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Radial Infall onto a Massive Molecular Filament

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Abstract. The newly discovered Massive Molecular Filament (MMF) G32.02+0.05 ($\sim$ 70 pc long, 10^5 $M_\odot$) has been shaped and compressed by older generations of massive stars. The similarity of this filament in physical structure (density profile, temperature) to much smaller star-forming filaments, suggests that the mechanism to form such filaments may be a universal process. The densest portion of the filament, apparent as an Infrared Dark Cloud (IRDC) shows a range of massive star formation signatures throughout. We investigate the kinematics in this filament and find widespread inverse P cygni asymmetric line profiles. These line asymmetries are interpreted as a signature of large-scale radial collapse. Using line asymmetries observed with optically thick HCO^+ (1-0) and optically thin $H^{13}CO^+$ (1-0) across a range of massive star forming regions in the filament, we estimate the global radial infall rate of the filament to range from a few 100 to a few 1000 $M_\odot Myr^{-1}$ pc^{-1}. At its current infall rate the densest portions of the cloud will more than double their current mass within a Myr.

Keywords. stars: formation, ISM: kinematics and dynamics

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1. Data and Modelling

We observed 19 pointings toward the highest infrared-extinction region of the G32.02 + 0.05 (G32) Massive Molecular Filament (MMF; see Figure 1) with the Arizona Radio Observatory 12m over 2 nights in March 2013. We used the MAC backend in 2 IF mode with 0.08 km s^{-1} resolution to observe the $HCO^+$and $H^{13}CO^+$ (1-0) lines. We used Saturn for main beam calibration, observed in position switching mode, and reduced the data using GILDAS CLASS† software. Our effective spatial resolution is $\sim 70''$, or 1.9 pc at the distance of G32 (5.5 kpc; Battersby *et al.* 2014).

We model the spectral line emission by implementing a physical model of the G32 filament based on Herschel data into the radiative transfer code MOLLIE (Keto & Rybicki 2010). We create $N(H_2)$ and T_{dust} maps of the filament with data from Hi-GAL (Molinari *et al.* 2010) using the methods described in Battersby *et al.* (2011). The average temperature profile across the filament (a cut perpendicular to the long axis of the filament) is relatively flat, with an average T_{dust} of 16 K, with a small decrease toward the center of the filament. The average $N(H_2)$ profile across the filament can be fit with a Plummer or Gaussian profile. A Plummer profile has the form of $\rho(r) = \rho_0 / \left[1 + (r/r_{flat})^2\right]^{p/2}$ and our best fit value for the inner flat radius, r_{flat}, is 0.5 pc and the power-law index, p, is 2.1. Our best Gaussian fit gave a width (FWHM) of 2.2 pc. *The Plummer profile index is very similar to that found in Arzoumanian et al. (2011), yet our inner flat region is 15 times larger.*

† http://www.iram.fr/IRAMFR/GILDAS

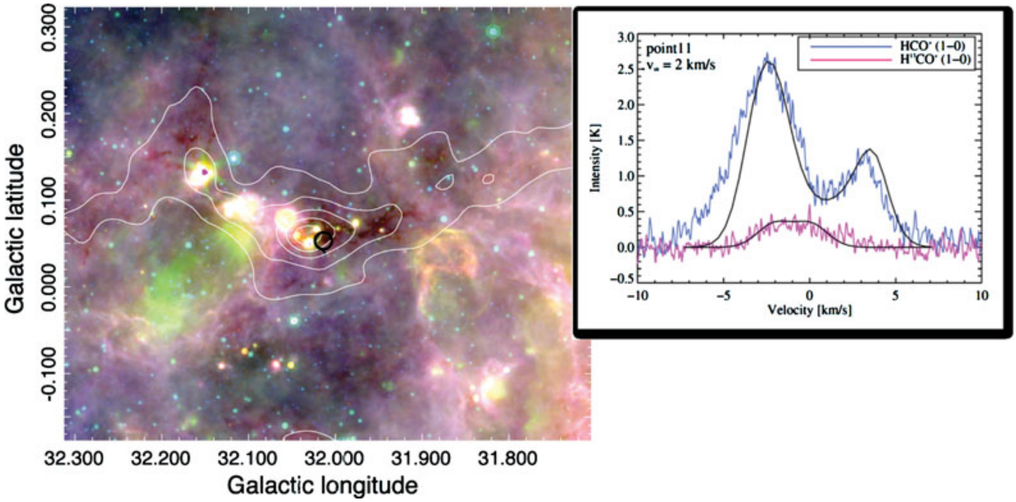

Figure 1. The G32.02+0.05 Massive Molecular Filament (MMF) shown on the *left* with 70 μm (Molinari *et al.* 2010) in red, 24 μm (Carey *et al.* 2009) in green, and 8 μm (Benjamin *et al.* 2003) in blue. The white contours show ^{13}CO-derived column density contours (N(H_2)=0.5-2.5 $\times\ 10^{22}$ cm^{-2}) from the Galactic Ring Survey (Jackson *et al.* 2006). The filament extends over 70 pc with a total mass of $\sim 10^5$ $M_\odot$ (Battersby *et al.* 2014). The spectra on the *right* is HCO^+ and $H^{13}CO^+$ (1-0) emission from the Arizona Radio Observatory 12m. The black line shows the MOLLIE radiative transfer model spectra for the filament with an infall speed of 2 km s^{-1}.

We create a physical model of a cylindrical filament using the average temperature and best-fit Plummer density profile and implement this into the radiative transfer code MOLLIE (Keto & Rybicki 2010). We add a variety of different uniform infall speeds to the physical model and run the radiative transfer code to produce simulated HCO^+ and $H^{13}CO^+$ (1-0) spectra. We compare these to our observations (see Figure 1) and find that an infall speed of 2 km s^{-1} best fits the data.

2. Results

We detect widespread infall signatures (inverse P cygni profiles) toward the G32 massive molecular filament. Herschel data show that the G32 filament density profile is well-modeled by a Gaussian or Plummer profile with an index of 2, while the temperature profile is mostly flat with a small dip in the center. We implement a physical model of the filament into a radiative transfer code and find that the inverse P cygni profile is best fit with an infall velocity of 2 km s^{-1}. Using a simple equation for the mass flow across a cylindrical surface, $\dot{M} = \rho\sigma v$, we find that at a radius of 1 pc, and a variety of reasonable densities from our Herschel fits, an infall speed of 2 km s^{-1} corresponds to several 100 to several 1000 $M_\odot$ pc^{-1} Myr^{-1}. The mass per unit length of the G32 filament varies from several 100 to several 1000 $M_\odot$pc^{-1}, so our infall rates correspond to roughly *doubling the mass of the filament on the timescale of a Myr.*

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