# Response to the comments of Reviewer #2

First of all, we would like to thank the two anonymous reviewers for their thoughtful reviews and valuable comments on the manuscript. In the revision, we have accommodated all the suggested changes into consideration and revised the manuscript accordingly. All changes are highlighted in the revised manuscript in **BLUE** in the revision. In this response, the questions and comments of reviewers are in **BLACK** font, and responses are highlighted in **BLUE.** The changes made in the revised manuscript are marked in **RED** font.

**Comments:** The paper "*The polarimetric characteristics of dust with irregular shapes: Evaluation of the spheroid model*" presents and discusses the development of a new dust shape model using DDA calculations.The authors simulate the effect of external forces (i.e. wind or rain) on initially perfectly shaped spheroid particles of dust nature, by removing dipoles close to the surface of the particle. Further, the effect of the binding force (the force from the particle centre of mass) is accounted for; and particles with larger binding force seem to turn to more spherical as the external force acts upon them. The authors further fit the resulting phase function of irregular shaped dust with spheroid particles (simulations for spheroids performed using the T-matrix algorithm) and compare the scattering matrix elements of irregular and spheroid particles. As a last step, radiative transfer simulations assuming both irregular shaped dust and the best-fitted spheroids are also performed and compared.

The study falls well within the scope of AMT and the results could be very significant for scientific community. Nevertheless, in order to help improving the manuscript, I would kindly suggest the authors to take into account the following specific comments.

**Response:** Thanks for your comments. The responses are shown in the following.

**Comments:** 1) As I also stated in my initial review of the manuscript, I consider the range of input parameter values selected for the calculations, quite limited. The simulations are performed in only one specific wavelength (670nm) which is a frequently used wavelength for ground-based and satellite polarimetric measurements. AOD, SZA, surface albedo and complex refractive index (m) were also selected as single values.

**Response:** Thanks for your comments. We selected 670 nm wavelength as a typical example to show the effects of irregular shape on the polarimetric characteristics because it is a frequently used wavelength for ground-based and satellite polarimetric measurements. For sensitivity analysis, we have added some cases in the 490nm and 865 nm in the revised manuscript. As you said, the AOD, SZA, surface albedo and complex refractive index (m) can have an important impact on polarimetric characteristics. In the revised manuscript, we added some sensitivity analysis to investigate how these parameters affect the effects of dust shapes. However, we think that these materials don't affect the main conclusion of this manuscript.

Thus, we put these materials in the support information.

**Comments:** For the latter, the authors select to use m = 1.52 + i0.005 for their calculations. However, the previous literature cited to justify this selection, corresponds to either dust mixtures with more absorbing particles (i.e. smoke; Dey at al., 2006) or results for dust have been omitted (Beelen et al. (2014). I realize that the main conclusions of the study won't change much, however I believe that additional values should be accounted for (see for example studies from Petzold et al. (2009) (k ranges from 0.0003 to 0.0017 at 700nm); Wagner et al. (2012) (k ranges from 0.0023 to 0.0051 at 655nm) or at least the authors should discuss possible effects of different refractive indices on their simulations.

In the following, I try to illustrate my concerns with a simple example where I have used the spheroid kernels developed and presented in Dubovik et al. (2006). Assuming a mono-modal, lognormal size distribution with geometric radius rg = 2.32μm with a standard deviation σ = 0.02 (see Fig. 1; as narrow as possible SD to simulate as closely a single particle), the normalized scattering matrix elements for particles of an axial ratio of 2.07 and 0.53 are plotted in Fig.2 and Fig.3 respectively. The elements are calculated for real part of the refractive index n = 1.54 and 2 different imaginary refractive index (k) values:

- m1 = 1.54 + i0.006 (green lines) which is more close to the value selected by the authors
- m2 = 1.54 + i0.0008 (purple lines)

As it can be seen from figures 2 and 3, the effect of k on the scattering matrix elements can –at certain angles- cause a relative difference (m1 – m2/m1) of up to 60% for the phase function, 20% for P12/P11 and even higher for P22/P11 for an axial ratio of 2.07 and similar for 0.53.

**Response:** Thanks for your comments. In the revised manuscript, we have added sensitivity analysis for the refractive index. Three other refractive indices are considered:

- m1 = 1.52 - i0.0007
- m2 = 1.52- i0.0014

- m2 = 1.52-i0.01

Figure 1 shows the effects of refractive indices on the scattering matrix. Similar phenomenon was found as the Figures you presented, larger k can lead to smaller $F_{11}$ at backscattering angles. Besides, larger $F_{22}/F_{11}$ values were observed for larger k. The imaginary part of refractive index has non-negligible impacts on the scattering matrix. The relative deviations in $F_{11}$ between cases of m = 1.52-0.01i and m = 1.52 – 0.0007i can also exceed 60% at backward angles.

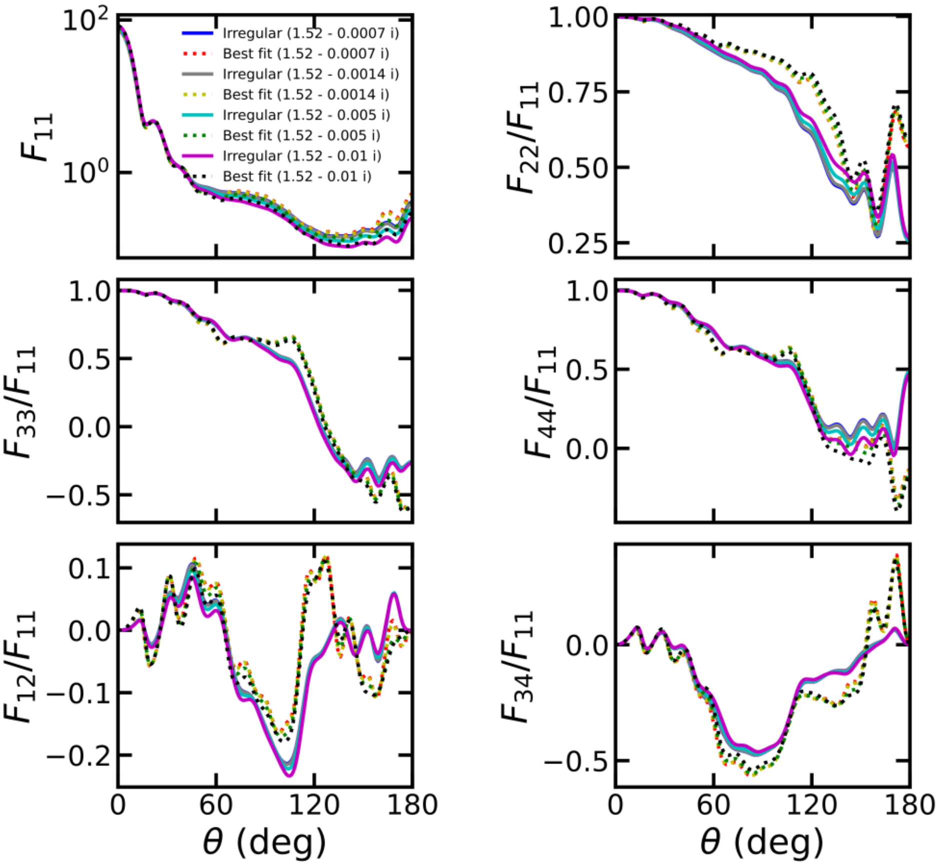


Figure 1 The sensitivity of scattering matrix of dust to the refractive index

Figure 2 shows the effects of k on the differences of scattering matrices between irregular dust and best-fitted spheroids. As shown in Figure 2, even though the angle distributions of the deviations between the irregular dust and best-fitted spheroids are similar for different k, some sizable differences for the deviations between irregular dust and best-fitted spheroids are observed at certain angles for different k. The differences of relative $\Delta$F11 between m = 1.52-0.01i and m =1.52 – 0.0007i can reach approximately 18% at backward scattering angles.

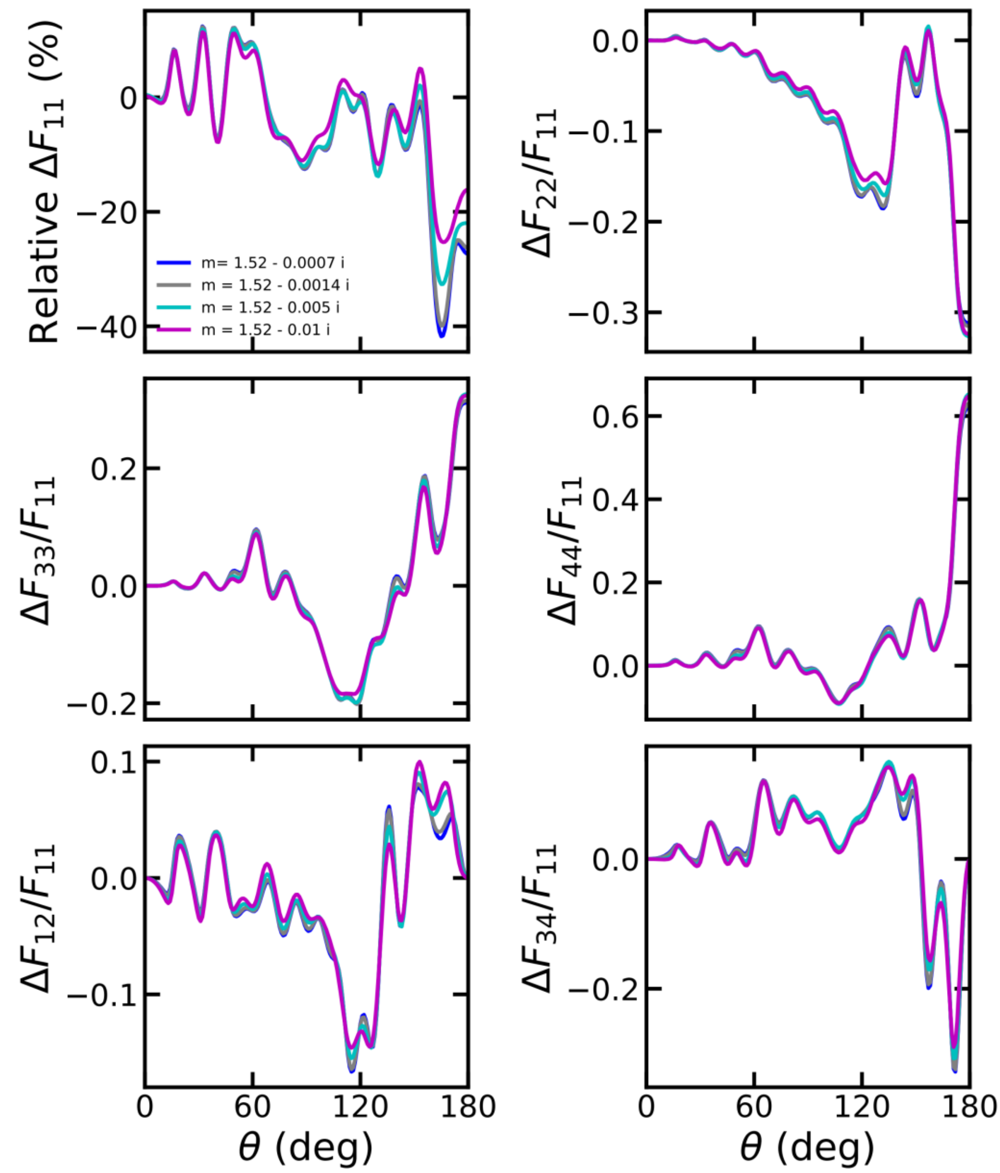


Figure 2 The differences of scattering matrices between irregular dust and best-fitted spheroids

We have also compared the polarimetric characteristics of dust with different aerosol optical depth (AOD), surface albedo, and imaginary parts of refractive indices. As shown in Figure 3 - 5 and Figure S14 – F16, the polarimetric characteristics of dust with irregular shapes share similar angular distributions for different AOD, surface albedo, and imaginary parts of the refractive index, and the modifications of AOD, surface albedo, and imaginary parts of the refractive index should not modify the main conclusions.

