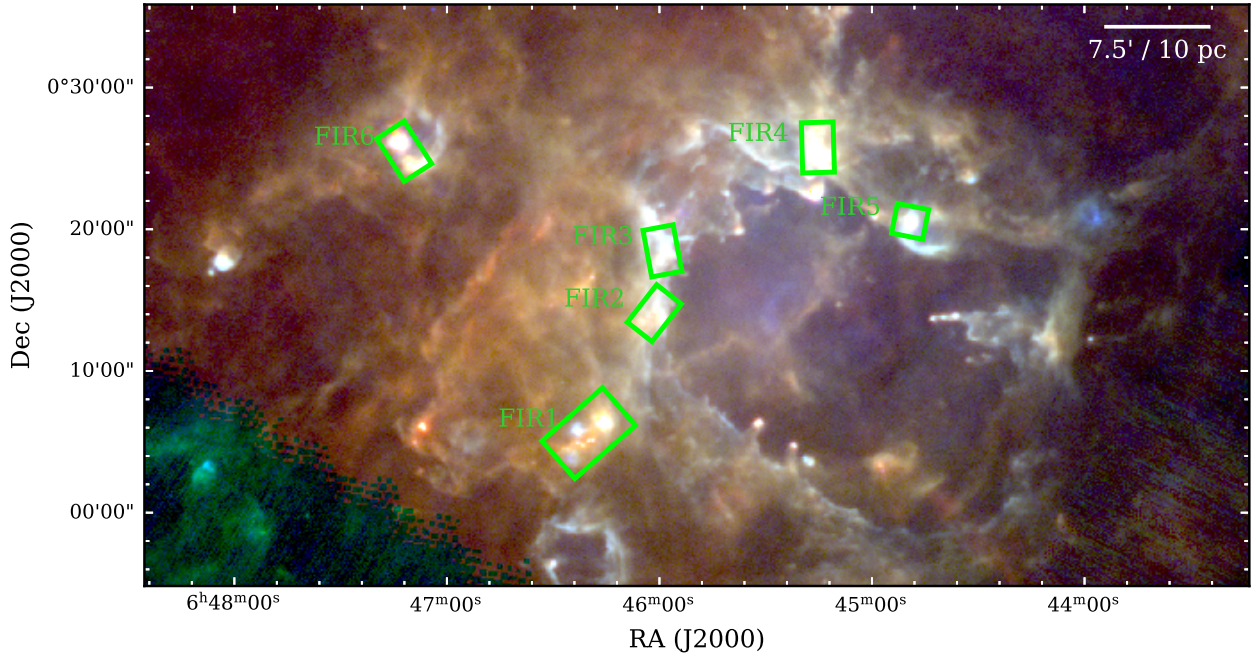


Figure 1. Color composite image of the Sh2-284 region constructed from Herschel 70 μm (blue), 160 μm (green), and 500 μm (red) images. The green rectangles show the ALMA mosaic fields.

Table 1
Properties of the Observed Regions in Sh2-284

Region	R.A. (J2000)	Decl. (J2000)	Size (arcmin $\times$ arcmin)	N_{H_2} (10^{21} cm^{-2})	T_{dust} (K)	Beam (arcsec $\times$ arcsec)	Sensitivity (mJy beam $^{-1}$)	N_{core}	$M_{\text{core,med}}$ $M_{\odot}$
FIR1	06:46:20.19	+00:05:33.4	3.5×5.7	6.1 (22.6)	16.4 (22.0)	0.64×0.54	0.11	22/21	2.1/2.9
FIR2	06:46:01.66	+00:14:01.6	2.2×3.4	6.9 (12.9)	17.8 (18.8)	0.69×0.57	0.13	1/1	5.7/6.5
FIR3	06:45:59.37	+00:18:25.4	2.2×3.3	6.2 (8.4)	18.5 (19.8)	0.78×0.55	0.11	2/2	1.2/1.9
FIR4	06:45:15.47	+00:25:43.2	2.2×3.5	8.6 (19.1)	18.5 (20.1)	0.78×0.60	0.12	13/9	1.2/2.5
FIR5	06:44:49.44	+00:20:30.1	2.2×2.1	4.6 (11.1)	19.5 (21.8)	0.76×0.60	0.11	17/12	0.9/2.1
FIR6	06:47:12.29	+00:25:27.2	2.3×3.6	6.5 (35.9)	16.8 (26.8)	0.78×0.60	0.13	36/23	1.7/3.4

Note. The N_{H_2} and T_{dust} values are derived from the Herschel SED fits within each region footprint and are reported as the median, with the peak value within the region given in parentheses. N_{core} gives the number of cores in the full catalog and in the robust catalog, respectively. $M_{\text{core,med}}$ gives the corresponding median core masses for the two catalogs, estimated from the 1.3 mm fluxes as described in Section 3.2.

(I. Negueruela et al. 2015), providing a complementary low-metallicity laboratory in a less extreme environment than the strongly irradiated, starburst-like regions studied in the Large Magellanic Cloud, while being a factor of 10 closer. Building on the multi-wavelength LZ-STAR survey of the region (M. Andersen et al. 2026; Y. Cheng et al. 2025), our ALMA data probe dense cores on ~ 3000 au scales across multiple subregions, enabling a first dust-continuum-based CMF measurement in the low-metallicity outer Galaxy environment.

2. Observations

The six targeted regions (FIR1 to FIR6) in Sh2-284 are shown in Figure 1 and summarized in Table 1. They represent the most active star-forming sites in the region, as indicated by strong dust emission in the Herschel images and numerous young stars identified in infrared surveys (E. Puga et al. 2009). The ALMA band 6 observations were carried out in Cycle 8 for FIR1 (project ID: 2021.1.01706.S; PI: Y. Cheng; see Y. Cheng et al. 2025 for details), while the other regions were observed in Cycle 11 (project ID: 2024.1.01580.S; PI: Y. Cheng). The six regions cover areas ranging from

approximately 5 to 20 arcmin 2 . The observations used the 12 m array in the C43-3 configuration for FIR1 and in the C43-4/C43-1 configurations for the other regions, together with the 7 m array to recover scales up to $\sim 29''$. Total power observations were also obtained for the recovery of larger-scale line emission.

The spectral setup was the same for all regions and is described in Y. Cheng et al. (2025). In this paper, we use the continuum spectral window with a bandwidth of 1.875 GHz centered at 231.00 GHz. The raw data were calibrated with the ALMA data reduction pipeline using CASA 6.2.1. The continuum visibility data were constructed from line-free channels. We imaged the 12 and 7 m array data using the `tclean` task in CASA using Briggs weighting with a robust parameter of 0.5. The resulting angular resolution is approximately 0.6 – $0.8''$ across different fields, and the rms sensitivities range from 0.11 to 0.13 mJy beam $^{-1}$ (see Table 1).

In addition, we also derive large-scale dust temperature and column density maps from archival Herschel 70–500 μm images by fitting a single temperature modified blackbody model, as described in detail in Appendix A.

