Large-scale filamentary structures around the Virgo Cluster

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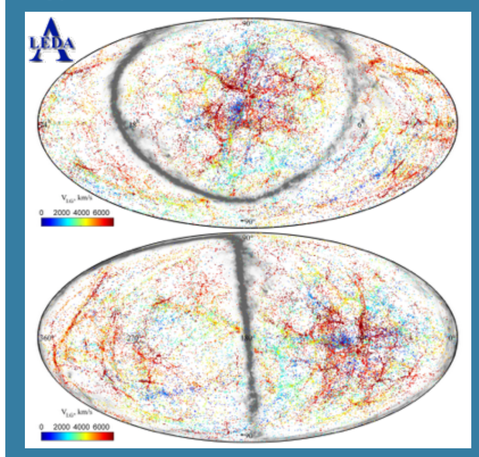
ABSTRACT

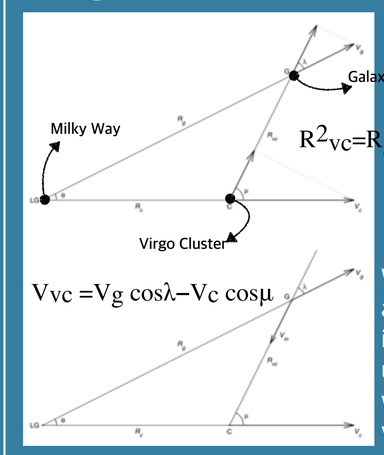
We report the finding of seven large-scale filamentary structures and one sheet of galaxies in the vicinity of the Virgo cluster, based on the HyperLeda database. We utilized available kinematic information of galaxies, including a large number of low luminosity galaxies. Six filaments are identified in the distance range 4 h^{-1} Mpc < SGY < 16 h^{-1} Mpc. The long axes of these filaments are directed toward the Virgo cluster. The Hubble diagram of the filament galaxies shows evidence of infall motion in the direction of the main body of the Virgo cluster. We also identified one filament (NGC 5353/4 filament) and one sheet (W-M sheet) located behind the Virgo cluster in the range 16 h^{-1} Mpc < SGY < 27 h^{-1} Mpc. The NGC 5353/4 filament is elongated toward the galaxy pair NGC 5353/4, while the W-M sheet includes galaxies from the W and M clouds of the Virgo cluster. In the Hubble diagram, the NGC 5353/4 filament galaxies exhibit infall motion toward the NGC 5353/4 group, whereas W-M sheet galaxies do not show hints of gravitational influence of the Virgo cluster. We found that the collinear distribution of giant elliptical galaxies along the fundamental axis of the Virgo cluster appears to be smoothly connected to these two filaments. The exact locations of these filament structures around the Virgo cluster are instrumental to better understand the large scale structure and its influence on the build-up of the galaxy cluster at z ~ 0.

1. DATA

HyperLeda database



2. Transformed into Virgocentric coordinates



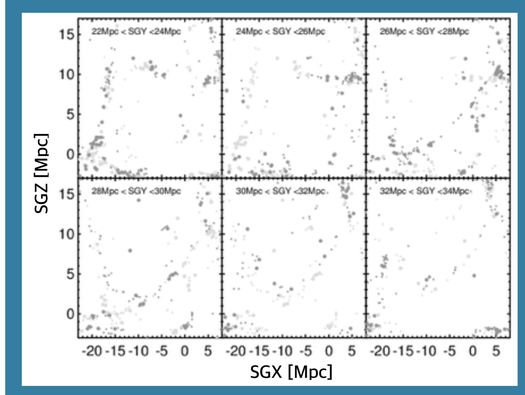
$$R^2_{VC} = R_g^2 + R_c^2 - 2R_gR_c\cos\Theta.$$

$$V_{VC} = V_g\cos\lambda - V_c\cos\mu$$

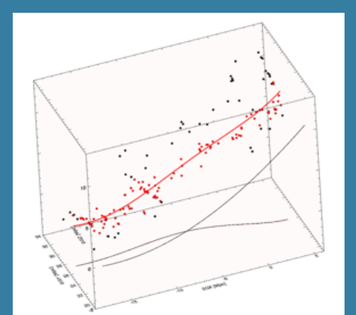
We assume that the galaxy and the cluster center are involved in an almost unperturbed Hubble flow with negligible peculiar velocities

