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Near–infrared luminosity function in the Coma cluster⋆

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Abstract. We present the near–infrared H band luminosity function (hereafter LF) of the Coma cluster of galaxies. It is the deepest ever computed in the near–infrared, for any type of environment, extending over 7 magnitudes, down to $\sim M_H^* + 6$. The LF was computed on a near–infrared selected sample of galaxies whose photometry, complete down to the typical dwarf luminosity, is presented in a companion paper. The Coma LF can be described by a Schechter function with intermediate slope ($\alpha \sim -1.3$), plus a dip at $M_H \sim -22$ mag. The shape of the Coma LF in H band is quite similar to the one found in the B band and, with less confidence, to the R band LF as well. The similarity of the LF in the optical and H bands implies that in the central region of Coma there is no new population of galaxies which is too faint to be observed in the optical band (because dust enshrouded, for instance), down to the magnitudes of dwarfs. The exponential cut of the LF at the bright end is in good agreement with the one derived from shallower near–infrared samples of galaxies, both in clusters and in the field. This fact is suggestive of a similarity of the tip of the mass function of galaxies, irrespective of the environment where they are found. The dip at $M_H \sim -22$ mag is instead unique among all the so far measured near–infrared LF, although several published observations are not deep enough or spanning a suitable wide field to distinctly detect this feature. The faint end of the LF, reaching $M_H \sim -19$ mag (roughly $M_B \sim -15$), is steep, but less than previously suggested from shallower near–infrared observations of an adjacent region in the Coma cluster. The differences between our measured LF and that measured previously in other regions suggest a dependency on environment of the faint end of the mass function (below $M^* + 2.5$).

Key words: galaxies: clusters: individual: Coma (= Abell 1656) – galaxies: luminosity function, mass function

1. Introduction

In the optical band, the cluster luminosity function (hereafter LF) has three regimes: a bright end ($M_r^* \sim -22$ mag, $H_0 = 50\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$), a flat slope ($\alpha \sim -1.0$) down to luminosity of dwarf galaxies (López–Cruz et al. 1997; Garilli et al. 1999), and then a steep increase (Impey et al. 1988; Ferguson 1989; Thompson & Gregory 1993; Secker & Harris 1996; Secker et al. 1997). Often a dip is found in the otherwise flat part of the LF (see, e.g., Godwin & Peach 1977; Bucknell, Godwin & Peach 1979). A few well studied clusters (Smith et al. 1997), as well as a number of LFs published a long time ago (Schechter 1976) display an intermediate slope ($\alpha \sim -1.3$) instead of a flat LF.

The LF represents the zero–order statistics of galaxy samples and gives the relative number of galaxies as a function of the magnitude. Almost every quantity is, therefore, "weighted" by the LF, including obvious quantities, such as the galaxy color distribution, and also less obvious ones, such as correlations involving the luminosity (see, for example, the discussion on the impact of magnitude limits in the size–luminosity relation by Simard et al. 1999). When the sample is not complete in volume a further "weight" should be added: the selection function. Thus, an accurate knowledge of the LF is important when comparing galaxies of different luminosities at different redshifts.

From a physical point of view, the optical LF is the convolution of the number of galaxies of a given mass with their M/L distribution. Then, any measure of the optical LF traces a complex mix of galaxy mass and M/L distributions, so that evolution in luminosity or mass could not be easily disentangled from the measurement of the optical LF. A better estimate of the galaxy mass than the optical luminosity will certainly help to separate the two dependencies. Such a measure has a particular relevance in the determination of the density of the Universe: a possible way to proceed is to compute the cluster mass per unit luminosity times the Universe luminosity density. As stressed by Carlberg et al. (1996), this calculation assumes that cluster galaxies have the same LF as field galaxies. Observations suggest instead that galaxies change their optical luminosity during their infall in the cluster (see, for example, Bothun & Dressler 1986; Andreon 1996, and most of the papers by the CNOC collaboration, such as Balogh et al. (1998) and references therein), although the amplitude and the sign of the luminosity variation is not yet settled. Of course, it would be preferable to measure the M/L of clusters using a luminosity indicator weakly affected by possible bursts or halt of star formation induced by interactions with the hostile cluster environment.

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⋆ Based on observations collected with the *Télescope Bernard Lyot*, at the Pic du Midi Observatory, operated by INSU (CNRS).

The near–infrared luminosity has several advantages with respect to optical luminosities. It is tightly correlated to the galaxy mass (at least for spirals, Gavazzi et al. 1996) and, with respect to the optical luminosity, it is less affected by short and recent star formation events (Bruzual & Charlot 1993), possibly induced by interactions, and by dust absorption. Therefore, the near–infrared LF traces more directly the mass function and gives a Universe density less affected by possible systematic errors due to a differential star formation history between galaxies in clusters and in the field.

There are several additional advantages in observing galaxies in the near–infrared: K corrections are relatively small and well known, thus allowing to observe and to compare galaxies at different redshifts, up to high redshift values. In particular, K corrections are almost independent from the spectral type of galaxies, in such a way that statistics on a population of galaxies are less affected by changes of the morphological composition induced by differential corrections from type to type. Furthermore, galaxies that undergo a starburst are not selected preferentially, as instead happens in the optical, and therefore a sample selection in the near–infrared is less biased by episodic events of star formation.

