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ORIGINAL ARTICLE

A graphical analysis of the systematic error of classical binned methods in constructing luminosity functions

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Abstract The classical $1/V_a$ and PC methods of constructing binned luminosity functions (LFs) are revisited and compared by graphical analysis. Using both theoretical analysis and illustration with an example, we show why the two methods give different results for the bins which are crossed by the flux limit curves $L = L_{lim}(z)$. Based on a combined sample simulated by a Monte Carlo method, the estimate ϕ of two methods are compared with the input model LFs. The two methods give identical and ideal estimate for the high luminosity points of each redshift interval. However, for the low luminosity bins of all the redshift intervals both methods give smaller estimate than the input model. We conclude that once the LF is evolving with redshift, the classical binned methods will unlikely give an ideal estimate over the total luminosity range. Page & Carrera (in Mon. Not. R. Astron. Soc. 311:433, 2000) noticed that for objects close to the flux limit ϕ_{1/V_a} nearly always to be too small. We believe this is due to the arbitrary choosing of redshift and luminosity intervals. Because ϕ_{1/V_a} is more sensitive to how the binning are chosen than ϕ_{PC}. We suggest a new binning method, which can improve the LFs produced by the $1/V_a$ method significantly, and also improve the LFs produced by the PC methods. Our simulations show that after adopting this new binning, both the $1/V_a$ and PC methods have comparable results.

Keywords Galaxies: luminosity function, mass function · Galaxies: quasars: general

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1 Introduction

From shortly after the first quasar was found until the present, considerable effort has been spent in obtaining samples to investigate their luminosity distribution as a function of redshift, known as the luminosity function (LF). The LF is very important because its shape and evolution provide constraints on the nature of activity and the cosmic evolution of quasars/active galactic nuclei (AGNs). Up to now many statistical approaches have been proposed to investigate the LFs. These include parametric techniques which assume analytical form for the LFs, and non-parametric methods which usually need binning the data (see Johnston 2011, for an overall review).

Among the non-parametric methods, the $1/V_a$ method (see Avni and Bahcall 1980; Eales 1993; Ellis et al. 1996) is the most classical binned method and is particularly prevalent for its simplicity. Although more than four decades have passed since its original version (i.e., the famous $1/V_{max}$ estimator, Schmidt 1968) was presented, the $1/V_a$ method is not outdated and continues to be widely used in the literature (see Civano et al. 2011; Mao et al. 2012; Marchesini et al. 2012; McAlpine and Jarvis 2011; Padovani et al. 2011; Patel et al. 2013; Hiroi et al. 2012; Yuan and Wang 2012; Marchã and Caccianiga 2013, for latest use of this method). On the other hand, authors have pointed out that the $1/V_a$ method introduces a significant error for objects close to the flux limit (e.g., Page and Carrera 2000; Cara and Lister 2008). Page and Carrera (2000) presented an improved method (hereafter the PC method) of constructing the binned LF.