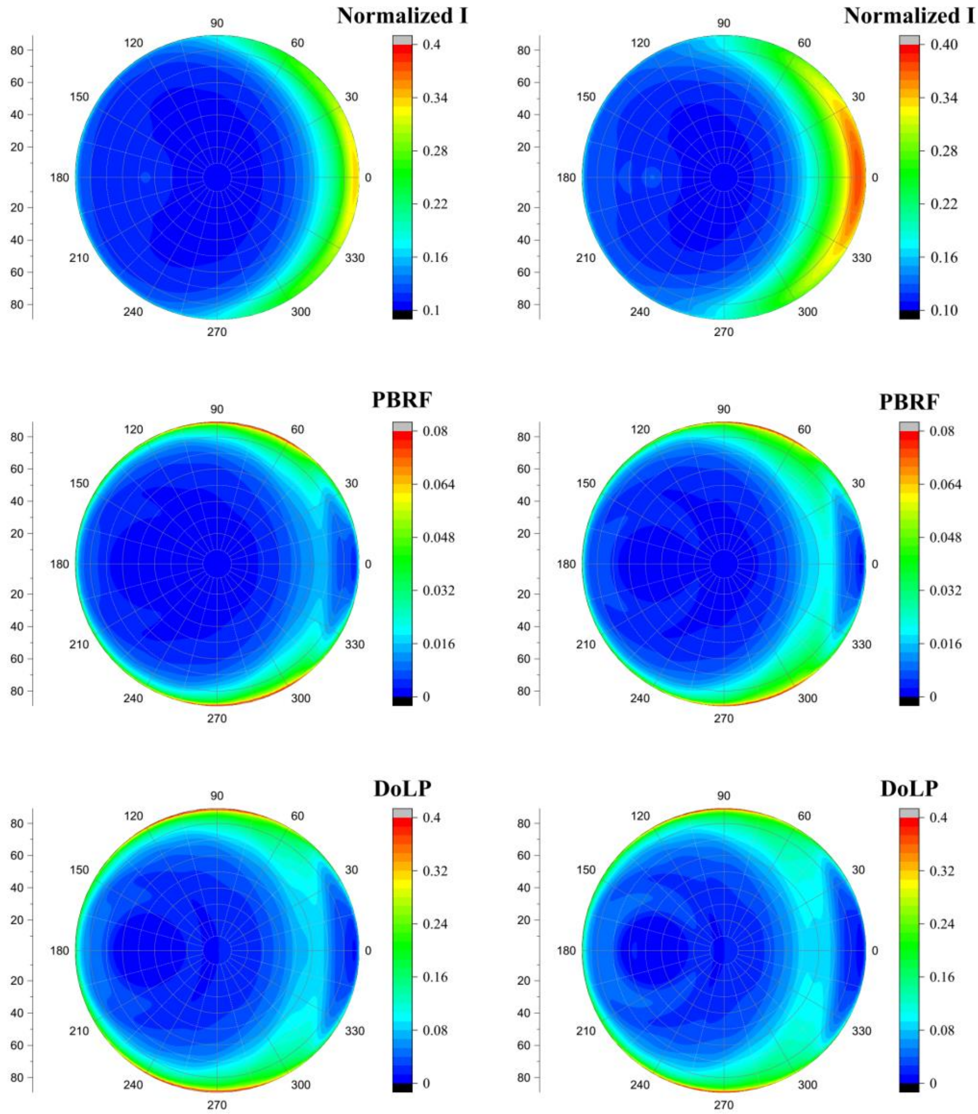


Figure 3 The polarimetric characteristics of dust with irregular shapes for different AOD, where the aspect ratio is 2:1, $d_p$ = 2.0 $\mu m$, $f$ =0.8.

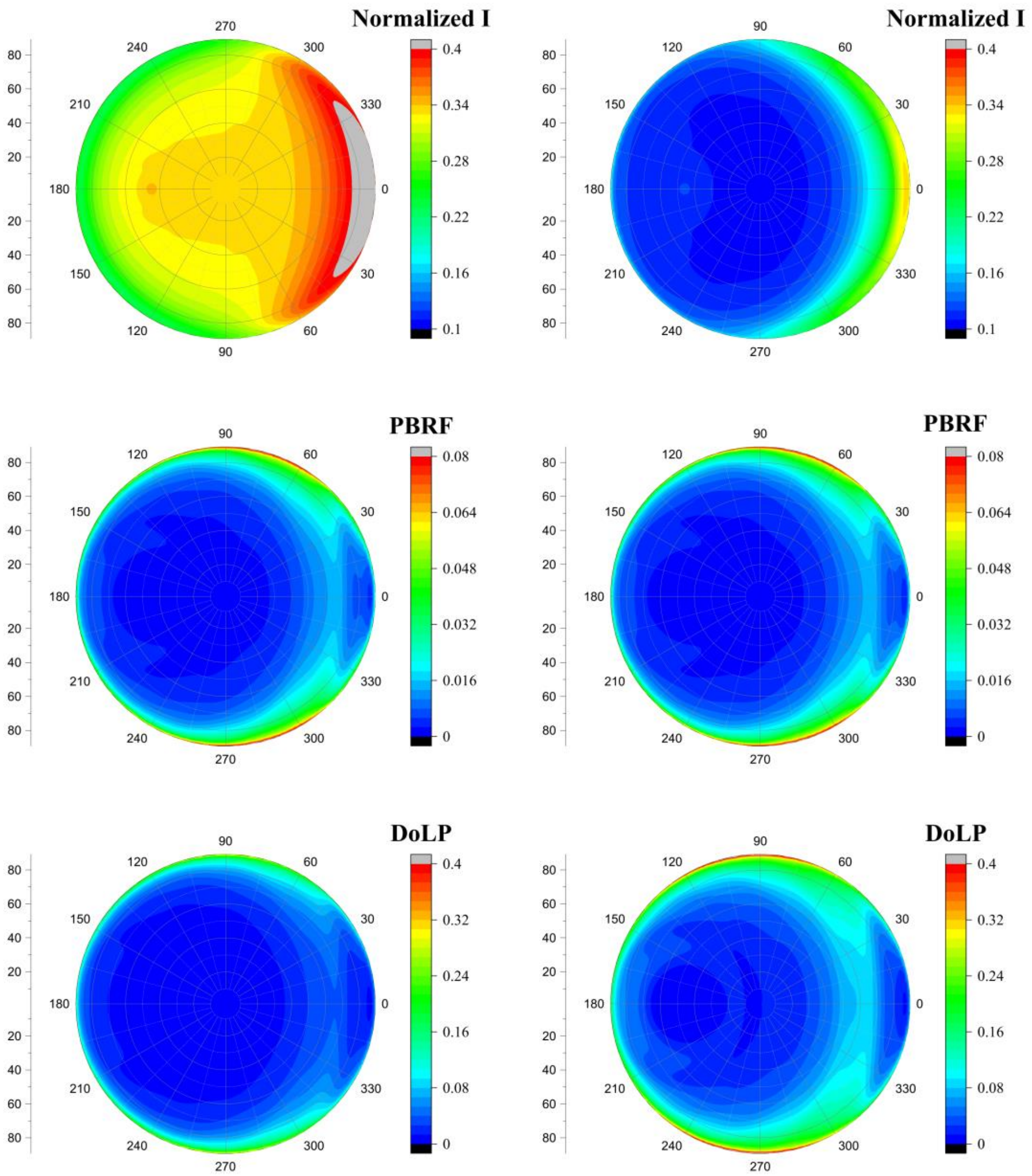


Figure 4 The polarimetric characteristics of dust with irregular shapes for different surface albedo, where the aspect ratio is 2:1, $d_p$ = 2.0 $\mu m$, $f$ = 0.8

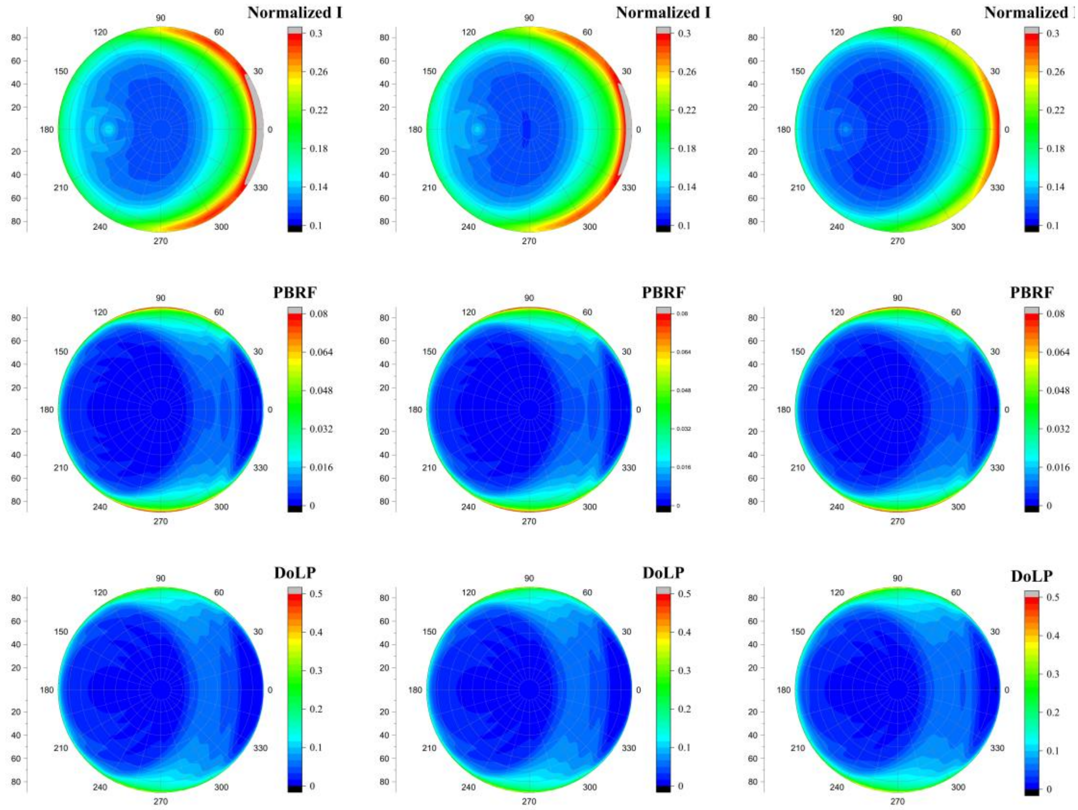


Figure 5 The polarimetric characteristics of dust with irregular shapes for different k, where the aspect ratio is 2:1, $d_p$ = 2.0 μm, *f* = 0.5.

