On the typical width of Herschel filaments

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ABSTRACT

Context. Dense molecular filaments are widely believed to be representative of the initial conditions of star formation in interstellar clouds. Characterizing their physical properties such as their transverse size is therefore of paramount importance. Herschel studies suggest that nearby (d < 500 pc) molecular filaments have a typical half-power width ~0.1 pc, but this finding has been questioned recently on the ground that the measured widths tend to increase with the distance to the filaments.

Aims. Here we revisit the dependence of measured filament widths on distance or equivalently spatial resolution, in an effort to determine whether nearby molecular filaments have a characteristic half-power width or whether this is an artifact of the finite resolution of the Herschel data.

Methods. We perform a convergence test on the well-documented B211/213 filament in Taurus, by degrading the resolution of the Herschel data several times and re-estimating the filament width from the resulting column density profiles. We also compare the widths measured for the Taurus filament and other filaments from the Herschel Gould Belt survey with those found for synthetic filaments with various types of simple, idealized column density profiles (Gaussian, power law, Plummer-like).

Results. We find that the measured filament widths do increase slightly as the spatial resolution worsens and/or the distance to the filaments increases. However, this trend is entirely consistent with what is expected from simple beam convolution for filaments with density profiles that are Plummer-like and have intrinsic half-power diameters ~0.08–0.1 pc and logarithmic slopes 1.5 < p < 2.5 at large radii, as directly observed in many cases including the Taurus filament. Due to the presence of background noise fluctuations, deconvolution of the measured widths from the telescope beam is difficult and quickly becomes inaccurate.

Conclusions. We conclude that the typical half-power width ~0.1 pc measured with Herschel in nearby clouds most likely reflects the presence of a true common scale in the filamentary structure of the cold interstellar medium, at least in the solar neighborhood. We suggest that this common scale may correspond to the magnetized turbulent correlation length in molecular clouds.

Key words. stars: formation – ISM: clouds – ISM: structure – submillimeter:ISM

1. Introduction

The filamentary texture of the cold interstellar medium (ISM) is often regarded as a central role in the star formation process (e.g., [Hacar et al. 2022; Pineda et al. 2022]). In particular, Herschel imaging surveys of nearby Galactic clouds (André et al. 2010; Molinari et al. 2010; Hill et al. 2011; Juvela et al. 2012) have shown that filaments dominate the mass budget of molecular clouds at high densities (e.g., Schisano et al. 2014) and correspond to the birthplaces of most prestellar cores (e.g., Könyves et al. 2015; Marsh et al. 2016; Di Francesco et al. 2020). These findings support the notion that molecular filaments are representative of the initial conditions of the bulk of star formation in the Galaxy (e.g., André et al. 2014). Characterizing their detailed physical properties is therefore of paramount importance. A key attribute of filamentary gas structures is their transverse diameter since the fragmentation properties of cylindrical filaments are expected to scale with the filament diameter, at least according to quasi-static fragmentation models (e.g., Nagasawa 1987; Inutsuka & Miyama 1992). Remarkably, Herschel observations suggest that nearby molecular filaments have a common width of ~0.1 pc, with some scatter around this value (Arzoumanian et al. 2011; 2019). Indeed, analyzing the radial column density profiles of 599 Herschel filaments in 8 nearby clouds at d < 500 pc, Arzoumanian et al. (2019) found that the filaments of their sample share approximately the same half-power width ~0.1 pc with a spread of a factor of ~2, regardless of their mass per unit length $M_\text{line}$, whether they are subcritical with $M_\text{line} < 0.5 M_{\text{line,crit}}$, transcritical with $0.5 M_{\text{line,crit}} < M_\text{line} < 2 M_{\text{line,crit}}$, or thermally supercritical with $M_\text{line} > 2 M_{\text{line,crit}}$, where $M_{\text{line,crit}} = 2 c_s^2 / G$ is the thermal value of the critical mass per unit length (e.g., Ostriker 1964), i.e., ~16 $M_\odot$ pc$^{-1}$ for a sound speed $c_s \sim 0.2$ km s$^{-1}$ or a gas temperature $T \sim 10$ K. If confirmed, the existence of a typical filament width may have far-reaching implications as it introduces a characteristic length scale, and possibly a characteristic mass scale as well (André et al. 2019), in the structure of molecular clouds believed to be hierarchical in nature and essentially scale-free.

