Two Mass Distributions in the L1641 Molecular Clouds: The *Herschel* connection of Dense Cores and Filaments in Orion A

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Abstract:

We present the *Herschel Gould Belt survey* (Andrè et al. 2010) maps of the L 1641 molecular clouds in Orion A. We extracted both the filaments and dense cores in the region. We identified which of our dense sources are proto- or pre-stellar and studied their association with the identified filaments. We find that although most (71%) of the pre-stellar sources are located on filaments there is still a significant fraction of sources not associated with such structures. We find that these two populations (on and off the identified filaments) have distinct mass distributions. The mass distribution of the sources on the filaments is found to peak at $4M_\odot$ and drives the shape of the CMF at higher masses, which we fit with a power law of the form $dN/dlogM \propto M^{-1.4\pm0.4}$. The mass distribution of the sources off the filaments, on the other hand, peaks at $0.8M_\odot$ and causes the flattening of the CMF at masses lower than $\sim 4M_\odot$. We postulate that this difference in the mass distributions at masses lower than $\sim 4M_\odot$ is due to the higher proportion of gas that is available in the filaments, rather than in the diffuse cloud.

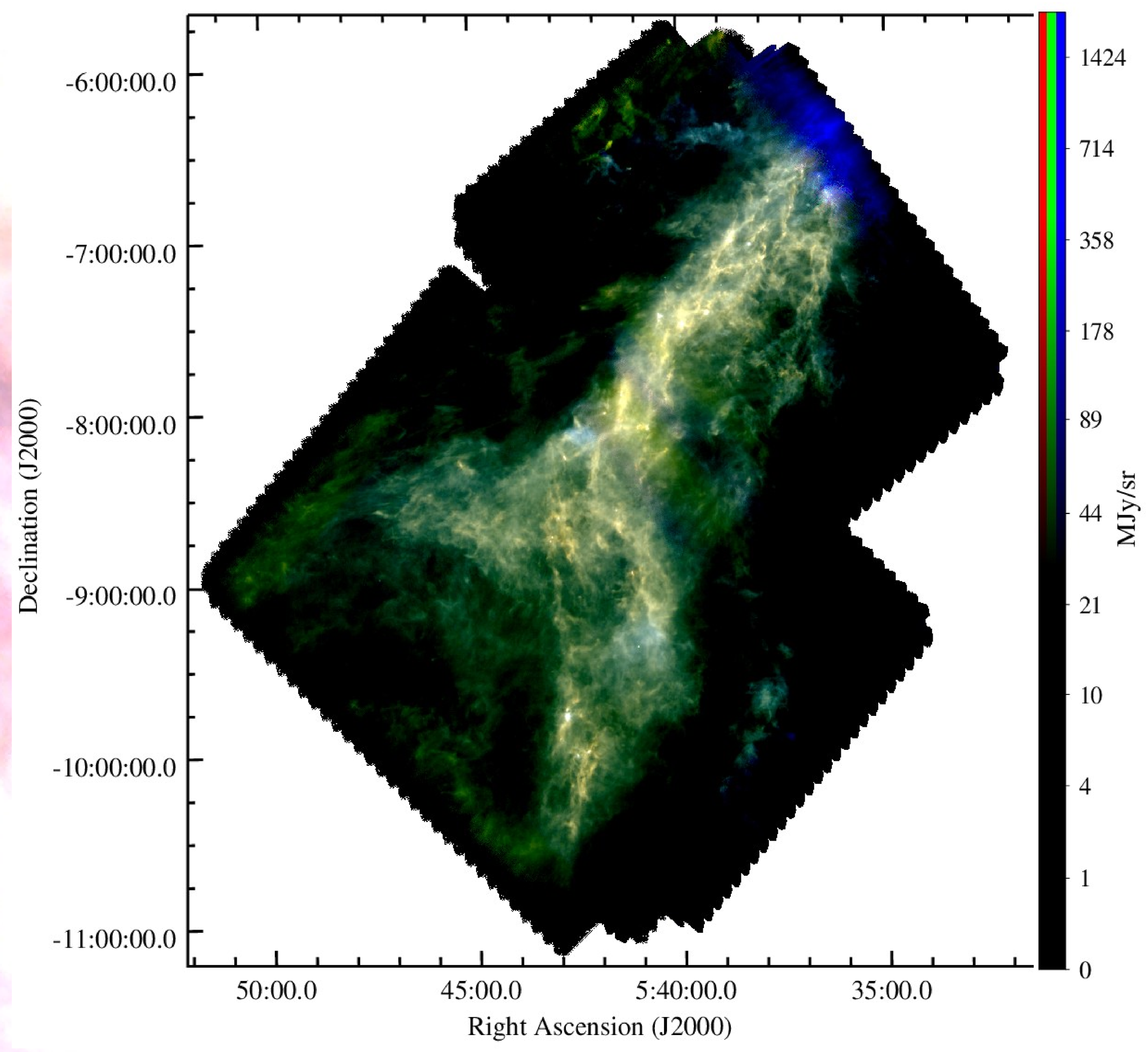