**Comments:** Calculations in the manuscript assume single particles both for irregular dust and the best-fitted spheroids. Although there is no doubt that more realistic representations of dust particle shapes are needed, I wonder what happens if the authors assume randomly oriented ensemble of such irregular particles, and average their properties over a size distribution. I would expect that the characteristics of the irregular shapes smooth out. How are your results compared to those assuming poly-dispersed spheroids?

**Response:** Thanks very much for your comments. In this work, only single particles were considered as a first step toward exploring the applicability of spheroidal shapes. The bulk optical properties are not considered in this work due to the expensive computation costs. However, we have considered three dust particles which represent small, medium, and large particles for dust in the fine mode. The applicability of ensembles of spheroidal particles should be further investigated in the future, and this is a drawback of this work. We have added some clarifications for the drawbacks. In the future, the optical properties of irregular dust with a realistic size distribution would be considered and they would be applied in the polarimetric remote sensing. We have added some descriptions in the revised manuscript to illustrate the drawbacks of this paper and the future works that need to be conducted in order to apply our models in polarimetric remote sensing.

**Comments:** Phrasing needs significant improvements throughout the manuscript to make it more easy to follow.

Some specific examples are provided below:

3) Page 2, line 25: "Dust can also modify the cloud properties by serving as the cloud condensation nucleus (CNN), so play an indirect effect on the climate"

Consider rephrasing to something like: "Dust particles can also indirectly affect the Earth's climate, as they can serve as highly effective cloud condensation and ice nuclei (CCN and IN) and thus modify cloud lifetimes, albedo and microphysical properties"

**Response:** Thanks very much for your comments. We have corrected it in the revised manuscript.

4) Page 2, line 30: "Ground-based remote sensing and satellite remote sensing are the main techniques to retrieve aerosols"

-//- : "Ground-based and satellite measurements are the main remote sensing techniques to derive aerosol particle properties"

**Response:** Thanks very much for your comments. We have corrected it in the revised manuscript.

5) Page 2, line 37: "mainly derive the whole floor of aerosols"

-//- : "Mainly derive the aerosol properties through the total atmospheric column along with surface characteristics"

**Response:** Thanks very much for your comments. We have corrected it in the revised manuscript.

6) Page 2, line 43: "The extinction coefficient"

Maybe the authors here mean the ensemble averaged extinction cross section?

**Response:** Thanks very much for your comments. We have corrected it in the revised manuscript.

7) Page 4, line 94: "Under the erosion of the external forces, the mass of the dust would be lost. On the other hand, the binding force could constrain the loss of dust mass"

-//- : "Due to erosion forces acting on the particles, part of dust mass would be lost in the form of dust granules leaving the particle surface. However, binding force from the particle centre of mass could constrain this loss"

**Response:** Thanks very much for your comments. We have corrected it in the revised manuscript.

8) Page 4, line 113: "V0 denotes the volume lost in the erosion process" V0 here should be

replaced with Vlost.

**Response:** Thanks very much for your comments. We have corrected it in the revised manuscript.

9) Page 4, line 114: "the dust shapes are easier becomes spherical due to larger binding force"
-//- : "Dust particles eroded under external forces are easier to become more spherical when the binding force is large"

**Response:** Thanks very much for your comments. We have corrected it in the revised manuscript.

10) Page 5, line 120: "To reflect the Stokes vector of polarization, the normalized Stokes scattering matrix has six independent elements"
-//- : "For rotationally symmetric, randomly oriented particles, the normalized Stokes scattering matrix has six independent elements"

**Response:** Thanks very much for your comments. We have corrected it in the revised manuscript.

11) Page 7, line 160: "The scattering matrices of dust with different shapes are shown in Figures 4 – 6"
-//- : "The scattering matrices of dust with different irregular shapes and the corresponding spheroids that best fit the phase function are shown in Figures 4 – 6"

**Response:** Thanks very much for your comments. We have corrected it in the revised manuscript.

# Supporting Information for "The polarimetric characteristics of dust with irregular shapes: Evaluation of the spheroid model"

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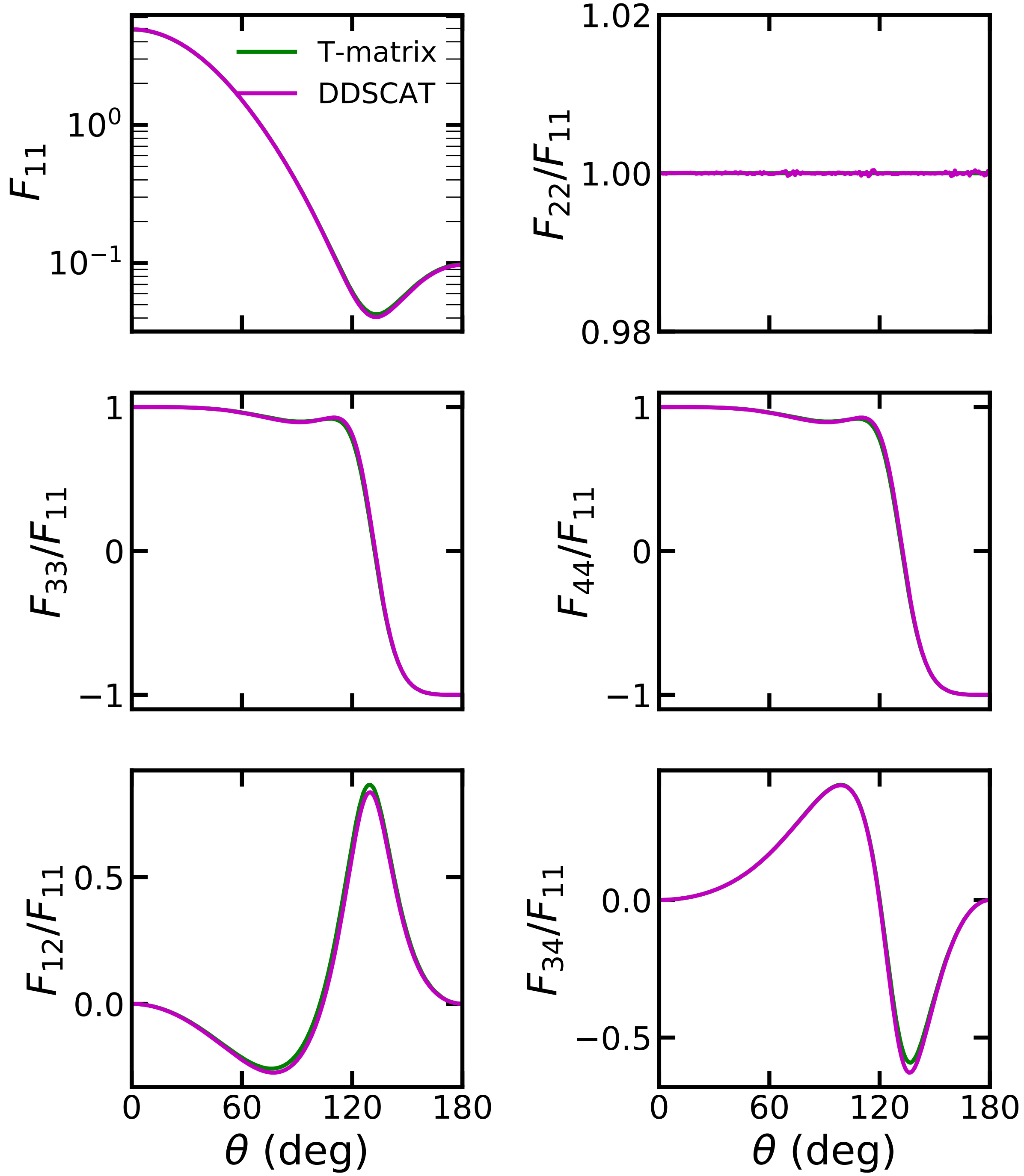


**Figure S1.** The scattering matrix of spherical particles calculated using the DDSCAT and T-matrix codes, respectively, where $d_p = 0.4$ $\mu$m.