However, the reliability of the filament widths derived from Herschel data has recently been questioned by Panopoulou et al. (2022) who reported an intriguing correlation between the measured widths and the distances of the Herschel filaments in the Arzoumanian et al. (2019) sample. Panopoulou et al. (2022) suggested that the filament widths derived by Arzoumanian et al. (2019) are strongly affected by the finite spatial resolution of the
Herschel data and inconsistent with a characteristic intrinsic filament diameter ~0.1 pc.

In this paper, we re-examine the effect of spatial resolution on the column density profiles derived from Herschel data and resulting estimates of filament widths. In Sect. 2, we perform a convergence test similar to that presented by Panopoulou et al. (2022) for the Taurus B211/B213 filament. In Sect. 3, we perform the same convergence test on synthetic data for model filaments with simple radial density profiles (Gaussian, power law, Plummer-like). In Sect. 4, the results of these tests are compared to the filament widths obtained by Arzoumanian et al. (2019) and Schisano et al. (2014). We find good agreement between all three sets of measured widths when the model filaments have Plummer-like density profiles with half-power diameters ~0.08–0.1 pc and logarithmic slopes $1 < p < 2.5$ at large radii. Our analysis therefore supports the conclusion that Herschel filaments tend to have similar column density profiles and a typical intrinsic half-power width ~0.08–0.1 pc. We conclude the paper in Sect. 5, where we suggest that the typical filament width may be directly related to the correlation length of turbulent density and magnetic field fluctuations in molecular clouds.

2. Convergence test for the Taurus filament

A detailed study of the radial (column) density profile of the B211/B213 filament in Taurus (at a distance $d$ ~140 pc) was presented by Palmeirim et al. (2013) based on data from the Herschel Gould Belt survey (HGBS – André et al. 2010). Briefly, the mean transverse column density profile observed perpendicular to the filament is very well described by a Plummer-like model function of the form:

$$N_p(r) = \frac{N_0}{[1 + \alpha_p (r/R_{HP})^2]^{5/2}} + N_{bg},$$

where $R_{HP}$ is the half-power (HP) radius of the model profile, $p$ the power-law exponent of the corresponding density profile at radii much larger than $R_{HP}$, $\alpha_p = 2^{5/2} - 1$, $N_0$ is the central column density, and $N_{bg}$ the column density of the background cloud in the immediate vicinity of the filament. At the native half-power beam width (HPBW) resolution of the Herschel column density map used by Palmeirim et al. (2013), i.e., 18.2" or 0.012 pc, the best-fit model profile has the following parameters: $D_{HPBW} = 2 \times R_{HP} = 0.10 \pm 0.02$ pc (taking beam convolution into account), $p = 2.0 \pm 0.4$, $N_0 = (1.5 \pm 0.2) \times 10^{22} \text{cm}^{-2}$, and $N_{bg} = (1.0 \pm 0.5) \times 10^{22} \text{cm}^{-2}$. The HP diameter $D_{HP}$ derived from fitting a Plummer model to the observed profile agrees well with the half-diameter $hd = 2 hr = 0.093$ pc estimated in a simpler way, without any fitting, as twice the half-radius $hr$ where the background-subtracted column density profile drops to half of its maximum value on the filament crest (Arzoumanian et al. 2019). At the native Herschel resolution, the measured HP width of the Taurus filament thus corresponds to 7.5–8.0 times the beam size.

To investigate the effect of spatial resolution on the column density profile and measured filament width, we performed a convergence test by degrading the resolution of the Herschel data, convolving the original column density map with progressively larger Gaussian kernels, and evaluating the filament width on the degraded maps in the same manner as on the original map. This is analogous to the convergence studies commonly performed on numerical simulations, where the resolution is progressively increased to check that the outcome eventually no longer depends on numerical resolution (cf. Raskutti et al. 2016). The results of our test are provided in Table A.1 (Appendix A) and displayed as blue and green symbols in Fig. 1 as a function of both spatial resolution and equivalent distance (i.e., the distance at which the 18.2" angular resolution of the Herschel column density data matches the specified spatial resolution). A similar convergence test for the Taurus filament was presented by Panopoulou et al. (2022), although they emphasized the effect of cloud distance while we emphasize the effect of spatial resolution. Both effects are essentially equivalent but using spatial resolution instead of equivalent distance as the primary parameter is simpler and less confusing. (Note that two figures in Panopoulou et al. 2022 were originally erroneous; see erratum of the paper.)