Figure 1: The RGB (red: SPIRE 350 μm; green: SPIRE 250μm; blue PACS 160μm) composite colour image of the L1641 molecular clouds. The region is seen to be permeated with a network of interconnecting filaments arranged in (partly) overlapping, V-shaped substructures. Most of the filaments lie on a coherent Northwest-to-Southeast axis, except in the southernmost parts of this map. Here, this generally collimated network of filaments splits in two directions, with some filamentary structures following an almost orthogonal direction to the above axis (i.e. from east to west).

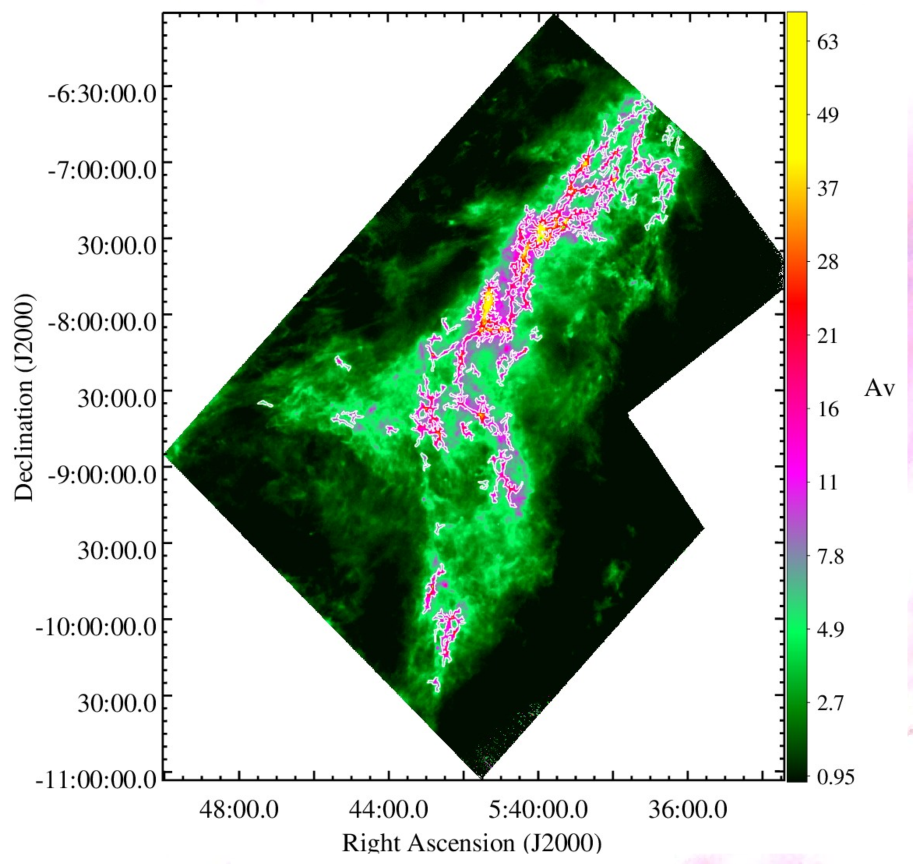


Figure 2: The column density map given in extinction scale ($NH_2 = 9.4\times10^{20}$ AV; Bohlin, Savage, & Drake 1978). The white contours trace identified filaments.

Filaments

We identify the filamentary regions on the column density map by means of algorithms for pattern recognition that start from the second derivative of the map, compute the eigenvalues of the Hessian matrix in each pixel and select the regions where the curvature along one of the eigendirections exceeds a certain threshold value. In such an approach the threshold defines the minimum variation in the contrast that is accepted to separate a filamentary region from its surrounding. Afterwards, morphological operators are applied to determine the central pixels of the identified regions (Schisano et al. in preperation). We plot the identified filaments in Figure 2.

