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Chiral Structured Illumination Microscopy

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Introduction

Chiral objects with opposite handedness interact differently with circularly polarized light (CPL), leading to circular dichroism (CD). These chiroptical responses provide structural information of the chiral objects which is important in many research fields. There have been attempts to perform direct chiral imaging. However, State-of-the-art chiral imaging methods suffer from low throughput, weak contrast and limited spatial resolution. Thus, a high-throughput wide-field imaging modality for chiral domain with sub-wavelength spatial resolution is highly desired. Here, we propose a wide-field super-resolution chiral imaging method, called "chiral SIM". By spatially modulating the OC of the illumination, a theoretical demonstration with super-resolution is presented.

Goal

- Wide-field microscopy method for chiral imaging ⟶ high-throughput
- Chiral imaging with super-resolution
- Ability to enhance the chiral response of the sample with optical chirality engineering ⟶ high chiral contrast

Theory

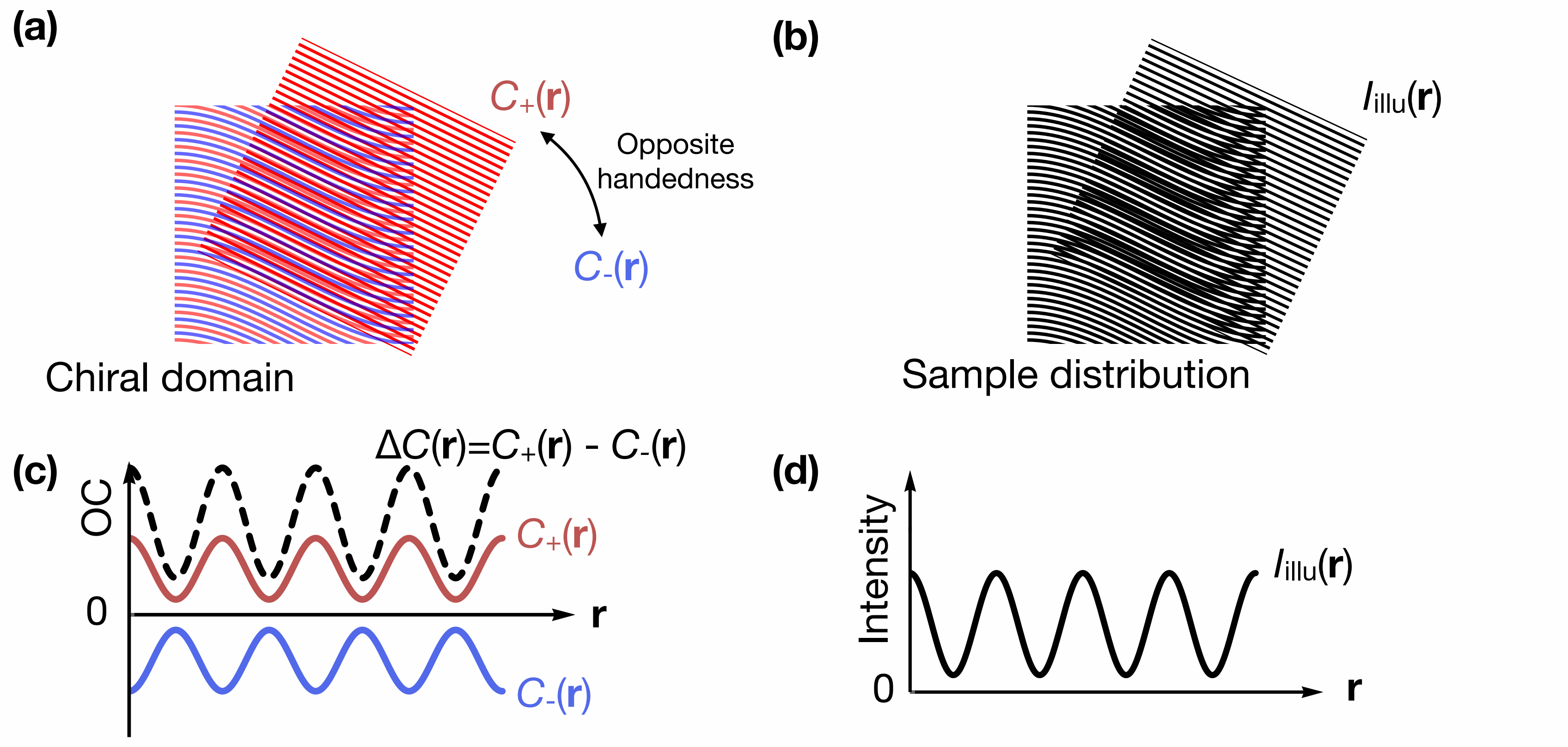

Figure 1. Moiré effect generated by the superposition of (a) structured OC pattern $C_\pm(\mathbf{r})$ and the chiral domain distribution, and (b) structured intensity pattern $I_{\mathrm{illu}}(\mathbf{r})$ and the sample distribution. (c) Spatially structured OC patterns employed in chiral SIM. (d) Spatially structured intensity pattern employed in conventional SIM.

