Chapter 5

ONFS data processing.

In the chapter 3, we showed that, under some given conditions, the correlation function of ONFS images can be used to derive the intensity of the light scattered by a sample. The calcultions were performed in the ideal case, in which the scattered light comes only from the sample. The presence of non ideal lenses and optical elements introduces an amount of undesired scattered light. This problem is common to every kind of scattering measurement; the undesired light, often referred to as stray light, is generally scattered at small angles.

In standard scattering measurements, the effect of the undesired light is additive. It can be subtracted, since the stray light can be measured by a blank measurement.

Dynamic scattering gives a way to distinguish the effect of the light scattered from elements that evolve with time from stationary ones. If the stray light comes from stationary elements, such as imperfections of the optical elements, its effect is to increase the correlation function, with no dependence on the delay. Thus the time dependent informations on the sample will be given by the bell shaped part of the correlation function, while the pedestal will contain informations on both the statically and dynamically scattered light.

If a blank measurement is possible, a more refined subtraction of the stray light becomes possible [18], provided that the stray light constitutes a speckle field, that is, the field is gaussian. Such a data processing can be extended to ONFS too. In the following sections, we will find a way to subtract the effect of the stray light, first considering an unlimited number of images, taken at different times, and then a finite set of images. Then, we will describe the whole data processing algorithm.

5.1 Effect of the stray light.

From a set of ONFS images $I(\vec{x})$, we can measure the intensity correlation function:

$$C_I(\Delta\vec{x}) = \{\langle I(\vec{x})\, I(\vec{x}+\Delta\vec{x})\rangle\}, \tag{5.1}$$

where $\langle\cdot\rangle$ is the mean over $\vec{x}$, $\{\cdot\}$ is the mean over different images, and the intensity of the images $I(\vec{x})$ is the intensity of the sum of $\delta E(\vec{x})$, the field scattered by the sample, and $E_{SL}(\vec{x})$, the field of the stray light:

$$I(\vec{x}) = |\delta E(\vec{x}) + E_{SL}(\vec{x})|^2 . \tag{5.2}$$

So we obtain:

$$C_I(\Delta\vec{x}) = \left\{\left\langle \left[|\delta E(\vec{x})|^2 + |E_{SL}(\vec{x})|^2 + \delta E(\vec{x}) E^*_{SL}(\vec{x}) + \delta E^*(\vec{x}) E_{SL}(\vec{x})\right] \left[|\delta E(\vec{x}+\Delta\vec{x})|^2 + \left|E_{SL}\left(x +\right.\right.\right.\right. \tag{5.3}$$

Since $\delta E(\vec{x})$ is a random, circular gaussian field, the mean over different images of its odd powers vanishes; since $E_{SL}(\vec{x})$ is static, it can be considered as a costant, with respect to $\{\cdot\}$, the average on the images:

$$\begin{aligned} C_I(\Delta\vec{x}) = &\left\{\left\langle |\delta E(\vec{x})|^2 |\delta E(\vec{x}+\Delta\vec{x})|^2 \right\rangle\right\} + \left\langle |E_{SL}(\vec{x})|^2 |E_{SL}(\vec{x}+\Delta\vec{x})|^2 \right\rangle + \\ &\left\langle \left\{|\delta E(\vec{x})|^2\right\} |E_{SL}(\vec{x}+\Delta\vec{x})|^2 \right\rangle + \left\langle |E_{SL}(\vec{x})|^2 \left\{|\delta E(\vec{x}+\Delta\vec{x})|^2\right\} \right\rangle + \\ &\langle \{\delta E(\vec{x}) \delta E^*(\vec{x}+\Delta\vec{x})\} E^*_{SL}(\vec{x}) E_{SL}(\vec{x}+\Delta\vec{x}) \rangle + \\ &\langle \{\delta E^*(\vec{x}) \delta E(\vec{x}+\Delta\vec{x})\} E_{SL}(\vec{x}) E^*_{SL}(\vec{x}+\Delta\vec{x}) \rangle . \end{aligned} \tag{5.4}$$

The mean over the images $\{\cdot\}$ equals the mean over $\vec{x}$, $\langle\cdot\rangle$, for the field $\delta E(\vec{x})$:

$$\begin{aligned} C_I(\Delta\vec{x}) = &\left\langle |\delta E(\vec{x})|^2 |\delta E(\vec{x}+\Delta\vec{x})|^2 \right\rangle + \left\langle |E_{SL}(\vec{x})|^2 |E_{SL}(\vec{x}+\Delta\vec{x})|^2 \right\rangle + \\ &\left\langle |\delta E(\vec{x})|^2 \right\rangle \left\langle |E_{SL}(\vec{x}+\Delta\vec{x})|^2 \right\rangle + \left\langle |E_{SL}(\vec{x})|^2 \right\rangle \left\langle |\delta E(\vec{x}+\Delta\vec{x})|^2 \right\rangle + \\ &\langle \delta E(\vec{x}) \delta E^*(\vec{x}+\Delta\vec{x}) \rangle \langle E^*_{SL}(\vec{x}) E_{SL}(\vec{x}+\Delta\vec{x}) \rangle + \\ &\langle \delta E^*(\vec{x}) \delta E(\vec{x}+\Delta\vec{x}) \rangle \langle E_{SL}(\vec{x}) E^*_{SL}(\vec{x}+\Delta\vec{x}) \rangle . \end{aligned} \tag{5.5}$$