It is therefore important to measure the near–infrared LF of clusters of galaxies over a magnitude range as wide as possible, in particular to characterize the properties of galaxies in the local Universe. So far, the near–infrared LF have been measured for a few clusters, but to bright limiting magnitudes (Barger et al. 1996, Trentham & Mobasher 1998, De Propris et al. 1999), and on a portion of the Coma cluster (De Propris et al. 1998), down to relatively faint magnitudes. According to De Propris et al. (1998), the Coma LF shows a flat slope, and a step increase ($\alpha \sim -1.7$) at faint magnitudes ($H = 16$ mag). However, this is presently the only LF determination attaining intermediate magnitudes, and such a survey could be improved in several respects. It is important to extend the study to other regions, and to reach deeper magnitudes. This is the aim of the present paper.

We present the near–infrared LF of the Coma cluster, based on independent observations, fully documented in a companion paper that also presents the photometric catalog. With respect to De Propris et al. (1998), this study has been performed on a different portion of the Coma cluster, slightly overlapping with their one, over an area which is $\sim$ 40% smaller, but it attains one magnitude deeper. All along this paper, we adopt $H_0 = 50\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ and $q_0 = 0.1$.

2. Data analysis

Coma galaxy counts and LF have been computed from the photometry presented in Andreon et al. (1999), to which we defer for details (hereafter Paper I). In summary, a $\sim 20 \times 24$ arcmin region of the Coma cluster, located ~ 15 arcmin from the centre, have been imaged with the Moicam camera at the 2.0m Bernard Lyot telescope at Pic du Midi. Images were taken in the H band under moderate to good seeing conditions (i.e. $1 < FWHM < 1.5$ arcsec), with average exposure time of ~ 300 sec. About 300 objects have been detected and classified by Sextractor version 2 (Bertin & Arnouts 1996) in the best exposed part of our mosaic ($\sim 380\,\mathrm{arcmin}^2$).

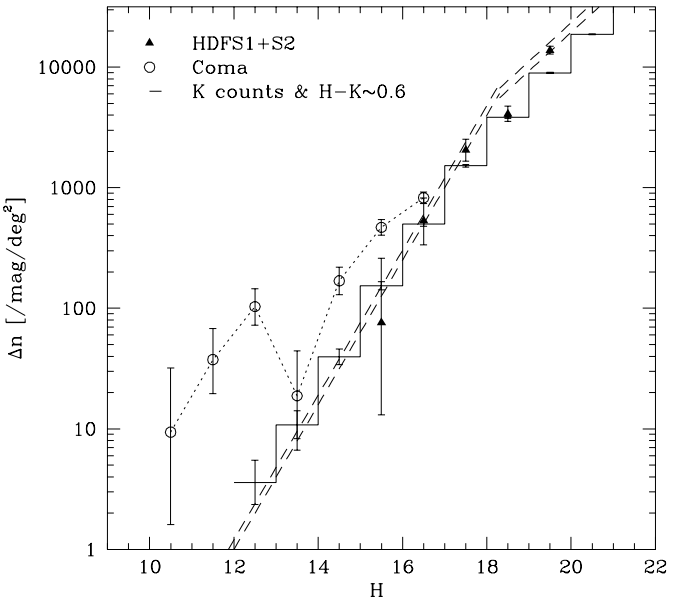

Fig. 1. Galaxy counts as a function of the apparent H magnitude. Open dots are the counts in the Coma cluster direction, solid triangles are counts in the HDF South 1 & 2 directions. The center of the strip marks the average K counts converted in H assuming $H - K \sim 0.6$. The strip width corresponds to a background variance of $\pm 15\%$, the typical value for the area surveyed in Coma. The solid line histogram gives for comparison the expected counts from our model. See text for details. Error bars are computed according to Gehrels (1986). Bins are 1 magnitude wide. The abscissa is given by Kron magnitudes for bright galaxies and aperture magnitudes for faint galaxies.

Different magnitudes are presented in Paper I. We adopt here the Kron magnitudes (see Kron 1980 for the exact definition, and Bertin & Arnouts 1996 for the software implementation). They are defined as the flux measured in a region which area is adapted to each galaxy. Unfortunately, they depend sensibly on the determination of the object size, in particular for faint objects, and therefore, for faint objects we prefer aperture magnitudes. More precisely, we adopt, as a measure of the magnitude for a galaxy, the magnitude computed within 2.5 Kron radii for galaxies brighter than $H = 14$ mag, and aperture magnitudes (within 10 arcsec aperture) for fainter galaxies. The two quantities are identical, within the errors, for galaxies in a large magnitude range including $H \sim 14$ mag (Paper I). The catalog is complete, in the 10 arcsec aperture magnitude, down to $H = 17.1$–17.2 mag[1]. To be safe and for easy computation, we cut the catalog at $H = 17.0$ mag. Given the galaxy catalog and the knowledge of the surveyed area, galaxy counts in the Coma direction are computed straightforwardly. They are presented in Fig. 1 (open dots), as derived for objects identified as galaxies (see Paper I for details).