Figure 1 also compares the results of the Taurus convergence experiment with the median apparent filament widths derived from Herschel data in the 8 nearby clouds of the Arzoumanian et al. (2019) sample (black dots). Overall, the latter measurements are roughly consistent with the linear dependence $H_{obs} \approx 4 \times HPBW$ (cf. Panopoulou et al. 2022), although the nearest HGBS clouds at $d \approx 200$ pc depart from this relation. In particular, it is clear from Fig. 1 that the trend between $H_{obs}$ and HPBW for the Taurus filament (blue diamonds) is not consistent with a linear dependence with zero intercept. In fact, extrapolating the width measurements to infinite resolution (i.e., $HPBW = 0$) suggests that the intrinsic HP diameter of the Taurus filament is $HP_{int} \approx 0.08–0.1$ pc. Moreover, within the error bars, the Taurus B211/B213 filament provides a fairly good template of the behavior observed in the whole HGBS sample, especially when deconvolved $D_{HP}^{obs}$ width estimates are compared.

3. Convergence curves for model filaments

To further clarify the influence of spatial resolution on real data, it is instructive to examine the effect for three simple types of cylindrical model filaments.
The simplest model is a filament with a Gaussian radial profile. In this case, the resolution effect due to convolution with the telescope beam (itself approximated by a Gaussian) is well known. The observed profile is also Gaussian with a full width at half maximum $\text{FWHM}_{\text{obs}} = \sqrt{\text{FWHM}_{\text{int}}^2 + \text{HPBW}^2}$, where $\text{FWHM}_{\text{int}} = \text{HP}_{\text{int}}$ is the intrinsic HP diameter of the filament profile and HPBW the half-power beam width. Provided that the data are sufficiently high signal to noise, the observations can easily be deconvolved from the telescope beam:

$$\text{FWHM}_{\text{dec}} = \sqrt{\text{FWHM}_{\text{obs}}^2 - \text{HPBW}^2} = \text{FWHM}_{\text{int}}$$

(a formula referred to as naive deconvolution in the following). It is obvious from this simple example that, in the absence of any deconvolution, one expects a positive correlation between the measured HP widths $\text{FWHM}_{\text{obs}}$ and the spatial resolution of the data HPBW.

Another simple model is a filament with a power-law radial column density profile, $N_p(r) = N_0 (r/r_0)^{-m}$, where $m = p - 1$ and $p = m + 1$ (with $m > 0$) are the exponents of the power law for the column density and density profiles, respectively. In this case, the measured size $\text{FWHM}_{\text{obs}}$ (or $\text{HP}_{\text{dec}}$) of the filament profile is expected to directly scale with, and to be always slightly larger than, the beam size (see, e.g., Adams [1991] and Ladd et al. [1991] for spherical sources). To quantify the $\text{FWHM}_{\text{obs}}$ vs. HPBW correlation, we performed the convolution with a Gaussian beam numerically for a wide range of power-law exponents from $p \geq 1$ to $p = 3$. The results are displayed in Fig. 2 (Appendix B), which plots the ratio $\text{FWHM}_{\text{obs}}/\text{HPBW} \equiv A_G(p)$ as a function of the index $p$ of the power-law profile. Observationally, both near-infrared extinction and submillimeter emission studies indicate that the column density profiles of dense molecular filaments have logarithmic slopes in the range $1.5 < p < 2.5$ at large radii (e.g., Alves et al. [1998], Lada et al. [1999], Arzoumanian et al. [2011, 2019], Juvela et al. [2012], Stutz & Gould [2016]). For this range of $p$ exponents, Fig. 2 shows that one expects the measured $\text{FWHM}_{\text{obs}}$ size to be from $-5\%$ (for $p = 2.5$) to $-90\%$ (for $p = 1.5$) larger than the beam size if the filament profile is a pure power law.