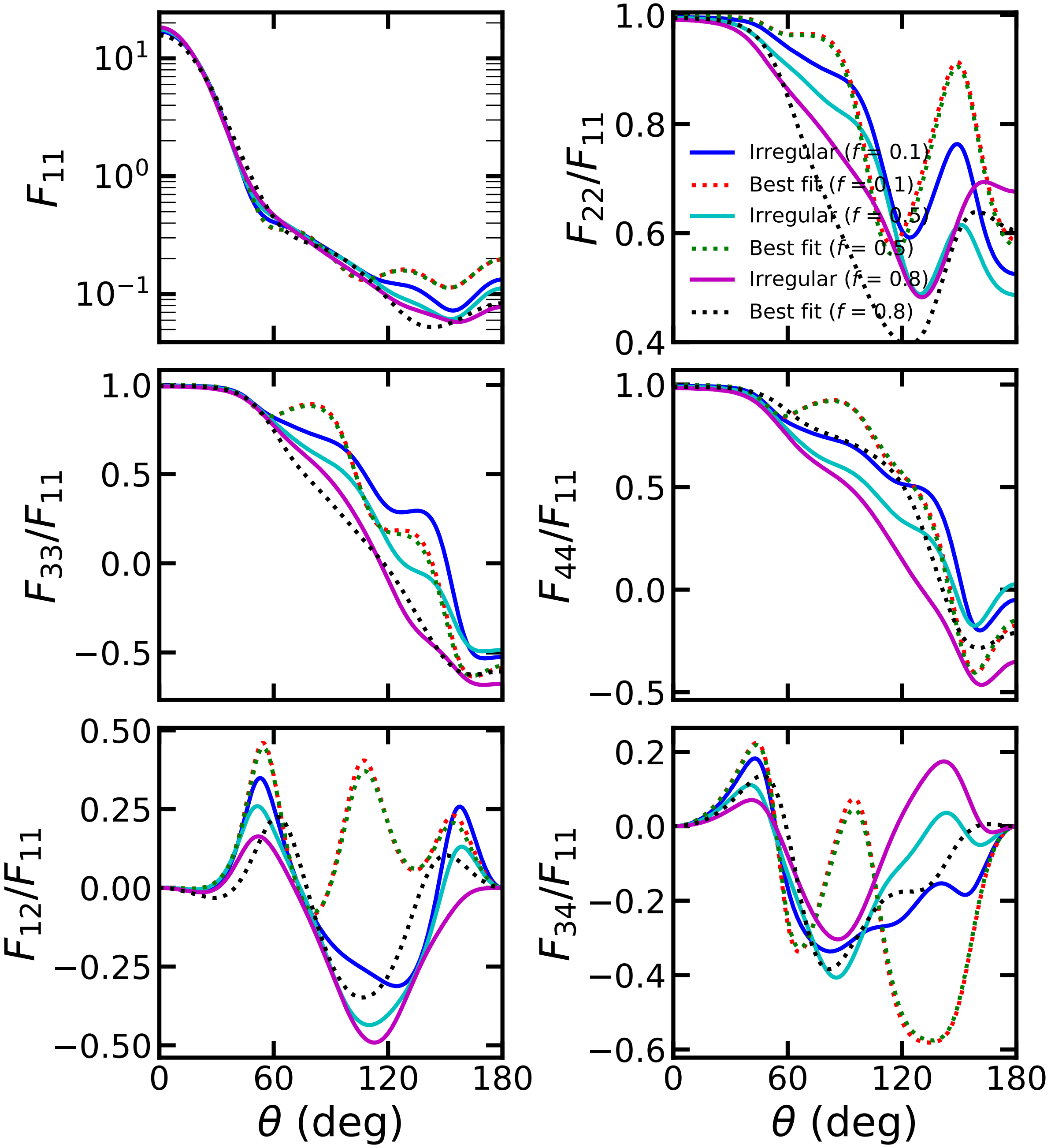


**Figure S2.** The scattering matrix of dust with irregular shapes, where the aspect ratio is 2:1, $d_p$=0.8 $\mu$m.

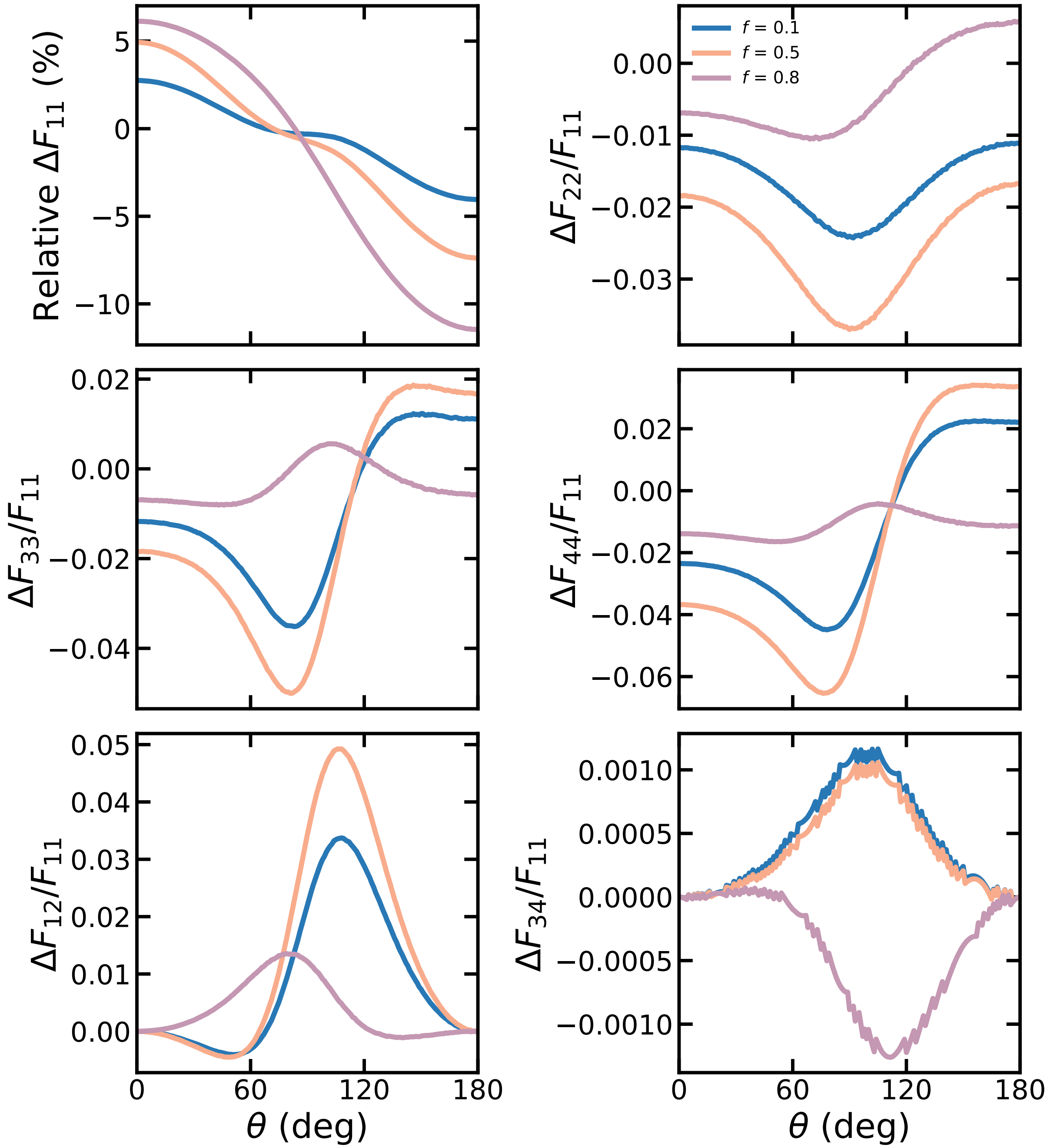


**Figure S3.** The differnces of scattering matrix bettween the best-fitted spheroids and dust with irregular shapes, where the aspect ratio is 2:1, $d_p$=0.2 $\mu$m.