[1] All magnitudes are refered to the Vega system

The Coma cluster LF is computed as the statistical excess of galaxies in the Coma cluster direction with respect to other directions. In order to estimate the fore and background contribution of the field, we use when possible observed values measured by different authors, as well as a simple standard model for number counts, based on pure luminosity evolution for galaxies (see Rocca-Volmerange & Guiderdoni, 1990, Pozzetti et al. 1996 and Pozzetti et al. 1998) and computed through the Bruzual & Charlot evolutionary code (1993, updated as GISSEL98). The parameters of the counts model have been set up in order to roughly reproduce the observed number counts to B = 28 mag (Williams et al. 1996), and normalized to the observed counts at $H = 17.0$ mag. This model is only used in order to derive the mean redshift of the dominant population at a given magnitude, when comparing with other LF estimates, computed with other filters.

Field counts have been measured on the H band images of the Hubble Deep Field South 1 & 2 (hereafter HDFS1+S2), presented in Da Costa et al. (1999). These images were taken at the NTT and they are much deeper (several magnitudes) than our Coma images, but extending to a smaller region and exposed in a non uniform way. We have used their uniformly exposed part, a central region 1000×1000 pixel wide (i.e. ~ 23.7 arcmin^2 large, thus more than 10 times smaller than the Coma area studied in this paper). We have detected and classified objects in this HDFS1+S2 area by means of Sextractor (Bertin & Arnouts 1996), using the same parameters as in Paper I. Fig. 1 presents the resulting counts (closed triangles). At $H \sim 16$ mag, field counts have large errors because the HDFS1+S2 is not tailored for measuring galaxy counts at such bright magnitudes, but for going deep on a small region. This fact prompts us to look for a H band survey more adapted to our aims, i.e. shallower and wider. Since it does not exist, we get a different estimate of the H band galaxy counts using K band galaxy counts and assuming a mean $H-K$ color for galaxies in the relevant magnitude range. The observed color of $H \sim 17$ mag galaxies is $H - K \sim 0.6$ mag (Stanford et al. 1995). This value is also in fairly good agreement with the mean $H - K$ expected from the counts model ($H - K \sim 0.55$ mag to $H \sim 19$ mag, where the population is dominated by galaxies with $0.1 \lesssim z \lesssim 0.4$ at $H \sim 17$ mag, and with $0.2 \lesssim z \lesssim 0.6$ at $H \sim 18$–19 mag). We apply the mean $H - K$ value to the Bershady et al. (1998) compilation of K band surveys. These counts are presented in Fig. 1 as a strip with center given by the average counts presented in their paper. There are also presented in Fig. 1 the expected number counts derived from our model (solid line histogram). In spite of unavoidable differences between the types of magnitude used by the different authors, and also the approximations involved in the conversions between photometric systems, the agreement between the galaxy counts in the HDFS1+S2 direction and the H counts estimated from K counts is very good. They are also in good agreement with the counts derived from our simple model. We adopt these counts as average background counts in the Coma direction.

An expected and important source of error in the LF determination is the background variance from field to field, in addition to Poissonian fluctuations: if the background variance is high, then the background in the Coma direction could be significatively different from the average computed above. Among the K band shallow surveys, two of them are adapted to roughly compute the order of magnitude of this variance. Gardner et al. (1993) presented galaxy counts for the HMDS (Hawaii Medium Deep Survey) extending over an area which is only half of that sampled for Coma, and also for the HMWS (Hawaii Medium Wide Survey), extending over a much wider area than the present one. The counts in the two surveys show a $\pm 15\%$ scatter, and we adopt this value as a typical fluctuation for the background (to be added quadratically to Poissonian fluctuations). The amplitude of the strip in Fig. 1 shows this scatter. This background variance seems plausible for two reasons: first, counts in the HDFS1+S2, which extend on an area ~ 10 times smaller than our one, and ~ 3 times smaller than the HDMS survey, are well within the strip, showing that background fluctuations are unlikely to be larger than our derived variance. Secondly, the expected field to field fluctuations are $\sim 11\%$, according to the formulas (and the hypothesis) in Huang et al. (1997).

Fig. 1 shows that at all magnitudes considered here, the Coma cluster counts have small errors and stand out with respect to the field counts, down to $H = 17$ mag. Therefore, errors on the Coma LF will be small and only slightly affected by the background subtraction. In order to judge on the progress achieved in this paper with respect to previous investigations, the reader can compare our magnitude–counts diagram with the analogous one in Mobasher & Trentham (1998) for a much smaller (and denser) region of Coma. These authors took an observational strategy quite different from ours: given the available telescope time, they went as deep as possible on a very small area, which resulted in a large field to field background variance.

3. Results

3.1. The shape of the LF

Given the counts in the Coma direction and in the field, and their errors, the computation of the Coma cluster LF is an algebrical exercise. We stress that our main sources of error on the Coma LF are Poissonian fluctuations of total counts over the Coma region and the background field to field variance. Therefore, the error on the background is not derived from the HDFS1+S2 error bars (which are not relevant for the determination of the LF errors).

