The two modes of PNLF

L. Hernández-Martínez[1], A. Rodríguez-González[2], A. Esquivel[2], M. Peña[1], A.C.Raga[2], Reyes-Pérez, J[1]

(1) IA-UNAM, (2) ICN-UNAM

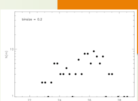
Abstract:

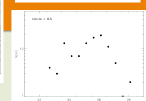
The [OIII] 5007 planetary nebulae luminosity function (PNLF) could be used as distance indicator. Many authors reported that the bright end of the PNLF seems invariant for many galaxies, up to the 3rd. brightest magnitude. However, for some galaxies (e.g. NGC6822, SMC), the shape of the PNLF do not increase monotonically but present a dip. In this work we propose a PNLF where one or two modes in the cumulative PNLF are considered. Using a genetic algorithm, we tested our new PNLF using a sample with different hubble-type galaxies and try to understand the origin of the two-modes (whether individuals PNe, symbiotics, etc, may affect the shape).

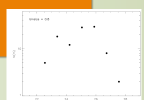
What happen with the bins?

The histogram is defined by four parameters: the bin-size m, number of bins k,and the minimum and maximum magnitude, m0 and ml, respectively. Of this four, only three parameters are free,as they are related by

$$\Delta m = \frac{(m_l - m_0)}{k}.$$







The usual technique is to build a histogram of the apparent magnitudes of the PNe and fit the brightest portion in this histogram to the functional form of the PNLF to estimate m* and NT. This procedure is particularly tricky because the number of bins, the bin size and the initial position of the first bin are treated as free parameters, and they are commonly determined arbitrarily. Infact, the choice of bin size and position of the first bin can determine whether a dip in the PNLF is present or not.

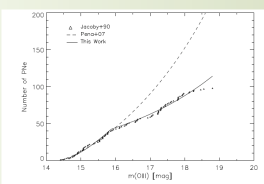


FIG. 1.— Cumulative PNLF of the Large Magallanic Cloud. The *triangles* are the data in Jacoby et al. (1990), the *dashed* line is the one mode fit obtained by Peña et al. (2007), and the *solid* line is our two mode fit.

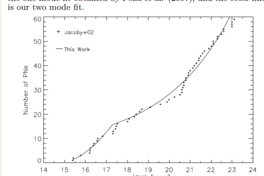


FIG. 2.— Cumulative PNLF of the Small Magallanic Cloud. The *plus symbols* are the data in Jacoby & De Marco (2002), the *solid* line is our two mode fit.

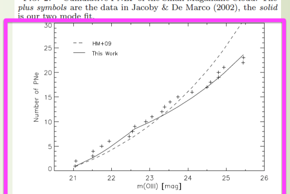


FIG. 4.— Cumulative PNLF of NGC 6822. The *plus* signs and the *dashed* line, are the data and the fit of HMP09, respectively. The *solid* line is our two mode fit.

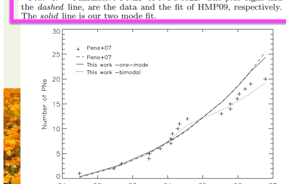


FIG. 6.— Cumulative PNLF of NGC 3109. The *plus* signs are the observational and the *dashed* line, are the observational data and the one mode fit in Pea et al (2007). The *solid* line and the *dotted* lines, are the one and two mode best fits, respectively, obtained with our genetic algorithm.

Cumulative PNLF

The already limited number of PNe available for a given galaxy often results in a problem of small statistics. At the same time, the binning procedure reduces this data to only a few points, of which only those corresponding to the most bright PNe are used to the fit, thus the issue of small statistics is only aggravated. A cumulative PNLF has the advantage of improving the statistics by using more points to do the fit, while the assumptions about the histogram bins (e.g. size and number) are no longer necessary.

$$I(m; N_T, m^*) = N_T[A\, e^{3m^* - Bm} + C\, e^{0.307m} - (A+C)\, e^{0.307m^*}],$$

What about physics?

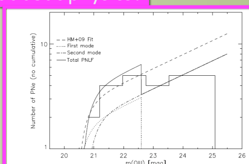
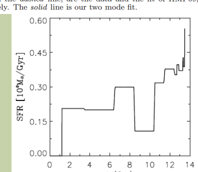
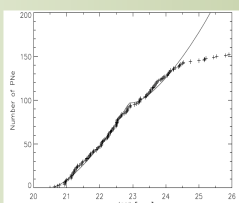
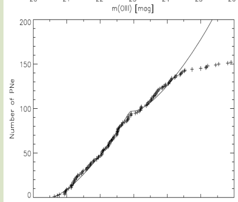
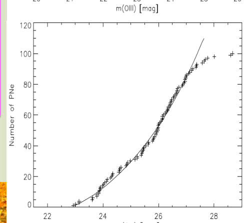


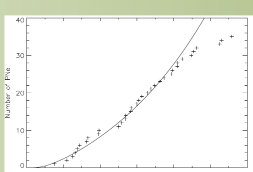
FIG. 5.— PNLF (non-cumulative) of NGC 6822. The *plus* signs and the *dashed* line, are the data and the fit of HMP09, respectively. The *solid* line is our two mode fit.