The third model we considered corresponds to a cylindrical filament with a Plummer-like radial column density profile as defined by Eq. (1), which provides a much better fit to the profiles of star-forming filaments such as Taurus B211/B213 (e.g., Palmeirim et al. [2013]). We convolved this intrinsic model profile numerically for a wide range of Gaussian beam sizes (expressed in units of the intrinsic HP diameter $D_{\text{HP}}^\text{int}$) and several values of the power-law exponent $p$. We then fitted the model function of Eq. (1) to the convolved profiles. The results are illustrated by the solid curves in Fig. 2, which plot the derived HP widths $D_{\text{HP}}^\text{obs}$ as a function of the HP beam resolution HPBW for three relevant values of $p$ ($p = 1.5$ in blue, $p = 2$ in red, and $p = 2.5$ in purple). Here, $D_{\text{HP}}^\text{obs}$ corresponds either to a “direct” HP estimate or to a HP estimate resulting from the Plummer-like fit in the terminology of Sect. 2 and Table A.1. (These two estimates are essentially indistinguishable.) With some care (cf. Sect. 3.3.3 of Arzoumanian et al. [2019]), reliable Gaussian fit estimates of the HP width of a Plummer-like profile can also be achieved. This is illustrated by the blue dash-dotted curve in Fig. 2, which shows that Gaussian fit estimates are only slightly ($<10\%$ lower than $D_{\text{HP}}^\text{obs}$ estimates in the $p = 1.5$ case. (For $p = 2$ and $p = 2.5$, the Gaussian results are even closer to the $D_{\text{HP}}^\text{obs}$ estimates.)

The dependence of $D_{\text{HP}}^\text{obs}$ on HPBW for Plummer models is qualitatively similar to the relation between $\text{FWHM}_{\text{obs}}$ and HPBW for Gaussian models at small beam sizes (HPBW/ $D_{\text{HP}}^\text{int}$ $\lesssim 1/3$) and asymptotically approaches the linear relation $D_{\text{HP}}^\text{obs} = A_G(p) \times \text{HPBW}$ expected for filaments with power-law density profiles of index $p$ at large beam sizes (HPBW/ $D_{\text{HP}}^\text{int}$ $\gtrsim 1$). In the presence of negligible noise, it is possible to derive reliable deconvolved estimates of the HP diameter, denoted $D_{\text{HP}}^\text{dec}$, by fitting a model corresponding to Eq. (1) convolved with a Gaussian beam to the data. This is illustrated by the black dashed line in Fig. 2, which shows that the Plummer deconvolution process is perfect in the absence of noise. In contrast, naively deconvolved Gaussian $\text{FWHM}_{\text{dec}}$ values (see above) largely overestimate the intrinsic $D_{\text{HP}}^\text{int}$ diameters of Plummer models when HPBW/ $D_{\text{HP}}^\text{int}$ $\gtrsim 1/3$, even in the absence of noise (see dashed blue, red, and purple curves in Fig. 2). In the presence of a realistic level of background noise fluctuations (see Appendix C), the Plummer deconvolution process also quickly degrades when HPBW/ $D_{\text{HP}}^\text{int}$ $\gtrsim 1/3$ (see Fig. 3) and $D_{\text{HP}}^\text{dec}$ typically starts to increase with resolution (see red curve and error
bars in Fig. 3). $D_{\text{obs}}$ estimates of the HP width nevertheless remain more accurate than naively deconvolved FWHM$_{\text{sec}}$ or $h_{\text{dec}}$ values. Moreover, the curves of Fig. 2c can be inverted to provide average deconvolution factors as a function of the observable $D_{\text{obs}}$/HPBW for Plummer profiles with any given $p$ index. This was used to derive the deconvolved estimates shown as light brown symbols in Fig. 4. Comparison of the blue and green diamonds in Fig. 4 with the blue and red curves in Fig. 3 supports the conclusion that the Taurus B211/B213 filament has an intrinsic mean HP diameter $D_{\text{int}}$ corresponding to $\sim$8 times the HPBW resolution of the Herschel column density map (see Sect. 3 and Palmeirim et al. 2013).