Since both $\delta E(\vec{x})$ and $E_{SL}(\vec{x})$ are gaussian fields, we can use Siegert relation Eq. (3.65) to express four-point correlation functions in terms of two-point ones.

$$\begin{aligned} C_I(\Delta\vec{x}) = &\left\langle |\delta E(\vec{x})|^2 \right\rangle \left\langle |\delta E(\vec{x}+\Delta\vec{x})|^2 \right\rangle + |\langle \delta E(\vec{x}) \delta E^*(\vec{x}+\Delta\vec{x}) \rangle|^2 + \\ &\left\langle |E_{SL}(\vec{x})|^2 \right\rangle \left\langle |E_{SL}(\vec{x}+\Delta\vec{x})|^2 \right\rangle + |\langle E_{SL}(\vec{x}) E^*_{SL}(\vec{x}+\Delta\vec{x}) \rangle|^2 + \\ &\left\langle |\delta E(\vec{x})|^2 \right\rangle \left\langle |E_{SL}(\vec{x}+\Delta\vec{x})|^2 \right\rangle + \left\langle |E_{SL}(\vec{x})|^2 \right\rangle \left\langle |\delta E(\vec{x}+\Delta\vec{x})|^2 \right\rangle + \\ &\langle \delta E(\vec{x}) \delta E^*(\vec{x}+\Delta\vec{x}) \rangle \langle E^*_{SL}(\vec{x}) E_{SL}(\vec{x}+\Delta\vec{x}) \rangle + \\ &\langle \delta E^*(\vec{x}) \delta E(\vec{x}+\Delta\vec{x}) \rangle \langle E_{SL}(\vec{x}) E^*_{SL}(\vec{x}+\Delta\vec{x}) \rangle . \end{aligned} \tag{5.6}$$

We define $\langle \delta I \rangle = \left\langle |\delta E(\vec{x})|^2 \right\rangle$, $\langle I_{SL} \rangle = \left\langle |E_{SL}(\vec{x})|^2 \right\rangle$, $C_{\delta E}(\Delta\vec{x}) = \langle \delta E(\vec{x}) \delta E^*(\vec{x}+\Delta\vec{x}) \rangle$, $C_{SL}(\Delta\vec{x}) = \langle E_{SL}(\vec{x}) E^*_{SL}(\vec{x}+\Delta\vec{x}) \rangle$:

$$\begin{aligned} C_I(\Delta\vec{x}) = &\langle \delta I \rangle^2 + |C_{\delta E}(\Delta\vec{x})|^2 + \langle I_{SL} \rangle^2 + |C_{SL}(\Delta\vec{x})|^2 + \\ &2 \langle \delta I \rangle \langle I_{SL} \rangle + C_{\delta E}(\Delta\vec{x}) C^*_{SL}(\Delta\vec{x}) + C^*_{\delta E}(\Delta\vec{x}) C_{SL}(\Delta\vec{x}) . \end{aligned} \tag{5.7}$$

The result is that the stray light field correlation sums to the scattered field correlation:

$$C_I\left(\Delta\vec{x}\right) = \left(\langle\delta I\rangle + \langle I_{SL}\rangle\right)^2 + \left|C_{\delta E}\left(\Delta\vec{x}\right) + C_{SL}\left(\Delta\vec{x}\right)\right|^2 . \tag{5.8}$$

In order to obtain informations about the correlation of the stray light field, we acquire a great number of images, with different scattered field, and we average them, thus obtaining the correlation function of the mean intensity $\{I\left(\vec{x}\right)\}$. Then, we measure the correlation function of the mean intensity:

$$C_{\{I\}}\left(\Delta\vec{x}\right) = \left\langle\{I\left(\vec{x}\right)\}\{I\left(\vec{x}+\Delta\vec{x}\right)\}\right\rangle . \tag{5.9}$$

