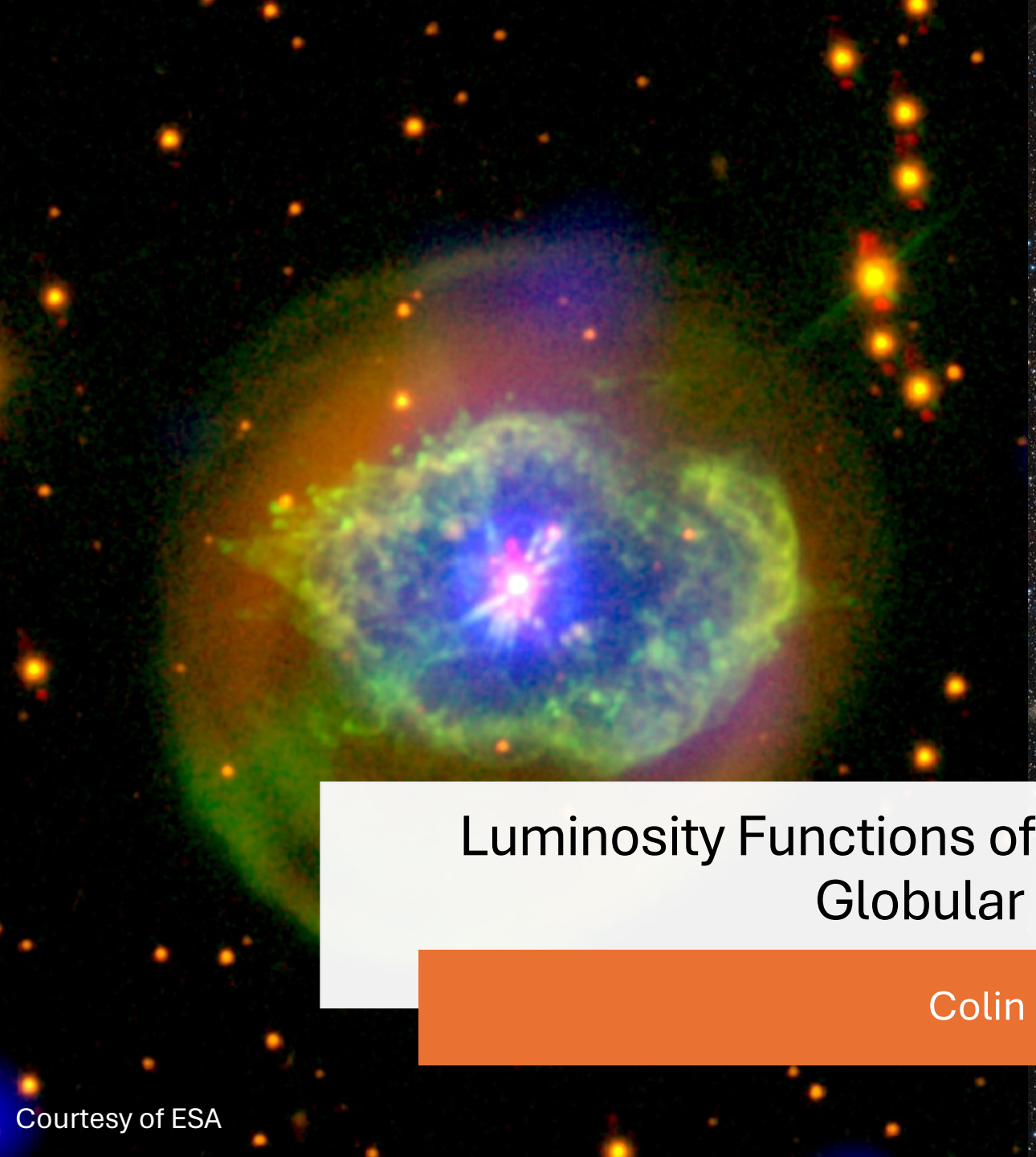