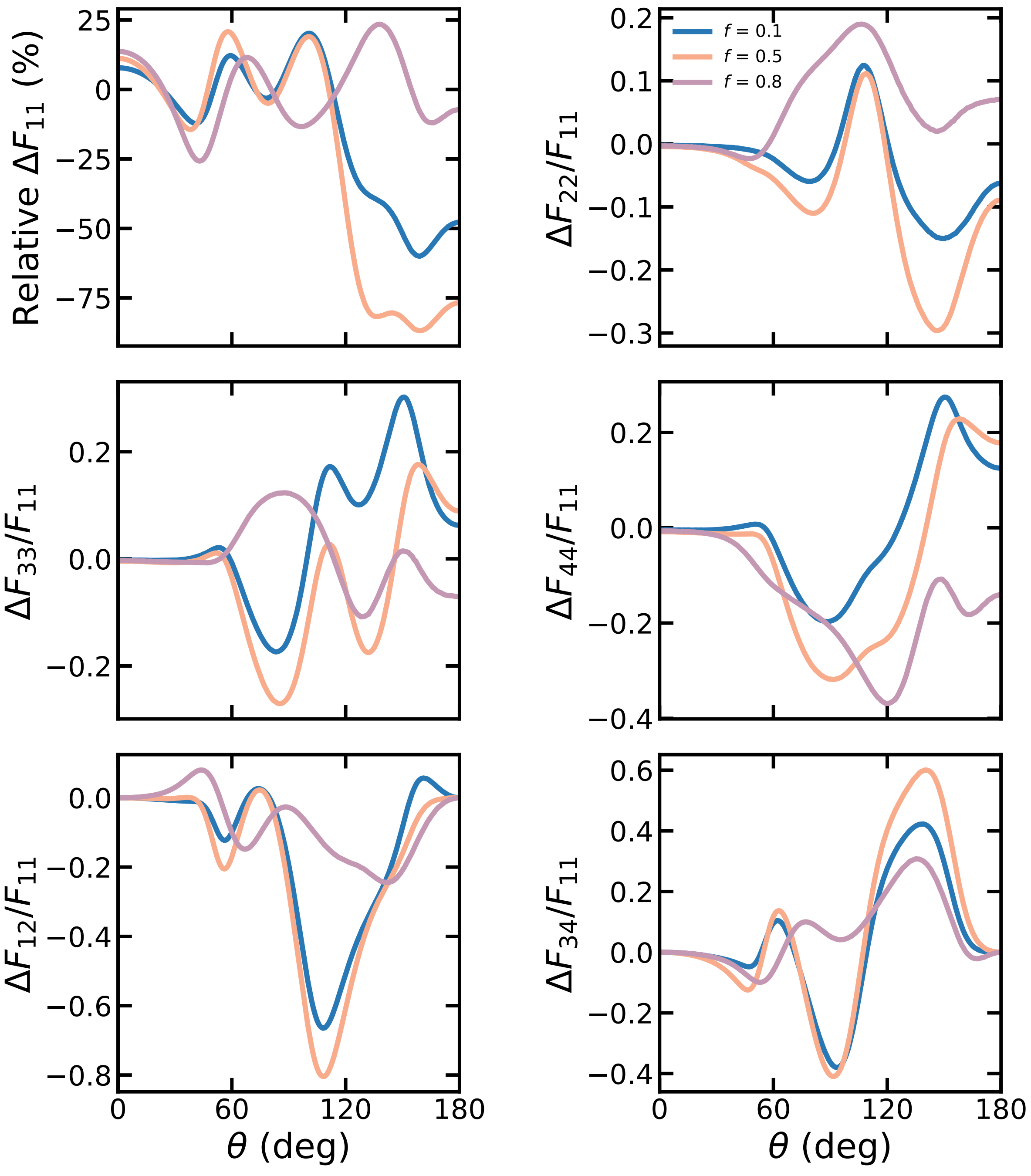


**Figure S4.** Similar to Figure S3, but for $d_p$=0.8 $\mu$m.

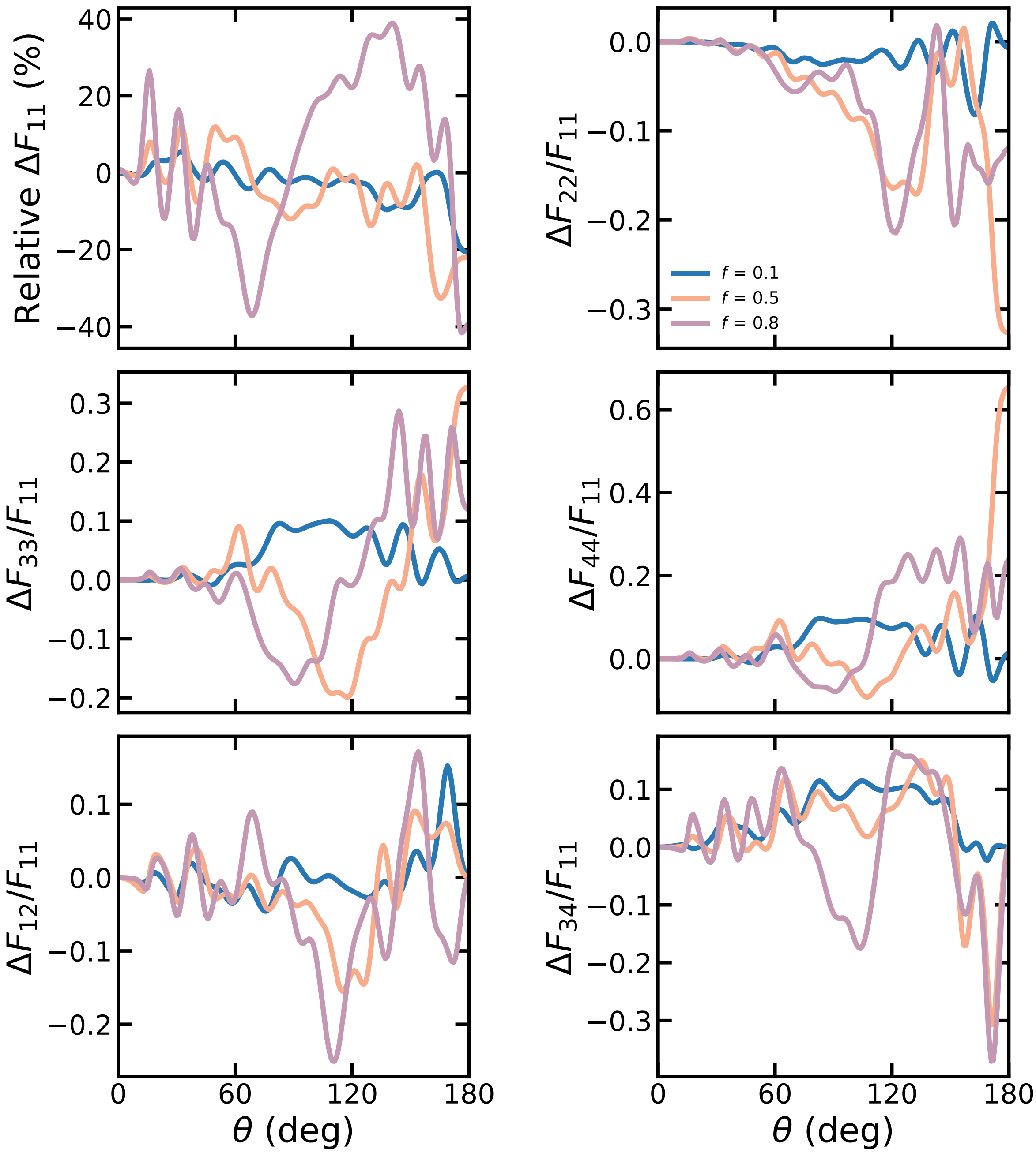


**Figure S5.** Similar to Figure S3, but for $d_p$=2.0 $\mu$m.

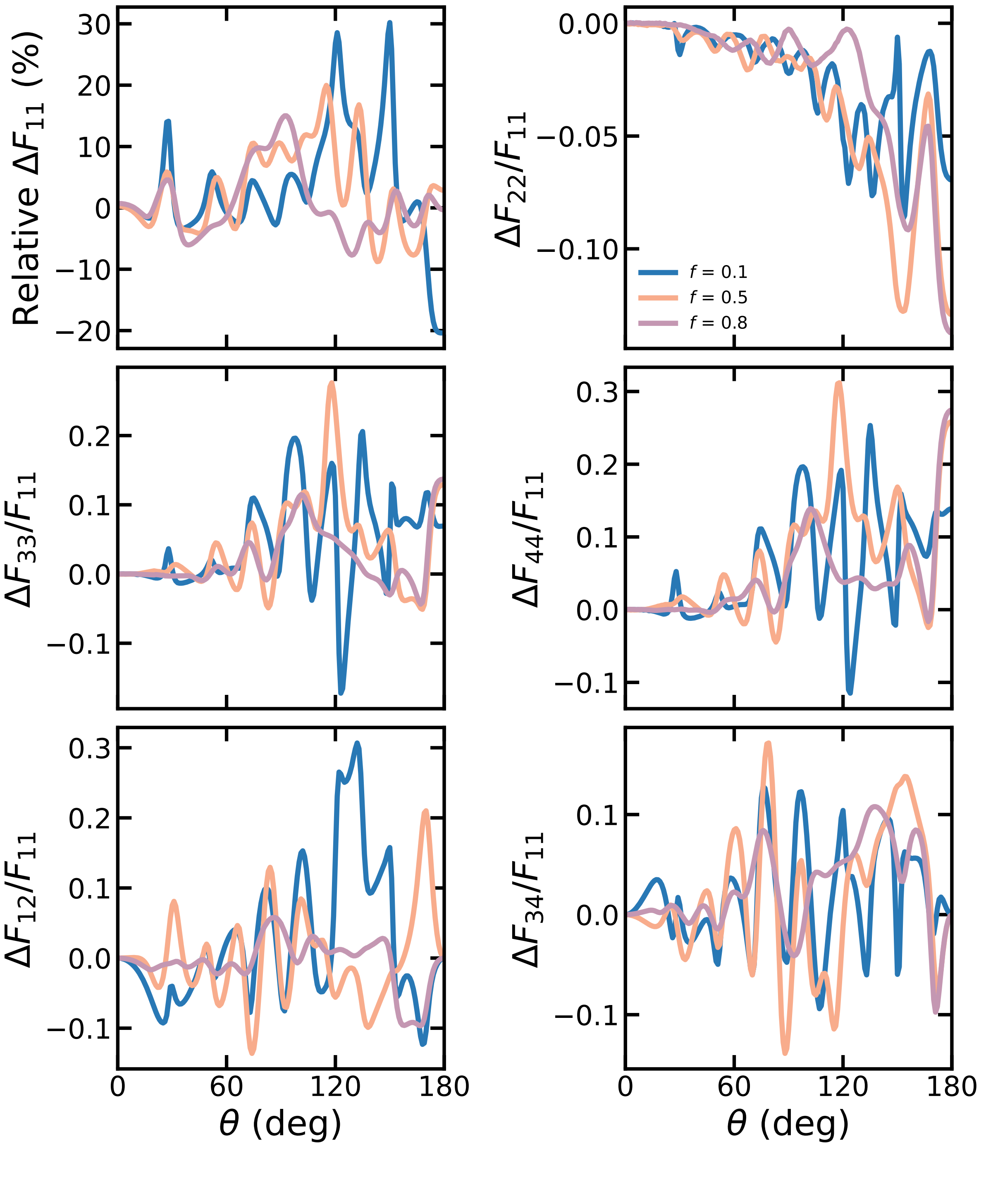


**Figure S6.** Similar to Figure S5, but for a aspect ratio of 1:1.

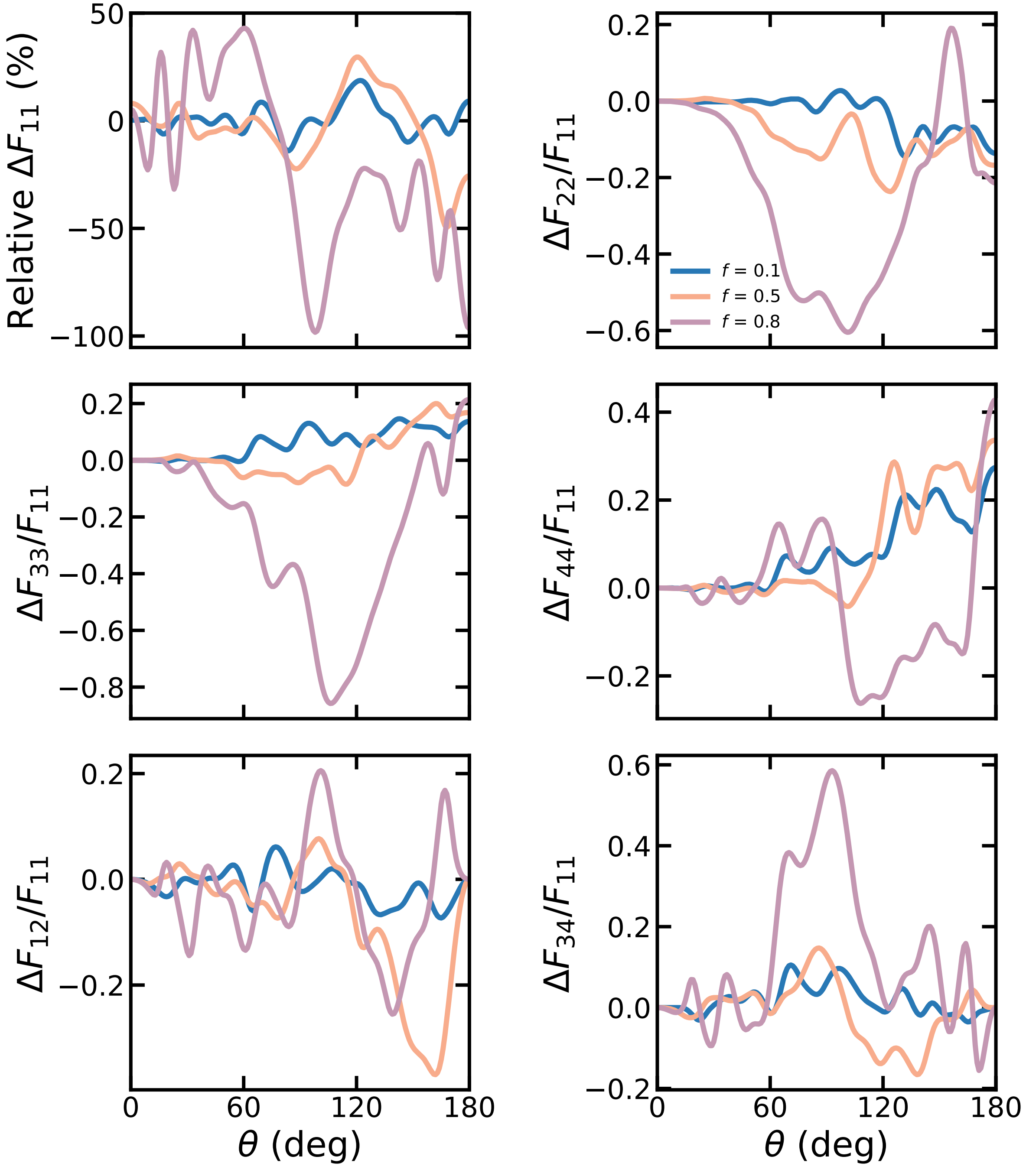


**Figure S7.** Similar to Figure S5, but for a aspect ratio of 1:2.

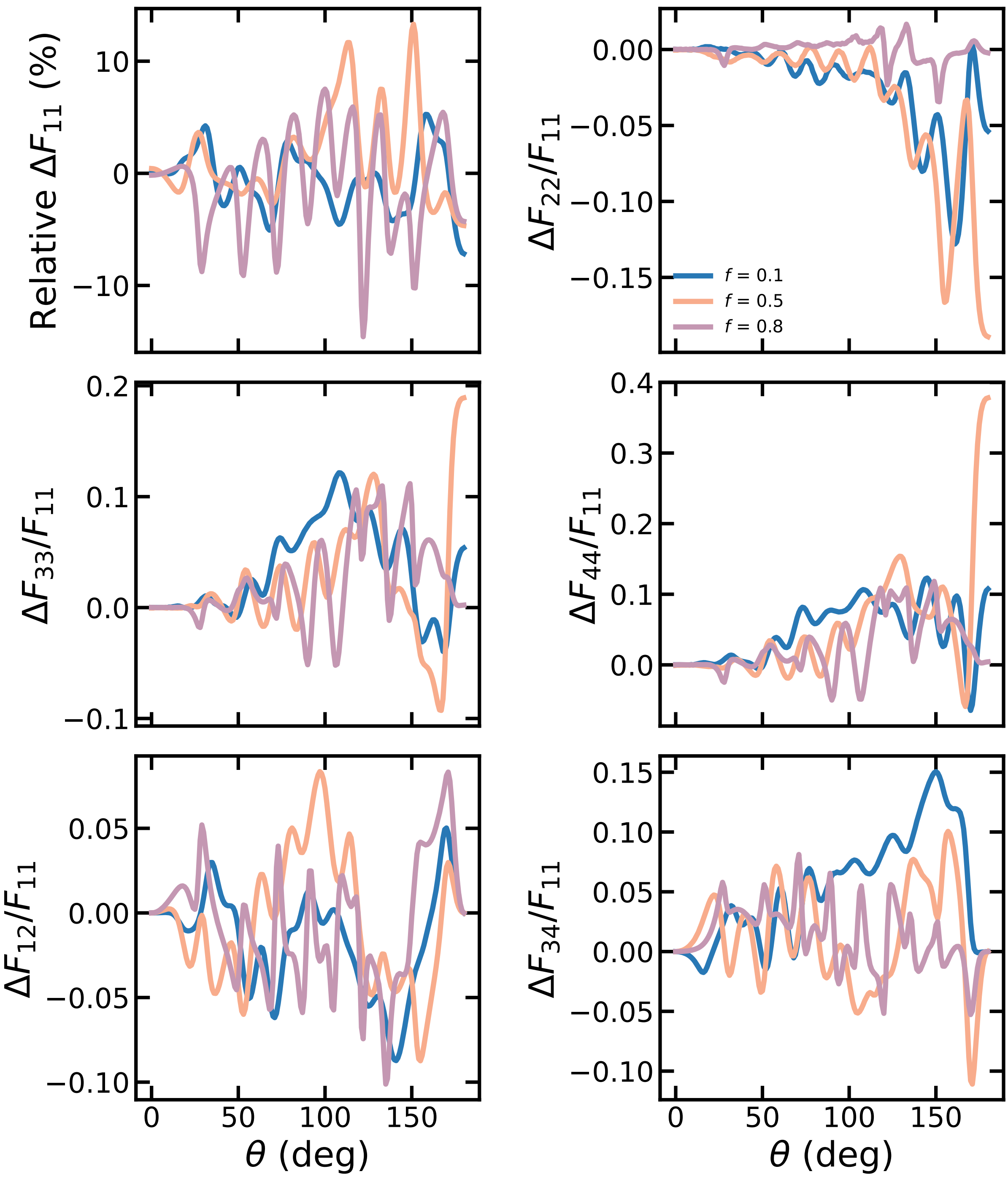


