Angular and three–dimensional correlation functions, determined from the Muenster Red Sky Survey

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Abstract

We measured the two dimensional galaxy–galaxy correlation function from the Muenster Red Sky Survey (Ungruhe 1999). This survey has a slightly larger surface as the APM survey and complete up to \( r_F < 18.3 \) mag \( (z_{med} \sim 0.14) \). The large dynamical range of the survey made it possible to examine sub-catalogues with different limiting magnitudes. The positive part of our measured angular correlation functions (after the colour correction) agree excellently with those measured by Maddox, Efstathiou and Shutherland 1996 from the APM galaxy catalogue (Maddox et al. 1990). From the measured angular correlation functions the three dimensional two-point correlation function \( \xi(r) \) was calculated. We have chosen the evolution parameter \( \epsilon \) so that the change of the correlation length \( r_0 \) with the depth of the sub-catalogue were minimal. This prescription gives \( r_0 = 5.82 \pm 0.05 \) h\(^{-1}\) Mpc and a very high, positive evolution parameter \( \epsilon = 2.6 \). The position of the point, where the 3d correlation function breaks away from the power law depends on the depth of the sub-catalogues: for low magnitude limits the break-down comes earlier, for higher later.
1. Introduction

Since almost half a century the two-point correlation function has been the most popular statistic to describe the galaxy clustering in astrophysics. It has been firmly established (Peebles 1980 and references therein) that the three dimensional two-point correlation function (3d CF) is of the form $\xi(r) = (r_0/r)^\gamma$ in a wide range of distances, breaks away from the power law form at certain distance $r_1$ and becomes negative at $r_2$. The 3d CF can be measured by using magnitude or volume limited three dimensional galaxy catalogues or can be calculated from the 2d CF, measured from large surface two dimensional catalogues. The parameters $r_0$ and $\gamma$ measured from local and medium deep catalogues are $r_0 \approx 5 h^{-1} \text{Mpc}$, $\gamma = 1.7 - 1.8$. Some authors estimate also the parameter $r_2$. Baugh 1996 finds by using the APM galaxy survey (Maddox et al. 1990) $r_2 \approx 30 h^{-1} \text{Mpc}$, Tucker et al. 1997 measure from the LCRS (Shechtman et al. 1996) $r_2 \sim 30 - 40 h^{-1} \text{Mpc}$ while Cappi et al. 1998 on the basis of the Southern Sky Redshift Survey (SSRS2, da Costa et al. 1994) find that the first zero point of the autocorrelation function $\xi(r)$ increases linearly with the sample depth. Several authors notices that the 3d CF rises above the power law before it breaks down (Baugh 1996, Guzzo et al. 1991).

To measure the detailed form of the $r_0(z)$ function large surface deep 3d catalogues are needed. At present the deep 3d surveys (say $z_{\text{med}} > 0.3$) contain several hundred galaxies and are not large enough for this purposes. Usually the evolution of the CF is parametrised and the parameter is measured. The customary parametrisation of the correlation length $r_0$ as a function of the redshift is

$$r_0(z) = r_0(1 + z)^{\frac{3-\epsilon}{\gamma}}. \quad (1)$$

This relation was proposed in 1977 (Groth & Peebles 1977) when the observable redshifts were much smaller than 1. For $z \ll 1$ the first term of expansion of $r_0(z)$ by $z$ is $r_0(z) = r_0(0)(1 - \frac{3+\epsilon}{\gamma} z)$ ($r_0$ measured in physical coordinates). However, for large $z$ with $\epsilon = \text{const.}$ (1) has no solid physical basis. In a model proposed by Ma 1999 $\epsilon$ varies from $\gamma - 1$ at high redshift trough 0 at medium $z$ down to $\gamma - 3$ for low redshift. The first value corresponds to the linear grows of the perturbations (over the general expansion), $\epsilon = 0$ if the structures are fix in comoving coordinates and $\epsilon = \gamma - 3$ when the clustering is stable in physical coordinates. The canonical value of the correlation length is $r_0(0) = 5.4 h^{-1} \text{Mpc}$ (Davis & Peebles 1983). From small catalogues in general, one can only measure only a combination of $r_0$ and $\epsilon$ (Le Fèvre et al. 1996, Carlberg et al. 1997, Connolly et al. 1998, Small et al. 1999) therefore it is difficult to compare the results. The $\epsilon$ evolution parameter can be roughly estimated from the equation $r_0(z_{\text{med}}) = r_0(0)(1 + z_{\text{med}})^{-\frac{3+\epsilon}{\gamma}}$, where $z_{\text{med}}$ is the median redshift of the catalogue, $r_0$ measured in physical coordinates. It is clear that the amplitude of the 3d CF decreases strongly with increasing redshift and for fix $r_0(0)$ the measured $\epsilon$ is between 0 and 2.6. Postman et al. 1998 determined the 3d CF from an I selected 2d catalogue. From the $I \leq 20$ sub-catalogue they found $r_0 = 5.2 \pm 0.4 h^{-1} \text{Mpc}$ and $\epsilon$ positive. Deeper the catalogue ($I \leq 23$, $z_{\text{med}} = 0.5$), $\epsilon$ is smaller ie. the evolution is slower what is in contradiction with the results of Ma 1999. Small et al. 1999 find no evidence that the comoving correlation length changes between the redshift intervals (0.2 - 0.3) and (0.3 - 0.5).

From a large surface catalogue with large dynamical range (as APM or MRSS) one can separate a number of sub-catalogues eg. different limiting magnitudes $m$. In this case by
taking the same \( r_0 \) for every sub-catalogue, one can determine the parameter \( \epsilon \) (at least for \( z \ll 1 \)).

A further important question is, where the CF breaks away from scaling, at which distance \( r \) becomes negative and are there measurable anti-correlations and correlations after that point. These problems are related with the question of the size of the largest structures in the Universe. Wu, Lahav & Rees 1998 and 1999 find using several indicators that on scales larger than 300 \( h^{-1} \) Mpc the fluctuations become negligible.

Pietronero and coworkers (Coleman & Pietronero 1992, Sylos–Labini et al. 1998, Joyce et al. 2000 and references therein) question the applicability of the CF to characterise the large scale structure of the Universe. They state, on the basis of conditional probability analysis of different catalogues that the correlation length \( r_0 \) for clustering of galaxies do not characterises intrinsic properties of the distribution, but the particular sample one is considering and no statistical evidence for the usually assumed homogeneity on a scale large enough.