We evaluate the mean intensity $\{I\left(\vec{x}\right)\}$:

$$\{I\left(\vec{x}\right)\} = \left\{\left|\delta E\left(\vec{x}\right) + E_{SL}\left(\vec{x}\right)\right|^2\right\} =$$
$$\left\{\left|\delta E\left(\vec{x}\right)\right|^2\right\} + \left\{\left|E_{SL}\left(\vec{x}\right)\right|^2\right\} + \left\{\delta E\left(\vec{x}\right)E^*_{SL}\left(\vec{x}\right)\right\} + \left\{\delta E^*\left(\vec{x}\right)E_{SL}\left(\vec{x}\right)\right\} . \tag{5.10}$$

Since E_{SL} does not depend on the image:

$$\{I\left(\vec{x}\right)\} = \left\{\left|\delta E\left(\vec{x}\right)\right|^2\right\} + \left|E_{SL}\left(\vec{x}\right)\right|^2 + \left\{\delta E\left(\vec{x}\right)\right\}E^*_{SL}\left(\vec{x}\right) + \left\{\delta E^*\left(\vec{x}\right)\right\}E_{SL}\left(\vec{x}\right) . \tag{5.11}$$

Using the gaussian properties of the scattered light:

$$\{I\left(\vec{x}\right)\} = \langle\delta I\rangle + \left|E_{SL}\left(\vec{x}\right)\right|^2 . \tag{5.12}$$

Now we can evluate the correlation function of the mean intensity:

$$C_{\{I\}}\left(\Delta\vec{x}\right) = \left\langle\left[\langle\delta I\rangle + \left|E_{SL}\left(\vec{x}\right)\right|^2\right]\left[\langle\delta I\rangle + \left|E_{SL}\left(\vec{x}+\Delta\vec{x}\right)\right|^2\right]\right\rangle =$$
$$\langle\delta I\rangle^2 + \langle\delta I\rangle\left\langle\left|E_{SL}\left(\vec{x}\right)\right|^2\right\rangle + \langle\delta I\rangle\left\langle\left|E_{SL}\left(\vec{x}+\Delta\vec{x}\right)\right|^2\right\rangle + \left\langle\left|E_{SL}\left(\vec{x}\right)\right|^2\left|E_{SL}\left(\vec{x}+\Delta\vec{x}\right)\right|^2\right\rangle . \tag{5.13}$$

Using the gaussian properties of the field E_{SL}:

$$C_{\{I\}}\left(\Delta\vec{x}\right) = \left(\langle\delta I\rangle + \langle I_{SL}\rangle\right)^2 + \left|C_{SL}\left(\Delta\vec{x}\right)\right|^2 \tag{5.14}$$

From eq. (5.12), we can evaluate the mean value of the intensity of the images:

$$\{\langle I\rangle\} = \langle\delta I\rangle + \langle I_{SL}\rangle \tag{5.15}$$

Eq. (5.8), (5.14), (5.15) give some informations about the field correlation of the scattered and stray light. If both the correlation functions are real and positive, the best evaluation of the field correlation function of the scattered field is:

$$C_E\left(\Delta\vec{x}\right) = \sqrt{C_I\left(\Delta\vec{x}\right) - \{\langle I\rangle\}^2} - \sqrt{C_{\{I\}}\left(\Delta\vec{x}\right) - \{\langle I\rangle\}^2} \tag{5.16}$$

5.2 Correction for finite samples.

In order to evaluate the correlation function of the mean intensity, we average a given amount of images, then we evaluate the correlation function of the obtained mean value. Since the number of images we average is finite, the correlation function will not correspond to that of eq. (5.14). For example, if the stray light vanishes, the mean intensity will still present fluctuations, due to the scattered light. These fluctuations vanish as the square root of the number of the averaged images, and consequently the correlation function becomes flat only for infinite samples.

A similar problem arises when working with a stochastic, gaussian variable. If we have N values of the stocastic variable x, distributed with probability $P\left(x\right) \propto \exp\left[-\left(x - x_0\right) / \left(2\sigma^2\right)\right]$, we find that the best value for x_0 is the mean of the values x, and the best value for σ is the root mean square displacement of the values x from x_0. On the other hand, the average on a finite number of elements will be displaced from x_0 of an amount, vanishing as the square root of the number of the samples N, but so that the root mean square displacement of the data from the mean is alwais smaller than σ. It is thus necessary to use the Bessel correction, dependent on the number of the samples N.

Generally the Bessel correction is obtained in consequence of the "maximum likelihood" condition. This means that, given a set of values of a stochastic variable, and given a family of probability distributions, the parameters of the family must be selected in order to maximize the probability of finding the given data. Another approach is to find a suitable algorithm which gives the values of the parameters, from a set of data. The algorithm will be selected in order that the output values will be distributed around the true ones, with minimum square displacement. For a gaussian distribution, the two approaches give the same result. It is easy to show that, for example for a Heaviside distribution, the maximum likelihood condition fails to obtain the best results.

