Filamentary Structures in Star Forming Regions

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Abstract: Herschel maps reveal the rich and complex structure of molecular clouds with gas and dust arranged in filaments, often containing embedded pre/proto-stellar cores. Filamentary structures are ubiquitous and are believed to play an active role in star formation, being the intermediate products of the compression and the sweeping of matter by the turbulence present in the molecular cloud. Despite their importance, few studies on filaments are still available in the literature, mostly due to the difficulties in identifying them in an objective way.

Here we present the first results of an automatic algorithm, still under development, able to detect filamentary structures on the maps of the Galactic plane observed by the Herschel Space Telescope in the framework of the Hi-GAL survey.

1. Filaments and their Connection with the Star Formation

The current accepted paradigm of star formation predicts that stars form naturally by the action of turbulence within a self gravitating molecular cloud (see e.g. the review by McKee & Ostriker 2007). Numerical simulations show that the large-scale turbulence by compressing and sweeping the matter, is able to build up a complex network of coherent (filamentary) structures (Klessen 2001, Heitsch et al. 2008). Within such filaments or in their intersections the density enhancements on spatial scales smaller than the local Jeans lenght, thus those density fluctuations become quickly unstable and collapse forming highly clustered protostellar cores.

The filamentary pattern predicted by gravo-turbulent scenario has been observed in several star forming regions, like Orion (Mitchell et al. 2001), Perseus (Hatchell et al. 2005) and Taurus (Hartmann et al. 2002). Recent observations conducted with Herschel confirmed that filaments are visible everywhere in the active star-forming regions. More important, those observations detected pre/protostellar cores spatially associated with the filaments (Molinari et al. 2010; Men'shkivov et al. 2010), in agreement with the theory of star formation triggered by the large-scale turbulence. Filaments are then an intermediate stage in the star formation process, that is still mostly unexplored.