Karachentsev and Nasonova (2010)

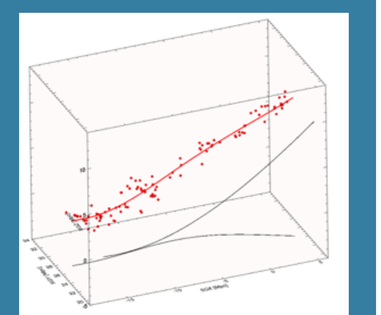
3. Finding Filament structures



The overdense, long thin filament structures were selected by visual inspection in the SGX-SGZ plane for a series of SGY slices with 2 h^{-1} Mpc thickness. If a filament was continuously shown in consecutive SGY slices, we determined its full range of the SGX, SGY, and SGZ.



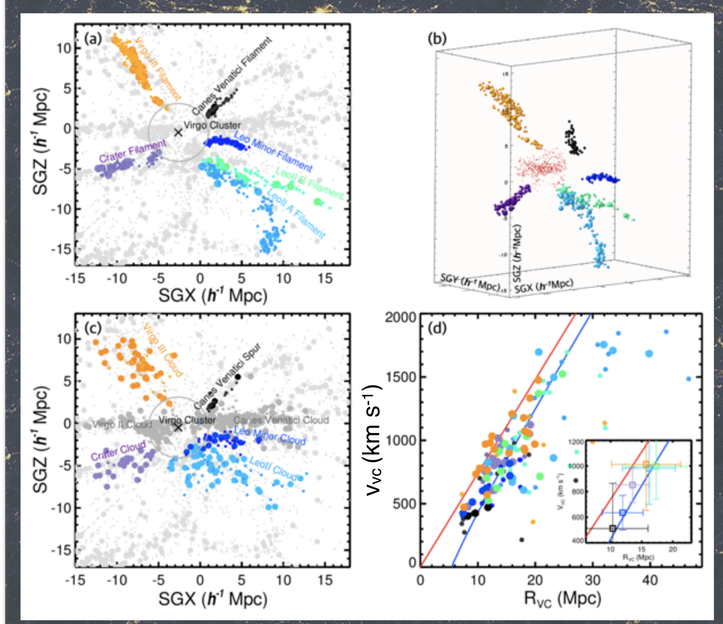
In the SGX-SGY-SGZ three-dimensional space, we performed third-order polynomial fitting with weighting of local galaxy density to the visually selected filament structures. If the standard deviation of the fitting was less than 1.5 h^{-1} Mpc, the structure was defined as a final filament.



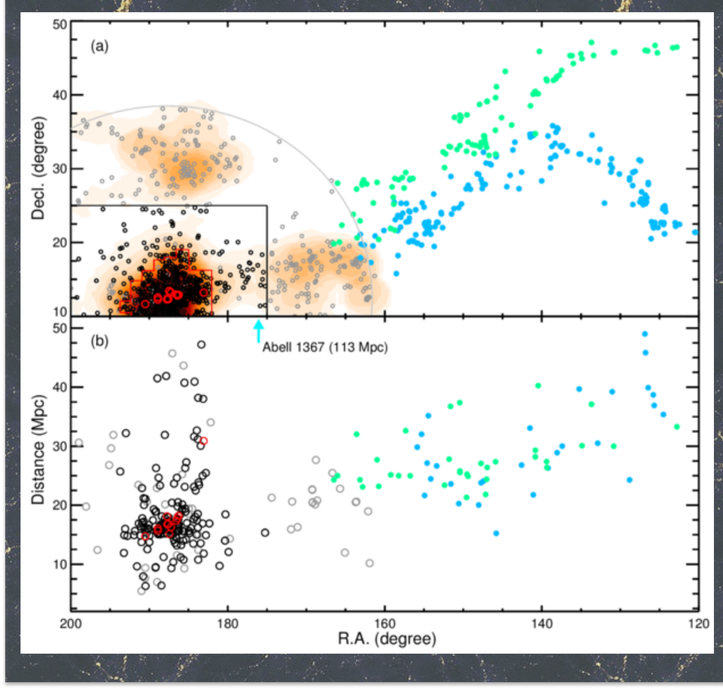
We applied two-sigma clipping to the polynomial fitting line (i.e., filament spine) for the extraction of galaxies that belong to each filament.