In this paper we determine the two-point correlation function from the Muenster Red Sky Survey (MRSS, Ungruhe 1999). Section 2 contains a brief description of the survey. Section 3 presents the measuring methods of the 2d CF, the analysis of the results and comparison with the APM 2d correlation function as determined by Maddox, Efstathiou and Shutherland 1996 (in the following MES). In section 4 we calculate the 3d CF from different sub-catalogues using the Limber-equation, discuss the scaling properties of the CFs and determine the correlation length \( r_0 \), as well as the evolution parameter \( \epsilon \). The interpretation of the results is discussed in Section 5.

The two-point CFs give only partial information about the galaxy distribution, for more detailed description higher order CFs are needed. On this correlation function we report elsewhere.

2. The catalogue

The Muenster red sky survey (MRSS, R. Ungruhe 1999) is based on 217 contiguous plate of the ESO Southern Sky Atlas R, covering more than 5000 square degree. The plates were digitalised using two PDS 2020 GMplus machine of the Astronomical Institute Muenster. The image surface brightness profiles were used to distinguish galaxies from stars and other objects. The catalogue contains more than 7 million galaxies and out of these about 2.3 million brighter than \( r_F=19.5 \) mag, but to avoid the ”last magnitude effect” we do not use in the determination of the CF the galaxies fainter then 18.5 mag. After corrections the magnitudes are accurate to \( \leq 0.05 \) mag across each of the 217 plate. Images in the overlapping regions of neighbouring plates are used to establish a uniform magnitude system over the entire survey. In order to calibrate the matched magnitudes, CCD photometrie of 1766 galaxies and 1876 stars, homogeneously distributed on 92 plates were used. The estimated plate to plate zero-point-error is less than 0.10 mag. The extinction was corrected using the maps of Schlegel et al. 1998. The catalogue is complete up to 18.3 mag (Ungruhe 1999).

The catalogue is complemented with galaxy images digitalised in pixels with 1.01 arcsec edge length. The pictures of objects were stored in frames (out-cuts) with side length 21, 51 and 101 pixels, choosed by the software. The computer classification of about 2.6
million objects were carefully controlled visually (Ungruhe 1999), what reduce essentially the possible star–galaxy misclassification.

The corresponding J-atlas was digitalised at two UK institutions: at the Institute for Astronomy in Cambridge using the APM machine (186 Schmidt-plate, Maddox et al. 1990) and at the Royal Observatory Edinburgh (154 Schmidt-plate) with the COSMOS machine Stevenson et al. 1985. Both catalogues are included in MRSS that makes possible the comparison of the positions and other quantities, as well as the determination of the \( r_F - b_J \) colours of the galaxies. Because of the large surface of the survey the integral corrections are negligible.

The F band has some advantages over the J band: the vignetting and desensitization corrections are 2 - 3 times smaller, consequently the magnitudes towards the edges of plates are better determined. Furthermore, the K - correction is also smaller and varies mildly with the depth of the catalogue. In spectral range of the MRSS the average \( r_F - b_J \) is 1.5 mag (Jones et al. 1991). In addition the MRSS catalogue contains other data such as surface brightness, ellipticity, length of small and large axes, large-scale alignments etc. Schuecker et al. (1990, 1994) measured the objective prism redshifts for 900 000 galaxies, and Spiekermann 1994 gave an automated morphology classification of all galaxies brighter than \( r_F = 18.5 \) mag.

3. Measuring the correlation function

As it was emphasised by Maddox, Efstathiou and Shutherland (1996), large areas of the sky are required to determine the 2d CF \( w \) reliably on angular scales of a few degrees. They used 80 to 120 contiguous plates to compute the CF. Here we determine the \( w(\theta; m) \) from 152 contiguous plates.

For measuring the galaxy - galaxy correlation function we use two essentially different, independent methods: (i) count in annuli around galaxies and (ii) count in cells.

3.1 Count in annuli around galaxies

The most direct method to measure the over-density around galaxies is to count the number of galaxies between circles of radius \( \theta_i \) and \( \theta_{i+1} \). The corresponding density can be calculated by dividing by the surface of the annulus. If the first galaxy is near to the border of the sample only a part of the annulus is taken into account being inside the sample. For very small angular distances this method is more precise than measuring the surface by the number of random points in the annulus. This method does not need gridding of the data, it is simple and fast to apply but, as it was shown (Hamilton 1993, Maddox et al. 1996), subject of first order errors in the galaxy density contrast. We use this estimation only for small angular scales \( \theta < 1^\circ \), when the amplitude is high.

3.2 Count in annuli around bins

For larger angular distances we do not need the exact position of the galaxies. We
binned the galaxies in square cells in an equal area projection, and applied the count in annulus method for the cells. A cell belongs to a given ring when its centre is inside the ring. The surface of an annulus is taken to be equal to the sum of the surfaces of cells in the annulus. That is we use the usual estimator

\[ w(\theta) = \frac{< n_i n_j >}{< n_i > < n_j >} - 1. \]  

(2)

In the angular range \(0.08^\circ < \theta < 0.8^\circ\) we use a grid of edge length \(s = 0.01^\circ\), while for \(0.5^\circ < \theta \leq 4^\circ\) we have \(s = 0.1^\circ\) and \(s = 0.25^\circ\) for \(\theta > 4^\circ\). The overlapping parts of the CFs calculated in different intervals agree well with each others.

3.3 The count-in-cells method

Another possibility to determine the CF is to measure its average on square cells of edge \(\theta\):

\[ \overline{w}(\theta) = \frac{1}{\theta^4} \int_0^\theta d^2 \theta_1 \int_0^\theta d^2 \theta_2 w(|\theta_1 - \theta_2|). \]  

(3)

This quantity can be expressed in terms of the moments of galaxy-number in a cell as follows (Rubin 1957, Peebles 1980)

\[ \overline{w}(\theta) = \frac{N^2 - N_i^2 - N_j}{N^2}. \]  

(4)

To compute \(N = N(\theta)\) we put a grid with edge length of \(\theta\) on the equal-area-projection. In order to be sure not to cut structures in parts we shift the grid in steps \(\ll \theta\) in \(\delta\) and \(\alpha\) directions and count the galaxies in cells for every position. By calculating the averages the catalogue is heavily oversampled. The – mostly beneficial – consequences of oversampling was discussed by Szapudi et al. 1997.