4. Global comparison with Herschel filaments

We may now confront the simple models of Sect. 3 with the global results obtained on Herschel filaments. Figure 4 shows the mean HP diameters found by Arzoumanian et al. (2019) in 8 nearby HGBS clouds and by Schisano et al. (2014) for a sample of Hi-GAL filaments in the Galactic Plane, as a function of the HPBW spatial resolution of the Herschel data in each case. To generate this plot, the Schisano et al. sample was divided into 7 bins of spatial resolution between ~0.1 pc and ~1 pc (according to filament distance), and the mean filament width in each bin calculated from the results of Schisano et al. (2014). First, it can be seen in Fig. 4 that the whole set of Herschel width measurements is not consistent with a single linear correlation such as $D_{\text{HPBW}} = A(p) \times \text{HPBW}$, expected for scale-free filaments. In particular, the Herschel data are inconsistent with the linear relation $D_{\text{HPBW}} = 4 \times \text{HPBW}$ advocated by Panopoulou et al. (2022) for the HGBS filaments. The Hi-GAL filaments analyzed by Schisano et al. (2014) have measured HP diameters that are typically $1.9 \pm 0.2$ times the HPBW spatial resolution (see green lines in Fig. 4). This is consistent with either pure power-law or unresolved Plummer-like density profiles with logarithmic slopes $p \sim 1.5$ at large radii. In contrast, the measured HP widths of nearby HGBS filaments are a factor $\sim$4–8 times the spatial resolution depending on filament distance, which is incompatible with pure power-law density profiles given the observed range of logarithmic slopes ($1.5 < p < 2.5$). A much lower FWHM$_{\text{sec}}$/HPBW ratio $\sim 1.9$ would indeed be expected in the latter case (see Sect. 3 and Fig. B.1). Quite remarkably, a single Plummer-like model with $D_{\text{HPBW}} = 0.08–0.1$ pc and $p = 1.7$ (see pink curves in Fig. 4) can account for all of the Herschel measurements reasonably well. This suggests that Herschel filaments do have a typical HP width $\sim 0.08–0.1$ pc and typical power-law wings with $p \sim 1.5–2$, but that the flat inner portion of their column density profiles is unresolved by Herschel at the distances $d \sim 1–3$ kpc of the Hi-GAL filaments in Fig. 4.

5. Concluding remarks

The convergence tests we performed on synthetic filaments indicate that filament width measurements are difficult to decon-
volve from the telescope beam. In particular, naive Gaussian deconvolution of width measurements obtained on filaments with Plummer-like density profiles is ineffective (cf. Fig. 2b) and proper deconvolution assuming a Plummer model quickly becomes inaccurate in the presence of noise (Fig. 3b). Given the logarithmic slopes $1 < p < 2.5$ of observed density profiles at large radii, our tests suggest that, without deconvolution, filament width measurements are reasonably accurate and overestimate the intrinsic HP widths of filaments by less than 10%, 15%, and 30% on average when the apparent angular widths exceed the beam HPBW by a factor of ~8, ~6, and ~4, respectively (cf. Fig. 3b). When the apparent filament width is only a factor of ~2.5 higher than the HPBW, it may overestimate the intrinsic HP width by up to a factor of ~2–3 and higher-resolution observations are desirable to improve the width estimates. When the apparent filament width is less than a factor of ~2 broader than the HPBW, the measurements are dominated by the power-law wing of the filament profile and provide little information on the physical width of any flat inner region in the profile.