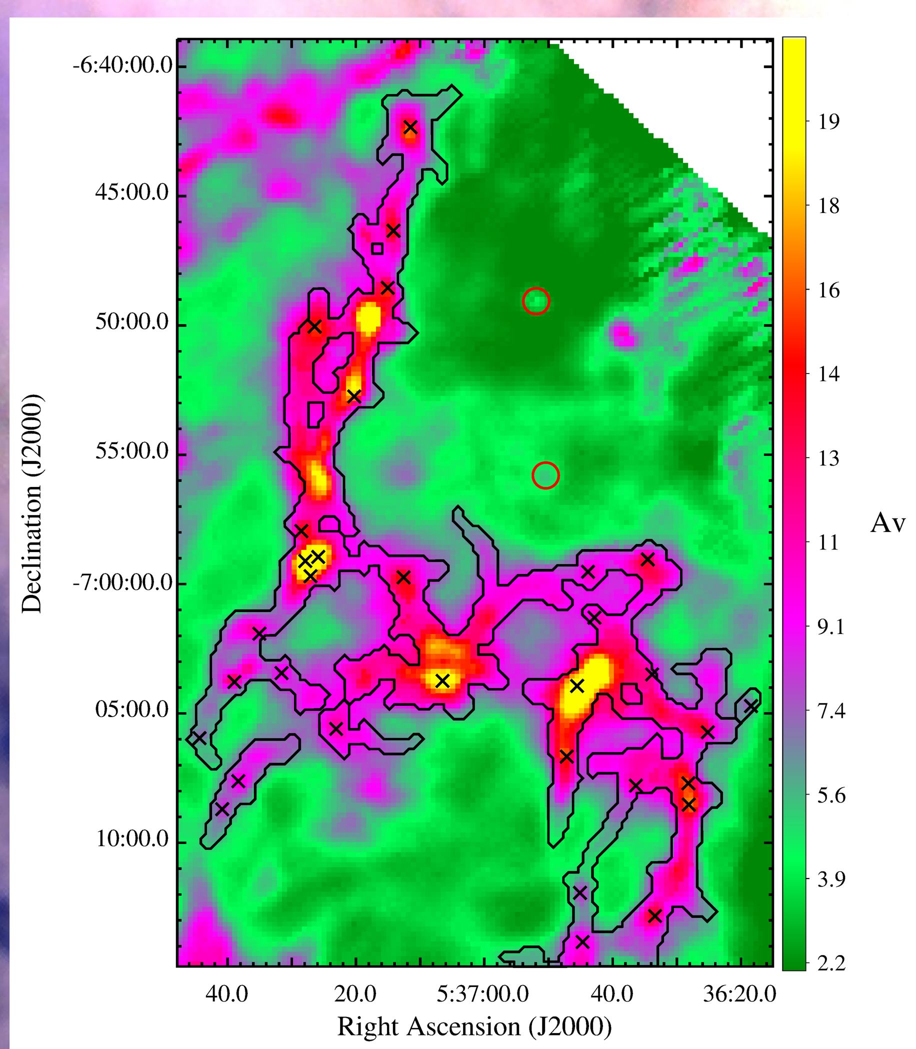
We find that the filaments across L1641 have an average width of 0.15pc, comparable to what Arzoumanian et al. (2011) find. Their lengths very from 0.5pc to 9pc, while their temperatures are generally lower than the surrounding medium at 12-13K. Their masses range from $\sim 5\ M_\odot$ to $5\times10^3\ M_\odot$. Note that all filaments have extinction higher than 5 Av and most exhibit region with extinction in excess of 20 Av.