- **Optical chirality** $$C = -\frac{\varepsilon_0\omega}{2}\mathrm{Im}(\vec{E}^* \cdot \vec{B})$$
- **Electric Energy density** $$U_e = \frac{\varepsilon_0}{4}|\vec{E}|^2$$
- **Chiral molecule absorption** $$A = \frac{2\beta}{\varepsilon_0}[\omega U_e \alpha'' - CG'']$$
- **Fluorescence subimage** $$\Delta M(\vec{r}) = -\frac{2\beta}{\varepsilon_0}[C_+(\vec{r}) - C_-(\vec{r})]G''(\vec{r}) \otimes h(\vec{r})$$

Operational Procedure

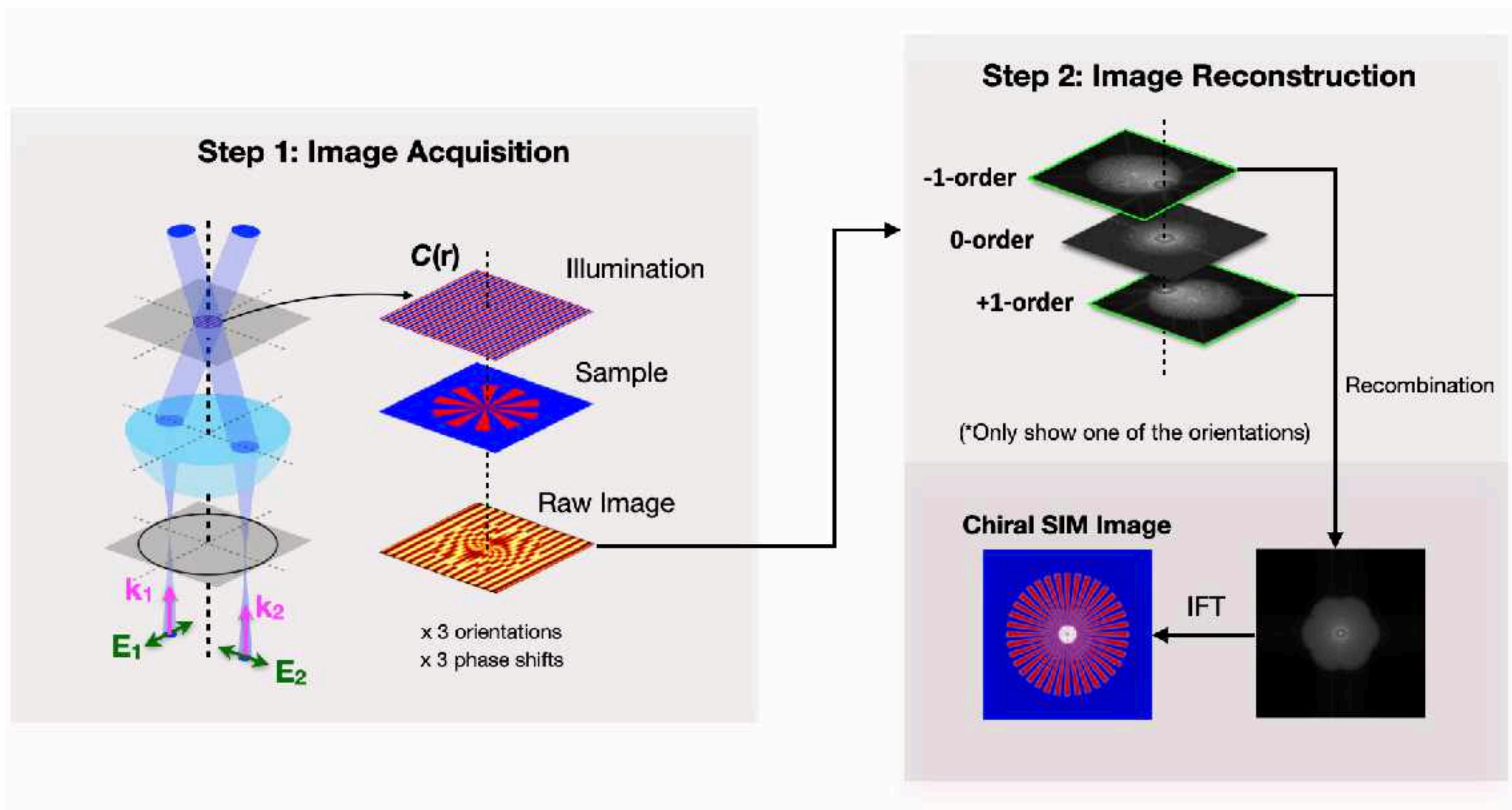

Figure 2. Illustration of the operational procedure for chiral SIM demonstration using far-field optics. Possible experimental configurations to generate structured and flat OC are illustrated on the left hand side of step 1.

