Profiling filaments: comparing near-infrared and submillimetre data in TMC-1

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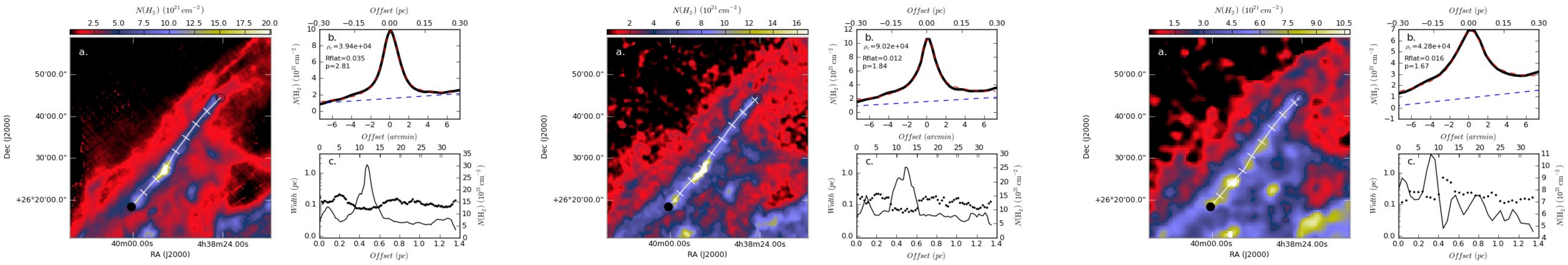

Figure 1. TMC-1N column density map and filament profile derived from Herschel emission map (left), WFCAM extinction map (middle) and 2MASS extinction map (right). a) Column density map. The part of filament used in the fitting is marked with white line (based on the Herschel column density map). b) Average column density profile of the filament (black line), fitted Plummer profile (red dashed line) and the baseline of the fit (blue dashed line). Values for fitted Plummer parameters ρ, R_flat, and p are marked in the figure. c) FWHM values (black circles and left hand scale) and column density along the ridge of the filament (solid line and the right hand scale).

Introduction Interstellar filaments have long been recognised as an important part of the star formation process. In order to understand the structure and formation of filaments, the filament cross-section profiles are often fitted with the so-called Plummer profile function. Currently this profiling is often approached with submm studies, especially with Herschel. If these data are not available, it would be more convenient if filament properties could be studied using ground-based near-infrared (NIR) observations. Mass estimates based on dust emission and on the estimation of colour temperature can also be biased because of line-of-sight temperature variations, especially in potentially star forming high density clouds (e.g., Malinen et al. 2011). It would be useful to compare mass structures obtained using different methods. We compare the filament profiles obtained by NIR extinction and submm observations to find out if reliable profiles can be derived using NIR data. This poster is based on our article Malinen et al. (2012). Here we show results only for filament TMC-1N, which is situated in the Taurus molecular cloud north of TMC-1. See the article for more details and results. See also Malinen et al. (2013), where we study TMC-1N with scattered NIR light and Juvela et al. (2012) where we study the observational effects in determining filament profiles from synthetic submm observations.

Methods We use NIR J-, H-, and K-band data obtained with WFCAM instrument of the UK InfraRed Telescope (UKIRT) to derive an extinction map from colour excesses of background stars. We calculate extinction values with the NICER method (Lombardi & Alves 2001) and convert them to a column density map. For comparison, we make a map also with lower resolution 2MASS data. We calculate a column density map also using SPIRE maps obtained from the Herschel Gould Belt Survey consortium (André et al. 2010).

We fit the filament column density profiles N(r) with Plummer-like profiles

$$\rho_p(r) = \frac{\rho_c}{[1+(r/R_{\rm flat})^2]^{p/2}} \Rightarrow N(r) = A_p \frac{\rho_c R_{\rm flat}}{[1+(r/R_{\rm flat})^2]^{(p-1)/2}}$$

(see e.g. Nutter et al. 2008; Arzoumanian et al. 2011). The equation includes the central density ρ_c , the size of the flat inner part R_flat, and the parameter p that describes the steepness of the profile in the outer parts. We include in the fits two additional parameters to describe a linear background. The factor A_p is obtained from the formula

$$A_p = \frac{1}{cos\, i} \int_{-\infty}^{\infty} \frac{du}{(1+u^2)^{p/2}}$$

where we assume an inclination angle of i = 0. In addition to the fitted Plummer profile parameters, we also derive the mass per unit length M_line of the filament by integrating column density over the profile.