From the average of the CF one can determine the true CF by inverting the integral (3). If the CF is of the form \(w_0(\theta) = A \theta^{1-\gamma}\) then its average can be calculated by numerical integration from (3):

\[ \overline{w}_0(\theta) = 1.968 A \theta^{1-\gamma} = 1.968 w_0(\theta). \]  

(5)

3.5. Variation of \(w(\theta)\) with the limiting magnitude

By computing the CF from sub-catalogues with different limiting magnitudes we can mimic the changes in depth. The limiting magnitude \(m\) was varied from \(m = r_F(\text{max}) = 15.5\ \text{mag}\) up to \(m=18.5\ \text{mag}\) in half magnitude steps. The result is shown in Figure 1. The CFs on a broad, on a log–log plot more than two decades range are straight lines, i.e. \(w(\theta,m) = A(m) \theta^{1-\gamma}\). The parameter in the exponent is \(\gamma = 1.69 \pm 0.02\). Using this value of \(\gamma\), we can measure the amplitudes of the straight part of the CF. The parameters log \((A(m))\ \text{deg}^{\gamma-1}\) are given in the Table 1.
Table 1.

| m   | 15.5 | 16.0 | 16.5 | 17.0 | 17.5 | 18.0 | 18.5 |
|-----|------|------|------|------|------|------|------|
| \log(A \text{ deg}^{-1}) | -.64 | -.79 | -.95 | -1.12 | -1.28 | -1.465 | -1.63 |

In the $15.5 \leq m \leq 18.5$ interval the amplitude of the CFs $A(m)$, measured from the horizontal part of the function $w(\theta; m)/\theta^{1-\gamma}$ can be parametrised as

$$A(m) = 0.0148 \cdot 10^{0.33\cdot(15.5-m)} \text{deg}^{-1}. \quad (6)$$

The amplitude changes a factor of ten in the three magnitude range, as in MES or Postman et al. 1998. The whole 2d CF, can be parametrised as

$$w_p(\theta; m) = A_p(m)\theta^{1-\gamma_p} \left[ 1 + \left( \frac{\theta_1}{\theta} \right)^\alpha \right]^{-1} \left\{ \left[ 1 + \left( \frac{\theta_2}{\theta} \right)^\nu \right]^{-1} - \left[ 1 + \left( \frac{\theta_3}{\theta} \right)^\nu \right]^{-1} \right\}. \quad (7)$$

We use $\alpha = 9$ and $\nu = 2.5$. The first bracket on the right hand side describes the breakdown of the scaling at small angles, while the break away from the power law at large angular distances contained in the second. In this formula we take into account that for small limiting magnitudes the 2d CFs are somewhat steeper, and $\gamma_p$ varies slightly with the limiting magnitude, consequently $A_p(m)$ does not agree exactly with $A(m)$ given above, where we have used the value $\gamma = 1.69$. The parameters in (7) are given in Table 2.

Table 2.

| m   | $A_p \text{ deg}^{-1}$ | $\gamma_p$ | $\theta_1 \text{ deg}$ | $\theta_2 \text{ deg}$ | $\theta_3 \text{ deg}$ |
|-----|------------------------|-------------|-------------------------|-------------------------|-------------------------|
| 15.5 | 0.2352 | 1.73 | 8.8 $10^{-3}$ | 6.5 | 40 |
| 16.0 | 0.1740 | 1.71 | 7.1 $10^{-3}$ | 8.5 | 40 |
| 16.5 | 0.1350 | 1.69 | 5.5 $10^{-3}$ | 8.0 | 40 |
| 17.0 | 0.0860 | 1.68 | 4.5 $10^{-3}$ | 7.5 | 40 |
| 17.5 | 0.0550 | 1.68 | 4.1 $10^{-3}$ | 7.0 | 40 |
| 18.0 | 0.0350 | 1.68 | 3.7 $10^{-3}$ | 6.3 | 40 |
| 18.5 | 0.0245 | 1.68 | 3.4 $10^{-3}$ | 6.0 | 40 |

The maxima of the CFs are shifted toward smaller angles as the limiting magnitude grows. This corresponds to the change of the average apparent galaxy diameter with $m$. When the apparent picture of the galaxies overlap, the software identifies them in the “unknown objects”. One can parametrise the maxima of the CFs as function of $m$ as $\theta_{\text{max}} = 2.83 \cdot 10^{-0.657m}$.

The slope of the straight-line part of the log($w$)–log($\theta$) function is between -1.73 and -1.68 in agreement with earlier results. The functions with lower limiting magnitudes are somewhat steeper. This could mean that the intrinsically brighter galaxies are more correlated (Hamilton 1988, Davis et al. 1988, Benoist et al. 1996).

Between $6^\circ$ and $10^\circ$ the CFs go through zero (Figure 12 - 14). The amplitude of the negative part decreases with increasing magnitude limit.
3.6. Consistency of the two methods

The CF measured by count in annuli method and the average of the CF measured by counts-in-cells for galaxies brighter than $r_F = 18$ mag are shown in Figure 2. First of all we check whether the two methods are consistent by computing the average of the CF determined by count in annuli method.

The broken line in Figure 2 shows the the parametrised CF $w_p(\theta)$. We compute the average of this function on squares with edge length $\theta$. The direct Monte Carlo integration of $w$ would be dangerous because of the peak at $\theta = 0$. The average of $w_0(\theta)$ is known and the average of the difference $w_p(\theta) - w_0(\theta)$ is not singular any more and can be easily calculated from (8). The resulting averaged CF is shown by the dashed line in Fig. 2. The agreement of the two methods is excellent.

3.7 Comparison with $w(\theta,m)$ from the APM survey

Maddox, Efstathiou and Sutherland 1996 have compared in detail the CFs, calculated from the APM survey with $w(\theta,m)$ from other surveys. An important result of their analysis that large area surveys are required to determine $w$ reliably on angular scales of a few degrees. They found that the deviation of $w$ from a power law seen in the small area catalogues are caused by the integral constraint in the estimator of $w$.

The APM CF agrees well with that calculated from the Lick-survey (Groth and Peebles 1977) for $\theta \leq 3^\circ$, but the APM CF breaks less sharply from the power law on scales larger than $\sim 3^\circ$. By comparing with the CF calculated from the Edinburgh–Durham Southern Galaxy Catalogue (Collins et al. 1989, 1993) MES found that up to $2^\circ$ the two CFs agree well but for larger angular distances the EDSGC gives more correlation than the APM catalogue.