In our case, the distribution function of the intensity is not gaussian. We will use weak condition, that is, we will look for an algorithm giving values which average to the true ones. In other words: we will try to avoid sistematic erroneous evaluations of the correlation function.

We define $\bar{\cdot}$ as the mean over N samples. In particular $C_{\bar{i}}$ is the correlation function of the averaged N images. To avoid sistematic errors, we must first evaluate $\{C_{\bar{I}}\}$:

$$\left\{C_{\bar{I}}\left(\Delta\vec{x}\right)\right\} = \left\{\left\langle \bar{I}\left(\vec{x}\right)\bar{I}\left(\vec{x} + \Delta\vec{x}\right)\right\rangle\right\}, \tag{5.17}$$

where the average intensity of N images $\bar{I}$ is given by the sum of the field scattered by the sample $\delta E\left(\vec{x}\right)$ and the field of the stray light $E_{SL}\left(\vec{x}\right)$:

$$\bar{I}\left(\vec{x}\right) = \frac{1}{N}\sum_n \left|\delta E_n\left(\vec{x}\right) + E_{SL}\left(\vec{x}\right)\right|^2. \tag{5.18}$$

So we obtain:

$$\{C_{\bar{I}}(\Delta\vec{x})\} = \frac{1}{N^2}\sum_{n,m}\left\{\left\langle\left[|\delta E_n(\vec{x})|^2 + |E_{SL}(\vec{x})|^2 + \delta E_n(\vec{x})E^*_{SL}(\vec{x}) + \delta E^*_n(\vec{x})E_{SL}(\vec{x})\right]\left[|\delta E_m(\vec{x}+\Delta\vec{x})|^2 + \left|E_{SL}\left(x\right.\right.\right.\right.\right.\right. \tag{5.19}$$

We can follow the calculations performed in Section 5.1 to obtain Eq. (5.8). In this case we obtain:

$$\begin{aligned}\{C_{\bar{I}}(\Delta\vec{x})\} = {} & \frac{1}{N^2}\sum_{n,m}\left\langle|\delta E_n(\vec{x})|^2\right\rangle\left\langle|\delta E_m(\vec{x}+\Delta\vec{x})|^2\right\rangle + \\ & \frac{1}{N^2}\sum_{n,m}|\langle\delta E_n(\vec{x})\,\delta E^*_m(\vec{x}+\Delta\vec{x})\rangle|^2 + \\ & \left\langle|E_{SL}(\vec{x})|^2\right\rangle\left\langle|E_{SL}(\vec{x}+\Delta\vec{x})|^2\right\rangle + |\langle E_{SL}(\vec{x})\,E^*_{SL}(\vec{x}+\Delta\vec{x})\rangle|^2 + \\ & \frac{1}{N^2}\sum_{n,m}\left\langle|\delta E_n(\vec{x})|^2\right\rangle\left\langle|E_{SL}(\vec{x}+\Delta\vec{x})|^2\right\rangle + \\ & \left\langle|E_{SL}(\vec{x})|^2\right\rangle\frac{1}{N^2}\sum_{n,m}\left\langle|\delta E_m(\vec{x}+\Delta\vec{x})|^2\right\rangle + \\ & \frac{1}{N^2}\sum_{n,m}\langle\delta E_n(\vec{x})\,\delta E^*_m(\vec{x}+\Delta\vec{x})\rangle\langle E^*_{SL}(\vec{x})\,E_{SL}(\vec{x}+\Delta\vec{x})\rangle + \\ & \frac{1}{N^2}\sum_{n,m}\langle\delta E^*_n(\vec{x})\,\delta E_m(\vec{x}+\Delta\vec{x})\rangle\langle E_{SL}(\vec{x})\,E^*_{SL}(\vec{x}+\Delta\vec{x})\rangle\,.\end{aligned} \tag{5.20}$$

The mean values can be calculated, provided that the two cases, $n = m$ and $n \neq m$ are taken into account:

$$\begin{aligned}\{C_{\bar{I}}(\Delta\vec{x})\} = {} & \langle\delta I\rangle^2 + \frac{1}{N}|C_{\delta E}(\Delta\vec{x})|^2 + \langle I_{SL}\rangle^2 + |C_{SL}(\Delta\vec{x})|^2 + 2\langle\delta I\rangle\langle I_{SL}\rangle + \\ & \frac{1}{N}C_{\delta E}(\Delta\vec{x})\,C^*_{SL}(\Delta\vec{x}) + \frac{1}{N}C^*_{\delta E}(\Delta\vec{x})\,C_{SL}(\Delta\vec{x})\,.\end{aligned} \tag{5.21}$$

The result reduces to eq. (5.14) in the limit $N \to \infty$:

$$\{C_{\bar{I}}(\Delta\vec{x})\} = (\langle\delta I\rangle + \langle I_{SL}\rangle)^2 + \frac{N-1}{N}|C_{SL}(\Delta\vec{x})|^2 + \frac{1}{N}|C_{\delta E}(\Delta\vec{x}) + C_{SL}(\Delta\vec{x})|^2\,. \tag{5.22}$$