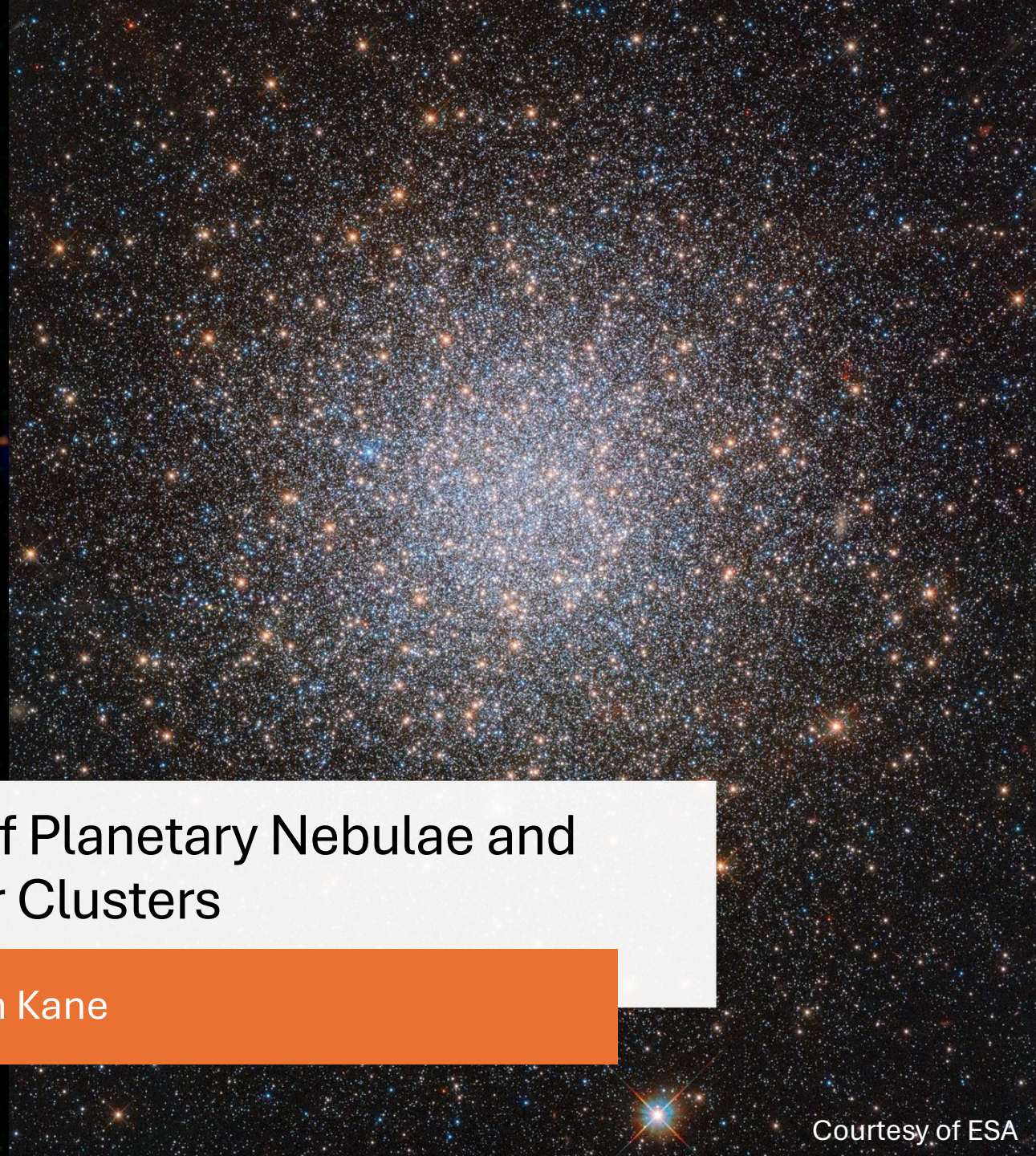