In Figure 3 we compare our CFs with that of MES (their Figure 23). The magnitude limit (after the colour correction $b_J - r_F = 1.5$ mag) for the two upper curves on both panel are not exactly the same and this causes the small relative shift of the CFs. The agreement of the other pairs of curves are excellent. We confirm the results of MES concerning the $\theta$ and $m$ dependence of the 2d CFs. Note that the APM CFs were calculated by using 80 - 120 Schmidt plates, the MRSS 152 plates; the plate sizes and their overlaps in the two catalogues are not the same, furthermore the $N(b_J)$ and $N(r_F)$ functions are different, the photometry and the star–galaxy separation software are independent etc. In spite of all these differences the CFs measured from the two catalogues agree in a range of several magnitudes. After the colour correction our CFs, determined from sub-catalogues with different limiting magnitude $m$, agrees excellently with the CFs measured from the APM catalogue. For lower magnitude limits ($m \leq 17.0$ mag) the MRSS functions show less correlation in the region $\theta > 4^\circ$. MES give the negative part of the 2d CF only for one magnitude limit. Their CF shows much less anti-correlation as ours (Figure 4).
3.8. Scaling of the correlation functions

Groth and Peebles 1977 have shown that the CFs of different \( m_{\text{lim}} \) can be transformed into one curve by shifting them with appropriate amounts \( \Delta_x(m) \) and \( \Delta_y(m) \) in the \( \log(\theta) \) and \( \log(w) \) directions. As it is shown in Figure 5 one can approximate the measured CFs on log–log scale with straight lines with slopes \( \delta_1 = -0.68 \) and \( \delta_2 = -3.0 \). We could scale the section point into one points, in accord with to the Groth–Peebles 1978 prescription. When scaling the \( m = 18 \) mag CF to \( m = 17 \) mag we must use \( \Delta_x = 0.0055, \Delta_y = 0.332 \) and for \( m = 16 \) mag CF to \( m = 17 \) mag the parameters \( \Delta_x = -0.0038, \Delta_y = -0.231 \). For the APM catalog MES obtained a reasonable overlap of the transformed CFs. Using the EDSGC catalogue CNL92 demonstrated similar scaling. However, it will be shown by assuming the scaling of the CFs that the shifts in the \( \log(\theta) \) and \( \log(w) \) directions are not independent from each other. We discuss further the scaling properties in the section 4.2.

An other way to demonstrate the scaling is to divide the measured CFs by \( A_p(m)\theta^{1-\gamma_p(m)} \). The resulting function \( f(\theta) \), is independent of the limiting magnitude \( m \) in a large angular range, at least up to 6° (Figure 6). The semilogarithmic presentation of the \( f(\theta) \) function emphasises the dip at about 0.4°. A similar dip is seen in Figure 23 of MES96 and Figure 2 of CNL92. The reason for this dip seems to be obscure.

The CFs measured from MRSS and from the APM catalogue deviate from the power law at about 2°, independent of the limiting magnitude. The CFs determined from EDSGC break away from scaling at about 19°, also independent of \( m \) (CNL92 Figure 2).

The fact that the function \( f(\theta) \) does not depend on \( m \) in a bright range of \( \theta \) shows already that the 3d CF, calculated from the 2d CFs, must depend on the limiting magnitude \( m \), i.e. on the depth of the catalogue.

4. Relation between two dimensional and three dimensional correlation functions

From a large surface deep 3d catalogue one could determine the luminosity function of the galaxies, together with their luminosity evolution, as well as the 3d correlation function and its evolution with the redshift. The 2d catalogues, like MRSS, contain at least one order of magnitude more galaxies but the problems of the selection function is not solved. In some sense the informations got from the two type of catalogues complement each other.

Here we determine from the measured 2d CF the \( r_0 \) and \( \epsilon \) parameters of the 3d CF. In the literature there are several way to simplify the problems. One possibility is to take a \( dN/dz \) function, measured from a smaller catalogue, fix the parameter \( \epsilon \) and calculate \( r_0 \) as a function of the magnitude limit. The second way is to fix \( r_0 \) and \( \epsilon \) and choose appropriate parameters in the selection function. A further method is to use a reliable \( dN/dz \) function and to choose \( \epsilon \) so that \( r_0 \) doesn’t depend on the limiting magnitude (depth) of the sub-catalogues.
4.1 The Limber-equation

The Limber-equation connects the 3d CF with the 2d CFs:

\[
w(\Theta; m) = \frac{1}{\Theta} \int_{0}^{\infty} r K(r/\Theta; m) \xi(r) dr
\]

where \( \Theta = 2 \sin(\theta/2) \), and the kernel is

\[
K(t; m) = \frac{2}{(N_\ast \omega)^2} \int_{0}^{t} \frac{F(x)(dN/dx)^2}{\sqrt{t^2 - x^2}} \frac{dx}{(1 + z)^{3+\epsilon}}.
\]

Here \( \omega \) is the solid angle covered by the survey, \( N_\ast (m) \) is the number of galaxies per steradian, \( F(x) - 1 \) is a relativistic correction (Peebles 1980, §56), which is exactly zero for \( \Omega_0 = 1 \), and small for any \( \Omega_0 \) for the depth covered in MRSS. For the simplicity we use the Einstein– de Sitter model \((\Omega_0 = 1, \Lambda = 0)\). In this case the metric distance depends on the redshift as

\[
x = \frac{2c}{H_0} (1 - \sqrt{1 + z}).
\]

We use \( H_0 = 100h \) km/s Mpc.

If the 3d CF is of the form \( \xi(r) = (\frac{r}{r_0})^\gamma \) then from (8) and (9) follows that \( w(\theta; m) = A(m) \theta^{1-\gamma} \). The amplitude \( A(m) \) can be calculated from \( \xi(r) \) and the normalised galaxy number distribution \( p(x; m) \):

\[
p(x; m) = q(z; m) \frac{dz}{dx} = \frac{1}{N_\ast (m) \omega} \frac{dN(z; m)}{dz} \frac{dz}{dx};
\]

with

\[
\int_{0}^{\infty} p(x; m) dx = \int_{0}^{\infty} q(z; m) dz = 1.
\]

The amplitude \( A(m) \) dependent only on the form of the \( \frac{dN}{dz} \) function and independent of its amplitude. If we know \( p(x; m) \), there is a unique connection between the correlation length \( r_0 \) and the 2d amplitudes \( A(m) \).