**Figure S8.** Similar to Figure S5, but for R = 1.

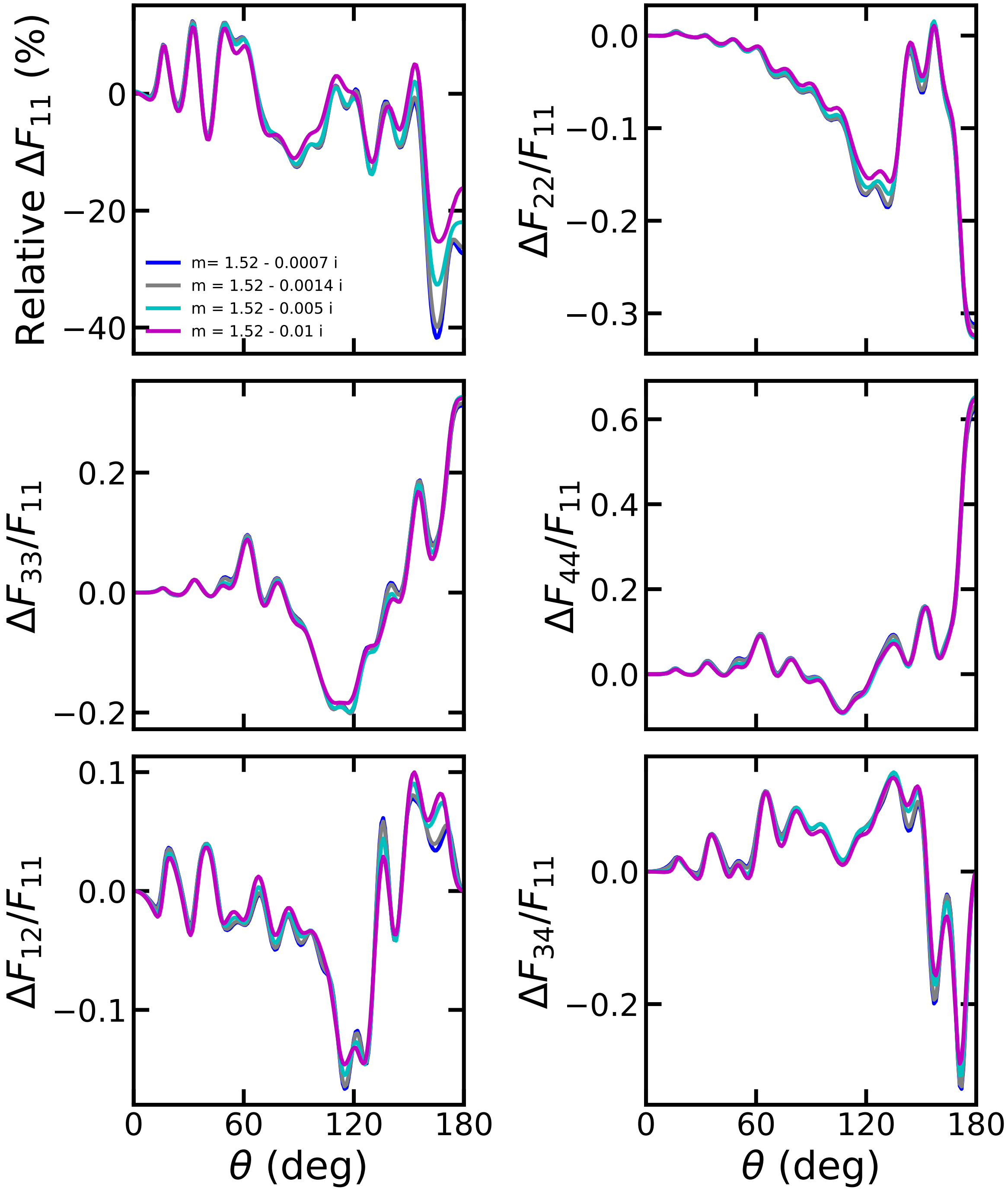


**Figure S9.** Similar to Figure S5, but for different imaginary parts of dust refractive indices (k), where $f = 0.5$.

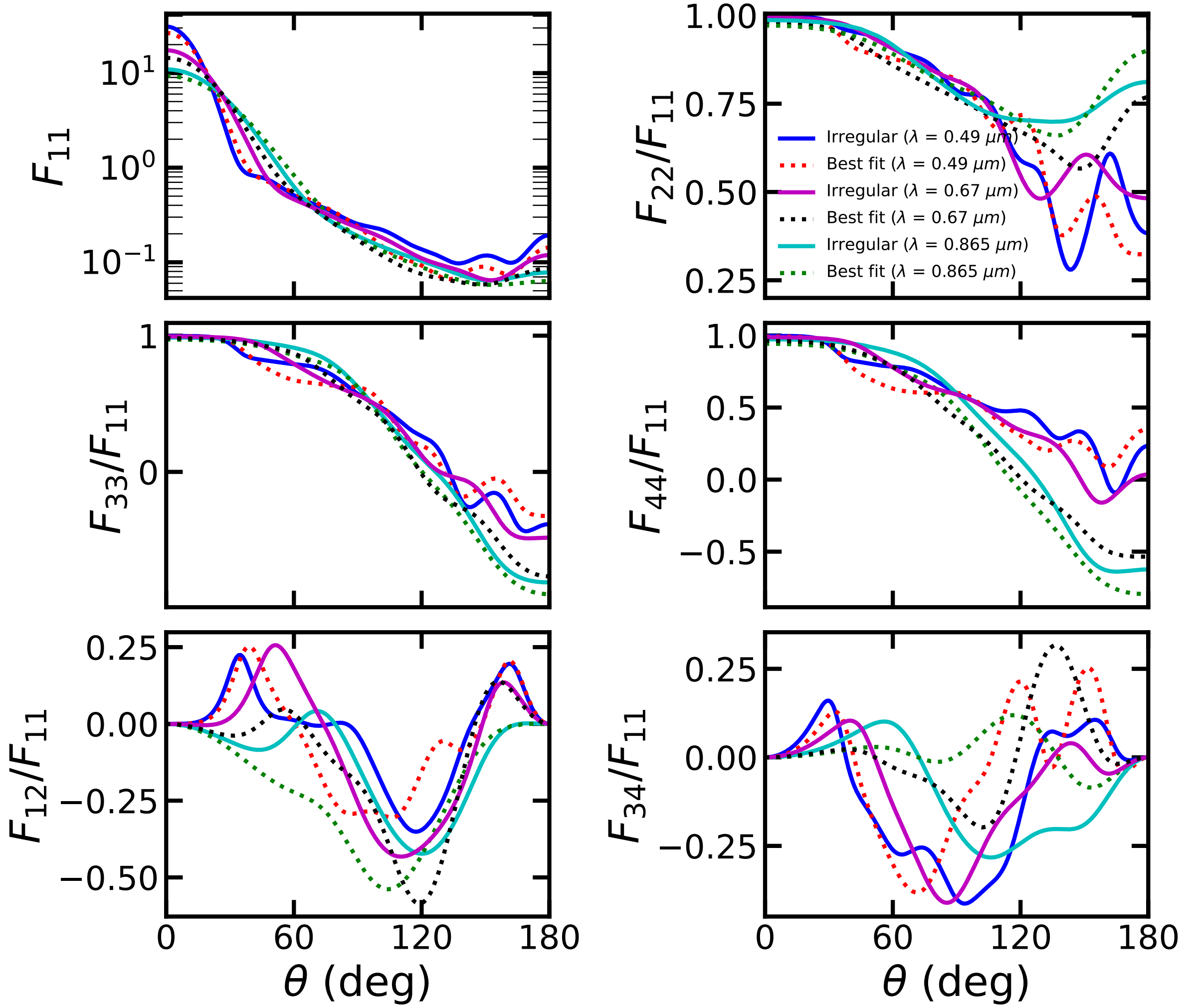


**Figure S10.** The scattering matrix of dust with irregular shapes at different wavelenths, where the aspect ratio is 2:1, $d_p$=2.0 $\mu$m, m = 1.52 - 0.0014i.