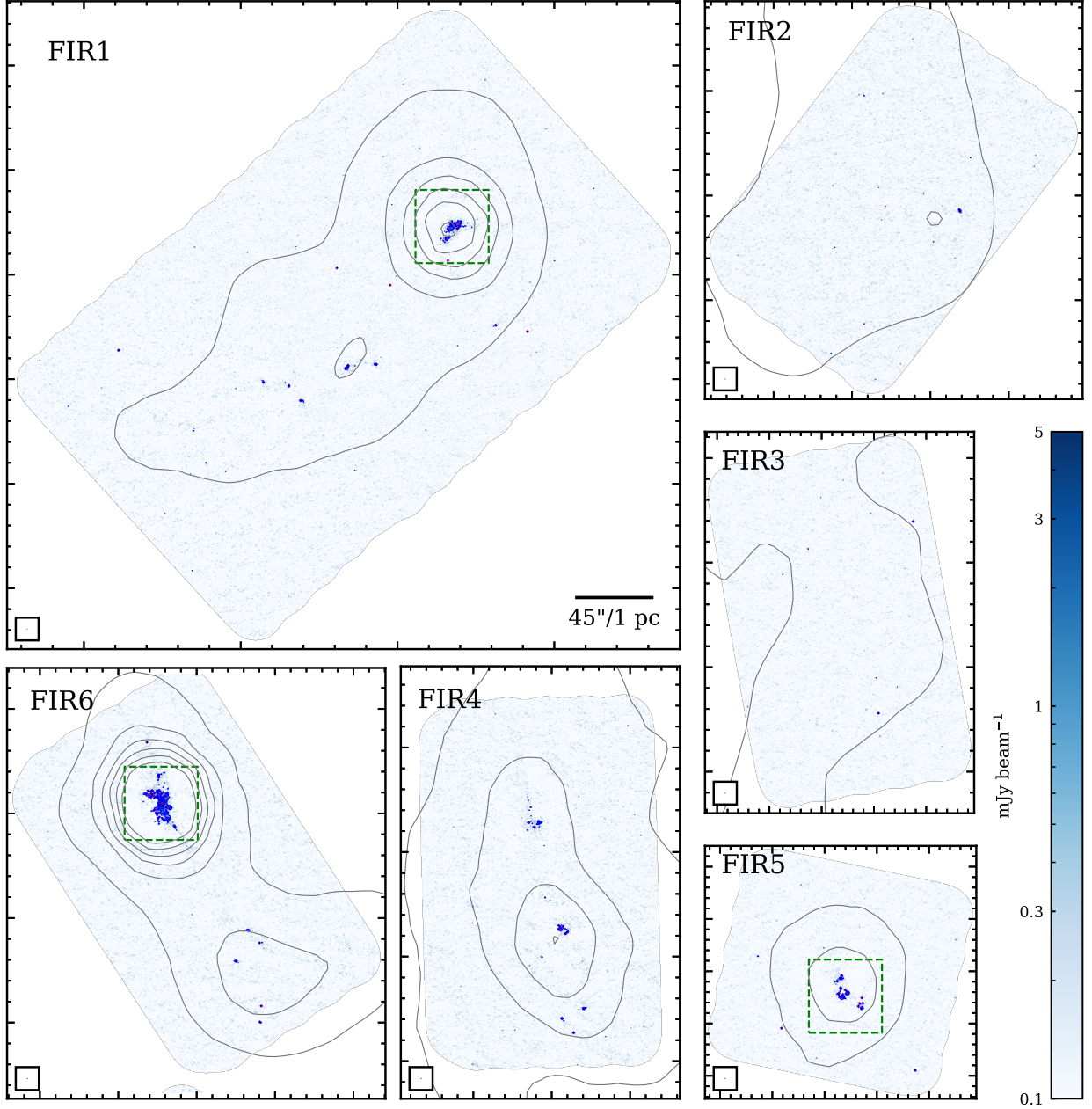


Figure 2. ALMA 1.3 mm continuum images of the six targeted regions in Sh2-284. The blue color scale and blue contours show the ALMA continuum emission, with contour levels of $(4, 8, 16, 32, 64) \times \sigma$, where σ is the rms sensitivity of each field listed in Table 1. Gray contours show the Herschel 500 μm emission at $(30, 60, 90, 120, 150, 180) \text{ MJy sr}^{-1}$, tracing the larger-scale cloud structure. The green dashed boxes indicate the regions shown in Figure 3. All panels are displayed with the same physical scale; the scale bar and color bar are shared by all panels.

3. Results

3.1. 1.3 mm Continuum

Figure 2 presents the 1.3 mm continuum images of the six regions, overlaid with Herschel 500 μm contours tracing the large-scale emission. The regions show very different levels of fragmentation on ~ 3000 au scales. Clustered groups of cores are seen in the northwestern part of FIR1, the northeastern part of FIR6, and FIR5, with ~ 10 – 20 cores within ~ 1 pc; these regions are generally associated with strong Herschel 500 μm emission and are shown in greater detail in Figure 3. In other regions, the cores are more sparsely distributed. In particular, FIR2 and FIR3, which have the weakest 500 μm emission in the sample, show almost no detected dense structures on

~ 3000 au scales. Overall, the number of dense cores appears to be closely linked to the parsec-scale cloud conditions.

3.2. Identification and Characterization of Cores

We use the *astrodendro* algorithm (E. W. Rosolowsky et al. 2008) to search for dense cores. This algorithm is designed for identifying hierarchical structures in continuum or line data, and we define the leaves, i.e., the base element in the dendrogram hierarchy without further substructures, as cores. We adopt a base flux density threshold of 4σ , a minimum significance of 1σ , and a minimum area of half the synthesized beam. The same parameter choices have been used in previous CMF studies (Y. Cheng et al. 2018;

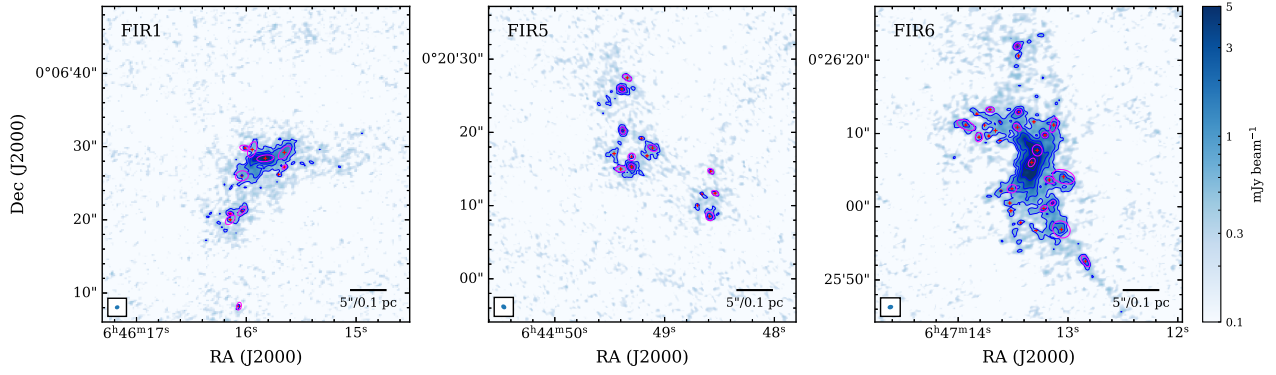


Figure 3. Zoom-in views of the ALMA 1.3 mm continuum emission toward the clustered regions in FIR1, FIR5, and FIR6. The blue color scale and blue contours show the continuum emission, with contour levels the same as in Figure 2. Red crosses mark the cores identified in the full dendrogram catalog, while magenta ellipses show the Gaussian components for cores retained in the robust dendrogram+Gaussian catalog. The synthesized beam and scale bar are shown in the bottom-left and bottom-right corners of each panel, respectively.

M. Liu et al. 2018; T. J. O’Neill et al. 2021; A. V. I. Kinman et al. 2025). Cores are identified on the maps before primary beam correction, while their flux densities are measured on the corrected maps by summing over the pixels assigned to each leaf.

Astrodendro detects 91 cores with the adopted criteria. The identified cores are marked in Figures 2 and 3. The number of cores varies among the six regions, ranging from one in FIR2 to 36 in FIR6 (see Table 1). Visual inspection shows that some faint leaves returned by *astrodendro* have low contrast and may partly reflect local background fluctuations rather than compact cores. This is expected because *astrodendro* is a pixel-assignment-based algorithm and does not explicitly subtract large-scale or background emission; as a result, small 1σ – 2σ fluctuations on top of extended emission above the 4σ threshold can satisfy the adopted criteria. We therefore retain this initial list as a full catalog of potential cores, and further define a robust catalog using two-dimensional Gaussian fitting. For each leaf, we fit a 2D Gaussian together with a constant background level as a free parameter, and include only sources with fitted Gaussian amplitudes exceeding 5σ in the robust catalog. This selection yields 68 robust cores, with those in the clustered regions marked in Figure 3.

We estimate core gas masses assuming optically thin, isothermal dust emission:

$$M_{\text{gas}} = R_{\text{gd}} \frac{d^2 F_{\nu}}{\kappa_{\nu} B_{\nu}(T_d)}, \quad (1)$$

where d is the distance of 4.5 kpc, R_{gd} is the gas-to-dust mass ratio, F_{ν} is the observed flux density, $B_{\nu}(T_d)$ is the Planck function at dust temperature T_d , and κ_{ν} is the dust opacity at the observed frequency. We assume a uniform dust temperature of 20 K and adopt $\kappa_{1.3\text{mm}} = 0.899 \text{ cm}^2 \text{ g}^{-1}$, corresponding to the moderately coagulated thin ice mantle dust model of V. Ossenkopf & T. Henning (1994). We adopt $R_{\text{gd}} = 282$, obtained by scaling the local Galactic gas-to-dust mass ratio of 141 (B. T. Draine 2011) by the inverse of the assumed half-solar metallicity. The resulting core masses range from 0.37 to $90 M_{\odot}$ for the full catalog, based on the dendrogram-assigned flux densities, and from 1.0 to $57 M_{\odot}$ for the robust catalog, based on the Gaussian-fit fluxes. A full catalog of the core properties is listed in Appendix B.