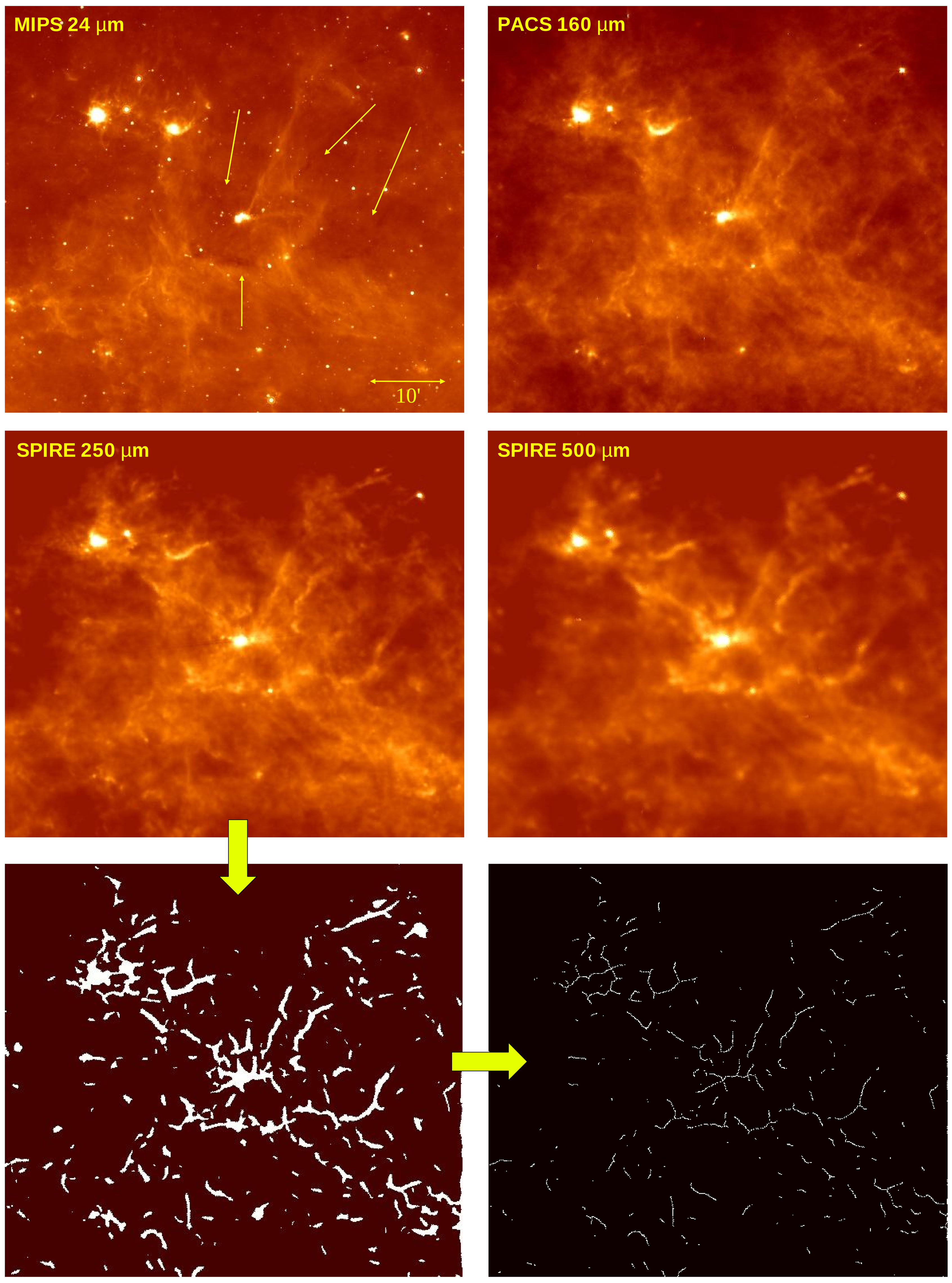

Figure 1: (*First four panels*) Detail of the Vulpecula region centered at Galactic coordinates (l,b) = (58.5°, 0.4°) observed at different wavelengths (Image from Hi-GAL survey) . In spite of the decreasing resolution, it is evident that the emission is clearly arranged in a rich and complex filamentary network. The few infrared dark clouds in the 24 μm image (indicated by the yellow arrows) are bright at longer wavelengths and appear strongly elongated. The bright overdensities, tracing the pre/protostellar cores, are distribuited along the structures. (*Lower left panel*) Regions containing the filament candidates identified at 250 μm by the algorithm described in Section 2. Extended but not elongated regions, like the clumps, are identified as candidate regions, but they are rejected by criteria on the highest eigenvalue and the eigenvectors. (*Lower right panel*) Results of the morphological operator that determines the axis of each identified region of interest.

2. The Automatic Filament Detection

We used image processing techniques to develop a code for identifying filamentary structures. Our approach relies on a filtering using the second derivative to determine the intensity shape near each pixel. Elongated elliptical-like patterns are traced by the eigenvalues (λ_1,λ_2) and the eigen-vectors $(\vec{A}_1,\vec{A}_2)$ of the Hessian matrix computed in each pixel by selecting the ones whose the local intensity shape is concave down along the two principal axes ($\lambda_1 < \lambda_2 < 0$, Aragón et al. 2007; Bond et al. 2010). The regions of interest (RoIs) including different filaments are determined with a fixed threshold on the lowest eigenvalue λ_1 (see Figure 2). Noise impact on the derivative filtering is reduced by smoothing the images with specific anisotropic diffusion filters (Perona & Malik 1990) that preserve the filaments edges. Finally different morphological operators (Gonzales & Wood 2002) are applied on the RoI to determine the position of the filament and the coherence of multiple nearby structures for future multi-scale analysis.

General Scheme of the algorithm

1. Prefiltering with Anisotropic Diffusion Filters
2. Hessian Matrix Computation and Diagonalization
3. Identification of Region of Interest (RoI)
4. Morphological analysis of RoI