From eq. (5.8), (5.22) and (5.15) we can evaluate the field correlation function:

$$C_E(\Delta\vec{x}) = \sqrt{C_I(\Delta\vec{x}) - \{\langle I\rangle\}^2} - \sqrt{\frac{N}{N-1}C_{\bar{I}}(\Delta\vec{x}) - \frac{1}{N-1}C_I(\Delta\vec{x}) - \{\langle I\rangle\}^2} \tag{5.23}$$

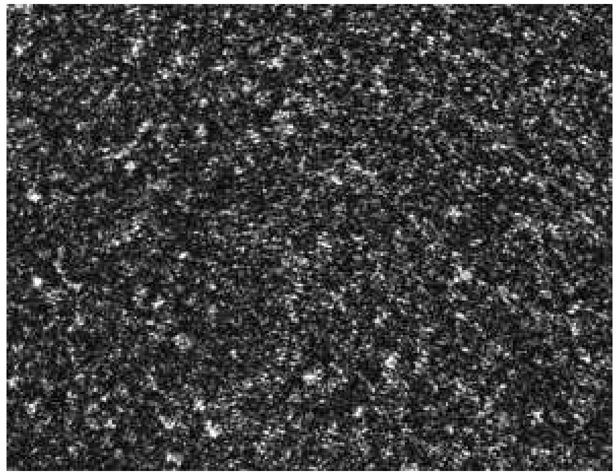

Figure 5.1: Near field intensity of the light scattered by a colloid of 5.2μm.

5.3 Data processing algorithm.

Once the experimental apparatus has been built, as described in Chapter 4, and the sample is placed in it, we acquire one hundred images. The electronic shutter of the CCD and its interlacement time must be so short that no evident evolution of the system happens during the exposure: for the samples we measured, that is colloids some microns large, with brownian movements, and non equilibrium fluctuations in the free diffusion of simple liquids, an interlacement delay of 1/25s is sufficient. Moreover, different images must be completely uncorrelated. For a 10.0μm colloid, images must be grabbed at intervals longer than one minute, if only brownian movements are the source of decorrelation. For the non equilibrium fluctuations we studied, the interval was about one second.

In figure 5.1 and 5.2 we show two typical images of the near field intensity of the light scattered by colloids of 5.2μm and 10.0μm. We can notice the different typical size of the speckles.

For each image, we evaluate the correlation function. This operation is quite fast, since we can use a Fast Fourier Transform (FFT) algorithm. An FFT algorithm allows to evaluate the Fourier tranform of an $M \times N$ matrix, with a number of arithmetic operations proportional to $MN \log(MN)$. By using Perceval relation, we can obtain the correlation function by making an FFT, evaluating the square modulus, and making an Inverse FFT (IFFT). This only requires a number of operation of the order of $MN \log(MN)$. By scanning every value of Δx, and averaging over every $N \times M$ pixels, the number of operations would be of the order of $(MN)^2$. Using FFT, care must be taken in order to correcly evaluate the correlations near the boundarys: FFT assumes periodic boundarys, so the image must be embedded in a bigger matrix, filled with zeroes. Since the FFT is faster if N and M are powers of 2 [19], we used a

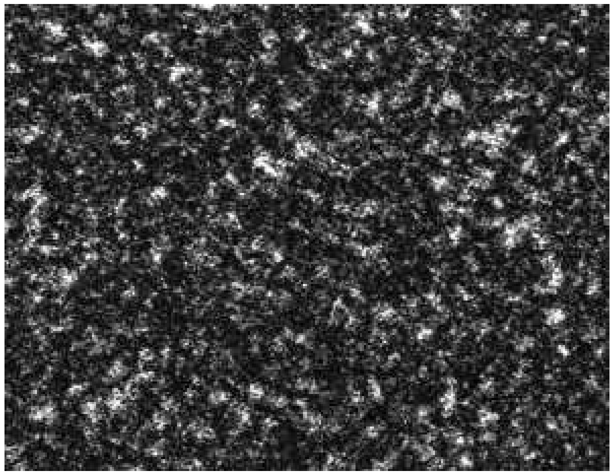

Figure 5.2: Near field intensity of the light scattered by a colloid of 10.0μm.

matrix of 1024×1024 points. After the correlation function has been evaluated, we normalize it, by dividing by the number of independent couples used to evaluate the correlation function.