Overall, our analysis of the effects of finite spatial resolution on filament width measurements reinforces the conclusion of Arzoumanian et al. (2011, 2019) about the existence of a typical half-power filament diameter ~0.1 pc, at least in the case of nearby, high-contrast filamentary structures (i.e. with a contrast over the local background exceeding ~50%). Our findings further emphasize the need for a robust theoretical explanation for the common filament width in nearby molecular clouds. While none of the current explanations is fully satisfactory from a theoretical point of view (e.g., Hennebelle & Inutsuka 2019), a promising interpretation is that the common filament width may be linked, at least initially, to the magneto-sonic scale below which interstellar turbulent flows become subsonic and incompressible (primarily solenoidal) in diffuse molecular gas (Federrath 2016, Federrath et al. 2021). The ubiquity of filamentary structures in both diffuse, non-self-gravitating molecular clouds such as the Polaris cirrus (e.g., Miville-Deschênes et al. 2010, André et al. 2010) and numerical simulations of supersonic turbulence without gravity (e.g., Padoan et al. 2001, Pudritz & Kevlahan 2013) suggests that dense molecular filaments somehow result from large-scale turbulent compression of interstellar material before gravity becomes important. Recently, Prieslsey & Whitworth (2022a,b) argued that the observed distribution of filament widths can be explained if filaments are formed dynamically via converging, mildly supersonic flows arising from large-scale turbulent motions. As pointed out by Jaupart & Chabrier (2021), the sonic scale is directly related to the correlation length $l_c$ of initial density fluctuations generated by supersonic isothermal turbulence (before gravity starts to play a significant role). In other words, the typical filament width found in Herschel observations may correspond to the average size of the most correlated structures produced by turbulence in diffuse molecular clouds. We stress that there is no contradiction between the existence of a finite correlation length for the (column) density field and the essentially scale-free power spectrum observed for column density fluctuations (e.g., Miville-Deschênes et al. 2010), since the correlation length $l_c \propto P(0)/\int P(k) \, dk$ only depends on the integral of the power spectrum $\int P(k) \, dk$ (i.e., the variance of the density field) and its value at zero spatial frequency $P(0)$ but not on the detailed shape of the power spectrum $P(k)$. Using column density data from the HGBS, Jaupart & Chabrier (2022) made rough estimates of the turbulent correlation length in the Polaris and Orion B clouds and found values broadly consistent with $l_c \sim 0.1$ pc, albeit with large uncertainties (up to a factor of ~3–10). Following the method introduced by Houde et al. (2009), independent estimates of the magnetized turbulent correlation length have also been obtained from analyses of the angular dispersion function of polarization angles in recent high-quality dust polarimetry maps. For instance, using SOFIA HAWC+ data, Guerra et al. (2021) found $l_c \sim 0.05–0.15$ pc in most of the Orion OMC-1 field they observed and Li et al. (2022) estimated $l_c \sim 0.075–0.095$ pc in a significant portion of the Taurus B211 filament. One merit of interpreting the typical filament width as the turbulent correlation length is that it naturally accounts for the dispersion of width measurements around the mean ~0.1 pc value (both along the crest of each filament and from filament to filament), since the initial filament widths are only expected to match the sonic scale in a statistical sense. This interpretation is incomplete, however, because it does not explain how self-gravitating, thermally supercritical filaments maintain a roughly constant inner width while evolving. Further work is therefore clearly needed to provide a more complete explanation and clarify the role of the turbulent correlation length.

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References

Adams, F. C. 1991, ApJ, 382, 544
Alves, J., Lada, C. J., Lada, E. A., Kenyon, S. J., & Phillips, R. H., 1998, ApJ, 506, 292
André, P., Arzoumanian, D., Könyves, V., et al. 2019, A&A, 629, L4
André, P., Di Francesco, J., Ward-Thompson, D., et al., 2014, in Protostars and Planets VI, ed. H. Beuther et al., 27
André, P., Men’shchikov, A., Bontemps, S., et al., 2010, A&A, 518, L102
Aniano, G., Graine, B. T., Gordon, K. D., & Sandstrom, K. 2011, PASP, 123, 1218
Arzoumanian, D., André, P., Didelon, P., et al., 2011, A&A, 529, L6
Arzoumanian, D., André, P., Könyves, V., et al. 2019, A&A, 621, A42
Di Francesco, J., Kovács, J., et al. 2020, ApJ, 904, 172
Federrath, C., Klessen, R. S., Ipachino, L., & Beattie, J. R. 2021, Nature Astronomy, 5, 365
Guerrero, J. A., Chuss, D. T., Dowell, C. D., et al., 2021, ApJ, 908, 98
Hacar, A., Clark, S., Heitsch, F., et al., 2022, in PPVI, arXiv:2203.09562
Hennebelle, P. & Inutsuka, S.-I. 2019, Front. Astron. Space Sci., 6, 5
Hill, T., Motte, F., Didelon, P., et al., 2011, A&A, 533, A94
Houde, M., Vaillancourt, J. E., Hildebrand, R. H., Chisazzadeh, S., & Kirby, L. 2009, ApJ, 706, 1504
Inutsuka, S.-I., & Miyama, S. M. 1992, ApJ, 388, 392
Jaupart, E. & Chabrier, G. 2021, ApJ, 922, L35
Jaupart, E. & Chabrier, G. 2022, A&A, in press, arXiv:2205.12571
Juvela, M., Ristorcelli, I., Paganu, L., et al., 2012, A&A, 541, A12
Könyves, V., André, P., Men’shchikov, A., et al., 2015, A&A, 584, A91
Lada, C. J., Alves, J., & Lada, E. A., 1999, ApJ, 512, 250
Ladd, E. F., Adams, F. C., Casey, S., et al., 1991, ApJ, 382, 555
Li, P. S., Lopez-Rodriguez, E., Ajeddig, H., et al. 2022, MNRAS, 510, 6085
Mardones, D., Kirk, J. M., André, P., et al. 2016, MNRAS, 463, 343
Miville-Deschênes, M.-A., Martin, F. G., Aberleg, A., et al., 2016, A&A, 518, L104
Molnari, S., Swinyard, B., Bally, J., et al., 2010, A&A, 518, L100
Nagasawa, M. 1987, Prog. Theoret. Phys., 77, 935
Ostriker, J. 1964, ApJ, 140, 1056
Padoan, P., Juvela, M., Goodman, A. A., & Nordlund, Å., 2001, ApJ, 553, 227
Palmeirim, P., André, P., Kirk, J., et al., 2013, A&A, 550, A38
Panopoulou, G. V., Clark, S. E., Hacar, A., et al. 2022, A&A, 657, L13
Pineda, J. E., Arzoumanian, D., et al. 2012, arXiv:2205.09395
Presley, F. D. & Whitworth, A. P. 2022a, MNRAS, 509, 1494
Presley, F. D. & Whitworth, A. P. 2022b, MNRAS, 512, 1407
Pudritz, R. E. & Kevlahan, N. K. R., 2013, Phil. Trans. R. Soc. A, 371, 20248
Raskutti, S., Ostriker, E. C., & Skinner, M. A., 2016, ApJ, 829, 130
Schisano, E., Rygl, K. L. J., Molnari, S., et al., 2014, ApJ, 791, 27
Stutz, A. M. & Gould, A. 2016, A&A, 590, A2
Appendix A: Results of the convergence test on the Taurus filament

