Rotations and translations are correlated in a two-dimensional chiral fluid of active particles

M. A. López-Castaño[1], A. Márquez Seco[1], A. Márquez Seco[1],
A. Rodríguez-Rivas[3] and F. Vega Reyes[1,2*]
[1]Departamento de Física, Universidad de Extremadura, 06071, Badajoz, Spain
[2] Instituto de Computación Científica Avanzada (ICCAEx), Universidad de Extremadura, 06071, Badajoz, Spain
[2]Department of Physical, Chemical and Natural Systems, Pablo de Olavide University, 41013, Sevilla, Spain
∗ email: fvega@eaphysics.xyz

Chiral fluids have recently received much attention, mainly because they are ubiquitous in important biological processes, and their dynamics is specially relevant in transport mechanisms at the cellular level (see [1] and references therein). These chiral fluids are usually composed of particles with some kind of geometric or dynamic asymmetry, which breaks the system symmetry under parity and temporal inversion, i.e., they are composed of particles whose geometrical/dynamical configuration has *chirality* [1].

Moreover, the conventional hydrodynamic theory of fluids does not describe the complex behavior observed in chiral fluids. For instance, a whole new set of transport coefficients emerges in these fluids, generically termed as *odd* (diffusion, viscosity…) [2].

We demonstrate in this work, by means of a theoretical analysis, that translations and rotations are intrinsically correlated in the experimental data we obtained. Furthermore, their correlations essentially determine the hydrodynamics of chiral fluids in such a way that the global vorticity sign (particle chirality yields chiral flow and hence global fluid vorticity can be non-null, contrary to standard fluid convection) mimics the sign of a specific cumulant of the distribution function that we named *bend coefficient*, in close analogy with glassy systems. As we will explain in our presentation, the distribution function first 4 cumulants (that characterize deviations out of the equilibrium distribution function) can be defined as

$$a_{20}^{(0)}(r) = \frac{1}{2}\left(\frac{1}{2}\frac{\langle V^4\rangle}{\langle V^2\rangle^2} - 1\right),$$
$$a_{02}^{(0)}(r) = \frac{1}{2}\left(\frac{1}{2}\frac{\langle W^4\rangle}{\langle W^2\rangle^2} - 1\right)$$
$$a_{11}^{(0)}(r) = \frac{1}{2}\left(\frac{\langle V^2W^2\rangle}{\langle V^2\rangle\langle W^2\rangle} - 1\right),$$
$$a_{00}^{(b)}(r) = \frac{3}{2}\frac{\langle(\mathbf{v}\times\mathbf{w})\cdot\hat{\mathbf{e}}_\varphi\rangle}{\sqrt{\langle V^2\rangle\langle W^2\rangle}}. \tag{1}$$

Where W, V denote particle angular and translational peculiar velocity (i.e., measured with respect to their corresponding average [1]), respectively, and $\hat{e}_\varphi$ the unit vector in the azimuthal direction. The bend coefficient is $a_{00}^{(b)}$. Additionally, the ratio between translational and rotational global average kinetic energies, $\overline{T}_t/\overline{T}_r^*$, also plays an important role in the chiral flow phase behavior [1].

We acknowledge funding from the Government of Spain (AEI) and Junta de Extremadura through projects No. PID2020-116567GB-C22) and GR21091 respectively. A.R.-R. also acknowledges financial support from Conserjera de Transformacin Econmica, Industria, Conocimiento y Universidades (Junta de Andalucía) through post-doctoral grant no. DC 00316 (PAIDI 2020), co-funded by the EU Fondo Social Europeo (FSE).

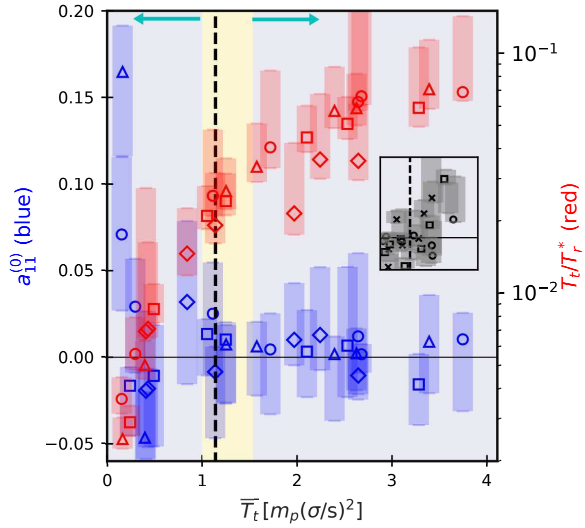

Fig. 1. (a) Particle velocity-spin correlations, vs. $\overline{T_t} \equiv \langle T_t\rangle_r$, as measured from the cumulant $a_{11}^{(0)} = \frac{1}{2}\left(\frac{\langle V^2W^2\rangle}{\langle V^2\rangle\langle W^2\rangle} - 1\right)$ (blue series, left Y axis), and the ratio $\overline{T}_t/\overline{T}_r^*$ (red series, right Y axis). Inset represents cumulant $a_{00}^{(b)}$ (dark grey color). The error bars of series of $a_{11}^{(0)}$, $\overline{T}_t/\overline{T}_r^*$ and $a_{00}^{(b)}$ points are highlighted in blueish, reddish and grey backgrounds respectively. The transition interval in $\overline{T_t}$, with complex chirality, is highlighted in yellow; a dashed line marks the chirality transition point T_c. Magnitudes are measured in different annuli of the system, each annulus marked with a different symbol: $\circ$: 0.49 σ, $\triangle$: 1.47 σ, : 2.45 σ, $\diamond$: 3.43 σ for $a_{11}^{(0)}$ and $\overline{T}_t/\overline{T}_r^*$ and $\circ$: 0.87 σ, : 2.62 σ, $\times$: 4.36 σ for $a_{00}^{(b)}$; area fraction is $\phi = 0.25$. Yellow region marks the transition of the global vorticity sign (which we observed to be continuous), and as we see coincides with the sign reversal of the bend coefficient.

[1] M. A. López-Castaño and A. Márquez Seco and A. Márquez Seco and A. Rodríguez-Rivas and F. Vega Reyes (2022), Chirality transitions in a system of active flat spinners. Preprint: arXiv:2105.02850.

[2] D. Banerjee and A. Souslov and A. G. Abanov and V. Vitelli, *Nat. Commun.* **8** 1573 (2017).