3.3. CMF

We construct the CMFs for both the full and robust catalogs in Figure 4. We consider two corrections that may influence the measured CMFs. First, the detection completeness (or number recovery fraction, f_{num}) depends on core fluxes, and therefore directly affects the number distribution in each mass bin. Second, the dendrogram flux measurement can be affected by two competing effects. Because the flux is summed only over pixels assigned to each leaf, low-intensity source emission outside the isophotal leaf boundary is not included. On the other hand, because no background emission is subtracted, extended large-scale emission within the leaf aperture may increase the measured flux. We thus define f_{flux} as an empirical flux correction factor that accounts for the net bias introduced by the dendrogram extraction procedure.

To derive the correction factors, we perform artificial core injection experiments, as described in detail in Appendix C. Briefly, we generate artificial cores with a range of flux densities or masses, assigning realistic sizes and shapes empirically determined from the observed core population. The artificial core positions are drawn from a two-dimensional kernel density estimate (KDE) constructed from the observed core positions in each field, so that the injections follow the spatial distribution of observed cores. For each flux density, we inject five artificial cores per region in each realization and repeat the experiment 1000 times. We then run the same core identification and flux measurement procedures used for the real data to determine both the number recovery fraction, f_{num} , and the flux recovery fraction, f_{flux} . We treat the full dendrogram catalog and the robust dendrogram+Gaussian catalog as two separate catalog construction methods. The latter applies an additional local contrast criterion and measures fluxes from Gaussian fits rather than dendrogram-assigned pixels. The resulting correction factors for the two methods are discussed in Appendix C. Overall, the f_{flux} curve for the dendrogram+Gaussian method remains close to unity, indicating more stable flux recovery. We therefore apply the flux correction only to the pure dendrogram catalog, while the robust catalog is corrected only for number recovery.

As an initial characterization, we fit the high-mass end ($M > 2.5 M_{\odot}$) of the raw CMF with a power-law function,

$$\frac{dN}{d \log M} \propto M^{-\alpha}, \quad (2)$$

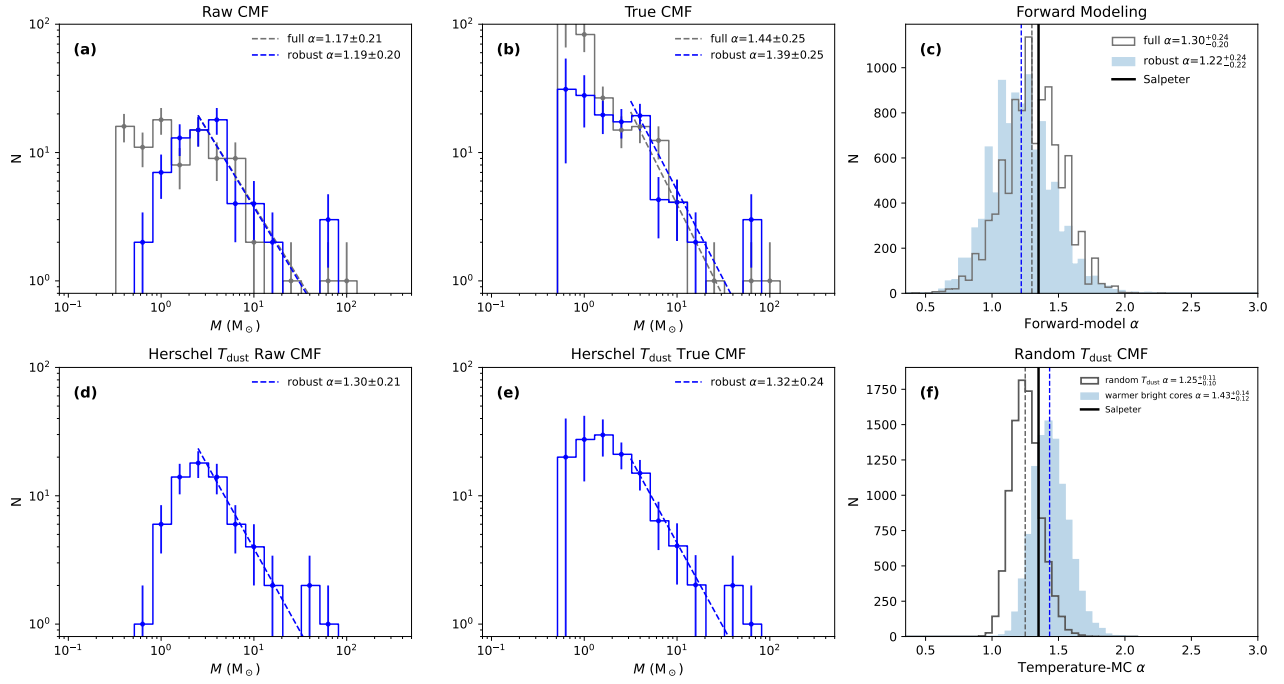


Figure 4. CMFs of Sh2-284. (a) Raw CMFs derived from the full dendrogram catalog and the robust dendrogram+Gaussian catalog, assuming a uniform dust temperature of 20 K. Dashed lines show the MLE power-law fits above $M > 2.5 M_\odot$. (b) Recovery-corrected true CMFs; for the full catalog, both flux and number corrections are applied, while for the robust catalog only the number correction is applied. Dashed lines show the binned MLE power-law fits above $M > 2.5 M_\odot$. With the adopted logarithmic binning, the first included bin has a lower edge of $3.162 M_\odot$. (c) Forward-modeling distributions of the intrinsic CMF slope for the two catalogs; the vertical solid line marks the Salpeter value, $\alpha = 1.35$. (d) Raw CMF for the robust catalog after assigning each core the local Herschel-derived dust temperature. The dashed line shows the MLE power-law fit for $M > 2.5 M_\odot$. (e) Number-corrected CMF for the same temperature assignment. The dashed line shows the binned MLE power-law fits for $M > 2.5 M_\odot$. (f) Monte Carlo temperature test in which core temperatures are randomly varied around the local Herschel values, with an additional warmer bright core case to test unresolved internal heating (see Section 3.4 for details). The vertical line marks the Salpeter slope.

Table 2
CMF Slope Measurements for Different Lower Fitting Limits and Core Temperature Treatments

Catalog	Core Temperature	Fitting Method	$M_{\min}$ ($M_\odot$)	N_{fit}^b	α
Full catalog, raw	Fixed 20 K	MLE	2.0, fixed	38	1.15 ± 0.19
			2.5, fixed	30	1.17 ± 0.21
			3.0, fixed	24	1.18 ± 0.24
			2.11, KS selected ^a	38	1.22 ± 0.20
Robust catalog, raw	Fixed 20 K	MLE	2.0, fixed	46	1.13 ± 0.17
			2.5, fixed	37	1.19 ± 0.20
			3.0, fixed	33	1.34 ± 0.23
			2.36, KS selected ^a	43	1.29 ± 0.20
Full catalog, flux and number corrected	Fixed 20 K	Binned MLE	1.995, fixed	47 [50.44]	1.14 ± 0.16
			3.162, fixed	34 [35.47]	1.44 ± 0.25
			3.162, KS selected ^a	34 [35.47]	1.44 ± 0.25
Robust catalog, number corrected	Fixed 20 K	Binned MLE	1.995, fixed	46 [50.13]	1.18 ± 0.17
			3.162, fixed	31 [32.78]	1.39 ± 0.25
			1.995, KS selected ^a	46 [50.13]	1.18 ± 0.17
Robust catalog, raw	Herschel T_{dust}	MLE	2.0, fixed	47	1.16 ± 0.17
			2.5, fixed	40	1.30 ± 0.21
			3.0, fixed	30	1.21 ± 0.22
			2.44, KS selected ^a	42	1.32 ± 0.20
Robust catalog, number corrected	Herschel T_{dust}	Binned MLE	1.995, fixed	47 [51.51]	1.24 ± 0.17
			3.162, fixed	29 [30.47]	1.32 ± 0.24
			1.995, KS selected ^a	47 [51.51]	1.24 ± 0.17

Notes.

^a The KS-selected lower limit is chosen by minimizing the KS distance between the observed cumulative mass distribution and the fitted power-law model after restricting candidate lower limits for mass bins with completeness above 80%. For the binned MLE, the data are represented by counts in fixed 0.2 dex logarithmic mass bins. Consequently, the fitted lower limit is necessarily the lower edge of the first included bin (e.g., 1.995, 3.162, or $5.012 M_\odot$), rather than an arbitrary intra-bin mass value.