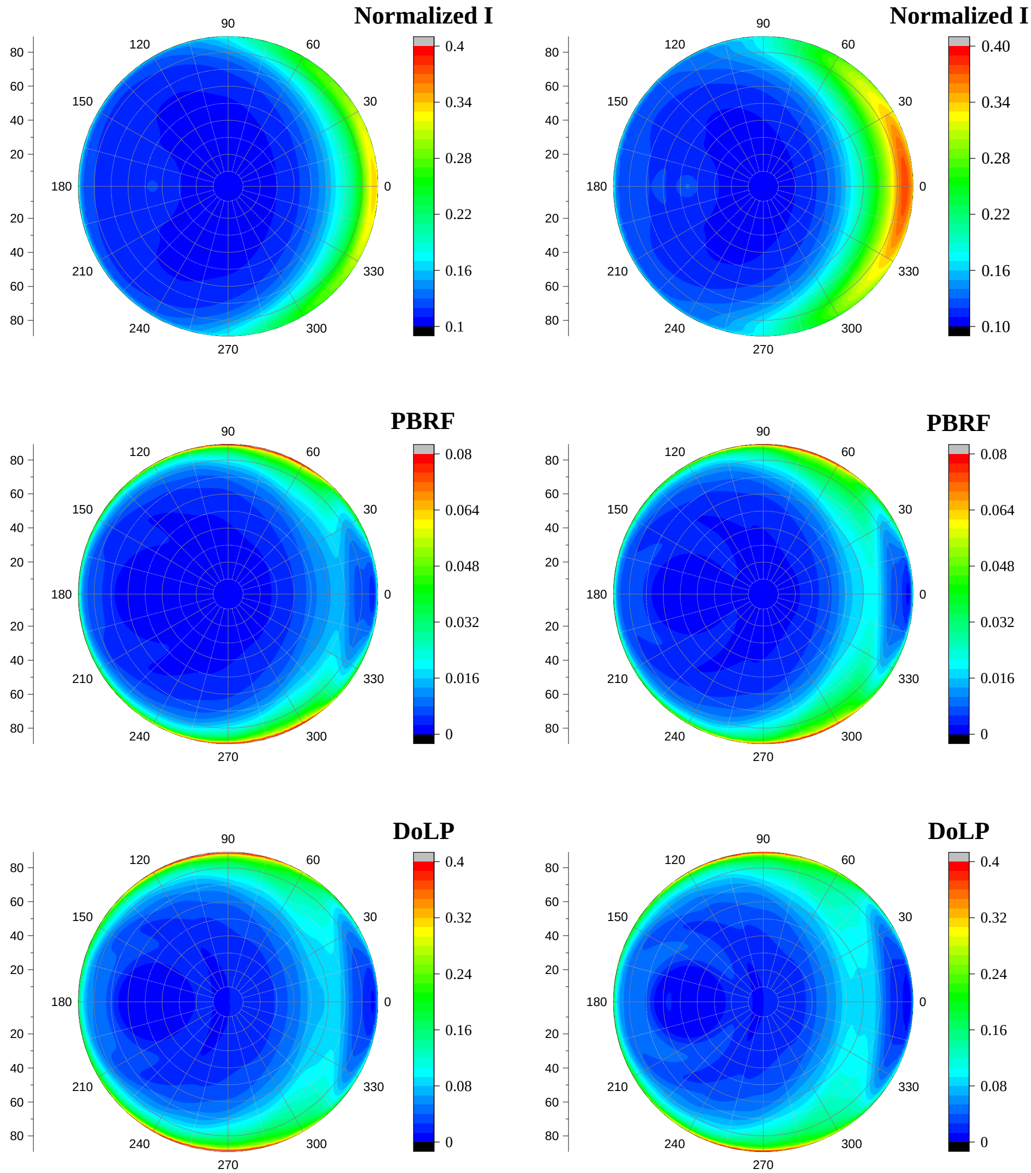


**Figure S11.** The polarimetric characteristics of dust with irregular shapes for different AOD, where the aspect ratio is 2:1, $d_p$ = 2.0 $\mu$m, $f$ = 0.8.

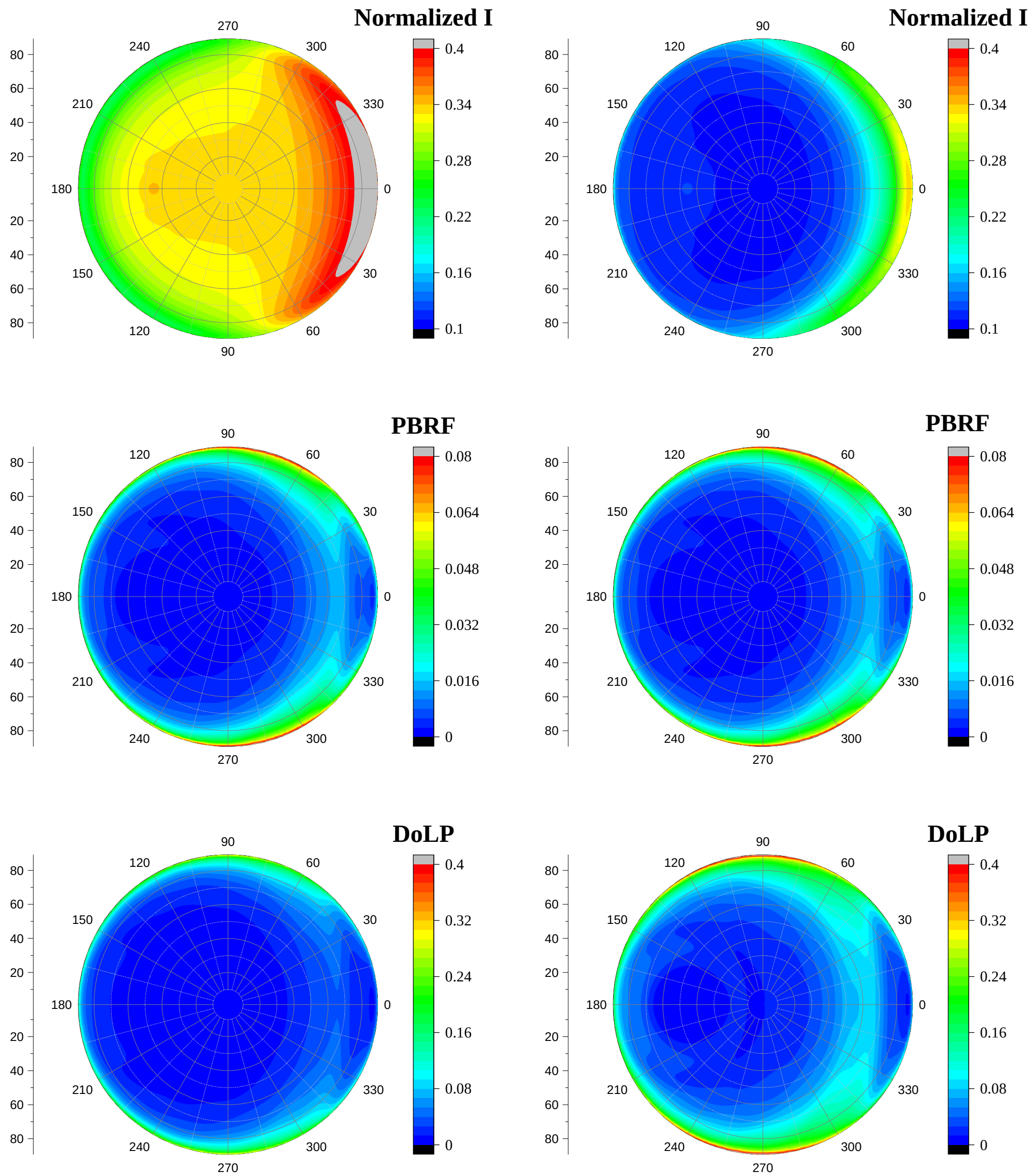


**Figure S12.** The polarimetric characteristics of dust with irregular shapes for different surface albedo, where the aspect ratio is 2:1, $d_p$ = 2.0 $\mu$m, $f$ = 0.8.

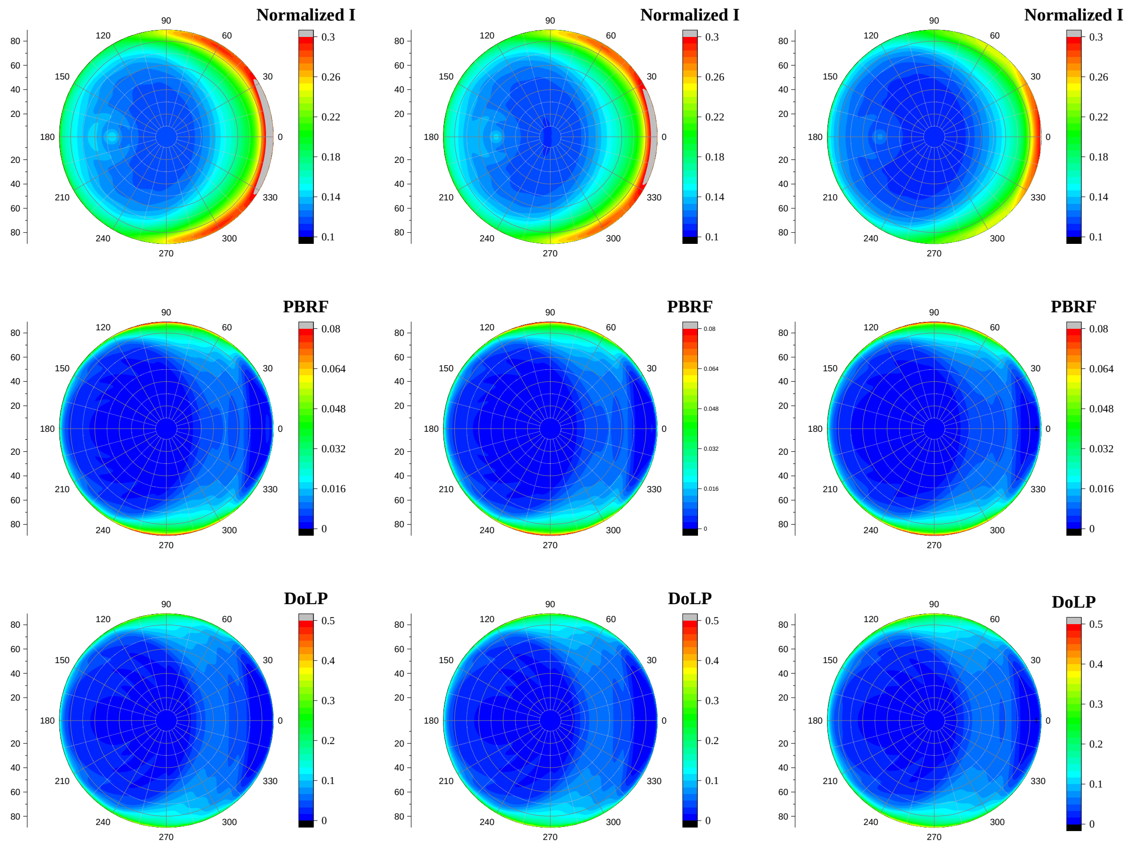


**Figure S13.** The polarimetric characteristics of dust with irregular shapes for different k, where the aspect ratio is 2:1, $d_p$ = 2.0 $\mu$m, $f$ = 0.5.