The near–infrared Coma LF is presented in Fig. 2. It is characterized by a bright end (at $M_H \sim -25$ mag), a part increasing gently down to $M_H \sim -18.5$ mag, and an "outlier" point at $M_H = -22.2$ mag, which produce, if real, a dip in the Coma LF. The LF displayed in Fig. 2 is the deepest ever measured in any near–infrared band for any type of environment for a near–infrared selected sample.

In the optical, the Coma cluster exhibits a similar shape (Godwin & Peach 1977; Secker & Harris 1996). Using Godwin et al. (1983) data, we computed the b (a photographic J-like blue filter) Coma LF in almost exactly the same area surveyed in the H band. For simplicity, we have considered a rectangular

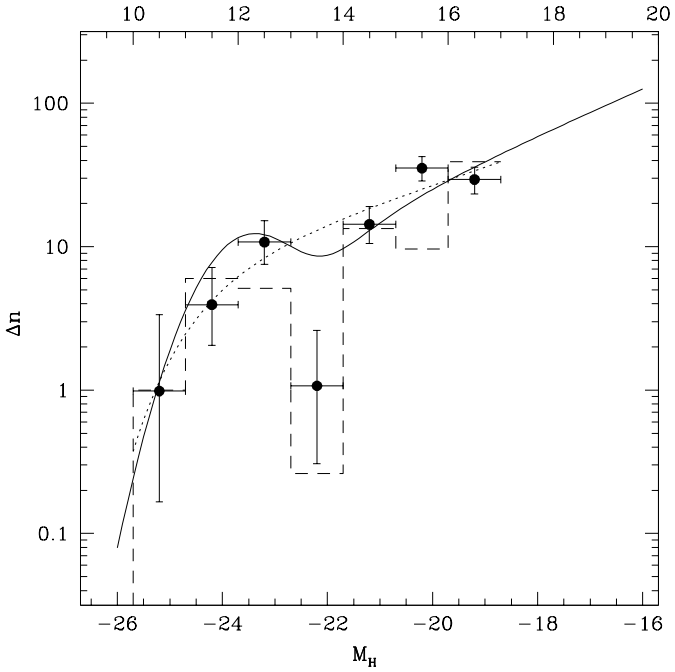

Fig. 2. Coma LF in the H band, as computed from the present data alone (closed dots). The solid line is the R Coma LF, shifted by a color $R - H = 2.3$ mag. The dashed histogram is the b Coma LF, shifted by a pseudo-color $b - H = 3.5$ mag. The dotted line is the best fit by a Schechter function, once the dip point is flagged. Error bars in the ordinate axis are computed according to Gehrels (1986) and include also the field to field variance of the background. Error bars in the abscissa show the bin width. Error bars on the histogram are similar to those of points. The upper abscissa scale shows the apparent H magnitude, and the lower one gives the corresponding absolute H magnitude. Δn is the number of Coma galaxies in the studied field.

area enclosing our H band region, without taking into account the complex geometry of our region in details. Then, because the H and b band magnitudes are available for all galaxies in this area, we have computed a mean $b - H$ pseudo-color[2]. In order to compare the two LFs, we have shifted the b band LF by the mean $b - H$ pseudo-color: $b - H = 3.5$ mag. The expected values according to Bruzual & Charlot models are $b - H = 4.0$ for elliptical galaxies and up to $b - H = 2.8$ for blue constant star-forming systems; thus an averaged population of $2/3$ of ellipticals versus $1/3$ of blue systems gives roughly the right mean value as expected. No normalization in Δn has been applied. The result of this exercise is shown in Fig. 2 as a dashed-line histogram. The two LFs are remarkably similar: there is a close agreement between the cut at $M_H = -25$ mag, the dip location ($M_H = -22.2$ mag), the dip amplitude and the increase observed at fainter magnitudes (closed dots) and expected from the b LF (dashed histogram). We have performed the same exercise with the R band photometry by Secker & Harris (1996), who studied an adjacent region of the Coma cluster. The expected values according to Bruzual & Charlot models are $R - H = 2.5$ for early–type galaxies and $R - H = 2.0$ for blue star-forming systems, giving an averaged value of $R - H = 2.3$ for the same weighted population taken above ($2/3$ of ellipticals versus $1/3$ of blue systems). This time we adopt the predicted value because the R catalog is not published. The two surveyed regions are different, thus we normalize their LF to our H LF. We obtain similar results, with the difference that the importance of the dip is smaller in R than in H (see Fig. 2).

Thus, the shape and the amplitude of the Coma LF seems not to be strongly dependent on the wavelength when we compare the results in b and in H bands, and also, with less confidence, in the R band. The strong similarity of the optical and near–infrared LF implies that in the near–infrared there is no new population of galaxies which disappears in the optical band (because dust obscured, for example), down to the magnitude of dwarfs. Furthermore, if the H band LF traces the galaxy mass function in this cluster, the same holds for the blue LF. This result has been obtained in a particular region of Coma, wich is a cluster rich in elliptical and lenticular galaxies. Before any generalization, this result should be checked in other regions of the cluster, and also in other environment conditions (cluster outskirts, clusters rich in spiral galaxies, groups,...).