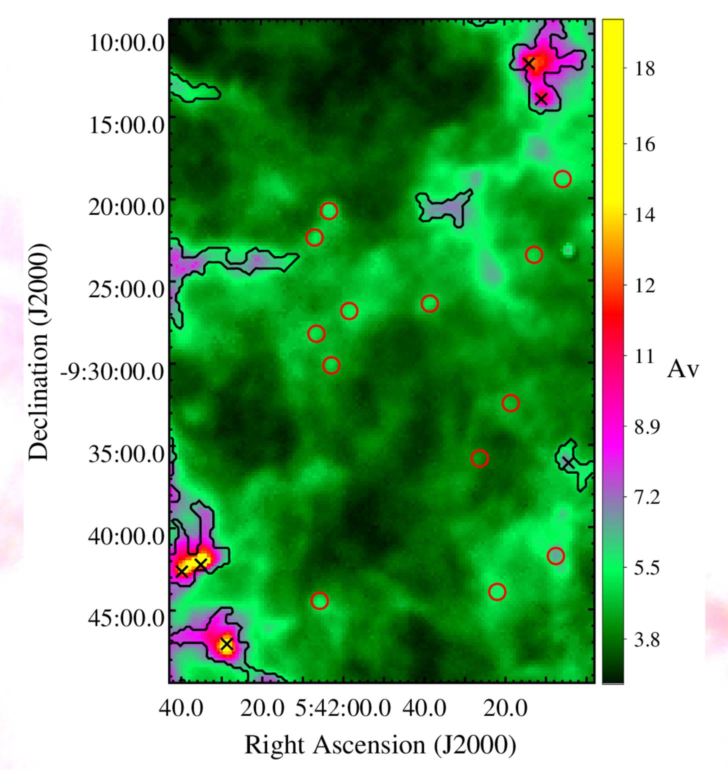
& Dense Sources

We use CuTEx (Molinari et al. 2001) to detect and extract the sources individually from each band. We accept only sources with a S/N higher than 5. We merge the five catalogues following Elia et al. 2010. We select only sources that are found in three consecutive bands and keep only those with FWHM less than 0.1pc. We find 493 sources which we fit with a grey body model, where we fix the dust emissivity index to 2 and assume $k_{1THz}=0.1cm^2g^{-1}$ (Hildenbrand 1983).

We base our proto-/pre-stellar classification on the existence of a *Herschel* 70 μm and a *Spitzer* 24μm counterpart for each of our cores. We find 109 of our sources are proto-stellar. We further differentiate between pre-stellar cores (i.e. starless, gravitationally bound cores) from starless gravitationally unbound, transient objects using the critical Bonor-Ebert mass, $M_{BE}\approx 2.4R_{BE}a^2/G$ (Bonnor 1956). We define pre-Stellar cores as those sources with $M_{obs}/M_{BE}\geq 1$.

We find that 321 of our starless sources can be classified as single core pre-stellar bound objects (84%), while 63 are starless, unbound objects. We find that the ratio between the bound and unbound sources changes from 92% when considering pre-stellar sources *on* filaments to 68% when considering those *off* filaments. In Figures 3&4 we show examples of pre-stellar sources located *on* and *off* the filaments.





Figures 3 & 4: Close up examples of two regions in the clouds. The black contours trace the identified filaments, while the crosses denote the dense cores *on* the filaments and the circles those *off* them.