Here, we provide a table with the detailed results of the convergence test described in Sect. 2 on the Taurus B211/B213 filament:

Table A.1. Estimated widths of the B211/B213 filament at various resolutions

| Resol. (pc) | Resol. ("') | hd (pc) | $D_{\text{HP}}$ (pc) | $D_{\text{HP}}^\text{dec}$ (pc) |
|------------|-------------|--------|----------------------|-----------------------------|
| 18.2       | 0.012       | 0.093 ± 0.006 | 0.11 ± 0.01 | 0.10 ± 0.02 |
| 25.7       | 0.018       | 0.099 ± 0.007 | 0.11 ± 0.01 | 0.10 ± 0.02 |
| 36.4       | 0.025       | 0.108 ± 0.008 | 0.12 ± 0.01 | 0.11 ± 0.02 |
| 51.5       | 0.035       | 0.123 ± 0.009 | 0.14 ± 0.01 | 0.11 ± 0.02 |
| 72.8       | 0.050       | 0.145 ± 0.011 | 0.16 ± 0.02 | 0.12 ± 0.03 |
| 99.0       | 0.067       | 0.173 ± 0.013 | 0.20 ± 0.02 | 0.15 ± 0.04 |

Notes. Col. (3): Half-diameter $hd \equiv 2hr$ estimated without any fitting. Col. (4): Half-power diameter $D_{\text{HP}}$ derived by fitting Eq. (1) to the observed mean column density profile (without any deconvolution). Col. (5): Deconvolved half-power diameter $D_{\text{HP}}^\text{dec}$ derived by fitting a model corresponding to Eq. (1) convolved with a Gaussian beam of HPBW given in Col. (1) (in "') and Col. (2) (in pc).

Appendix B: Tests on model filaments with power-law profiles

Figure B.1 illustrates and summarizes the results of the simple tests we performed for model filaments with power-law column density profiles (see Sect. 3).

Appendix C: Generating synthetic data for Plummer-like filaments with realistic background noise

Here, we provide details on the method employed in Sect. 3 to construct synthetic data corresponding to the observation of a cylindrical model filament with a Plummer-like column density profile (cf. Eq. 1) in the presence of realistic background “noise” fluctuations. The noise in Herschel maps of molecular clouds at wavelengths $\lambda \geq 160\mu m$ is usually dominated by the “structure noise” induced by the fluctuations of the background cloud emission. Moreover, the power spectrum measured for far-infrared images of interstellar clouds is typically Kolmogorov-like with $P(k) \propto k^{-\gamma}$ (e.g. Miville-Deschênes et al. 2010). For the tests illustrated in Fig. 3, we thus constructed a series of synthetic column density maps by adding randomly-generated maps of background fluctuations with such a $P(k) \propto k^{-2.7}$ power spectrum to the column density map of a Plummer model filament with a logarithmic density slope $p = 1.7$ (assumed to lie in the plane of the sky). The standard deviation of the background noise map was fixed to 1/10 of the central column density of the model filament. We also introduced realistic random fluctuations of the intrinsic HP diameter of the model filament along its length; these random fluctuations had a lognormal distribution centered at $D_{\text{HP}}^\text{obs}$ with a standard deviation 0.3 dex, as observed for HGBS filaments (see Fig. 7 of Pineda et al. 2022). The synthetic maps were smoothed
to a wide range of effective resolutions by convolving them with circular Gaussian kernels. Two examples of such smoothed column density maps are displayed in Fig. C.1, including the map corresponding to the filament column density profile shown in Fig. 3a. In both panels, positional offsets are given in units of the intrinsic HP width of the model filament, $D_{\text{HP}}^\text{int}$.

