Globular Cluster & Planetary Nebulae Luminosity Functions

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Distance Modulus

\[ m - M = 5 \log \left( \frac{d}{10} \right) \]

M = Absolute Magnitude
m = Apparent Magnitude
d = distance

\[ d = 10 \times 10^\left( \frac{m-M}{5} \right) \]
Globular Clusters

- Large spherically distributed collection of (generally) old stars
- Usually in halos
Why use GCLF?

• Misnommer
• Brighter than other standard candles
• Do not vary
• Usually in the Halo so reddening is not a big concern
• Secondary distance measurement- Cepheids/GC in M31
How to use GCLF?

- Count Globular clusters in a region
- Make a histogram of their apparent magnitudes
- Relative to MW or relative M31
- TOM (Turn Over Magnitude)
Fitting GCLF

\[ \frac{dN}{dm} \sim \exp \left( -\frac{(m - m_0)^2}{2\sigma^2} \right) \]

Gaussian

\[ \frac{dN}{dm} \sim \frac{1}{\sigma} \left( 1 + \frac{(m - m_0)^2}{5\sigma^2} \right)^{-3} \]
Planetary Nebulae

Myung Gyoon Lee et al. 2018 (NGC 4993)
GCLF

• Region-Background

(a) Galaxy region (20" < r < 50")

(b) Background region (r > 60")

(c) Background subtracted GCLF

\[ F606W(\text{max}) = 25.65 \pm 0.04 \]

\[ \sigma = 0.69 \pm 0.05 \]
GCLF Example Calculation

\[ d = 10 \times 10 \frac{(25.65 + 7.6)}{5} \approx 44.7 \text{Mpc} \]
GCLF Errors

• Must correct for luminosity function of background galaxies (fainter TOM)
• Reddening (Reddening map)
• Aperture correction to account for extended clusters
• The function of your fit
• Calibration Cluster system
• errors sum up to several tenths of a magnitude ~ 0.3
Planetary Nebulae

• Emission spectra from hot ionized gas expanding from a central red giant star near the end of its life

• [OIII]
PNLF

• only standard candle that can be applied to all the large galaxies of the Local Supercluster

\[ N(M) \propto e^{0.307M} \left\{ 1 - e^{3(M^* - M)} \right\} \]
Blanco/Mosaic II and WIYN/OPTIC

- NGC 628
- M74
Blanco/Mosaic II and WIYN/OPTIC

• ROYGBV increasing magnitudes

Hermann et al 2008
Contaminants (HII)

- Less prevalent for ellipticals but can masquerade as PNe in spirals
- O & B stars HII regions will outnumber PNe
- Ratio of $\frac{[OIII]}{H\alpha+[NII]} \sim 1.6$ (Andromeda Bulge)
Contaminants (Lyman alpha galaxies)

• At $z = 3.12$ $L\alpha$ is redshifted toward 5007 A.

• Small for starburst objects

• Larger for intracluster environments
Contaminants (Supernovae Remnants)

• Compact remnants are rare so it has a minimal effect on the PNLR

• Still have to be taken into account especially around the turn over magnitude
Contaminants

- HII Regions
- Lyman alpha galaxies
- Supernovae remnants
Contaminants

- HII Regions
- Lyman alpha galaxies
- Supernovae remnants
MUSE at VLA

• IFU Spectograph

Kreckel & Schinnerer et al 2018
MUSE at VLA
Muse Results

PNe sample only including SNR contaminants
## Muse Results

<table>
<thead>
<tr>
<th>(m-M) (mag)</th>
<th>D (Mpc)</th>
<th>Method</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.32 ± 0.40</td>
<td>7.31 ± 1.35</td>
<td>Brightest supergiants</td>
<td>Sharina et al. (1996)</td>
</tr>
<tr>
<td>29.44 ± 0.48</td>
<td>7.73 ± 1.71</td>
<td>Brightest supergiants</td>
<td>Hendry et al. (2005)</td>
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<tr>
<td>29.91 ± 0.49</td>
<td>9.59 ± 2.16</td>
<td>Brightest supergiants (alternate calibration)</td>
<td>Hendry et al. (2005)</td>
</tr>
<tr>
<td>29.91 ± 0.63</td>
<td>9.59 ± 2.78</td>
<td>SN II standard candle</td>
<td>Herrmann et al. (2005)</td>
</tr>
<tr>
<td>29.67^{+0.06}_{-0.07}</td>
<td>8.59^{+0.24}_{-0.28}</td>
<td>PNLF</td>
<td>Herrmann et al. (2008)</td>
</tr>
<tr>
<td>29.98 ± 0.28</td>
<td>9.91 ± 1.28</td>
<td>SN II standard candle</td>
<td>Olivares et al. (2010)</td>
</tr>
<tr>
<td>29.76 ± 0.24</td>
<td>8.95 ± 0.99</td>
<td>SN II photospheric magnitude</td>
<td>Rodríguez et al. (2014)</td>
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<tr>
<td>29.74 ± 0.18</td>
<td>8.87 ± 0.74</td>
<td>SN II photospheric magnitude</td>
<td>Rodríguez et al. (2014)</td>
</tr>
<tr>
<td>30.01 ± 0.07</td>
<td>10.05 ± 0.32</td>
<td>SN II photospheric magnitude</td>
<td>Rodríguez et al. (2014)</td>
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<tr>
<td>29.88 ± 0.05</td>
<td>9.46 ± 0.22</td>
<td>SN II photospheric magnitude</td>
<td>Rodríguez et al. (2014)</td>
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<tr>
<td>30.04 ± 0.03</td>
<td>10.19 ± 0.14</td>
<td>TRGB</td>
<td>Jang &amp; Lee (2014)</td>
</tr>
<tr>
<td>29.91^{+0.08}_{-0.13}</td>
<td>9.59^{+0.35}_{-0.57}</td>
<td>PNLF</td>
<td>this work</td>
</tr>
</tbody>
</table>
References


• Ciardullo, Robin (July 2004), *The Planetary Nebula Luminosity Function*,