3.2. The dip at $M_H \sim -22$

Let us consider in more details the dip point. The question is: Is it really an outlier? The statistical significance of the possible outlier point must be evaluated from the galaxy counts, since they are the original source of fluctuations. The $M_H = -22.2$ mag bin in Fig. 2 corresponds to the $H = 13.5$ mag bin in Fig. 1. First of all, we exclude the possibility that we have missed some galaxies of this magnitude, because we are complete 2.5 mag fainter, and because a typical galaxy of $H = 13.5$ mag has a central brightness of 100 times the sky noise. Secondly, there is no relation between the location of the dip and the discontinuity of the magnitude system adopted (Kron magnitudes for bright galaxies and aperture magnitudes for faint ones): galaxy counts do not change because the separation is set to $H = 14$ mag. In fact, Kron and aperture magnitudes have almost the same value down to the last magnitude bin (see Fig. 10 in Paper 1). There are two galaxies in the $H = 13.5$ mag bin, whereas ~ 13 are needed to make the counts smooth. Therefore, this point is more than 3 σ away from the average of adjacent bins. To be precise, according to Poissonian statistics we can reject at more than 99.95% confidence level the hypothesis that the observed number of galaxies is drawn from a parent distribution which counts ~ 13 galaxies in that bin. Therefore, the dip is a real feature of the Coma near–infrared LF in this region.

The dip in the Coma LF had firstly been noticed in the optical band (for example, Godwin et al. 1983) and it had been interpreted in two different ways. Biviano et al. (1995) suggested that galaxies brighter than the dip were subjected to a recent episode of star formation induced by the hostile Coma environment, which have made them brighter. Andreon (1998) has shown that the LF of the different morphological types of galaxies are equal in Coma and in much poorer environments, and

[2] As long as the two magnitudes are not computed within the same aperture, the difference is not actually a color.

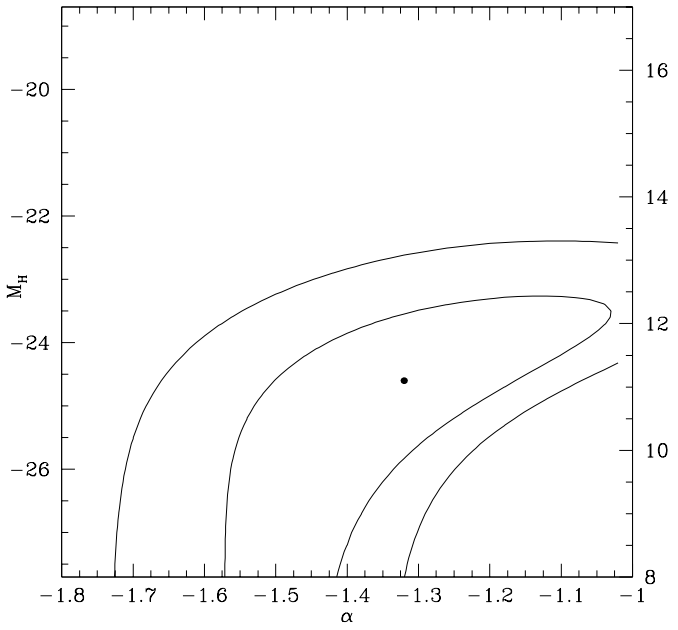

Fig. 3. 68% and 95% confidence contours for the fit of the LF by a Schechter function. The units of the left and right ordinates are absolute and apparent H magnitudes, respectively.

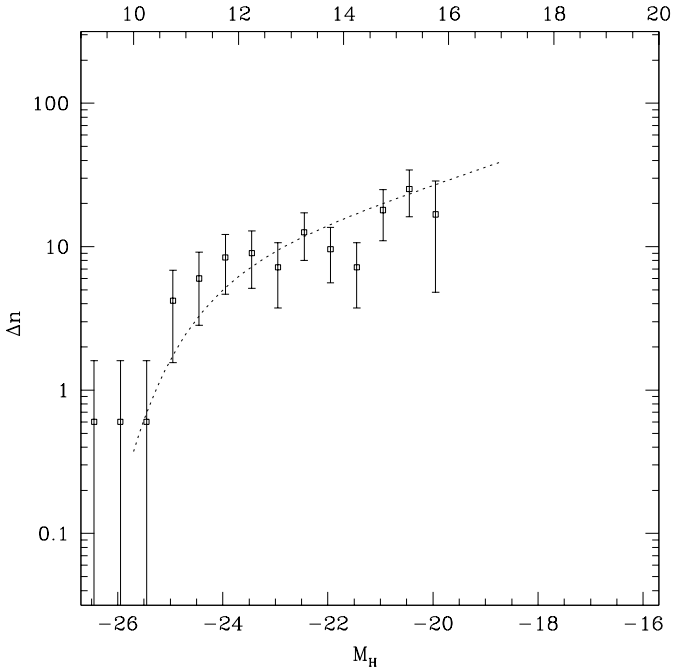

Fig. 4. De Propris et al. (1998) LF (open squares) compared to the best Schechter fit to the present data (dotted line). Error bars and scales are as described in Fig. 2.

that the dip is simply the combined result of the Coma cluster morphological composition together with the shape of the type–dependent LFs. If the induced star-formation interpretation by Biviano et al. (1995) was correct, the dip should be absent or at least highly attenuated in H, because the near–infrared luminosity traces the galaxy mass and it is less affected by the short timescale starbursts that make a few galaxies brighter than the magnitude of the dip. Instead the dip is observed in the H band.