^b Bracketed values of N_{fit} are recovery-weighted effective counts.

using the maximum likelihood estimation (MLE) method of A. Clauset et al. (2009), as implemented in the `plfit` package. This threshold of $2.5 M_{\odot}$ corresponds to a typical injected peak significance of $\sim 10\sigma$ for the empirical core size distribution adopted in the insertion experiments, and to $\gtrsim 80\%$ detection completeness (see Appendix C), providing a good compromise between rejecting false detections and retaining sufficient statistics for the fit. This gives slopes of $\alpha = 1.17 \pm 0.21$ and $\alpha = 1.19 \pm 0.20$ for the two catalogs, shown in Figure 4(a) and Table 2.

We also test the sensitivity of the inferred slope to different fitting limits. For the raw CMFs, we repeat the MLE fits using fixed values of $M_{\min} = 2.0, 2.5$, and $3.0 M_{\odot}$. We also estimate $M_{\min}$ by minimizing the Kolmogorov–Smirnov (KS) distance between the observed cumulative mass distribution and the fitted power-law model. Candidate lower limits are considered only within the mass range where the number completeness exceeds 80%. The KS-selected lower limits are 2.11 and $2.36 M_{\odot}$ for the full and robust catalogs, respectively. As summarized in Table 2, the fitted slopes remain consistent within their uncertainties for all tested lower limits. We retain $M_{\min} = 2.5 M_{\odot}$ as a common fiducial threshold in the following analysis, while the results obtained with alternative fixed and KS-selected lower limits are summarized in Table 2.

We then correct the measured masses of the catalog using the corresponding f_{flux} values (for the full catalog), and then correct the number counts in each mass bin using f_{num} (for both catalogs) to get the “true” CMF. Because the number-corrected CMF is defined only through binned counts, the standard unbinned MLE cannot be applied directly. We therefore use the binned MLE of Y. Virkar & A. Clauset (2014) to fit the number-corrected CMF. For consistency with the fiducial raw-CMF threshold, we include only bins lying entirely above $2.5 M_{\odot}$. With the adopted 0.2 dex logarithmic binning, the first such bin has a lower edge of $3.162 M_{\odot}$. The resulting slopes are $\alpha = 1.44 \pm 0.25$ and $\alpha = 1.39 \pm 0.25$ for the full and robust catalogs, respectively. We also repeat the binned fits using alternative lower bin edges and select the preferred $M_{\min}$ through KS minimization. Since the data are binned, $M_{\min}$ is restricted to the adopted bin edges. As summarized in Table 2, the resulting slopes remain consistent within their uncertainties, although the fits beginning at $3.162 M_{\odot}$ yield slightly steeper values.

Although the binned MLE provides a likelihood-based treatment of binned power-law distributions, it cannot recover the information lost during the binning process, where individual core masses are replaced by counts within finite mass intervals. We therefore further adopt a forward-modeling approach to constrain the intrinsic CMF slope. The idea is to ask what the observed cumulative mass distribution would look like if the underlying CMF were a power law, after accounting for the fact that cores of different masses are recovered with different probabilities and, for the dendrogram-only method, with different flux recovery fractions. For each trial slope α from 0 to 2 in steps of 0.01, where $dN/d \log M \propto M^{-\alpha}$, we represent the intrinsic CMF on a fine logarithmic mass grid over $2.5 \leq M/M_{\odot} \leq 100$. Each grid point represents a small logarithmic mass interval and is assigned a relative expected number of cores proportional to $M^{-\alpha}$. This model number at each mass is then multiplied by the number recovery fraction, $f_{\text{num}}(M)$, because only this fraction of cores with that true mass would be detected in the artificial core experiments. Thus, the weights on the mass grid

represent the expected observed number distribution for a given input slope. For the dendrogram-only method, we also account for flux loss by mapping each true mass on the grid to the corresponding measured mass, $M_{\text{obs}} = M \cdot f_{\text{flux}}(M)$; for the dendrogram+Gaussian method, the masses are left unchanged, and only the number recovery is applied. The resulting model points, now described by an observed mass and an expected observed number weight, are sorted by observed mass and cumulatively summed to form the model cumulative distribution function. This procedure is applied separately to each field using its own recovery curves, and the field-specific cumulative distributions are then combined, weighted by the number of observed cores in the fitted mass range.

We then compare this model cumulative distribution with the cumulative distribution of the observed core masses using a KS statistic. The KS statistic measures the maximum vertical separation between the observed cumulative mass distribution and the model prediction for a given input slope. The best-fit slope is the trial value that minimizes this separation. To estimate the uncertainty, we bootstrap the observed cores within each field, repeat the KS comparison for each bootstrap realization, and record the best-fit slope. The resulting distribution of best-fit slopes is shown in Figure 4(c). We report the slope as $1.30^{+0.24}_{-0.20}$ and $1.22^{+0.24}_{-0.22}$ for the two catalogs, using the median and 68% central interval.

3.4. Robustness of the CMF

The derived CMF depends on the assumptions made when converting 1.3 mm flux density into core mass. For the gas-to-dust ratio, we adopt $R_{\text{gd}} = 282$, obtained by scaling the Galactic reference value of 141 (B. T. Draine 2011) by the inverse of the assumed half-solar metallicity. Since the metallicity of Sh2-284 has been estimated to be $\sim 1/3-1/2 Z_{\odot}$ (I. Negueruela et al. 2015), adopting the lower end of this range would increase all core masses by a factor of 1.5. This would shift the CMF horizontally but does not affect the measured high-mass slope.

Overall, Sh2-284 appears to be dominated by relatively low-to-intermediate-mass star formation. Even within the targeted fields, the Herschel-derived column densities typically lie in the range of $N_{\text{H}_2} \sim 10^{21}-10^{22} \text{ cm}^{-2}$ (see Appendix A), comparable to nearby low-mass clouds such as Taurus (P. André et al. 2010). Only one or two localized structures, most notably the dense clump in FIR6, reach column densities exceeding 10^{23} cm^{-2} , where conditions may be more favorable for forming higher-mass stars; FIR1 is another region where high-mass stars may be forming (Y. Cheng et al. 2025). Therefore, we do not expect free-free emission to affect the CMF at the population level.

We also test the effect of temperature variations using the Herschel-derived dust temperature map (Figure 4(d), (e)). For the robust catalog, we assign each core the dust temperature at its position and rederive the CMF. Across the six regions studied here, the dust temperature of cores ranges from 15.0 to 25.2 K with a median of 20.8 K. Because the source detection and completeness depend on flux density rather than mass, the number recovery correction is applied as a function of the observed core flux. Adopting a lower mass threshold of $M_{\min} = 2.5 M_{\odot}$, we apply the unbinned MLE to the individual core masses above this limit for the raw Herschel-temperature CMF. For the number-corrected CMF that is defined using binned counts, we apply the binned MLE beginning at the first

logarithmic bin lying above $2.5 M_{\odot}$, corresponding to a lower bin edge of $3.162 M_{\odot}$. The resulting raw and number-corrected slopes are $\alpha = 1.30 \pm 0.21$ and $\alpha = 1.32 \pm 0.24$, respectively. Results obtained using alternative fixed and KS-selected lower-mass limits are also listed in Table 2. These slopes are consistent with the fiducial result derived assuming a uniform temperature.

Since the Herschel-derived temperatures are measured at much coarser resolution than the ALMA cores and may not capture local heating by embedded protostars, we further test the impact of uncertain core temperatures with a Monte Carlo resampling experiment. For each realization, we assign each robust core a random dust temperature drawn uniformly from $T_{\text{Herschel}} - 5$ K to $+15$ K, convert the observed 1.3 mm fluxes to core masses, apply the same flux-dependent number recovery correction, and repeat the binned MLE fit starting from the first mass bin with mean completeness above 80%. This yields a distribution of α , with $\alpha = 1.25^{+0.11}_{-0.10}$ determined from the median and the central 68% interval. As a more extreme test for unresolved internal heating, we repeat the same experiment but assign the brightest cores, defined as those with $M_{T_{\text{Herschel}}} > 10 M_{\odot}$, warmer temperatures drawn uniformly from 30 to 70 K. This warmer bright core case gives $\alpha = 1.43^{+0.14}_{-0.12}$. Both distributions are shown in Figure 4(f). Thus, plausible core-to-core temperature variations shift the inferred slope slightly but remain consistent with a Salpeter-like high-mass CMF.