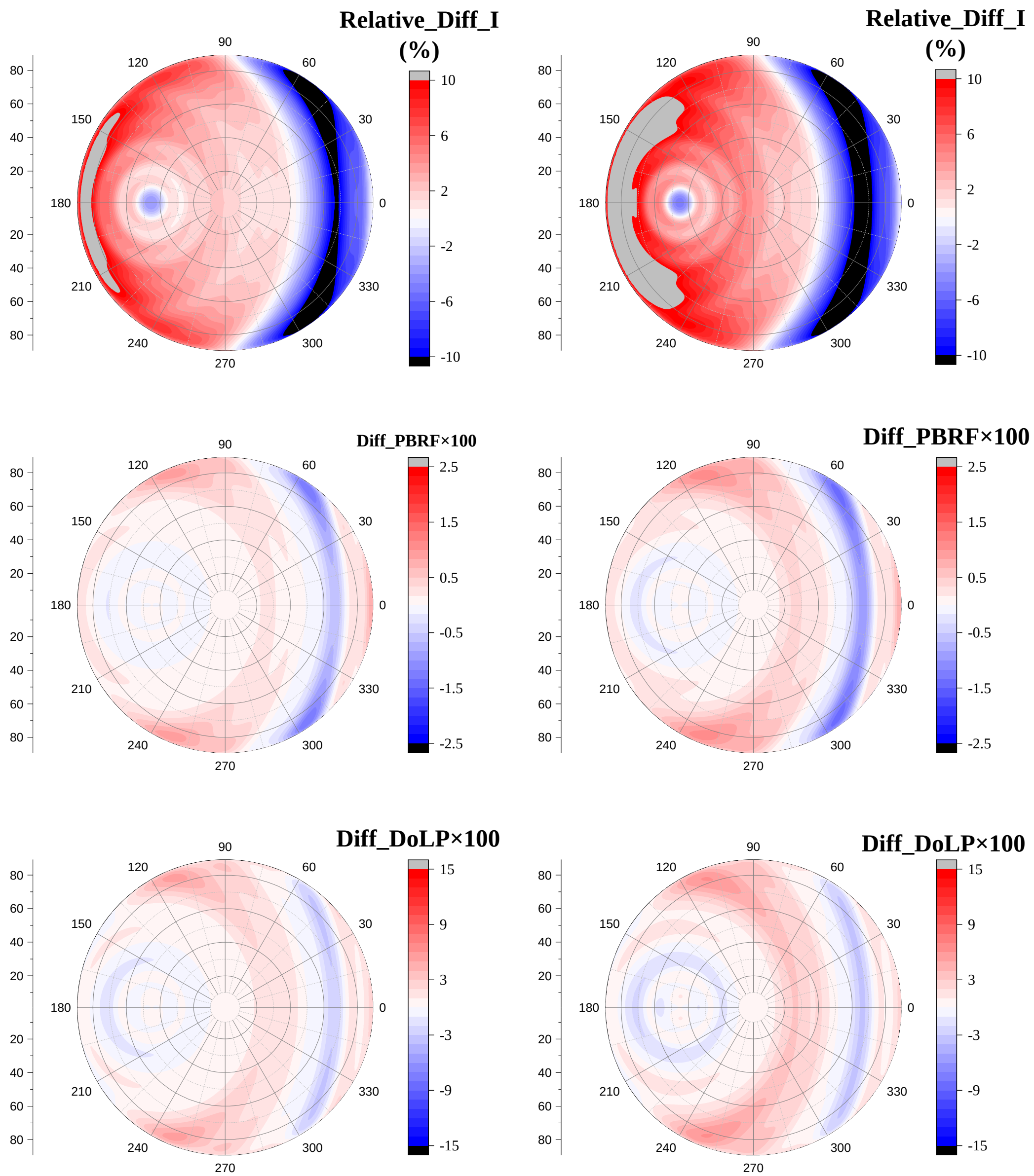


**Figure S14.** The difference of polarimetric characteristics between dust with irregular shapes and spheriods for different AOD, where the aspect ratio is 2:1, $d_p = 2.0\ \mu$m, $f = 0.8$.

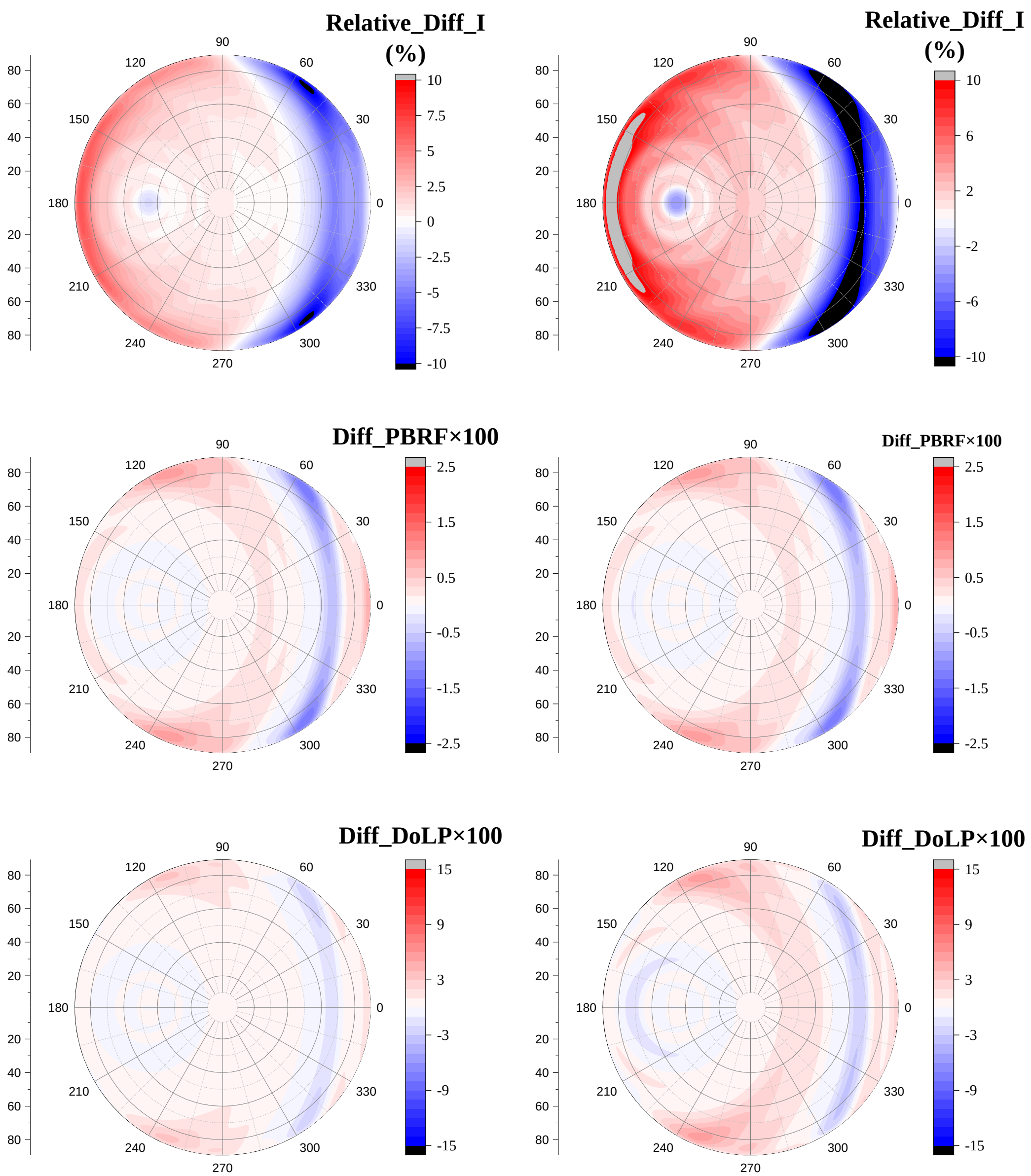


**Figure S15.** The difference of polarimetric characteristics between dust with irregular shapes and spheriods for different surface albedo, where the aspect ratio is 2:1, $d_p$ = 2.0 $\mu$m, $f$ = 0.8.

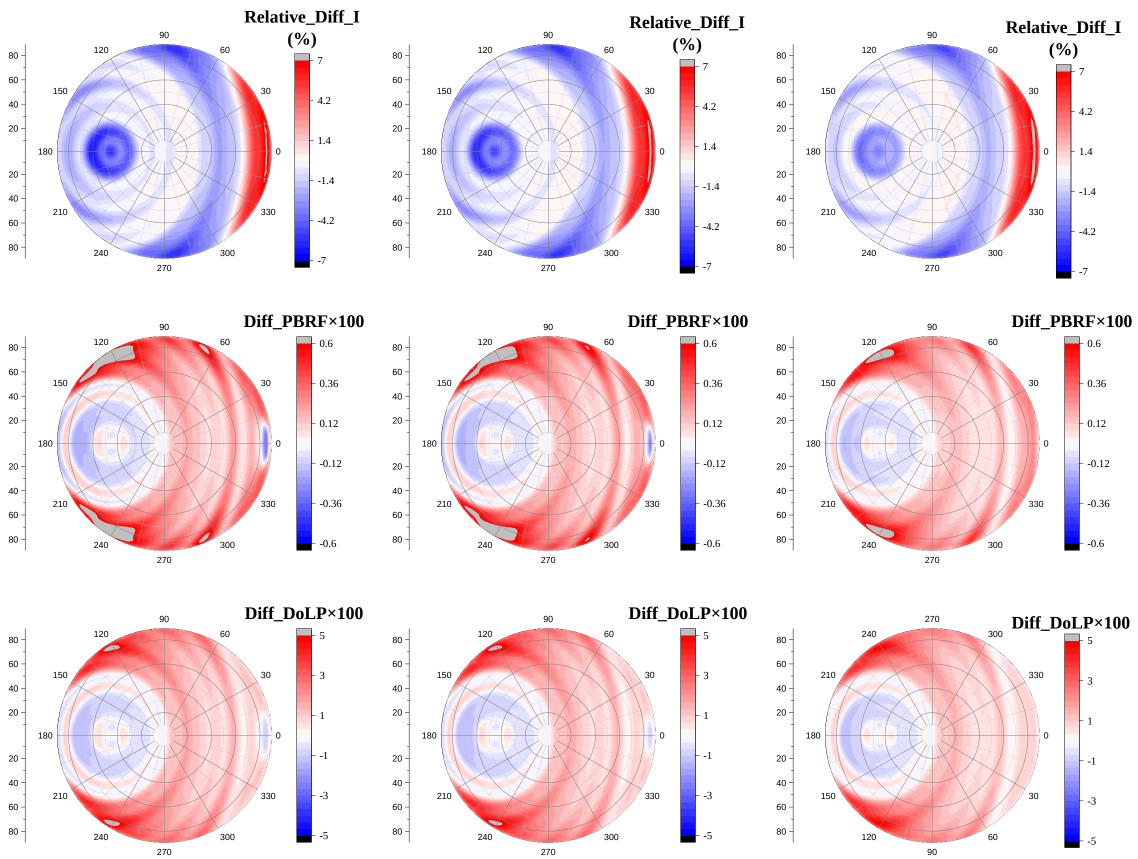


**Figure S16.** The defference of polarimetric characteristics between dust with irregular shapes and spheriods for different k, where the aspect ratio is 2:1, $d_p$ = 2.0 $\mu$m, $f$ = 0.5.