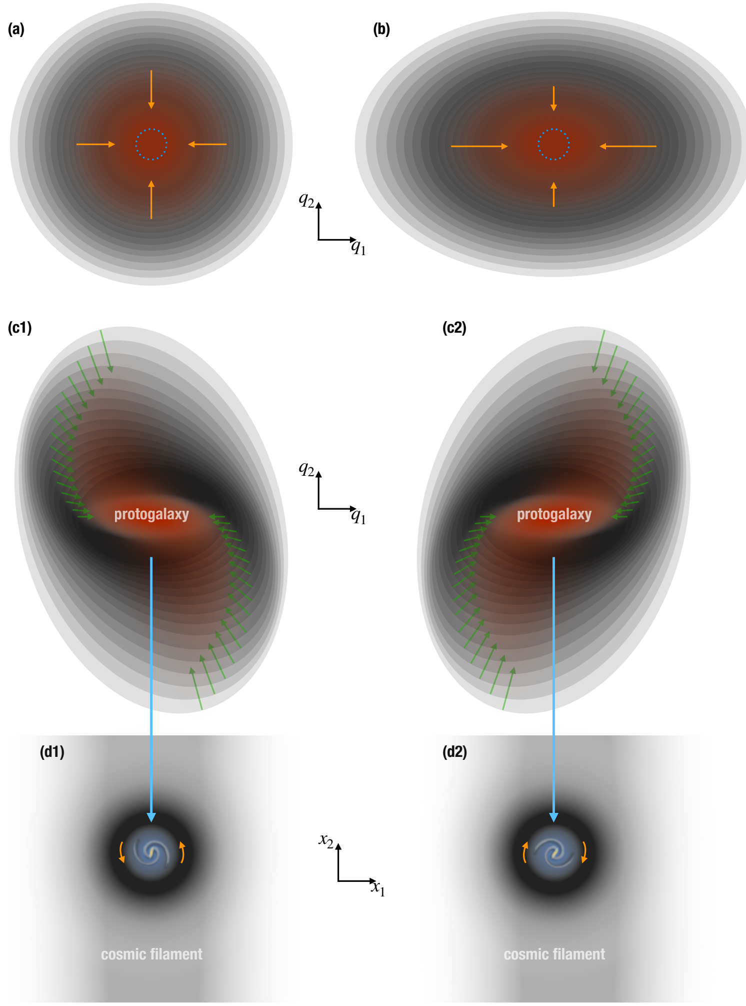

Figure 1 — Prediction of the galaxy spin in a 2D universe.

In a 2D universe, we use the axes a_1, a_2 (and their alignments) of the ellipses to represent the eigenvalues λ_1, λ_2 (and the alignments of their eigenvectors $\pm v_1, \pm v_2$) of a tidal tensor $\mathbf{T} = (T_{ij}) = \partial_{q_i}\partial_{q_j}\phi$. Longer axes mean relatively greater convergence forces. Larger ellipses mean averaged tidal tensors over a larger area, equivalently $\mathbf{T}$ on a larger smoothing scale.

(a) Isotropic tidal field. Due to the isotropy, a rivialized round object (inside the blue dotted circle) was clustered by an isotropic Lagrangian region (red cloud).

(b) Anisotropic, scale-independent tidal field. The convergence of gravity along q_1 is larger than that of q_2, and on different smoothing scales major axes of $\mathbf{T}$ are aligned with q_1. In contrast with (a), more matter along q_1 is clustered (longer orange arrows along q_1) and thus the Lagrangian region is elongated along q_1.

(c) Anisotropic, scale-dependent tidal fields. Similar to (b), but the alignment of the major axes of $\mathbf{T}$ is varying anticlockwise (c1) and clockwise (c2) on larger scales. As a result, in contrast with (b), the Lagrangian regions will be slightly tilted due to the hierarchically differential inflows and the hierarchically differential tidal torques. They are illustrated by the major axes (pairs of green arrows) of $\mathbf{T}$ on different scales.

(d) Evolution of the two systems from (c) into two halo-galaxy systems inside a filament (grey bar). The tidal torques have opposite signs, spinning the halo-galaxy systems in opposite directions. As a result, (d1) ends up with spin pointing out of the screen $(j > 0)$ and we observe an "S"-shaped spiral galaxy, while (d2) has spin pointing into the screen $(j < 0)$ and we observe a "Z"-shaped spiral galaxy.

Comments:

(1) In our Universe, we are able to reconstruct the initial gravitational potential (c1,c2) from the positions of galaxies, and thus predict the oriented spins of galaxies (d1,d2).

(2) We are able to predict the full 3D direction of the spin, so we can explicitly distinguish between j and $-j$. Measurements of galaxy shapes (intrinsic alignments) cannot provide such a distinction.