4. Discussion

The measured high-mass CMF slope in Sh2-284, $\alpha = 1.22^{+0.24}_{-0.22}$, is statistically consistent with the Salpeter slope of $\alpha = 1.35$ (E. E. Salpeter 1955). A comparison with CMFs measured using a uniform analysis framework across different Galactic environments is presented in Section Appendix D. In the context of a possible CMF-IMF connection, it is useful to compare this result with IMF measurements in other low-metallicity environments. Previous near-infrared studies of low-metallicity clusters in the outer Galaxy reached stellar masses of order $\sim 0.1\text{--}0.2 M_{\odot}$ and favored canonical Galactic IMFs based on fitting the K -band luminosity functions (C. Yasui et al. 2008, 2016a, 2016b, 2021). In the Magellanic Clouds, several studies of young clusters and associations have also found high- or intermediate-mass stellar mass functions consistent with canonical forms for $M \gtrsim 1 M_{\odot}$ (e.g., M. Schmalzl et al. 2008; M. Andersen et al. 2009; N. Da Rio et al. 2009, 2012; Q. Liu et al. 2009; R. E. Cohen et al. 2026). Within Sh2-284 itself, optical/near-infrared studies of Dolidze 25 have found stellar mass functions broadly consistent with a Salpeter/Kroupa form over the low- to intermediate-mass pre-main-sequence regime: A. J. Delgado et al. (2010) reported a Salpeter-like mass function over $\sim 1.3\text{--}3.5 M_{\odot}$, while M. G. Guarcello et al. (2021), using X-ray and infrared-selected members, found no significant deviation from a Salpeter slope over $\sim 0.8\text{--}2 M_{\odot}$. Therefore, the CMF slope found here is consistent with the available IMF constraints in Sh2-284. This resembles the empirical CMF-IMF correspondence observed in nearby Galactic clouds (e.g., F. Motte et al. 1998; J. Alves et al. 2007; V. Könyves et al. 2015), suggesting that the shape of the IMF at the high-mass end may already be imprinted in the dense core population in a metal-poor environment in the outer Galaxy.

This picture is not universal, however. A shallower slope or more top-heavy IMF has been reported in some moderately

metal-poor environments, including 30 Doradus, where the massive star IMF over $15\text{--}200 M_{\odot}$ is significantly shallower than the Salpeter value (F. R. N. Schneider et al. 2018); similar tendencies have also been suggested in Sh2-209 and NGC 796 (V. M. Kalari et al. 2018; C. Yasui et al. 2023). These results imply that the high-mass IMF is likely regulated by other environmental factors in addition to the metallicity. Interestingly, recent ALMA observations of 30Dor-10 find a Salpeter-like CMF at ~ 2000 au resolution over core masses of approximately $10\text{--}100 M_{\odot}$, despite the top-heavy massive star IMF inferred for the broader 30 Dor region (A. Traficante et al. 2026). This suggests that the observed CMF may not map directly onto the final IMF, with later core evolution and stellar mass assembly playing an important role. As discussed in Section 3.4, Sh2-284 samples a regime of relatively quiescent low- to intermediate-mass star formation in the low surface density regions, rather than the high-pressure, massive cluster environment represented by 30 Dor. Its Salpeter-like CMF therefore provides a useful low-metallicity comparison case in which the CMF-IMF resemblance appears closer to that seen in solar neighbor clouds. In more extreme environments, the core population may undergo more substantial evolution after the observed CMF stage, leading to a more complex mapping between the CMF and the final IMF (A. Traficante et al. 2026).

While both the CMF and IMF in Sh2-284 are Salpeter-like at the high-mass end, the JWST/NIRCam census of S284-EC 1 (FIR1 region in this work) suggests a lower IMF turnover mass of $m_c = 0.16 \pm 0.02 M_{\odot}$ than typically measured in local young clusters (M. Andersen et al. 2026). Similar low characteristic or turnover masses have also been reported in other metal-poor regions in the outer Galaxy and the Magellanic Clouds (C. Yasui et al. 2024; R. E. Cohen et al. 2026). These results may hint that metallicity-dependent effects, if present, may be more readily identified through the mass scale of the IMF than through its high-mass slope. One likely interpretation is that the high-mass slope reflects a broad combination of fragmentation, accretion, and dynamical evolution, whereas the turnover mass is tied to a characteristic fragmentation scale set by thermal balance, dust opacity, and radiative heating, where metallicity may play a larger role. Our ALMA data are not sensitive enough to probe the expected CMF turnover regime, so it is unclear whether the low stellar characteristic mass is already imprinted in the core population.

5. Summary

We have measured the CMF across six far-infrared (FIR) bright regions in Sh2-284 with ALMA 1.3 mm observations at ~ 3000 au resolution. The core population is highly nonuniform, with clustered groups in FIR1, FIR5, and FIR6 but little compact emission in FIR2 and FIR3. Using both a full dendrogram catalog (91 cores) and a robust dendrogram +Gaussian catalog (68 cores), and correcting for number completeness and flux recovery, we find Salpeter-like high-mass CMF slopes. Forward modeling gives $\alpha = 1.30^{+0.24}_{-0.20}$ and $\alpha = 1.22^{+0.24}_{-0.22}$ for the two catalogs, respectively, and tests with Herschel-based and Monte Carlo dust temperatures yield consistent slopes. Together with the available IMF constraints in Sh2-284, this suggests that the high-mass CMF-IMF resemblance seen in solar neighborhood clouds can also be present in a low-metallicity outer Galaxy environment. The next key step is to push the CMF measurement to lower

masses, where the connection to the possibly low stellar characteristic mass can be tested directly.

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Software: CASA (J. P. McMullin et al. 2007; CASA Team et al. 2022), APLpy (T. Robitaille & E. Bressert 2012), astropy (Astropy Collaboration et al. 2013, 2018, 2022).

Appendix A Herschel SED Fit

For the spectral energy distribution (SED) fits, we assume that the far-infrared emission in each pixel is described by a

single-component modified blackbody. Before performing the fitting, all Herschel images at 70, 160, 250, 350, and 500 μm were smoothed to the common angular resolution of the SPIRE 500 μm beam, $\sim 37''$, and regridded to the 500 μm pixel grid.

The flux density is given by

$$S_\nu = \Omega_m B_\nu(T_d)(1 - e^{-\tau_\nu}), \quad (\text{A1})$$

and the column density is

$$N_{\text{H}_2} = \frac{\tau_\nu M_g}{\kappa_\nu \mu_{\text{H}} M_d}, \quad (\text{A2})$$

where $B(T_d)$ is the Planck function at T_d , μ is the mean molecular weight per H_2 molecule of 2.8, and $\kappa = \kappa_{230}(\nu/230 \text{ GHz})^\beta$, Ω_m is the solid angle. We adopt $\kappa_{230} = 0.899 \text{ cm}^2 \text{ g}^{-1}$ as in V. Ossenkopf & T. Henning (1994) for the moderately coagulated thin ice mantle model. We fix $\beta = 1.8$. To account for the subsolar metallicity of Sh2-284, we adopt a gas-to-dust ratio $M_g/M_d = 282$, corresponding to $141/Z$ with $Z = 0.5$.

We performed pixel-by-pixel least squares fits to the 160/250/350/500 μm SEDs. The fits were weighted by the inverse variance of the Herschel uncertainty maps. The error maps were smoothed and regridded in the same way as the science images, converted to Jy per pixel on the common grid, and a median positive-error floor was applied in each band. We excluded the 70 μm data from the fitting, since the 70 μm emission can contain excess contribution from warmer dust heated by embedded protostars that is not well described by a single temperature component (D. Elia et al. 2017). Our tests also show that excluding 70 μm yields an improved fit in the target regions. Pixels were fitted when at least four bands had finite positive fluxes and uncertainties. The resulting column density and dust temperature maps have an angular resolution of $\sim 37''$, and are shown in Figure A1.

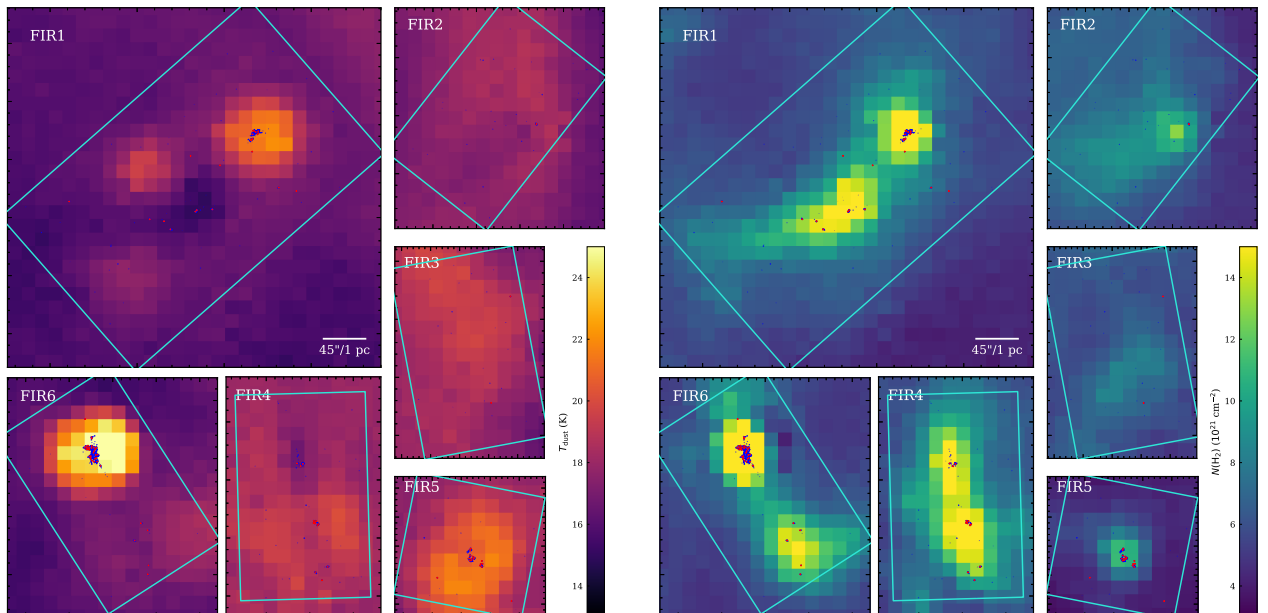


Figure A1. Dust temperature T_{dust} and column density N_{H_2} map from the SED fit for the six regions. The blue contours and red crosses show the ALMA cores.