A few other near–infrared LF of clusters are (poorly) known. None of the five clusters studied by Mobasher & Trentham (1998) show such a dip. However, the area sampled in each cluster includes a tiny number of galaxies, so that errors are large and the visibility of a possible dip (if present) is arguable. The cumulative LF of three clusters at $z \sim 0.3$ (Barger et al. 1996) does not seem to show a dip, but it barely reaches the dip magnitude. The only truly comparable LF has been presented by De Propris et al. (1998), and it is reproduced here in Fig. 4 (open squares), together with the best Schechter fit LF (dotted line) to our data. The fitting machinery adopted here is discussed in the next subsection. De Propris et al. (1998) have used Kron magnitudes for faint galaxies and aperture magnitudes (within a 62 arcsec diameter) for large galaxies (De Propris 1999, private communication). The two LFs are in remarkable good agreement ($\chi^2_\nu < 1$) on the common range ($M_H < -20$ mag), with the exception of the dip bin, wich is present in our data and absent in De Propris et al. (1998) data. It is worth noticing that the position of the dip is well within the spectroscopic sample of De Propris and collaborators, and thus it could be hardly missed. The agreement would be even better at $M_H < -24$ if the De Propris et al. (1998) bright magnitudes were of Kron type, since Kron magnitudes integrate the galaxy flux inside a smaller area than those sampled by the 62 arcsec aperture they used.

Since De Propris et al. (1998) studied an almost complementary area of the Coma cluster with respect ours, and since the dip is present in our LF and absent in theirs, it is possible that the amplitude of the dip depends on the location in the cluster, as it seems to be the case in the optical (Sekiguchi 1998). Since the H band luminosity traces the galaxy mass, as stressed in the Introduction, the possible dependence of the dip amplitude on the cluster location points out a dependence of the mass function on the surveyed region, possibly due to a joint effect of morphological dependence of the LF and variation of the morphological composition over the Coma cluster. A similar trend is seen in the optical (Andreon 1998). Such differences in the LF as a function of the location in the cluster could be related to subcluster structure. Several evidences for cluster-cluster merger are present in Coma. Two main peaks appear in the X-ray flux density (White et al. 1993), in the projected distribution of galaxies (Fitchett & Webster 1987, Mellier et al. 1988) and in the radio source counts (Kim et al. 1994): a clump centered on NGC4874 and NGC 4889, and a secondary peak around NGC 4839, about 40' SW from the previous one. The field surveyed here is centered $\sim 15'$ NE from the main structure, at the opposite side with respect to the cluster center. Colless & Dunn (1996) have shown the complex dynamics and multiple substructure of the Coma cluster using a large redshift catalog. According to them, the NGC 4839 group is actually falling into the main cluster, there are two subclusters in the central region (associated with the two dominant galaxies), and late type galaxies are falling into the

main cluster (which is dominated by early type galaxies). These processes might be able to locally modify the LF as observed.

3.3. Fitting the LF

Let us consider now the overall shape of the LF. Usually, a χ^2 method is used to fit the LF of clusters by a Schechter (1976) function:

$$f(m) = \phi^* \; 10^{0.4(\alpha+1)(m^*-m)} \; exp(-10^{0.4(m^*-m)})$$

The χ^2 method is not the optimal one for fitting a function to a small number of bins, and it is even less suitable when bins are poorly populated. Furthermore, a χ^2 requires to bin the data with an arbitrary bin size. Although the χ^2 method is not optimal, we are forced to use it, since we do not know any other fitting method that could take into account, even roughly, background fluctuations together with Poissonian ones without binning the data. More elegant methods implemented so far, such as maximum–likelihood fitting, do not take into account the Poissonian fluctuations of the background counts, nor the field to field variance of the background, and therefore they systematically underestimate the true errors.

In order to take into account the amplitude of the bin in the fitting process (a technical detail seldom considered), we fit the data with a Schechter function convolved with the bin width (although in practice this detail makes almost no difference on the results). An additional problem arises: given the existence of a real dip in the Coma LF, the fit of the whole LF with any Schechter function is necessarily poor (and in fact we found a minimum χ^2 of 14 for 4 degrees of freedom). We are therefore left with two options: flag the dip point, or use a more complex function. Disposing of a very small number of points and lacking any physically motivated more elaborate function to be fitted, we simply flag the outlier bin.

In that case, and taking into account the finite amplitude of the bin, we found $M^*_H = -24.6$ mag and $\alpha = -1.3$, but with large confidence intervals (as shown in Fig. 3). Note that our magnitude limit, $H = 17$ mag, is roughly equivalent to $M_B \sim -15$ mag at the Coma distance for an early–type galaxy ($B-H \sim 4$ mag), which is well in the dwarf regime. M^* agrees well with the values expected from the optical photometry and usual colors for early–type galaxies ($M_B = -20.5$ mag and $B - H \sim 4$ mag). The slope is steeper than the typical value in optical bands (López–Cruz et al. 1997; Garilli et al. 1999), but nevertheless it is quite similar to that found for a few well studied clusters in optical bands (Smith et al. 1997; Schechter 1976).