Theoretical Demonstration

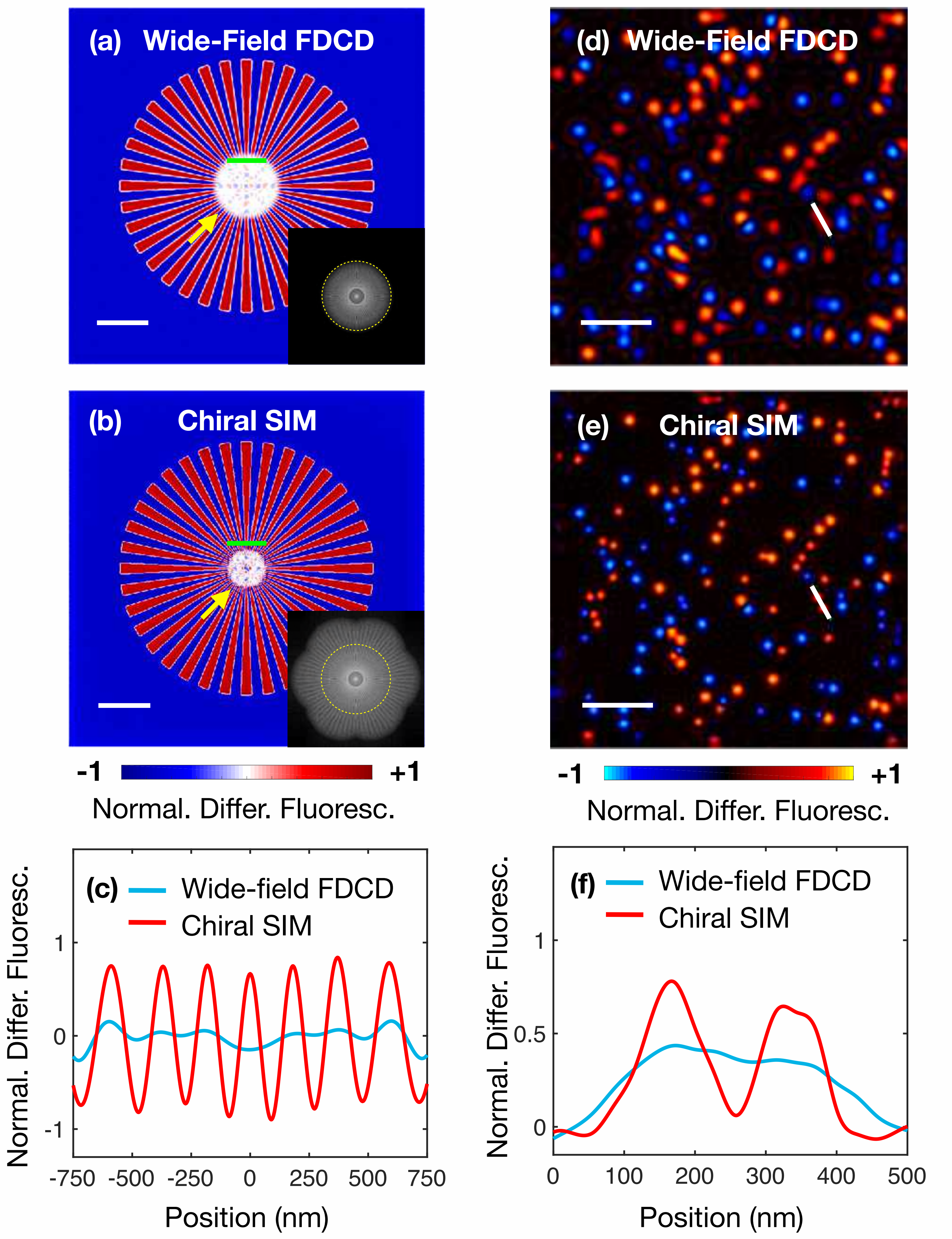

Figure 3. Theoretical demonstration of chiral SIM. Reconstructed (a) wide-field FDCD and (b) chiral SIM image of a chiral Siemens star. Inset: Corresponding Fourier domain images. Scale bar: 2 µm. (c) Spatial profiles along the line indicated by the black lines in (a) and (b). Reconstructed (d) wide-field FDCD and (e) chiral SIM image of randomly-distributed chiral beads in an achiral background. Scale bar: 1 µm. (f) Spatial profiles along the line indicated by the green lines in (d) and (e).

Conclusion

In summary, we have introduced and theoretically demonstrated chiral SIM, which utilizes illuminations with structured OC patterns, for wide-field super-resolution chiral domain imaging. The simulation results obtained with realistic parameters from the chiral polyfluorene film with noise consideration show that chiral SIM provides higher spatial resolution than conventional wide-field FDCD imaging. Compared to other chiral domain imaging methods, the developed chiral SIM modality has the advantages of sub-diffraction limited resolution and high image acquisition rate. In addition, chiral SIM provides a possible way to gain higher sensitivity and spatial resolution when rationally designed plasmonic nanostructures are implemented.