Appendix B Core Catalog

In Table B1, we list the properties of the identified cores.

Table B1
Properties of the Identified Dense Cores in Sh2-284

Region	Core	R.A. (J2000)	Decl. (J2000)	$S_{\nu,\text{dendro}}$ (mJy)	$M_{\text{dendro},20\text{K}}$ ($M_{\odot}$)	Area (arcsec ²)	$S_{\nu,\text{gauss}}$ (mJy)	$M_{\text{gauss},20\text{K}}$ ($M_{\odot}$)	$I_{\nu,\text{gauss,peak}}$ (mJy beam ⁻¹)	FWHM _{maj} (arcsec)	FWHM _{min} (arcsec)	PA (deg)	T_{SED} (K)
FIR1	1	06:46:15.83	+00:06:28.4	54.90	68.25	6.16	42.70	53.08	6.97	2.35	0.90	84.1	21.5
FIR1	2	06:46:19.89	+00:05:07.6	5.70	7.09	1.44	4.70	5.84	3.71	0.72	0.60	29.0	15.0
FIR1	3	06:46:15.65	+00:06:29.2	4.60	5.72	1.00	8.80	10.94	1.29	2.20	1.07	40.9	21.7
FIR1	4	06:46:18.81	+00:05:08.4	3.70	4.60	1.44	3.50	4.35	2.02	0.86	0.70	100.1	15.3
FIR1	5	06:46:21.71	+00:04:47.8	2.50	3.11	1.12	2.80	3.48	1.54	0.90	0.70	88.0	15.6

Note. A full version of this table is available in machine-readable form. Core masses are calculated from the listed 1.3 mm fluxes assuming $T_{\text{dust}} = 20$ K, $D = 4.5$ kpc, $\kappa_{1.3\text{ mm}} = 0.899\text{ cm}^2\text{ g}^{-1}$, and metallicity $Z = 0.5 Z_{\odot}$. Fluxes and peak intensities are listed in mJy and mJy per beam, respectively. Gaussian-fit columns are reported only for robust cores with fitted Gaussian peak S/N > 5; other entries are marked with “...”. T_{SED} is sampled from the Herschel SED dust temperature map at the core position.

(This table is available in its entirety in machine-readable form in the [online article](#).)

Appendix C

Artificial Core Insertion Experiment

We use artificial core injection experiments to estimate both the flux recovery fraction, f_{flux} , and the number recovery fraction, f_{num} , for the CMF analysis. The injected masses are chosen to match the logarithmic mass bin centers used for the CMF construction. These masses are converted to injected 1.3 mm flux densities using the fiducial mass-flux conversion adopted in the main analysis in Section 3.2. As noted by A. V. I. Kinman et al. (2025), the assumed core size can significantly affect the detection rate, because it changes the peak signal-to-noise ratio (S/N) at fixed total flux. We therefore construct artificial sources whose morphologies and positions are tied empirically to the observed core population.

To characterize the observed core morphology, we use the Gaussian-fit results from the robust catalog, which provide more well-defined measurements of the source sizes, aspect ratios, and flux densities. We plot the observed core size ($\theta_{\text{FWHM}} = (\theta_{\text{maj}}\theta_{\text{min}})^{1/2}$) and aspect ratio ($A = \theta_{\text{maj}}/\theta_{\text{min}}$) against core masses in Figure C1. We fit the observed sizes with a linear relation in the $\log M$ – $\log \theta_{\text{FWHM}}$ plane, and obtain $\log_{10}(\theta_{\text{FWHM}} \text{ arcsec}^{-1}) = -0.135 + 0.150 \log_{10}(M/M_{\odot})$. The scatter about this relation is estimated from the standard deviation of the residuals in $\log_{10}\theta_{\text{FWHM}}$, giving $\sigma_{\log \theta} = 0.097$ dex. For each inserted core, we draw $\log \theta_{\text{FWHM}}$ from this relation with a Gaussian scatter of 0.097 dex, truncated at $\pm 3\sigma$; the trend is held fixed above $10 M_{\odot}$ to avoid extrapolating beyond the sparsely sampled high-mass end.

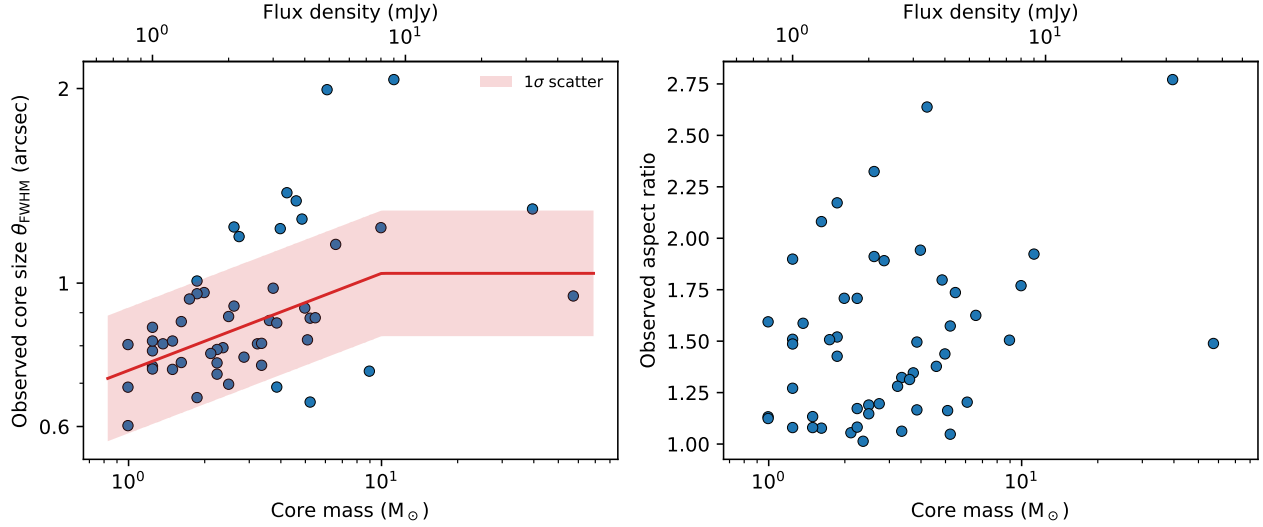


Figure C1. Observed core sizes and aspect ratios as a function of core mass. The left panel shows the observed core size, defined as the geometric mean FWHM, $\theta_{\text{FWHM}} = (\theta_{\text{maj}}\theta_{\text{min}})^{1/2}$, without deconvolving the ALMA synthesized beam. The red curve shows the empirical size model adopted for the core insertion experiments, obtained from a robust linear regression: $\log_{10}(\theta_{\text{FWHM}} \text{ arcsec}^{-1}) = -0.135 + 0.150 \log_{10}(M/M_{\odot})$. The shaded region shows the 1σ scatter, estimated as the standard deviation of the residuals in $\log_{10}\theta_{\text{FWHM}}$ around this relation. The trend is held fixed above $10 M_{\odot}$ since only a few cores are available. The right panel shows the observed aspect ratio, $\theta_{\text{maj}}/\theta_{\text{min}}$. The upper axis gives the corresponding 1.3 mm flux density.