3.4. Comparison to previous studies of Coma and to the field LF

Mobasher & Trentham (1998) studied a very small portion of the Coma cluster and were able to build a catalog 1.5 magnitudes deeper than ours. However, their studied field is too small to make the background variance small relative to the signal (the Coma LF), so that the resulting LF is completely unconstrained,

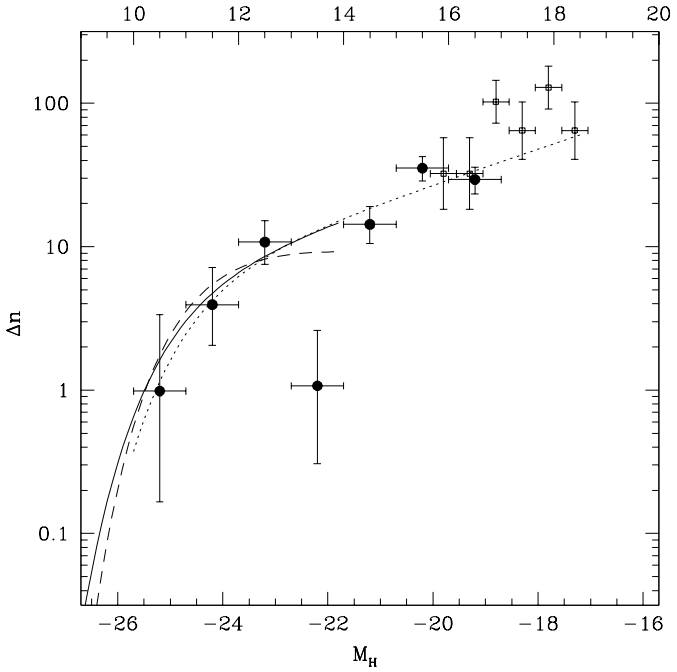

Fig. 5. Various determinations of the near–infrared LF. Our own data (solid dots) and Mobasher & Trentham (1998) data (open squares) are shown, after normalization of the LF in common bins. For details on the derivation of the Trentham & Mobasher (1998) data points, see the text. The dotted curve is the best fit of our data, extrapolated to fainter magnitudes. Local field LFs are also shown: Gardner et al. (1997) (dashed line) and Szokoly et al. (1998) (solid line). The field LF has been vertically shifted to reproduce the Coma LF in the three brightest bins. Error bars and scales are as described in Fig. 2.

as admitted by the authors. They computed also another LF, by performing a crude color selection, i.e. assuming that Coma cluster galaxies lay, in a color–color plane, in a region different from that occupied by the fore and background galaxies. In that case, a LF with error bars of reasonable size was derived, but under an hypothesis that should be demonstrated to be true. In Fig. 5, this LF is plotted overlapped to our H LF, after having matched the two LFs in the common bins. Their K magnitudes have been changed to H assuming $H - K = 0.24$ mag, the typical value expected for the Coma galaxies. Our error bars are smaller in the common bins, even using the same binning for the two LFs. Mobasher & Trentham (1998) points stay relatively near the extrapolation of the best Schechter fit to our data, suggesting that the LF could keep its $\alpha \sim -1.3$ slope even at these very faint magnitudes (roughly equivalent to $M_B \sim -13.5$ mag). The same points stay near the Secker & Harris (1996) R band Coma LF shifted in the H band, as plotted in Fig. 2.

Fig. 5 also compares the Coma cluster LF to the local field LFs, as computed by Gardner et al. (1997, dashed line) and Szokoly et al. (1998, solid line). The two field surveys differ in many respects. The former is based on a sample about 5 times larger than the latter, and it is computed from a near–infrared selected sample. Instead, the latter is optically selected

and no corrections have been applied for the optical selection. The slope of the field LF computed by Gardner et al. (1997) and by Szokoly et al. (1998) differ largely, with $\alpha \sim -0.9$ and $\alpha \sim -1.3$, respectively. However, the 68% confidence contours of the two LFs cross each other (figure not shown), implying that the two LFs are compatible to $\sim 1\sigma$, as also claimed by Szokoly et al. (1998). The two field LFs could have different slopes but they still remain compatible because they barely reach $M_H = -21.5$ mag[3], and therefore they sample only the exponentially declining part of the LF. Therefore, the slope of the field LF is constrained by the faintest bin (see Fig. 5) which, as in all field surveys, is quite uncertain because measured on a very small volume.

Our own data for the Coma H LF are three mag deeper than the local field ones, and the overall shape, as parametrized by the Schecther parameters, agrees with the field ones: the Coma LF has α and M^* indistinguishable from the Szokoly et al. (1998) LF and a M^* very similar to the Gardner et al. (1997) one. Its slope, $\alpha = -1.3$, is steeper than the Gardner et al. (1997) slope, but by less than $\sim 1\sigma$ difference, due to the large confidence level intervals of the two LFs. Also, the present Coma H band LF agrees with the field LF computed by Cowie et al. (1996) in a few redshift ranges, up to $z \sim 1$.