4. Virgo related structure (4 < SGY < 16 h^{-1} Mpc)

Six filaments are identified in the 4 h^{-1} Mpc < SGY < 16 h^{-1} Mpc. All the filaments coincide with structures designated as clouds or spurs by Tully (1982). Our sample includes a greater number of galaxies than that of Tully (1982), which al- lows us to define narrow, long filament structures. The spines of all filaments are directed toward the Virgo cluster. We found that most galaxies in all filaments show a distinct deviation of their radial velocities from the Hubble flow and are consistent with the expected radial velocity profile of infalling galaxies. This suggests that all filaments in this SGY range are associated with the Virgo cluster and under its gravitational influence. Furthermore, we have shown that the collinear distribution of gi- ant elliptical galaxies along the fundamental axis of the Virgo cluster appears to extend smoothly toward the Leo II A and B filaments.



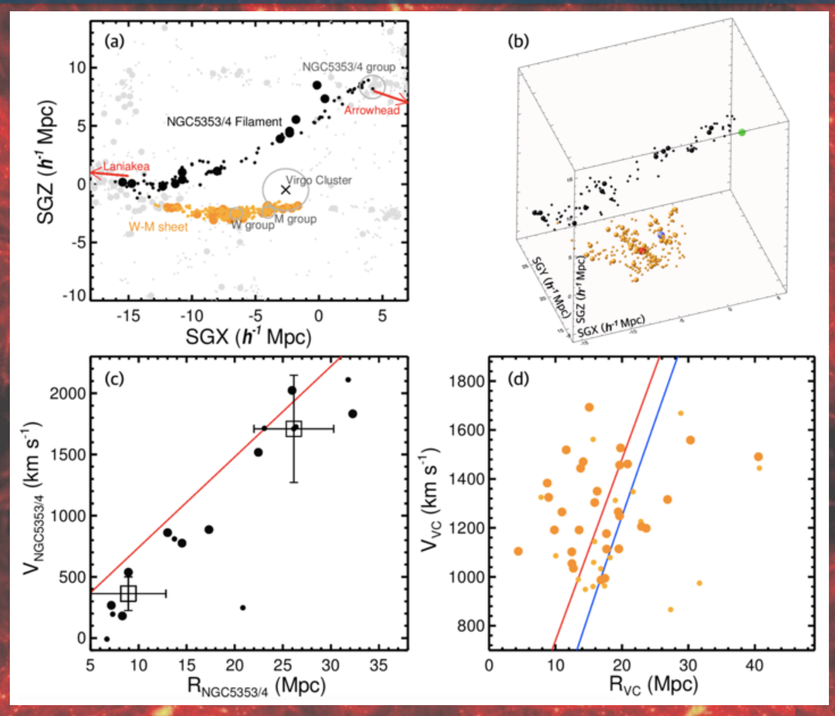
Spatial distribution (a-c) and Hubble diagram (d) of six filaments in the range of 4 h^{-1} Mpc < SGY < 16 h^{-1} Mpc. The filled circles with different colors denote galaxies in different filaments. The gray filled circles are all galaxies in the same SGY range from the HyperLeda data. Bright (M_B < -19) and faint (M_B > -19) galaxies are denoted by large and small filled circles, respectively. (a) Spatial distribution of the filaments in the SGX-SGZ plane. The large gray circle indicates the area of the Virgo cluster within two virial radius. (b) Spatial distribution of the filaments in the SGX-SGY-SGZ plane. The red dots are Virgo cluster galaxies from the EVCC (Kim et al. 2014). (c) Spatial distribution of the structures mentioned by Tully (1982). (d) Hubble diagram of the filament galaxies in the Virgo-centric reference frame. The red and blue solid lines represent the Hubble flow and the expected radial velocity profile caused by the gravitational pull of the Virgo cluster, respectively. The inset shows median values of radial velocities and distances of filament galaxies with R_{VC} < 30 Mpc and their standard deviations marked by error bars.