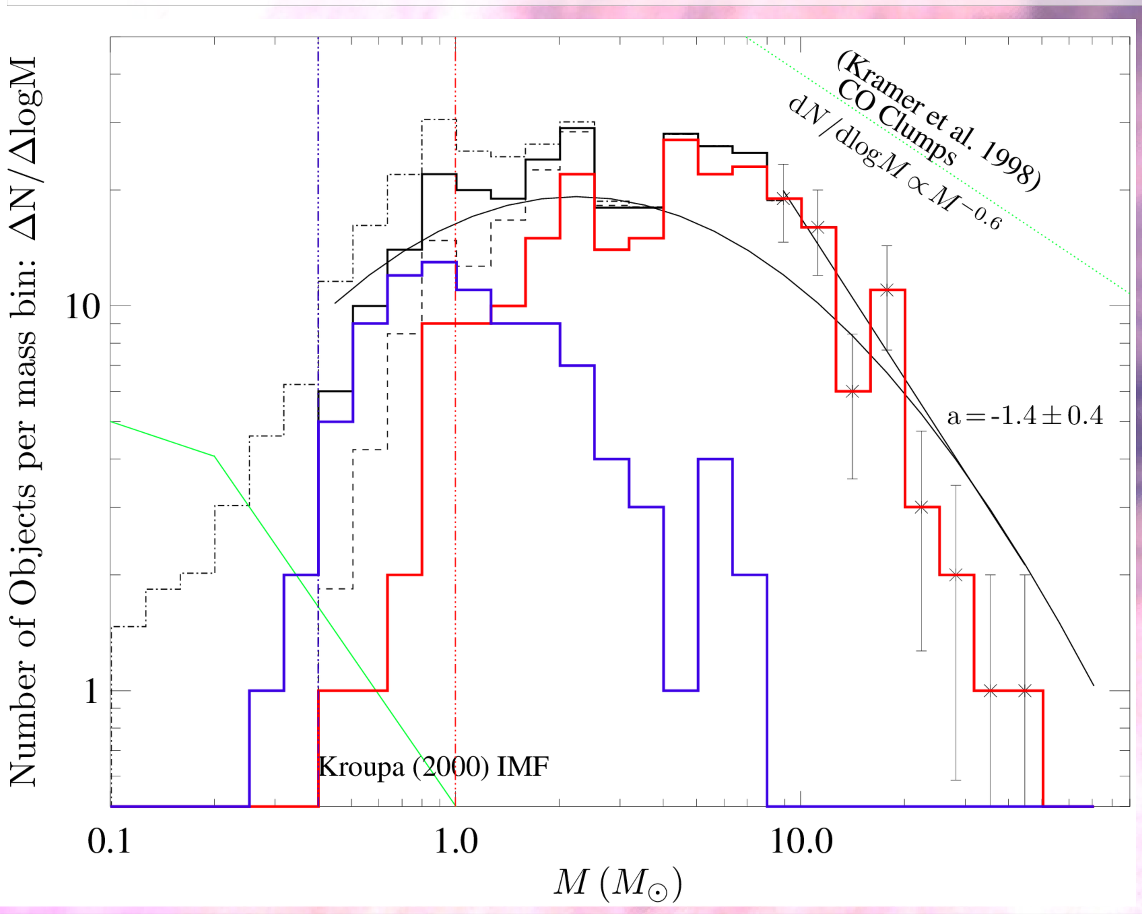


Figure 5: In black we plot the core mass function of the L1641 clouds. In red (dashed line) and blue (dash-dot line) are the mass distributions of the pre-stellar sources located on and off the identified filament regions respectively. The two vertical dashed lines represent the completeness limits of the field (at $0.4M_\odot$) and of the filament regions (at $1.0M_\odot$). The black curve is the lognormal fit to the data (peaking at $2.2\pm0.05M_\odot$ and with standard deviation of 0.6 ± 0.05) while a linear fit to the higher mass end of the CMF gives a slope of -1.4 ± 0.4.

Discussion

In Figure 5 we plot the mass distribution of the pre-stellar sources in L1641. The masses range between 0.2 and 55 $M_\odot$. The distribution of masses is seen to be quite flat between $1M_\odot$ and $4M_\odot$ and cannot be fit by a simple power law. This observed break of the core mass function at $M_\odot \sim 4M_\odot$ agrees very well with the recent models of Padoan & Nordlund (2011) where they predict such a change in slope at about this mass. A power law fit to high-mass end of the observed CMF (of the form dN/dNlogM) gives a slope of -1.4 ± 0.4, consistent with previous estimates for the Orion A molecular cloud (γ=-1.3; Ikeda, Sunada, & Kitamura 2007). In the same Figure we plot the mass distributions of those pre-stellar cores *on* filaments (71%) and those *off* them (29%). The two distributions are found to peak at two different masses; $0.8M_\odot$ for the objects located *off* filaments and $4M_\odot$ for those located *on* the filaments. We find that the slope of the CMF at larger masses is driven by the sources located *on* the filaments, while the flattening of the mass distribution at masses lower than $4M_\odot$ is the result of sources not associated with filaments.

As there is a significant difference of column densities between the filaments and the rest of the L1641, we have calculated two mass completeness limits by adding synthetic sources in each of the maps and extracting them using the same parameters as for the source extraction. For the filaments we find that the completeness limit (at the 80% level) is at $1.0M_\odot$ while *off* the filaments we are complete down to $0.4M_\odot$. Therefore, *the behaviour of the mass distributions of the two classes of cores should not be a result of incomplete sampling of cores.* We also run a Monte Carlo code to determine the degree to which filaments contribute flux to the sources located on them and if and how this affects our results. We find that generally the background contributes some flux to our sources but that only becomes significant below the completeness limits for both the distributions, thus leaving the main result unaffected.

Conclusions

We find that there are two separate mass distributions of the pre-stellar cores located *on* and *off* filaments. As filaments have higher column densities than the rest of the cloud, objects formed in situ have a larger reservoir of mass to accrete from, forming in general higher mass objects, than those *off* them. In other words, the dense cores may form in the same general way *on* or *off* the filaments, but the different environments these cores find themselves in may result in different mass distributions. The different masses probably result from simple statistical arguments, i.e. *on* the filaments there is more mass available and therefore there are higher chances of forming more massive objects. This results in a higher core formation efficiency measured on the filaments with respect to the whole of the cloud, making the filaments the preferred, but not unique, star formation site.

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References:

Andrè P., et al 2010, A&A, 518, L102 ; **Arzoumanian D.**, et al. 2011, A&A, 529, L6; **Bonnor W.B.**, 1956, MNRAS, 116, 351; **Hildenbrand R.H.**, 1983, QJRAS, 24,267; **Ikeda N.**, **Sunada K.** & **Kitamura Y.**, 2007, ApJ, 665,1194; **Molinari S.**, et al., 2001, A&A, 518, L100 **Padoan P.** & **Nordlund A.**, 2011, ApJ, 741, L22.

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