On the one side, the overall shape of the LF is similar both in the field and in the Coma cluster. On the other side, no dip is present in near–infrared field LFs, whereas instead in our Coma LF it is quite evident. This fact, and the absence of the dip in the Coma region studied by De Propris et al. (1998) seems to suggest that the dip amplitude could be related to the morphological mix of the studied environment. The alternative possibility requires that environmental effects change the H band luminosity preferentially at a given mass (corresponding to $H \sim -22$ mag), without altering too much the mass distribution for more massive galaxies. Otherwise, the Coma and the field LFs should have different bright tails.

4. Discussion and conclusions

We have presented the near–infrared LF of a nearby cluster of galaxies, Coma, down to faint magnitudes ($M_H = -18.5$ mag, i.e. $M^*_H + 6$ mag corresponding roughly to $M_B \sim -14.5$ mag). This has been made possible due by the relatively deepness of the present images *and* by the small background variance associated with the large surveyed area. The computed LF is the deepest ever measured in the near–infrared, on any type of environment.

The shape of the Coma LF in the region studied seems not to depend on wavelength, at least in b and H bands, and with less confidence, in R. The similarity of the LF implies that in the central region of Coma there is basically no new population of galaxies which disappears or becomes too faint to be observed in the optical bands (because of the presence of dust, for instance), down to the magnitudes of dwarfs. Furthermore, if the H band LF traces the galaxy mass function, also the blue LF traces the mass in this case. This is in apparent contradiction with the results by Gavazzi et al. (1996), who found that for spiral galaxies the M/L is approximatively constant in the near–infrared but not in the optical filters. Since our finding is based on just one sample in one particular environment, although selected with well understood selection criteria (volume–complete), it has to be verified on other samples of nearby galaxies, possibly spiral-rich clusters or groups, before any dangerous generalization.

The bright part of the Coma H band LF, i.e. the brightest three magnitudes, agrees with the expectations based on optical LFs and usual colors for galaxies, and with what is observed in shallower near–infrared surveys of clusters of galaxies and also on the field. This confirms that the shape of the tip of the mass function seems environment–independent and therefore environmental effects have a minor impact on the luminosity of bright galaxies ($M < M^* + 2$), and possibly on their masses. Coma and the field population differ by a factor of 100 in galaxy density. The extension of this sentence to faint ($M > M^* + 4$) galaxies still awaits a determination of the field LF in the dwarf regime.

The Coma near–infrared LF presents a real dip at a luminosity corresponding to that observed in the optical LF. This is the first detection of such a feature in the near–infrared. The existence of a dip in the Coma LF in the H band implies the presence of a dip also in the galaxy mass function. To our knowledge, there is presently no simulation of cluster formation which is able to produce such a feature in the galaxy mass or luminosity function. This feature, being distinctive, will set a strong constraint for the future simulations.

Kauffmann & Charlot (1998) have shown that the apparent passive evolution and the slope of the color–magnitude relation can be accommodated within a hierarchical model, even if the galaxies themselves grow by mergers until late times. One of the important remaining issues is the comparison between the predicted and the observed LF, in particular, the distribution of galaxies as a function of their morphological type, at least for early–type galaxies. Probably the main limitation till now has been the lack of suitable observational data to compare with model expectations. Our near–infrared catalog, published in Paper I, joint to the morphological types for the Coma galaxies, available from Andreon et al. (1996, 1997), fills this observational gap.

The overall slope of the Coma LF is intermediate ($\alpha \sim -1.3$). The slope is measured down to the dwarfs regime: we reach $M_B \sim -14.5$ using our own data alone and even fainter magnitudes ($M_H \sim -17$, roughly equivalent to $M_B \sim -13$) when including Mobasher & Trentham (1998) data and under their assumptions. When comparing Coma and the field LFs in the near–infrared, we have to take into account that both LFs have been derived with completely different data and methods, because of the different selection criteria for the two samples: the field LF is computed on a flux–limited sample, whereas the cluster LF is computed on a volume–limited sample. In particular, the field LF suffers from a 10% redshift incompleteness (or

[3] Both LsF are originally computed in the K band, and have been transformed in the H band assuming the same mean rest–frame color for all galaxies ($H - K = 0.2$ mag). This is a reasonable value for the brightest population, which is dominated by galaxies at $z \lesssim 0.1$

is based on an optical selection, as for the Szokoly et al. (1998) LF), and a poor sampling of faint luminosities, because of the small volume explored at that luminosities. Nevertheless, and even if the environments sampled are quite different, the bright tail of the Coma and the field LFs are in close agreement. In our opinion, this excludes the possibility of large systematic errors in the derivation of field LFs, and therefore indirectly confirms the disagreement between the observed near-infrared LF and that expected on theoretical grounds in the present simulations of a hierarchical Universe (Kauffmann et al. 1999). This also suggests that more detailed models are needed to reproduce the observed properties of galaxies, such as the LF. In particular, as mentioned before, the existence of a dip in the present LF and the large range on which this LF is computed (7 mag) provides a strong constraint to future simulations. It is worth to noting that theoretical predictions on the behaviour of high order statistics, such as the color distribution or the galaxy evolution, use a particular realization of the LF as a "weight". Thus, increasing the accuracy on the determination of the LF will certainly contribute to the improvement of the theoretical knowledge on galaxy formation and evolution.

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