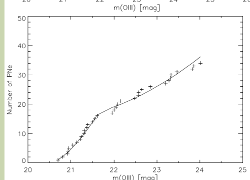












Two modes? - Our model

Since the number of PNe observable in extragalactic sources is rather limited, we would like to use as many objects as possible to characterize their luminosity function. In this regard the cumulative PNLF seems the most natural choice. However, a large number of galaxies show the decrease in their PNLF that has been associated with an additional stellar population. Instead of restricting the analysis to the brightest PNe in the sample, we propose to include the second mode into the luminosity function fit. Any new two-mode luminosity function must have the same properties of the canonical PNLF form in order to reproduce the results of galaxies with a single stellar population mode. We propose a two-mode PNLF as:

$$N(m) = N(m; N_{T1}, m_1^*) \times \mathrm{H}(m - m_{cut}) + N(m; N_{T2}, m_2^*)$$

$$\mathrm{H}(m - m_{cut}) = \begin{cases} 1, & m \le m_{cut}, \\ 0, & m > m_{cut}. \end{cases}$$

The function we propose is the sum of two standard PNLFs, allowing each mode to have a different N_T , and m*. One of the two modes is truncated abruptly at amagnitude (m_{cut}). Certainly, one could introduce another cutoff for the additional population, or extend the function to three or more modes. However, in the spirit of having as few free parameters as possible we will adopt this form.

We have taken observations of nine galaxies and construct their cumulative PNLF. We then use the aga-v1 code (Rodríguez-González et al. 2012) for each galaxy to obtain the best fit of one and two-mode cumulative PNLF luminosity functions. The aga-V1 code uses the Asexual Genetic Algorithm described in poster B21, and allows to find the best fit exploring a wide range of parameters. The code varies simultaneously, and independently the parameters of the fit in such space. To avoid a systematic error due the choice of parameter space covered we allow the code to find m^*_1, m^*_2, and m_{cut} anywhere from half a magnitude below the minumum in the sample to half a magnitude above the maximum in the sample, the range of $N_{T,1}$ and $N_{T,2}$ covered is from 10^{-7} to 10^2. An additional constraint that we have enforced is that $m_{cut} \ge m^*_1$, otherwise the results are unphysical. It is important, however, to mention that m^*_1 and m^*_2 are allowed to be smaller or larger to each other. In addition, we perform a Kolmogorov-Smirnov test to each of the fits, and it is presented along with the results.

References:
Carigi, et al, 2006, ApJ, 644, 924
Ciardullo, et al, 2002, ApJ, 577, 31
Herrmann, et al, 2008, ApJ, 683, 630
Jacoby, et al, 1990, ApJ, 356, 332
Jacoby, et al, 1990, ApJ, 365, 471
Peña, et al, 2007, A&A, 466, 75
Peña, et al, 2012, A&A, 547, 78
Rodríguez-González, et al, 2012, AJ, 143, 60.

KOLMOGOROV-SMIRNOV TEST RESULTS

Galaxy	Type	N_{PNe} Total	N_{PNe} used	K-S	D	Number of modes
LMC^a	Ir	98	95	0.999	0.051	2
LMC^b	Ir	164	158	0.999	0.037	2
SMC^a	Ir	31	31	0.997	0.094	2
SMC^c	Ir	59	55	0.970	0.097	2
NGC 6822	dIr	23	23	0.999	0.087	2
NGC 3109	dIr	20	19	0.993	0.136	1
NGC 3109†	dIr	20	19	0.888	0.206	2
NGC 300	Sp	100	95	0.999	0.052	1
M 33	Sc	152	144	0.995	0.047	2
M 31	Sb	298	288	0.879	0.048	2
NGC 205	Sph	35	32	0.795	0.156	1
M 32	E2	34	34	1.000	0.058	2

CUMULATIVE PLANETARY NEBULAE LUMINOSITY FUNCTION FITS

Galaxy	N_{T1}	m_1^*	m_{cut}	N_{T2}	m_2^*
LMC^a	$(2.11\pm0.03)\times10^{-1}$	14.22±0.01	15.87±0.01	$(1.16\pm0.01)\times10^{-1}$	14.56±0.28
LMC^b	$(1.71\pm0.04)\times10^{-1}$	14.18±0.14	15.95±0.40	$(1.19\pm0.01)\times10^{-1}$	15.62±0.76
SMC^a	$(4.86\pm0.01)\times10^{-2}$	14.65±0.05	16.81±0.12	$(3.39\pm0.01)\times10^{-2}$	15.24±0.64
SMC^c	$(3.97\pm0.01)\times10^{-2}$	14.82±0.20	17.29±0.27	$(1.46\pm0.01)\times10^{-2}$	15.65±0.40
NGC 6822	$(3.01\pm1.02)\times10^{-3}$	20.37±0.12	22.60±0.54	$(3.21\pm0.02)\times10^{-3}$	20.70±0.15
NGC 3109	$(2.58\pm0.52)\times10^{-3}$	21.05±0.35	26.67±1.20	$(1.68\pm0.07)\times10^{-1}$	28.04±1.30
NGC 3109†	$(2.35\pm0.03)\times10^{-3}$	20.99±0.06	—	—	—
NGC 300	$(9.23\pm0.05)\times10^{-3}$	22.66±0.03	27.62±0.26	$(2.69\pm1.71)\times10^{-1}$	28.48±0.56
M 31	$(6.49\pm0.04)\times10^{-2}$	20.24±0.01	22.29±0.6	$(8.66\pm0.08)\times10^{-2}$	22.17±0.49
M 33	$(5.6\pm0.02)\times10^{-2}$	20.46±0.06	22.89±0.12	$(2.83\pm0.37)\times10^{-2}$	22.95±0.30
NGC 205	$(8.19\pm0.02)\times10^{-3}$	20.19±0.04	24.29±0.10	$(3.37\pm1.37)\times10^{0}$	27.80±1.33
M 32	$(2.98\pm0.04)\times10^{-2}$	20.47±0.04	21.67±0.11	$(7.34\pm1.55)\times10^{-3}$	21.47±0.13