function of HPBW resolution, the mean $D_{\text{HP}}^\text{obs}$ and $D_{\text{HP}}^\text{dec}$ values averaged over the 1000 realizations, and the error bars correspond to the standard deviations measured for the distributions of values at each resolution.

### Appendix D: Distribution of Herschel filament widths

In this appendix, we show a plot of half-power width against spatial resolution similar to Fig. 4 but where we display all individual width measurements from Schisano et al. (2014) instead of binning the distribution of Hi-GAL widths (Fig. D.1). In this way, the full scatter of Hi-GAL width measurements may be better appreciated. Like in Fig. 1 and Fig. 4, the distances adopted in Fig. D.1 for the HGBS clouds are those indicated by Gaia data (cf. Panopoulou et al. 2022). The HGBS cloud with the most uncertain distance (IC5146) is represented by two connected symbols. The distances adopted for the Hi-GAL filaments are those used by Schisano et al. (2014), whose typical uncertainties are smaller than the horizontal error bars in Fig. 4.

![Fig. D.1. Mean HP width versus spatial resolution for both HGBS filaments (red squares from Arzoumanian et al. 2019) and Hi-GAL filaments (black circles from Schisano et al. 2014). The red error bars correspond to \pm the standard deviations of measured widths in each HGBS cloud. The black error bars correspond to \pm the standard deviation of individual width estimates along each Hi-GAL filament in the Schisano et al. sample. The lines, curves, and yellow shading are the same as in Fig. 4.](image-url)
Appendix E: Effect of a non-Gaussian beam

The synthetic data discussed in Sect. 3 were smoothed to various effective resolutions assuming a strictly Gaussian beam. In reality, the Herschel beams are not strictly Gaussian and include low-level non-Gaussian features (e.g., Aniano et al. 2011). To assess the potential impact of these non-Gaussian features on the tests performed in Sect. 3, we repeated the numerical experiment summarized in Fig. 2 assuming that the effective beam of Herschel column density maps had a shape similar to that of the true Herschel/SPIRE beam at 250 μm at all resolutions (see purple dash-dotted curve in Fig. E.1a). As shown in Fig. E.1b, the curves of derived HP widths (Plummer $D_{\text{HP}}^{\text{obs}}$ and Gaussian FWHM$_{\text{obs}}$) as a function of HP beam resolution HPBW are almost identical to those in Fig. 2b. This indicates that the non-Gaussian structure of the Herschel beams has very little influence on the results presented in Sect. 3. The only visible effect is that the Plummer deconvolution process and resulting $D_{\text{dec}}^{\text{HP}}$ estimates of the filament width (see black dashed lines in Fig. E.1b) are no longer perfectly accurate, even in the absence of noise. This is hardly surprising since accurate beam deconvolution requires both high signal to noise and excellent knowledge of the beam shape.

Fig. E.1. Similar to Fig. 2 but assuming that the effective beam corresponds to the real SPIRE 250 μm beam as opposed to a strictly Gaussian beam. a) Convolution of a model filament with a $p = 2$ Plummer-like radial profile by a non-Gaussian beam corresponding to the SPIRE beam at 250 μm. The purple dash-dotted curve shows this non-Gaussian beam on top of the same uniform background as in Fig. 2a. The purple dashed curve is the filament profile after convolution with this beam (assuming the same HPBW/$D_{\text{HP}}^{\text{int}} = 1/2$ ratio as in Fig. 2a). The black solid and dash-dotted curves are the same as in Fig. 2a. b) Same as in Fig. 2b when the convolved synthetic data are constructed with a non-Gaussian beam of shape as shown in panel a but the estimated $D_{\text{HP}}^{\text{obs}}$ diameters are derived as in Fig. 2b assuming a strictly Gaussian beam.