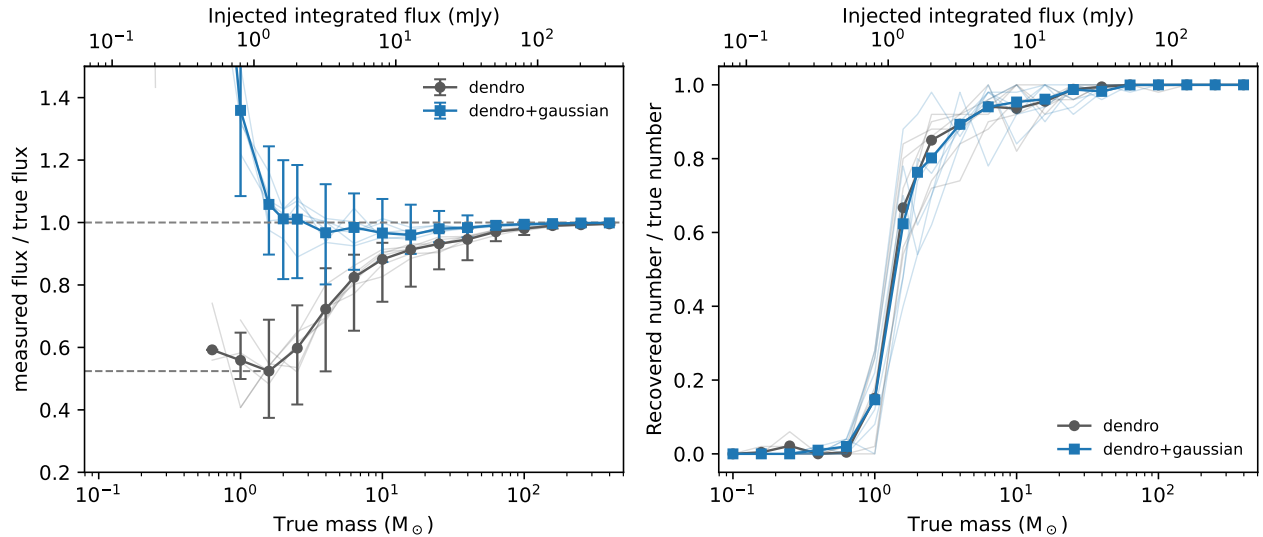


Figure C2. Recovery curves from the artificial core injection experiments. Left: flux recovery fraction, $f_{\text{flux}} = F_{\text{meas}}/F_{\text{true}}$, as a function of injected true mass, with the corresponding injected 1.3 mm flux density shown on the top axis. Right: number recovery fraction, $f_{\text{num}} = N_{\text{rec}}/N_{\text{inj}}$. Gray curves show the result for the dendrogram-only method, while blue curves show the dendrogram+Gaussian method. Thin curves show the results for individual ALMA fields, and the thick curves with points show the combined recovery functions weighted by core numbers.

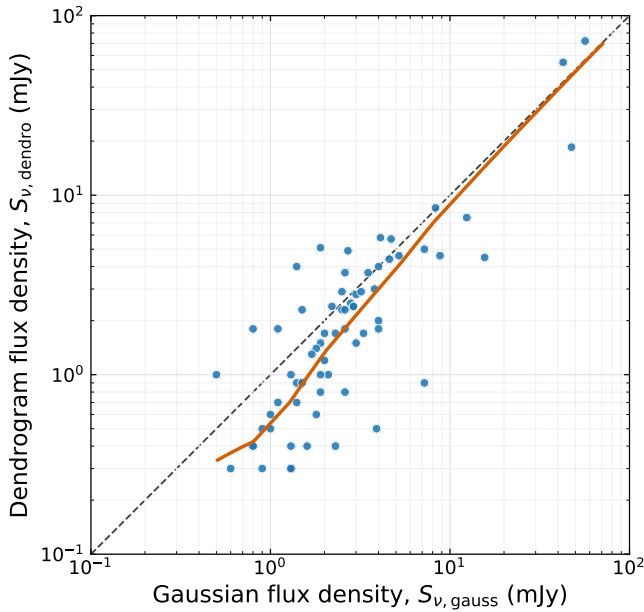


Figure C3. Comparison between the dendrogram-integrated and Gaussian-fit fluxes for the observed cores. The dashed line marks the one-to-one relation. Colored curves show the expected relation $S_{v,dendro} = f_{flux} S_{v,gauss}$ by treating the Gaussian-fit flux as the reference source flux and applying the corresponding flux recovery function derived from the artificial core experiments.

The inserted size is also required to be no smaller than the synthesized beam in the corresponding ALMA field. The aspect ratio is drawn independently from a smoothed empirical distribution of the observed Gaussian aspect ratios.

The injection positions are also chosen empirically. For each ALMA field, we construct a two-dimensional KDE from the observed core positions, using a smoothing scale of $30''$. Artificial core positions are drawn from this KDE, so that the injections approximately follow the observed spatial distribution of dense cores and sample similar background and crowding conditions. For each flux density, we inject five artificial cores per field in each realization and repeat the experiment 1000 times.

After each injection, we rerun the same core identification and flux measurement procedures used for the real data. An injected source is considered recovered if the peak pixel of a detected dendrogram leaf lies within 2 pixels of the injected position. In the pure dendrogram method, fluxes are measured by summing over the dendrogram-assigned pixels. In the dendrogram+Gaussian method, each dendrogram leaf is additionally fit with a Gaussian plus a constant background and is retained only if the fitted Gaussian component has a peak intensity greater than 5σ ; the fluxes are then measured from the fitted Gaussian models. For each injected flux or mass, we compute $f_{num} = N_{rec}/N_{inj}$ and $f_{flux} = F_{meas}/F_{true}$, where f_{flux} is evaluated only for detected sources. The resulting recovery curves are shown in Figure C2. Thin curves show the recovery functions measured separately for individual fields, while the thick curves show the core-number-weighted average over all fields. For the CMF correction, however, we treat each field independently and apply the recovery fractions appropriate for that field before combining the corrected core counts.

For the number recovery, both algorithms show similar trends. The pure dendrogram method has a higher f_{num} at

$M \sim 1-5 M_{\odot}$, as expected because the dendrogram+Gaussian catalog imposes an additional Gaussian peak S/N criterion. Note that the completeness derived here applies to the operationally defined population of compact cores satisfying our intensity, contrast, and area criteria. It quantifies the recovery of this population against observational effects such as finite sensitivity, noise, structured backgrounds, and source blending. Relatively diffuse or extended cores that do not satisfy the adopted criteria may remain undetected and are not represented by f_{num} . Assessing such a potentially distinct population would require synthetic observations of numerical simulations (e.g., C.-J. Hsu et al. 2023), and is beyond the scope of this work.

The dendrogram+Gaussian method gives f_{flux} values close to unity over most of the fitted mass range, indicating stable flux recovery. In contrast, the pure dendrogram method tends to underestimate the integrated flux at low masses because of its isophotal pixel assignment. We therefore apply the flux recovery correction only to the pure dendrogram catalog, while both catalogs are corrected for number completeness using their corresponding f_{num} curves.

Figure C3 compares the dendrogram-integrated and Gaussian-fit fluxes for the observed cores. Although there is substantial source-to-source scatter, most robust cores lie below the one-to-one relation, suggesting that exclusion of low-intensity source emission outside the leaf boundaries tends to dominate over the additional background included within the apertures. This may partly reflect that most cores are not located on strongly elevated backgrounds. The curve shows the expected dendrogram fluxes obtained by treating the Gaussian-fit fluxes as estimates of the intrinsic core fluxes and multiplying them by the field-dependent f_{flux} functions derived from the artificial core experiments. Their broad agreement with the observed distribution indicates that the insertion experiments capture the average flux bias of the dendrogram measurements. The remaining scatter likely reflects differences in core morphology, background structure, blending, and departures from the adopted Gaussian-plus-constant model. Thus, f_{flux} should be interpreted as a first-order, population-averaged correction for the net dendrogram flux bias, rather than an exact source-by-source correction.

The f_{flux} curves drop to around 0.5 at $M \sim 1-2 M_{\odot}$, but show an apparent upturn toward lower masses. This behavior reflects a selection effect near the detection limit. Around $1 M_{\odot}$, the peak S/N is close to 5, comparable to the detection thresholds of both algorithms. Lower-mass injected cores therefore can be detected only in favorable cases, such as when they lie on top of a bright background. For the dendrogram method, the measured flux can then include a contribution from this background, artificially increasing the flux recovery fraction. This effect is less severe for the dendrogram+Gaussian method because the fit includes a local background term, although in some cases the Gaussian component may still absorb part of the structured hierarchical background emission. For the flux recovery correction, we therefore hold f_{flux} fixed at its minimum value toward lower masses, avoiding a nonmonotonic mapping between observed flux and true mass. This treatment only affects masses below the adopted fitting threshold, the vast majority of which will not enter the high-mass CMF fit.