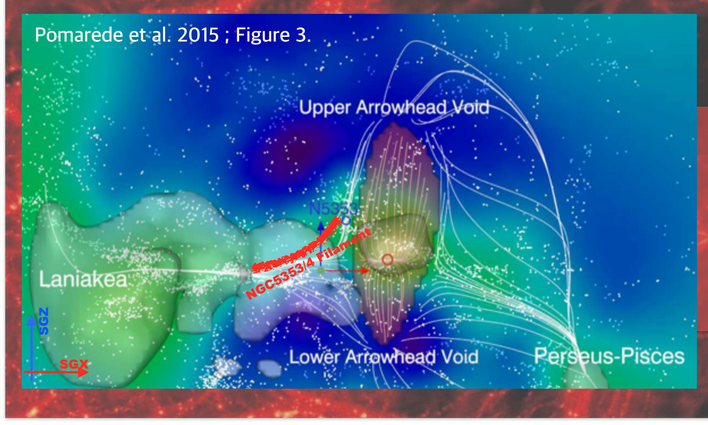
(a) Spatial distribution of galaxies in the Leo II A (cyan circles) and B (green circles) filaments around the Virgo cluster. The red and black open circles are the bright (M_r < -19) elliptical galaxies and certain member galaxies in the EVCC, respectively. The gray open circles represent the galaxies in the range of 4 h^{-1} Mpc < SGY < 16 h^{-1} Mpc from the HyperLeda data. The red contour and large rectangular box denote the regions of the VCC and the EVCC, respectively. The large gray circle is the upper limit of the zero-velocity surface with 26 deg radius. (b) The R.A. vs. distance from us of galaxies. The symbols are the same as in the top panel. The direction (cyan arrow) to the Abell 1367 and its distance are marked.

5. Background structure from the Virgo Cluster (16 Mpc < SGY < 24 Mpc)

One filament and one sheet are identified in the 16 h^{-1} Mpc < SGY < 27 h^{-1} Mpc, which are located behind the main body of the Virgo cluster. The filament, dubbed as the NGC 5353/4 filament, is a newly discovered structure in this study. The NGC 5353/4 filament is directed toward the NGC 5353/4 group. In the Hubble diagram, the NGC 5353/4 filament exhibits a hint of the infall motion toward the NGC 5353/4 group. The sheet structure (W- M sheet), which includes galaxies in the W and M clouds of the Virgo cluster, suggests no feature of its infall motion into the Virgo cluster.



Spatial distribution (a, b) and Hubble diagram (c, d) of NGC 5353/4 filament (black filled circles) and W-M sheet (yellow filled circles) in the range of 16 h^{-1} Mpc < SGY < 27 h^{-1} Mpc. Bright (M_B < -19) and faint (M_B > -19) galaxies are denoted by large and small filled circles, respectively. (a) Spatial distribution of the structures in the projected SGX-SGZ plane. The gray filled circles are all galaxies in the same SGY range. The directions to the Arrowhead and Laniakea superclusters are marked with red arrows. (b) Spatial distribution of the structures in the SGX-SGY-SGZ plane. The red, blue, and green filled circles denote the W cloud, M cloud, and the NGC 5353/4 group, respectively. (c) Hubble diagram of the NGC 5353/4 filament galaxies in the NGC 5353/4-centric reference frame. The red solid line represents the Hubble flow. The open squares denote the median values for the NGC 5353/4 filament galaxies in different distance ranges. The error bars are standard deviations of the values. (d) Hubble diagram of the W-M sheet galaxies in the Virgo-centric reference frame. The red and blue solid lines represent the Hubble flow and the expected radial velocity profile caused by the gravitational pull of the Virgo cluster, respectively.



NGC 5353/4 filament appear to connect two superclusters of the Arrowhead supercluster and the Laniakea supercluster (e.g., Pomarede et al. 2015).