The correlation functions of every image are averaged, thus obtaining $C_I(\Delta\vec{x})$. Fig. 5.3 and 5.4 show typical graphs of the intensity correlation function $C_I(\Delta\vec{x})$, for a colloid made of polystyrene spheres with diameters of 5.2μm and 10.0μm. We can notice that the correlation function has a maximum at $\Delta\vec{x} = 0$, then decreases, until it reaches the plateau value, about one half the peak value. This behaviour is typical of every speckle field.

Neglecting the stray ligth, we could evaluate the field correlation function by using the Siegert relation, Eq. (3.65):

$$C_E(\Delta\vec{x}) = \sqrt{C_I(\Delta\vec{x}) - \langle I \rangle^2} \tag{5.24}$$

where the mean intensity $\{\langle I \rangle\}$, is obtained by averaging the measured intensity over every pixel of the image and over every image. In Fig. 5.5 and 5.6 are shown typical graphs of the field correlation function, calculated from the intensity correlation function, without any correction for the stray light. The correlation should vanish for $\Delta x \to \infty$, in absence of stray light.

In order to subtract the contribution of the stray light, we evaluate the correlation function of the average of all the images, thus obtaining $C_{\bar{I}}(\Delta\vec{x})$. The evaluation of the correlation function is obtained with the above described algorithm. In Fig. 5.7 and 5.8 are shown typical graphs of the correlation function of the mean intensity, for the two colloids. The graphs are not flat, due to the stray light.

Through Eq. (5.23) we evaluate $C_E(\Delta\vec{x})$, under the hypothesis that both the stray light field and the scattered light field have a real and positive correlation

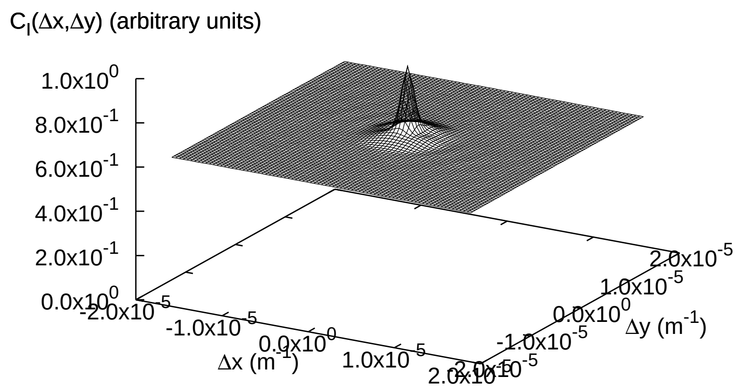

Figure 5.3: Intensity correlation function $C_I(\Delta\vec{x})$, for a colloid made of polystyrene spheres with diameter of 5.2μm

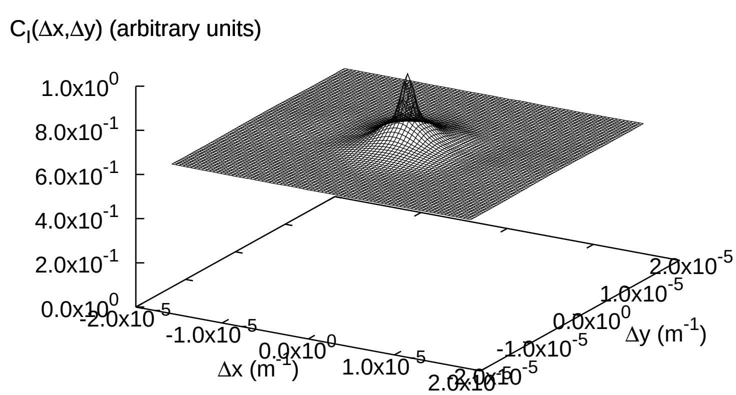

Figure 5.4: Intensity correlation function $C_I(\Delta\vec{x})$, for a colloid made of polystyrene spheres with diameter of 10.0μm

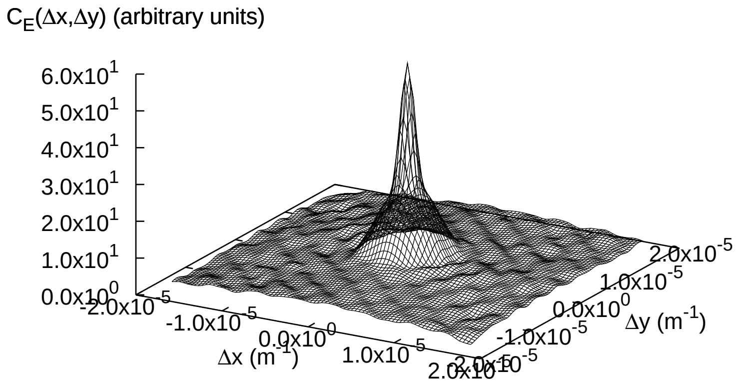

Figure 5.5: Field correlation function $C_E\left(\Delta\vec{x}\right)$, not corrected for the stray light, for the colloid made of polystyrene spheres with diameter of 5.2μm