4.2. Scaling and the Limber–equation

Let us now assume that the 2d CFs scale with the limiting magnitude \( m \), ie.

\[
w(\theta; m') = Cw(\lambda \theta; m).
\]

In this case from (13) follows that \( K(t; m) \) scales as

\[
K(t; m') = \frac{C}{\lambda} K(t/\lambda; m)
\]

and by (13) we have

\[
p(x; m') = \sqrt{\frac{\lambda}{C}} p(x/\lambda; m) \left[ \frac{1 + z(x)}{1 + z(x/\lambda)} \right]^{(3+\epsilon)/2}.
\]
From the normalisation condition of $p(x; m')$ follows that
\[ \lambda^2 C^{-\frac{3}{2}} I(\lambda, m, \epsilon) = 1, \] (16)
where
\[ I(\lambda, m, \epsilon) = \int_0^\infty \left[ \frac{1 + z(x\lambda)}{1 + z(x)} \right]^{(3+\epsilon)/2} p(x; m) dx. \] (17)
That means that the shift of the $w(\theta; m)$ functions in directions of the log($\theta$) axis and log($w$) axis are not independent but
\[ \Delta \log(w) \equiv \log(C) = 3\Delta \log(\theta) + 2\log(I(\lambda, m, \epsilon)). \] (18)
For a given realistic distribution function $p(x; m)$ or $q(z; m)$ the integral $I(\lambda, m, \epsilon)$ can be calculated. It turns out that it gives only a small contribution to $C$, corresponding to the fact that in the depth of MRSS the curvature effects are neglected and the redshift effects are small (see Groth & Peebles 1977).
Consequently, if we scale together on the log–log plot the less steep part of the CFs taking into account (13), their steeper parts will not fall together. That means that the correlation amplitudes and the position of the break in $w$, as measured from the MRSS are independent, ie $\log[w(\theta; m')]$ can not be transformed into $\log[w(\theta; m')]$ by a shift of $\Delta \log(\theta)$ and $\Delta \log(w)$ given by (18). We conclude that if there exists a 3d CF, independent of the depth of the catalogue, the 2d correlation functions do not scale with the limiting magnitude $m$. The slope of the 2d CFs and the position of the break down of the scaling are independent from each other.

4.3 The selection function

Maddox et al. 1990 proposed a selection function calculated from a redshift dependent luminosity function. Later, MES96 used a selection function deduced from the measured redshifts of a part of the galaxies in the 2d catalogue in the form of
\[ \frac{dN}{dz} = N_s \omega q(z; \alpha, \beta, z_0) \] (19)
where $q(z; \alpha, \beta, z_0)$ was parametrised as
\[ q(z; \alpha, \beta, z_0) = \frac{\beta}{\Gamma((\alpha+1)/\beta)} \frac{(z)}{z_0}^\alpha e^{-(\frac{z}{z_0})^\beta}. \] (20)
with $\alpha = 2$ and $\beta = 3/2$. The maximum of this distribution is $z_{\text{max}} = (\alpha/\beta)^{1/\beta} z_0$, the mean value of the $n$-th moment of the redshift $z^n(m)$ is
\[ \overline{z^n} = z_0 \frac{\Gamma((\alpha + 1 + n)/\beta)}{\Gamma((\alpha + 1)/\beta)}, \] (21)
and the modal value can be calculated from the following equation
\[ \Gamma\left(\frac{\alpha + 1}{\beta}, z_{\text{mod}}\right) = \frac{1}{2} \Gamma\left(\frac{\alpha + 1}{\beta}\right). \] (22)
For $\alpha = 2$ and $\beta = 1.5$ one has $z_{\text{max}} = 1.2114z_0$, $\tau = 1.5048z_0$ and $z_{\text{mod}} = 1.412z_0$. From these $dN/dz$ function one can determine the luminosity function. It depends mildly on $z$. This parametrisation is simple and general enough to describe the selection function.

We use two set of parameters $\alpha, \beta$ and $z_0$. First we take, following MES96 $\alpha = 2 \beta = 1.5$ and determine $z_0$ from the condition $r_0 = 5h^{-1}\text{Mpc}$ (and $\epsilon = -1.3$). The second set of parameters was calculated by using the luminosity function, determined from the Las Campanas survey (Lin et al. 1996). This must better approximate the real selection function, because the $R$ band used in the Las Campanas survey is not far from the $r_F$ band of the MRSS. The parameters are given in Table 3.

| Table 3. Parameters of the selection function |
|-----------------|-----------------|-----------------|
| $r_0 = 5h^{-1}\text{Mpc}$ | $b_j < m + 1.5$ | From Las Campanas LF |
| $m$ | $\alpha$ | $\beta$ | $z_0$ | $\alpha$ | $\beta$ | $z_0$ | $\tau$ |
| 15.5 | 2 | 1.5 | 0.0266 | 0.0326 | 2 | 1.50 | 0.0284 | 0.0436 |
| 16.0 | 2 | 1.5 | 0.0327 | 0.0366 | 2 | 1.50 | 0.0350 | 0.0527 |
| 16.5 | 2 | 1.5 | 0.0414 | 0.0439 | 2 | 1.52 | 0.0440 | 0.0651 |
| 17.0 | 2 | 1.5 | 0.0516 | 0.0534 | 2 | 1.57 | 0.0568 | 0.0804 |
| 17.5 | 2 | 1.5 | 0.0645 | 0.0646 | 1.95 | 1.62 | 0.0730 | 0.0965 |
| 18.0 | 2 | 1.5 | 0.0834 | 0.0774 | 1.90 | 1.66 | 0.0921 | 0.1205 |
| 18.5 | 2 | 1.5 | 0.1050 | 0.0915 | 1.90 | 1.695 | 0.1140 | 0.1461 |

In the second parameter set the parameter $\beta$ grows with the depth of the catalogue. This fits in the general picture. For deep ($\tau > 0.3$) catalogues several author (Lilly et al. 1995, Brainerd & Smail 1998) use the same function form with $\beta = 2$, or modifications of it (Postman et al. 1998). We note already here that our main results do not depend essentially on the exact form of the selection function.