We use four different methods for extracting the profiles, i.e., profiling. In short, the profiles are based on a fit to

A. a column density map derived from (submm) dust emission map

B. a column density map derived from NIR extinction map

C. median Av of stars within a certain offset from the filament centre

D. Av of individual stars.

Results Column density maps and filament profiles derived from Herschel emission map and WFCAM and 2MASS extinction maps of TMC-1N are shown in Fig. 1. For the profile fits to real observations the values of individual Plummer parameters are in general similar to within a factor of ~2 (in some cases up to a factor of ~5) when using different methods. Although the Plummer parameter values can show significant variation, the derived estimates of filament mass (per unit length) usually remain similar to within some tens of per cent.

The confidence regions of the Plummer parameters are quite wide. As the parameters are not always well constrained, even small changes in the data can lead to different parameter values. The correlations of the parameters should therefore be taken into account. The size and orientation of the confidence regions are not identical when Herschel maps or NIR data are used. The combination of the methods can significantly improve the accuracy of the filament parameter estimates.

Simulations We use simulations to examine the accuracy of our methods. The stellar colours are reddened according to the column density distribution that results from the presence of a filament. The density distribution of the filament follows the Plummer function with chosen parameters. The simulated observations are analysed as in the case of the WFCAM observations above. We show that in simulations, all the methods based on NIR extinction work best with modest densities ρ_c = 10⁴ –10⁵ cm⁻³ . Method D gives correct results for the fitted and derived parameters to within ~10% and methods B and C to within ~20% in most cases. At high densities (~10⁶ cm⁻³), only method D continues to work reliably.

Conclusions NIR extinction maps can be used as an alternative to submm observations to profile filaments. Direct fits of stars can also be a valuable tool in profiling. However, the Plummer profile parameters are not always well constrained, and caution should be taken when making the fits and interpreting the results. In the evaluation of the Plummer parameters, one can also make use of the independence of the dust emission and NIR data and the difference in the shapes of the associated confidence regions.

Mapping of interstellar clouds with infrared light scattered from cosmic dust: TMC-1N [Malinen et al. 2013]

Introduction Mapping of the NIR scattered light is a promising, complementary method for the study of interstellar clouds. Padoan et al. (2006) presented a method by which the cloud column density can be determined with high resolution from the intensity of NIR scattered light. Juvela et al. (2006) analysed the method in more detail. Our goal is to study the usability of this method on larger scale, and compare the properties of a filamentary structure using infrared scattering and other methods. We also study the radiation field and differences in grain emissivity between diffuse and dense areas.

Methods We have used scattered NIR J, H, and K band surface brightness observations with WFCAM instrument to map the filament TMC-1N, covering an area of 1 deg x 1 deg corresponding to ~(2.44 pc)². We have converted the data into an optical depth map and compared the results with NIR extinction and Herschel observations of sub-mm dust emission. We have also modelled the filament with 3D radiative transfer calculations of scattered light.

Results We see the filament in scattered light in all three NIR bands. We show that 3D radiative transfer simulations predict similar scattered surface brightness levels as seen in the observations. However, changing the assumptions about the background can change the results of simulations notably. We derive emissivity, the ratio of FIR dust emission to column density, by using τ_J, obtained from NIR extinction map, as an independent tracer of column density. We obtain a value 0.0013 for the ratio τ_250/τ_J. This leads to opacity or dust emission cross-section σ(250μm) values 1.7-2.4 x 10⁻²⁵ cm²/H, depending on assumptions of the extinction curve, which can change the results by over 40%. These values are twice as high as obtained for diffuse areas, at the lower limit of earlier results for denser areas.

Conclusions We show that NIR scattering can be a valuable tool in making high resolution maps. However, we conclude that NIR scattering observations can be complicated, as the data can show comparatively low-level artefacts. This suggests caution when planning and interpreting the observations.