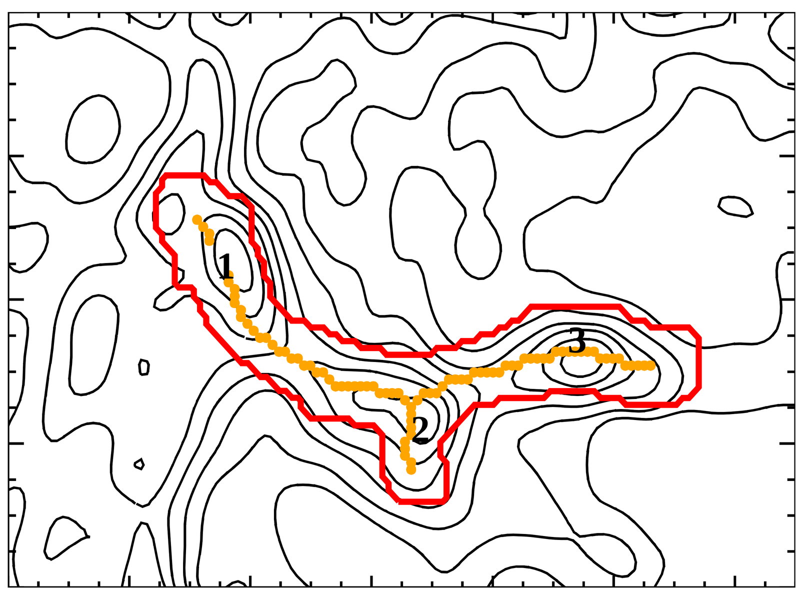

Figure 2: Example of filament extraction. The contours of the image are shown in black. The red contour defines the identified RoI while the orange dots trace out the computed filament axis. Three cold cores are found into the RoI.

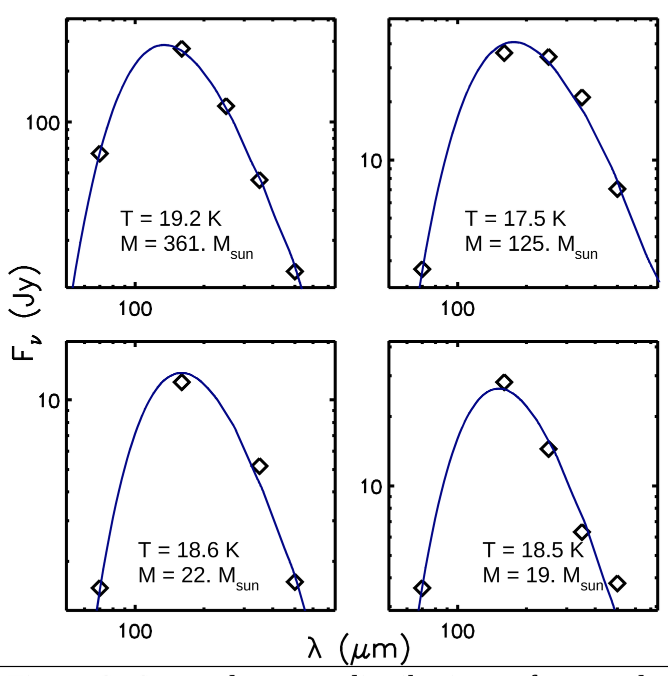

Figure 3: Spectral energy distributions of a sample of the identified filaments. The blue lines are the grey body best fitting the measured fluxes.

Temperatures are in the range 15-17 K and masses are of order of few tens solar masses.

3. Investigating Morphological and Physical Properties of Filaments

Applying the filament detection algorithms on various maps we plan to build up a robust catalog of filaments for which we will determine morphological (length, width) and physical (mass and temperature) properties. Lengths and widths provide an indirect probe of the original turbulence that compressed the matter (Nagai et al. 1998). Masses and temperatures are determined by modelling the spectral energy distributions built integrating the emission in the RoI at different wavelengths (see Figure 3). First indications from a limited sample of 8 filaments, 4 of which are shown in Figure 3, suggest that they have masses between 20 – 400 M_{sun} and temperatures in the range 10-20 K, in agreement with the fact that filamentary structures are not expected to represent an homogeneous class definite by particular physical properties. However larger samples have to be investigated before drawning any further conclusion.

4. Conclusions and Future Developments

We present here an automatic algorithm able to identify highly elongated structures (filaments) in interstellar medium images, and in particular in star forming regions. We applied the algorithm to Galactic plane maps observed with the Herschel Space Telescope in the framework of the Hi-GAL project (Molinari et al. 2010) obtaining the filamentary shape of the dust emission in such regions. The morphological and physical properties of all the detected structures will be included in a catalog of the Galactic plane filaments.

From a preliminary analysis (see Section 3) it came up the need to complement the obtained physical properties with with velocity dispersion measurements, to carry out a stability analysis of the detected filaments. By simple comparison with theoretical models (isothermal or magnetically supported filaments) it will be possible to clarify which are the active mechanisms inside the filaments (Fiege & Pudritz 2000; Fiege et al. 2004).

The present implementation of the algorithm is sensitive to small scale structures (up to few arcmins). We plan to adapt it to study larger scale patterns, as expected to form in turbulent regimes.

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