4.4. Solution of the Limber-equation for CF of power law form

When the 3d CF follows a power law and the normalised selection function is known, ie. the parameters $\alpha, \beta$ and $z_0$ are given, there is a simple relation between $A(m)$ and $r_0$ (Totsuji et Kihara 1969). For small $r$ the 3d CF is $\xi(t\Theta) = \left(\frac{H_0r_0}{c}\right)^\gamma$, and we get

$$A(m) = \Theta^{-1}w(\Theta; m) = r_0^\gamma \int_0^{\infty} t^{1-\gamma}K(t; m)dt.$$  \hfill (23)

By using (10) and developing $\frac{dz}{dz}(1+z)^{-(3+\epsilon)}$ by $z$ up to the second order, we can compute the integral (23):

$$A(m) = C \left(\frac{H_0r_0}{c z_0}\right)^\gamma \left[\Gamma(\tau) + C_1 \Gamma(\tau - 1/\beta) z_0 + C_2 \Gamma(\tau - 2/\beta) z_0^2\right]$$ \hfill (24)

where

$$\tau = \frac{2 + 2\alpha - \gamma}{\beta}, \quad C = 2^{1-\tau} \frac{\beta \sqrt{\pi} \Gamma(\frac{\tau-1}{2})}{\Gamma^2(\frac{\alpha+1}{\beta}) \Gamma(\frac{\gamma}{2})}$$ \hfill (25)
and
\[ C_1 = 2^{-\frac{1}{2}} \left( -\frac{9}{4} + 3\gamma - 4\epsilon \right), \quad C_2 = 2^{-\frac{1}{2}} \left( \frac{9\gamma^2 - 65\gamma + 16\epsilon^2 + 88\epsilon - 24\gamma\epsilon + 116}{32} \right). \]

With the selection function, calculated from the Las Campanas luminosity function (Lin et al. 1996) we can determine from the measured \( A(m) \) using (24) the parameter \( r_0 \):
\[ r_0 = \frac{c}{H_0} z_0 A(m)^{\frac{1}{2}} C^{-\frac{1}{2}} \left[ \Gamma(\tau) + C_1 \Gamma(\tau - 1/\beta) z_0 + C_2 \Gamma(\tau - 2/\beta) z_0^2 \right]^{-\frac{1}{2}}. \]

If we fix the correlation length \( r_0 \) and \( \epsilon \), the equation (24) can be solved for \( z_0 \) by iterations. First we neglect the terms containing \( z_0 \) in the square bracket. Then
\[ z_0^{(0)}(m) = A(m)^{-\frac{1}{2}} \frac{H_0 r_0}{c} \left[ \Gamma(\tau) \right]^{-\frac{1}{2}}. \]
substituting that into (24) one gets
\[ z_0^{(1)}(m) = z_0^{(0)} \left[ 1 + C_1 \frac{\Gamma(\tau - 1/\beta)}{\Gamma(\tau)} z_0^{(0)} + C_2 \frac{\Gamma(\tau - 2/\beta)}{\Gamma(\tau)} z_0^{(0)^2} \right]^{-\frac{1}{2}}. \]

For \( r_0 = 5h^{-1} \) Mpc and \( \epsilon = -1.3 \) \( z_0(m) \) is shown in Table 3, and can be parametrised as \( z_0(m) = 0.024 + 0.0117(m - 15.5)^{1.63} \). Of course, it is not granted that these \( z_0 \) values correspond to the real \( dN/dz \) distribution. This parametrisation agrees well with that of MES for \( m \sim 17 \) mag, but our \( z_0(m) \) changes somewhat faster with \( m \). The same is true for our second parametrisation.

Next, with the second parameter set we compute \( r_0(m) \), for \( \epsilon = -1.3 \). In Figure 7. we show our \( r_0(m) \) function with and compare it with the same function, calculated from the data given in MES (their formula 38b and Figure 26a) for the same \( \epsilon \). The correlation length \( r_0 \) depends in both calculation on the limiting magnitude. The redshift dependence of the CF is beside of the factor \( (1 + z)^{-3+\epsilon} \) also in \( r_0 \).

It is possible to concentrate the redshift dependence of the correlation function in the \( (1 + z)^{-\frac{1}{2+\epsilon}} \) factor. By minimising the change of \( r_0(m) \) with the limiting magnitude \( m \), we get
\[ r_{00} = 5.82 \pm 0.05 \quad \text{and} \quad \epsilon = 2.60. \]

This result shows that the correlation length \( r_0(z) \) decreases rapidly with the average redshift of the sub-catalogue. It means that the stable clustering is not yet reached, on small scales there is an inflow in physical coordinates.

We estimate the average inflow/outflow velocities from the continuity equation as follows:
\[ v = H(z) r \frac{1 - \frac{\epsilon}{3-\gamma} \left( \frac{r_0(z)}{r} \right)^\gamma}{1 + \left( \frac{r_0(z)}{r} \right)^\gamma}. \]
If \( r \gg r_0 \) \( v \) corresponds to the Hubble-flow and if \( r \ll r_0 \), then there is an inflow with \( v \approx -\frac{\epsilon}{3-\gamma} Hr \). This makes possible e.g. to estimate the rate of galaxy merging.
4.5 The kernel of the integral (3)

In the following sections we determine at which $r$ breaks the 3d CF down from the power law, by using the 2d CFs, measured from different sub-catalogues. To relate the 2d and 3d correlation functions of general form we must now determine the (3) kernel. The integral is easily calculated. The $Q(t, m) = t^{1-\gamma} K(t; m)$ functions are shown in Fig.8 for $15.5 \leq m \leq 18.5$ mag. We included in $Q(t, m)$ the multiplier $t^{1-\gamma}$, so the remaining factor under the integral is constant up to the point, where the 3d CF breaks down from scaling. With growing magnitude limit $m$, the maxima of the functions $Q(t, m)$ shifted towards higher $t = r \theta$, they become flatter and in the integral (3) the large $t$ part of the 3d CF will be more important.

The $Q(t, m)$ functions have a very simple scaling. As it is to see from the non-relativistic, curvature free approximation of (3)

$$Q(t, m) = b Q(t/a; m').$$

The coefficients for scaling on $Q(t; 17\text{mag})$ are given in Table 4.

Table 4. Scaling factors to 17 mag

| $m$  | $a$  | $b$  | log$a$ | log $a^\gamma$b |
|------|------|------|--------|------------------|
| 15.5 | 1.815| 0.187| 0.2589 | -0.2883          |
| 16.0 | 1.530| 0.302| 0.1847 | -0.2079          |
| 16.5 | 1.245| 0.545| 0.0952 | -0.1028          |
| 17.0 | 1.00 | 1.00 | 0.0     | 0.0              |
| 17.5 | 0.844| 1.655| -0.0731| -0.0952          |
| 18.0 | 0.690| 3.141| -0.1612| 0.2245           |
| 18.5 | 0.578| 5.467| -0.2381| 0.3354           |

Notice that $b \approx a^{-3}$. The scaled functions are shown in Figure 9. By taking a 3d CF, independent of the sample depth, one can deduce from (32) a scaling law for the 2d CFs:

$$w(\theta, m) = \frac{1}{ba^{\gamma}} w(a\theta; 17).$$

(33)

In Figure 10. we show the 2d CFs measured from sub-catalogues $m = 15.5$ mag and $m = 18.5$ mag scaled to $w(\theta; 17 \text{mag})$ by using (32). One sees again that if the 3d CF independent from the depth of the catalogue, the large $\theta$ part of the 2d CFs do not scale with the limiting magnitude.