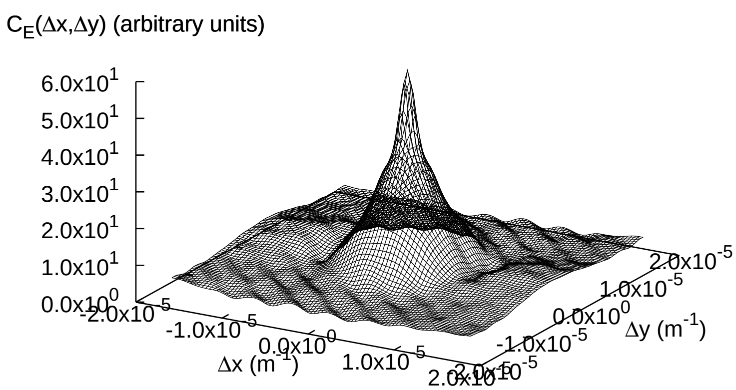

Figure 5.6: Field correlation function $C_E\left(\Delta\vec{x}\right)$, not corrected for the stray light, for the colloid made of polystyrene spheres with diameter of 10.0μm

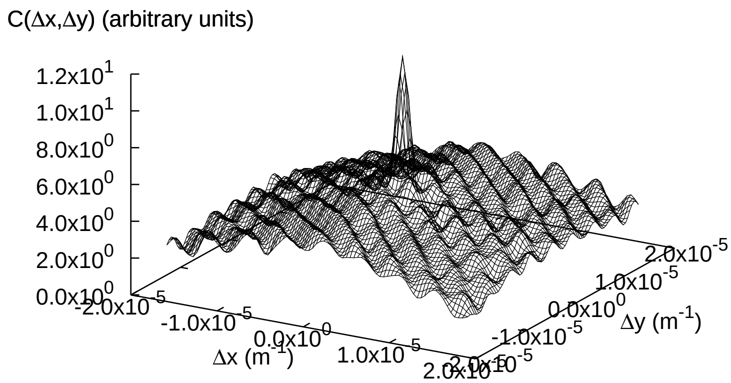

Figure 5.7: Correlation function of the mean intensity $C_{\bar{I}}\left(\Delta\vec{x}\right)$, for the colloid made of polystyrene spheres with diameter of 5.2μm

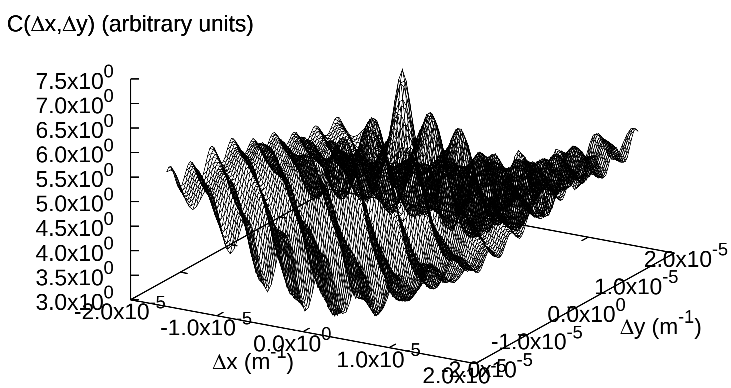

Figure 5.8: Correlation function of the mean intensity $C_{\bar{I}}\left(\Delta\vec{x}\right)$, for the colloid made of polystyrene spheres with diameter of 10.0μm

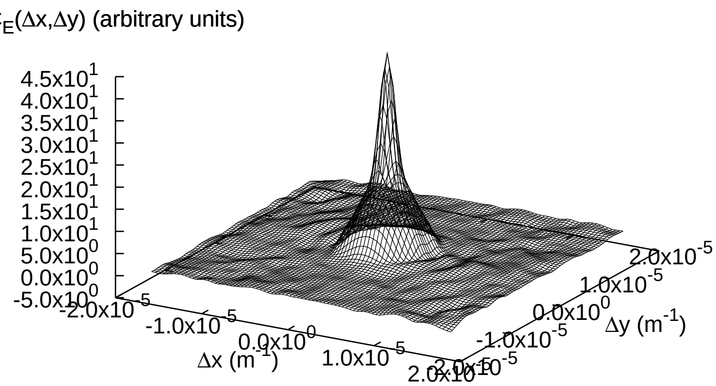

Figure 5.9: Field correlation function $C_E\left(\Delta\vec{x}\right)$ for the colloid made of polystyrene spheres with diameter of 5.2μm

function. Typical field correlation function, corrected for the stray light using Eq. (5.23), are shown in figure 5.9 and 5.10: we can notice a signitificative increase in the smoothness of the graphs, with respect to Fig. 5.5 and 5.6.