Appendix D

Comparison of CMFs in Different Galactic Environments

A sequence of ALMA studies has measured CMFs across a broad range of Galactic star-forming environments using a largely uniform analysis framework (Y. Cheng et al. 2018; M. Liu et al. 2018; T. J. O’Neill et al. 2021; A. V. I. Kinman et al. 2025). Paper I studied the massive protocluster G286.21 +0.17 (Y. Cheng et al. 2018); Paper II analyzed 30 clumps in seven infrared dark clouds (IRDCs; M. Liu et al. 2018); Paper III examined 28 high-mass surface density protocluster clumps observed by ALMAGAL (T. J. O’Neill et al. 2021); and Paper IV extended the sample to the Galactic center clouds: the Brick, Sgr C, and Sgr B2-DS (A. V. I. Kinman et al. 2025). These studies use the same basic analysis framework: cores are identified as *astrodendro* leaves using a minimum intensity of 4σ , a minimum significance of 1σ , and a minimum area of half the synthesized beam; core masses are derived from millimeter continuum emission using a fiducial dust temperature of 20 K; and flux and number recovery are quantified through artificial core insertion experiments. Paper IV further updated the insertion procedure to account for realistic, mass-dependent core sizes and applied this revised correction framework to the earlier samples. Our Sh2-284

analysis adopts the same dendrogram criteria and an analogous recovery analysis, although the gas-to-dust ratio is adjusted for its lower metallicity. This series therefore enables a more controlled comparison between environments.

Figure D1 compares Sh2-284 with the regions studied in this series (see also the summary in A. V. I. Kinman et al. 2025). For Sh2-284, we use the full catalog, which most closely matches the catalog construction method used for the comparison samples. All CMFs are constructed using the same 0.2 dex mass bins on an aligned logarithmic grid. We show both the raw CMFs and the true CMFs, in which the core masses have been corrected for flux recovery, and the binned counts have been corrected for number recovery. To avoid mixing slopes obtained using different fitting methods and mass ranges, we refit the raw CMFs with the MLE method and the true CMFs with the binned MLE method of Y. Virkar & A. Clauset (2014), all starting from $2 M_{\odot}$. The reported slopes can therefore differ slightly from those quoted in the original papers. Note that the fit range is different from the fiducial Sh2-284 analysis in Section 3.3, which applies a threshold of $M > 2.5 M_{\odot}$ to the individual masses or uses only complete bins above this threshold. The Sh2-284 slope reported in Figure D1 should thus be regarded as the value obtained specifically for this homogeneous comparison.

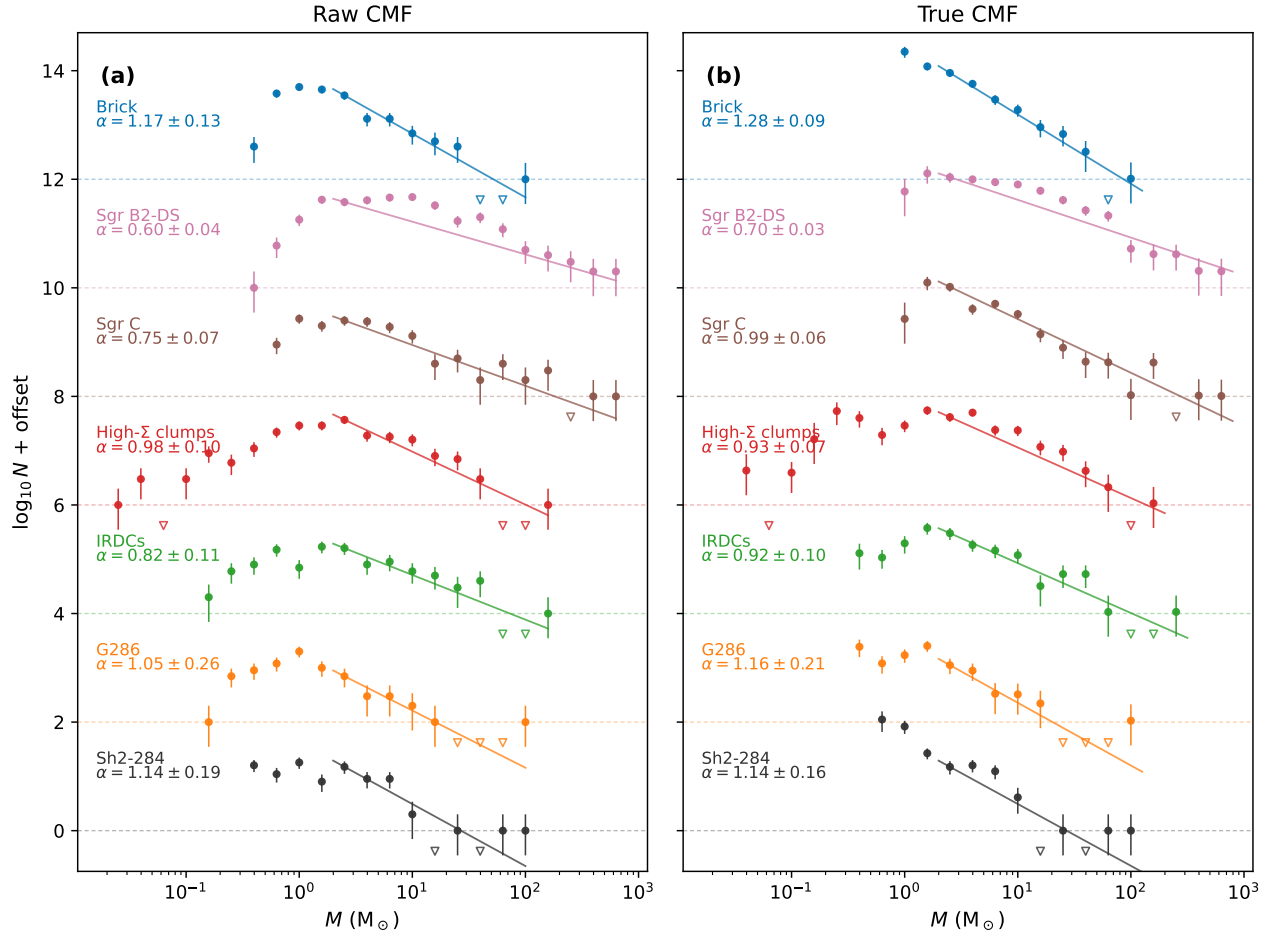


Figure D1. Comparison of the CMFs in Sh2-284 and the Galactic environments studied by Y. Cheng et al. (2018), M. Liu et al. (2018), T. J. O’Neill et al. (2021), and A. V. I. Kinman et al. (2025). Panel (a) shows the raw CMFs, while panel (b) shows the true CMFs, in which masses are corrected for flux recovery and the binned counts are corrected for number recovery. Dashed horizontal lines mark the level corresponding to one core per bin for each offset sequence, and open downward triangles mark zero-count bins. Solid lines show power-law fits obtained uniformly with the MLE method for panel (a) and the binned MLE method for panel (b), both starting from the bin centered at $2.51 M_{\odot}$ with a lower edge of $1.995 M_{\odot}$.

The true CMF slopes span a broad range, from $\alpha = 0.70 \pm 0.03$ in Sgr B2-DS to $\alpha = 1.28 \pm 0.09$ in the Brick. The Brick has the steepest, approximately Salpeter-like CMF, while Sgr B2-DS has a much shallower distribution. Sgr C, the IRDCs, and the high- Σ protocluster clumps occupy intermediate or relatively shallow ranges. Sh2-284, with $\alpha = 1.14 \pm 0.16$ under the common fitting prescription, lies close to G286 ($\alpha = 1.16 \pm 0.21$) and toward the steeper side of the overall distribution. Thus, even when similar identification, correction, binning, and fitting procedures are adopted, the CMFs do not converge to a single universal high-mass slope.

A. V. I. Kinman et al. (2025) suggested that the diversity of CMF slopes may reflect both environmental conditions and evolution. Regions with higher core mass surface densities may preferentially develop shallower CMFs, while continued accretion onto massive cores could flatten the CMF as star formation proceeds. However, the full sample does not follow a simple evolutionary sequence. Systematic temperature variations and differences in angular resolution, spatial filtering, and the mixture of prestellar and protostellar cores remain important caveats.

Within these limitations, the location of Sh2-284 toward the steeper part of the distribution is qualitatively consistent with its relatively low density and less extreme star-forming environment. In particular, it indicates that moderately low metallicity alone does not necessarily produce the shallow, top-heavy CMFs found in some dense and actively star-forming regions. Instead, the comparison likely suggests that the high-mass CMF is regulated by a combination of cloud environment, evolutionary state, and subsequent core growth.

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