4.6 Modelling of the 3d correlation function

Baugh 1996 solved the Limber-equation for $\xi(r)$ by inverting (3) through an iterative method. He used the full $17 \leq b J \leq 20$ slice of the APM catalog. The resulting 3d
CF (for $\epsilon = -3$) well fitted by the $(4.5\text{Mpc}/r)^{1.7}$ power law for $r \leq 4h^{-1}$ Mpc, between $4h^{-1} \leq r \leq 25$ Mpc $\xi(r)$ has a shoulder and rising over the quoted power law. For $r > 25h^{-1}$ Mpc the calculated 3d CF becomes negative and on the scales $r > 40h^{-1}$ Mpc consistent with zero. Baugh 1996 calculates also the 3d CF for other magnitude slices and finds small discrepancies between these functions recovered from various magnitude slice of the APM catalogue.

Here we use another method. We parametrise the 3d CF in different forms and compute the 2d CFs for several magnitude limits $m$ from the Limber–equation (8). The best fitting form and parameters determine the 3d correlation function. It is clear that the form of the 3d CF must be the same type as that of the 2d CFs. To describe the physics mirrored by the correlation function, several distance like parameter are used: $r_0$ gives its amplitude for small $r$. This parameter is simple connected with the amplitude of the 2d correlation function (24). It is also clear that the 3d CF must cross zero at some $r_2$, to permit the change of sign of the 2d CFs. It is generally assumed that there in no correlation between the galaxies at distances large enough ie for $r \rightarrow \infty$ the correlation function $\xi \rightarrow 0$. This asymptotic is characterised by a parameter $r_3$. Further, by considering some concrete form of the 3d CF $\xi(r; r_1, r_3)$, one can not reconstruct with (8) the elbow of the 2d CF. We must introduce a further parameter in $\xi$ what describe the “shoulder” seen by Baugh 96. We think, this shoulder corresponds to the extra correlation of the galaxies because of the cluster - cluster correlation.

If we use the integral constraint $\int r^2\xi(r)dr = 0$, we get a relation between the parameters. We have tried numerous function form. Here we describe only one parametrisation, since our main result, described in the next subsection do not depend sharply on the details of the parametrisation. Our best function has the form

$$\xi(r) = \left[ \left( \frac{r_0}{r} + \frac{r_0}{r_1} \right)^\gamma - \left( \frac{r_0}{r_1} + \frac{r_0}{r_2} \right)^\gamma \right] e^{-r/\lambda}. \quad (34)$$

As it was shown in the previous section, one can not fit all the 2d CFs with a magnitude limit independent 3d CF.

4.7 Three dimensional correlation function determined from different 2d sub-catalogues

The parameters $r_0$ and $\epsilon$ of the 3d CF are fixed by the scaling part of the 2d CFs and are given in (32). Now we determine the other parameters of the 3d CF $\xi(r)$ in (34). For $m=17$ mag we get $r_1 = 8.47 h^{-1}$ Mpc, $r_2 = 39.95 h^{-1}$ Mpc and $\lambda = 41.70 h^{-1}$ Mpc. The 3d CF determined by these parameters is not far from the correlation function computed by Baugh 1996 from the APM catalogue. However, if we use the same parameters for sub-catalogues with other magnitude limit, we find that for $m < 17$ mag the 2d CFs, calculated from (8) breaks down from scaling later than measured, for $m > 17$ mag earlier. We find that the 3d CF, calculated from different sub-catalogues, changes in a systematic manner. To stress that, we parametrise $r_1, r_2$ and $\lambda$ as follows

$$r_1 = 7.50 + 0.65(m - 15.5)h^{-1}\text{Mpc}$$
$$r_2 = 25.1 + 9.92(m - 15.5)h^{-1}\text{Mpc}$$
$$\lambda = 31.2 + 7.98(m - 15.5)h^{-1}\text{Mpc}$$
\[ \lambda_0 = 13.3 + 5.10(m - 15.5)h^{-1}\text{Mpc} \]  

The 3d CF determined from subcatalogues with different limiting magnitude \( m \) are shown in Figure 11. The 3d CF determined by the parameters \( r_1, r_2 \) and \( \lambda \) do not satisfy the integral condition. To fulfill it, we should use in the last factor of (34) \( \lambda_0 \) instead of \( \lambda \), but it would give a bad fit for the negative part of the 2d CFs (the tail of the calculated 2d CF would be much less negative). It could be explained by the oscillation of the large \( r \) part of the 3d CF as in Tucker et al. 1997.

The quality of the parametrisation and the choice of the parameters can be judged from the Figures 12 – 14. We have tried other \( dN/dz \) functions, other parametrisation for \( \xi \), other \( \epsilon \) value (with depth dependent \( r_0 \)) and we found always that the 3d CF, calculated from the measured 2d CFs depend on the catalogue depth.

5. Summary and discussion

We determined the two point correlation function from the Muenster Red Sky Survey (MRSS, Ungruhe 1999). This survey uses the F–band and larger than the APM survey (MES). Maddox & al. 1990 and MES have compared their measured correlation functions with those, determined from other catalogues. Here we compare our 2d CFs with the results of MES.

The large dynamics range of the survey made it possible to determine the correlation function from subcatalogues with different magnitude limit \( m \). The measured slope of the 2d CFs is somewhat larger for lower magnitude limit, but its average value \( \delta = \gamma - 1 = 0.69 \pm 0.02 \), agrees with the earlier measurements. The \( \theta_{\text{max}}(m) \) value, where the CFs measured from subcatalogues with different magnitude limits \( m \) correspond to about 30h\(^{-1}\) kpc projected distance, independent of \( m \). When the projected distance of two galaxies is smaller than that, the software can not separate the two objects. The amplitude of the correlation functions, after the color correction, agrees excellently with those measured from the APM catalogue. As it is shown in Figure 3, our CFs agree well with those, measured by MES also in the region where the CFs do not follow the power law. Note that the break away from the power law begins at about the same angle, almost independent of the magnitude limit of the subcatalogue. After the zero crossing the MES correlation function is zero. We find that the amplitude of the negative part of the CFs is several times \( 10^{-3} \), and decreasing with increasing magnitude limit \( m \) (Fig. 12 - 14). The non-vanishing anticorrelation is a natural consequence of the definition of the correlation function.