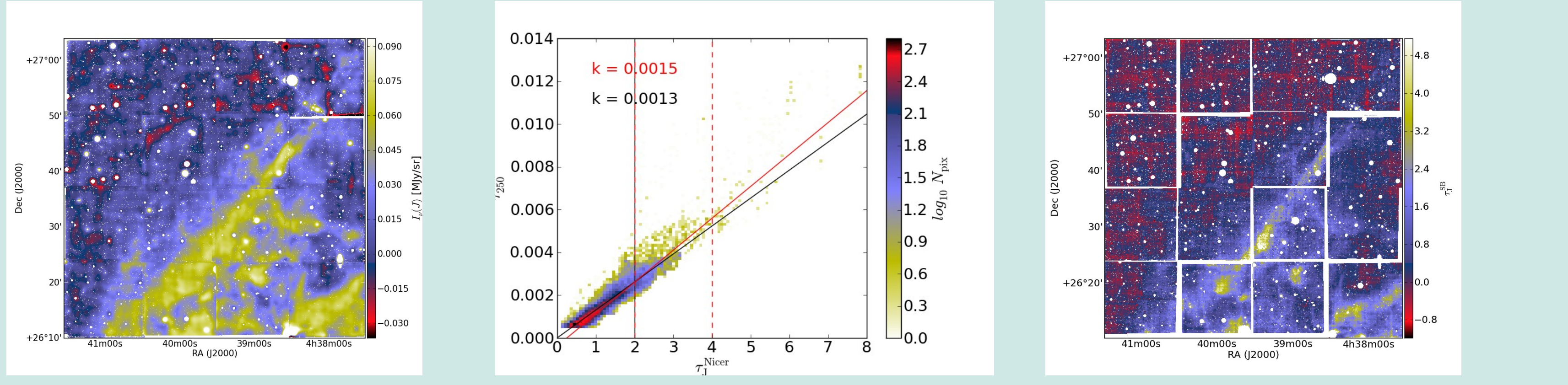

Figure 2. *Left:* Scattered J band surface brightness map (40" resolution), stars removed. *Middle*: Correlation between τ_J (from extinction) and τ_250 (Herschel). Slope k for range 0-2 (black) and 2-4 (red). *Right*: τ_J map derived from scattered light (2.2" resolution).

Profiles of interstellar cloud filaments: Observational effects in synthetic sub-millimetre observations [Juvela et al. 2012]

Study: Observational effects of filament profiles estimated from observations
Method: Synthetic submm observations based on 3D MHD simulations and radiative transfer
Conclusions: profile parameters sensitive to noise, but for nearby clouds can be determined with good accuracy using Herschel data
Caution: line-of-sight confusion = some of the filaments identified from 2D maps are discontinuous structures in 3D

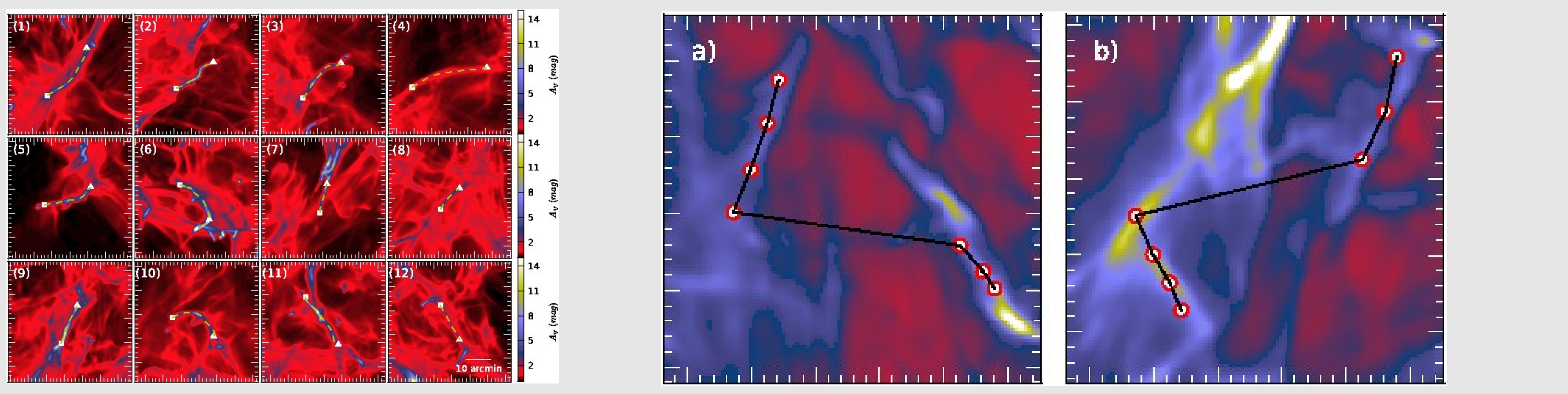

Figure 3. *Left*: Simulated cloud, zoomed into the selected filaments. *Right*: Filament number 1 seen from the two other orthogonal directions revealing a discontinuous structure in 3D.

References André et al. 2010, A&A, 518, L102; Arzoumanian et al. 2011, A&A, 529, L6; Juvela et al. 2006, A&A, 457, 877; Juvela, Malinen & Lunttila 2012, A&A, 544, A141; Lombardi & Alves 2001, A&A, 377, 1023; Malinen et al. 2011, A&A, 530, A101; Malinen et al. 2012, A&A, 544, A50; Malinen et al. 2013, submitted; Nutter et al. 2008, MNRAS, 384, 755; Padoan et al. 2006, ApJ, 636, L101