We apply a Fourier tranform to the two dimensional correlation function $C_E\left(\Delta\vec{x}\right)$, thus obtaining the field power spectrum $S_E\left(q\right)$. Since our samples are isotropic, we make an angular average of the power spectra, and represent our data as a function of the modulus q of $\vec{q}$. The scattered intensity $I\left(q\right)$ is then obtained by using Eq. (3.14), that is, simply relating each value of the power spectra, with wavelength q to a value of $I\left(Q\right)$, where the relation $Q\left(q\right)$ is given by Eq. (3.13). In Fig. 5.11 and 5.12 we show the measured $I\left(q\right)$.

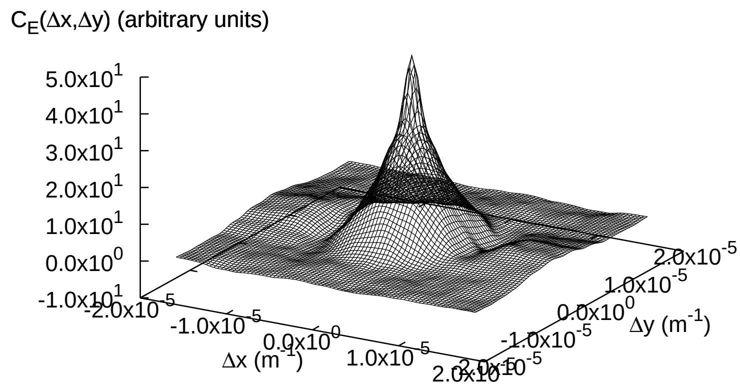

Figure 5.10: Field correlation function $C_E\left(\Delta\vec{x}\right)$ for the colloid made of polystyrene spheres with diameter of 10.0μm

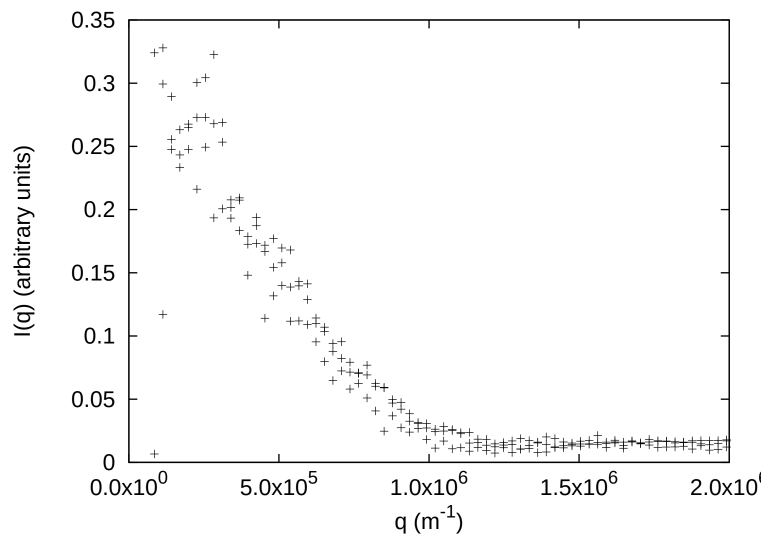

Figure 5.11: ONFS measurement of the scattered intensity of a 5.2μm colloid.

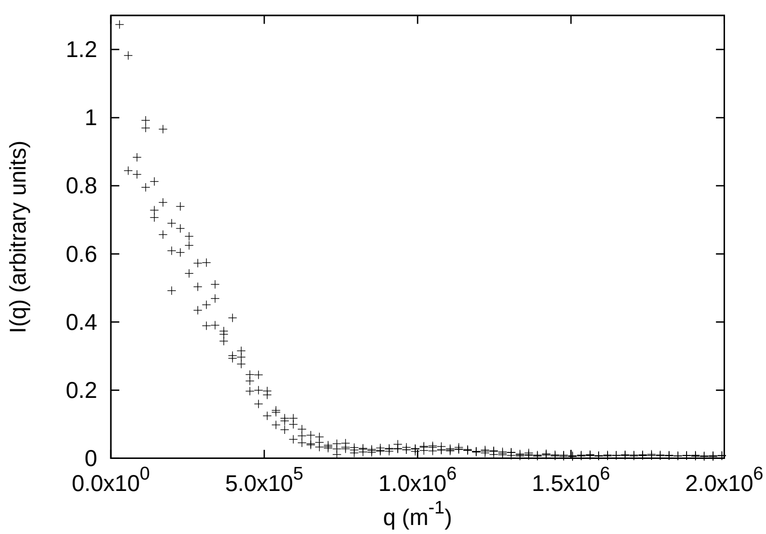

Figure 5.12: ONFS measurement of the scattered intensity of a 10.0μm colloid.