We have calculated from the measured 2d CFs the three dimensional two-point correlation function by using the Limber-equation. To determine the \( dN/dz \) function we used informations from 3d catalogues. We parametrize it in the usual form and the parameters were for each subcatalogue deduced from the luminosity function of the Las Campanas survey (Lin et al. 1996). As it is shown in Fig. 9, the kernel of the integral in the \( w(\theta) = -\xi(r) \) transformation (deprojection) scales with the limiting magnitude of the subcatalogue.

From a sub-catalogue with limiting magnitude \( m \) one can only determine a combination of \( r_0(m) \) and \( \epsilon \). There are several possibility to separate these parameters. The usual way
is to fix $\epsilon$ on the basis of physical considerations or simple ignore it. To compare our parameters with the $r_0(m)$ and $\epsilon$, determined from the APM catalogue, we used $\epsilon = -1.3$ and calculated $r_0(m)$ from the subcatalogues. The agreement (Fig. 7) is excellent. However, if one considers $\epsilon$ as evolution parameter it is more consequent to choose the correlation length $r_{00}$ independent from the depth of the subcatalogue, i.e. $r_0(\tau) = r_{00}(1 + \tau)^{-\frac{3+\epsilon}{3}}$. With this parametrisation we have got $r_{00} = 5.82 \pm 0.05 h^{-1}$ Mpc and $\epsilon = 2.60$. This result agrees with the general trend: deeper the catalogue lower the correlation length $r_0(\tau)$. This $\epsilon$ value is unusually high. That means that there is yet an evolution in clustering. It is not easy to compare our $r_0, \epsilon$ with that of other authors, because the separation of the two parameters is not standardised. From the Las Campanas survey Jing, Mo & Börner 1998 found $\gamma=1.86$ and $r_0=5.06 h^{-1}$ Mpc. With $\epsilon = \gamma - 3$ and $\tau = 0.1$ that gives $r_0 \approx 4.6$ Mpc, in agreement with our $5.82 \cdot 1.1^{-5.6/1.68} = 4.2$ Mpc. The limiting magnitude of the EPS catalogue (Guzzo & al., 1999) is $b_J < 19.4$ mag; they found $\gamma = 1.67$ and $r_0 = 4.15 \pm 0.2h^{-1}$ Mpc. We get for $r_F < 18$ mag $r_0 = 3.99 h^{-1}$ Mpc. For deep surveys it is questionable if the parametrisation (1) correct. Interestingly, extrapolating our parametrisation (30) to high $z$ values we are not far from the measured values. E.g. $z = 0.5$ we get $r_0 = 1.4 h^{-1}$ Mpc (in physical coordinates, $q_0 = 0.5$). This value agrees well with the result of Le Fèvre & al. 1996, ($r_0 = 1.33 h^{-1}$ Mpc). Our $r_{00}, \epsilon$ values are compatible with the result of Postman & al. 1998, who find that if $r_0$ is fixed to be $5.5 \pm 1.5 h^{-1}$ Mpc, then -0.4$\leq \epsilon \leq$ 1.3. Connolly & al. 1998 measure from a subcatalogue of HDF for fixed $r_0 = 5.4 h^{-1}$ Mpc $\epsilon = 2.37^{+0.37}_{-0.64}$.

By comparing our 3d CF determined from the $r_{F_i}$18.5 mag catalogue with that of Baugh 1996 for 17 mag $b_J<20$ mag, we see three minor differences. First, our correlation length $r_0$ (after taking into account the corrections for the different $\epsilon$’s) is about a factor of 1.3 larger. It can be explained by the difference of the $z_0$ parameters of the $dN/dz$ function. Second, our correlation function crosses zero at 50 $h^{-1}$ Mpc, that of Baugh at 40 $h^{-1}$ Mpc. Third, the CF of Baugh 1996 disappears at about 80 $h^{-1}$ Mpc, ours seems to be negative also for larger distances. This is a consequence of the difference of the measured 2d CFs in this region.

As it is shown in Fig. 11 and (35) the position of the break-away from the scaling of the 3d CF and the zero–crossing varies with the depth of the sub-catalogues. This agrees with the result of Cappi et al. 1998. We conclude that the MRSS is not deep enough ($z_{med} \approx 0.14$) to determine up to which physical distance follows the 3d CF the power law. The structures, found in large and deep (Sloan and 2dF) catalogues are much larger then those seen in the MRSS.

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Figure 1: Measured CFs for seven limiting magnitude from $r_F < 15.5$ to $r_F < 18.5$ derived from 152 plates.
Figure 2: Correlation function and the average of the correlation function
Figure 3: Correlation functions as measured from MRSS (small symbols) and from APM (large symbols) in MES Fig 23.
Figure 4: Comparison the APM and MRSS correlation function on linear scale
Figure 5: Approximation of the CFs with double power law
Figure 6: The function \( f(\theta) = \frac{w(\theta, m)}{A(m)\theta^{1-\gamma}} \).
Figure 7: Correlation length $r_0$ in function of the limiting magnitude calculated from the APM catalogue and from MRSS for $\epsilon = -1.3$
Figure 8: The kernel of the integral $\int \frac{d^3k}{(2\pi)^3} \delta^3(k)$ for different magnitude limits.
Figure 9: The function $t^{1-\gamma}K(t;17)$ and the other six $t^{1-\gamma}K(t;m \neq 17)$ functions, scaled on it with (32).
Figure 10: The 2CF, measured from a subsample \( r_F \leq 17 \) mag and the 2CFs \( \log w(\theta; 15.5) \) & \( \log w(\theta; 18.5) \) scaled on it with (33).
Figure 11: 3d correlation function determined from the subcatalogues with limiting magnitudes 15.5, 16.5, 17.5 and 18.5 mag.
Figure 12: The measured and from the Limber–equation, using selection function 2 and in (34) parametrised 3d CF calculated, 2d CFs for m=16.5 mag (upper panel), m=16 mag (lower panel)
Figure 13: The measured and and from the Limber–equation, using selection function 2 and in parametrised 3d CF calculated, 2d CFs for m=17.5 mag (upper panel), m=17 mag (lower panel)
Figure 14: The measured and and from the Limber–equation, using selection function 2 and in (34) parametrised 3d CF calculated, 2d CFs for $m=18.5$ mag (upper panel), $m=18$ mag (lower panel)