# Origin of magnetically elongated cold neutral media in multiphase interstellar media

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The atomic hydrogen cold neutral media (HI-CNM) is one of the most popular and important astrophysical observables that came to the researchers' eyes in the last decade. Observations like HP4PI [1], GALFA[2], THOR-HI, FAST have advanced our understanding of CNM, including its spatial distribution [6-7], relation to magnetic field [8-9] and its connection to underlying molecular phase [10] . CNM is ubiquitous in interstellar media (ISM), spanning from high latitude [6,9] to the galactic plane [11], and being highly filamentary with filament aligned along the magnetic field direction [6,12,13]. The observed parallel HI filaments generally have a very high aspect ratio, from 30-400 [6,11], and are proposed to be associated to cold features [14,15]. Given the ubiquity of these long, cold and thin filaments on the full sky (~0.1pc thick, [16,17]), there must be a universal mechanism favoring long CNM to form. One of the most common explanations is the equally ubiquitous magnetized turbulence [18] shaped the multiphase media according to the Goldreich-Sridhar scaling (GS95, [19], see also [20,21]). This scaling predicts filaments in the isothermal MHD turbulence could be scaled as $l_\parallel/l_\perp \sim M_A^{-4/3}\left(\frac{L_{inj}}{l_\perp}\right)^{1/3}$, and could left imprint to the observed velocity channel maps [22]. However, recent work [23] suggests that high density cold features under GS95 are significantly longer than what is expected in observations.

In this talk, we recognize a new type of instability due to the non-trivial nature of the pressure force in the unstable phase via theoretical and numerical efforts [24]. We provide a new estimation of the average CNM filament aspect ratio with the consideration of force balances at the phase boundary, which is roughly 5-20 in common CNM environment. By performing multiphase numerical simulations with realistic heating and cooling, we show that most of the cold filaments are less filamentary than what usually predicted via MHD turbulence theory or inferred from observations: (1) The average length of CNM filament is roughly 1/2 of that in isothermal MHD turbulence with similar turbulence conditions. (2) Filaments that are longer than the expected length are subjected to instability and fragmentate into smaller segments. (3) Anisotropic features observed in HI emission maps with aspect ratio of ~100 are unlikely to be cold density features, but warmer, thermally unstable features.

**References**

[1] Kalberla et.al (2015); [2] Peek et.al (2018); [3] Beuther et.al (2016); [4] Wang et.al (2020); [5] Li et.al (2021); [6] Kalberla et.al 2016; [7] Kalberla et.al 2018, [8] Heilis & Troland (2003); [9] Clark et.al (2015); [10] Kritsuk et.al (2017); [11] Solar et.al (2020); [12] Yuen & Lazarian (2017a); [13] Lazarian & Yuen (2018a); [14] Clark et.al 2019; [15] Peek & Clark (2019); [16] Kalberla et.al 2020; [17] Kalberla et.al (2021); [18] Yuen et.al 2022b; [19] Goldreich & Sridhar (1995); [20] Lazarian & Vishniac 1999; [21] Xu et.al 2019; [22] Yuen et.al (2021); [23] Yuen et.al (2022a); [24] Ho, Yuen, Lazarian (2022)

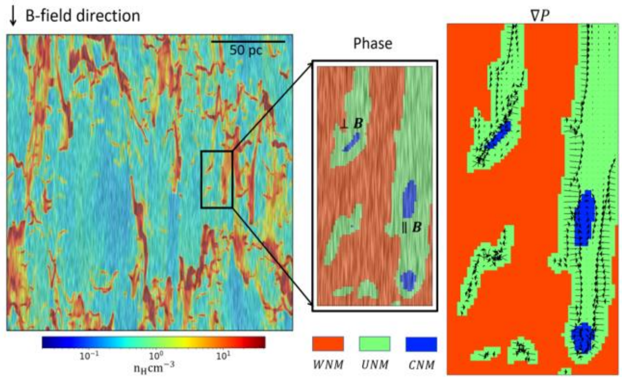


**Figure 1**: Left: 3D density plot in a MHD multiphase simulation overlaid with magnetic field. Middle: Phase recognition diagram from a selected local region based on the cut-off from the right panel of Fig 2 with magnetic field directions. This region features two different types of the CNM: the upper left has a perpendicular CNM filament formed due to collapses of UNM; and on the right-hand side a parallel CNM filament is formed. One can very easily recognize that the elongated features are UNM (green), but not CNM (blue region). CNM is generally more roundish. Right: Pressure gradient (UNM/CNM) overlaid with phase recognition diagram. The pressure force for UNM is pointing towards the CNM, while that of CNM is repelling, the balances of these two forces determine the geometry of CNM.