Luminosity Functions of Planetary Nebulae and Globular Clusters

Colin Kane

Courtesy of ESA

Courtesy of ESA

Luminosity Functions (PNe and GC)

- Indirect measurement methods
- Empirical relations of brightness and distance
  - via distance modulus
- Assumes intrinsic brightness of the object
- Calibrated using other distance techniques
  - Mainly Cepheids or RR Lyraes

Planetary Nebulae Luminosity Function

- First discovered by studying PNe in the SMC and LMC
- In 1980, George Jacoby discovered a relation between number of PNe and their magnitude in an [O III] λ5007 filter
- Originally believed it to be a power law relation
  - (shocker)

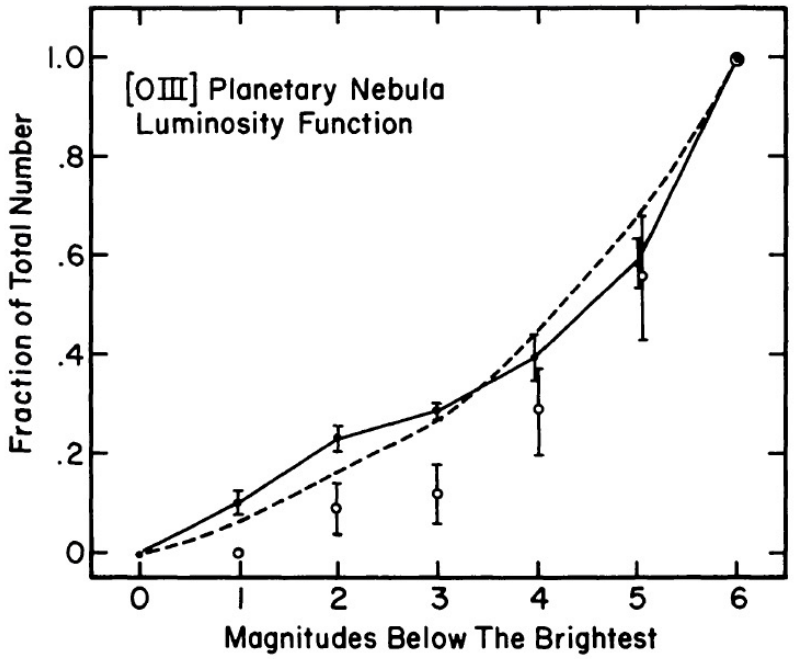
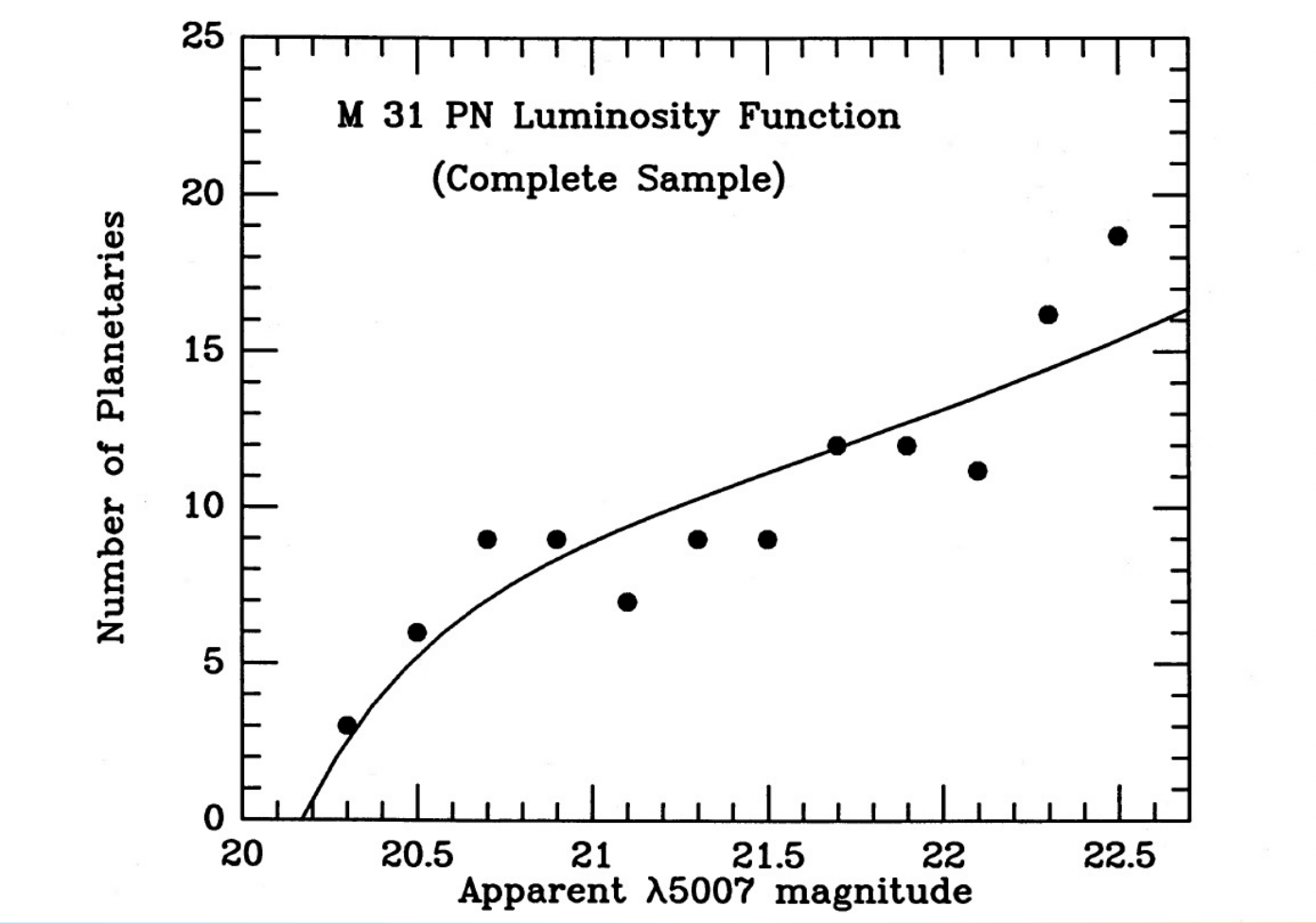


FIG. 5.—The average [O III] luminosity function for the Magellanic Clouds (*solid line*) and 1 standard deviation error bars. Also shown are the prediction given by Henize and Westerlund (1963) (*dashed line*) and the luminosity function for nearby optically thin galactic planetary nebulae (*open circles*).

Improved PNLF



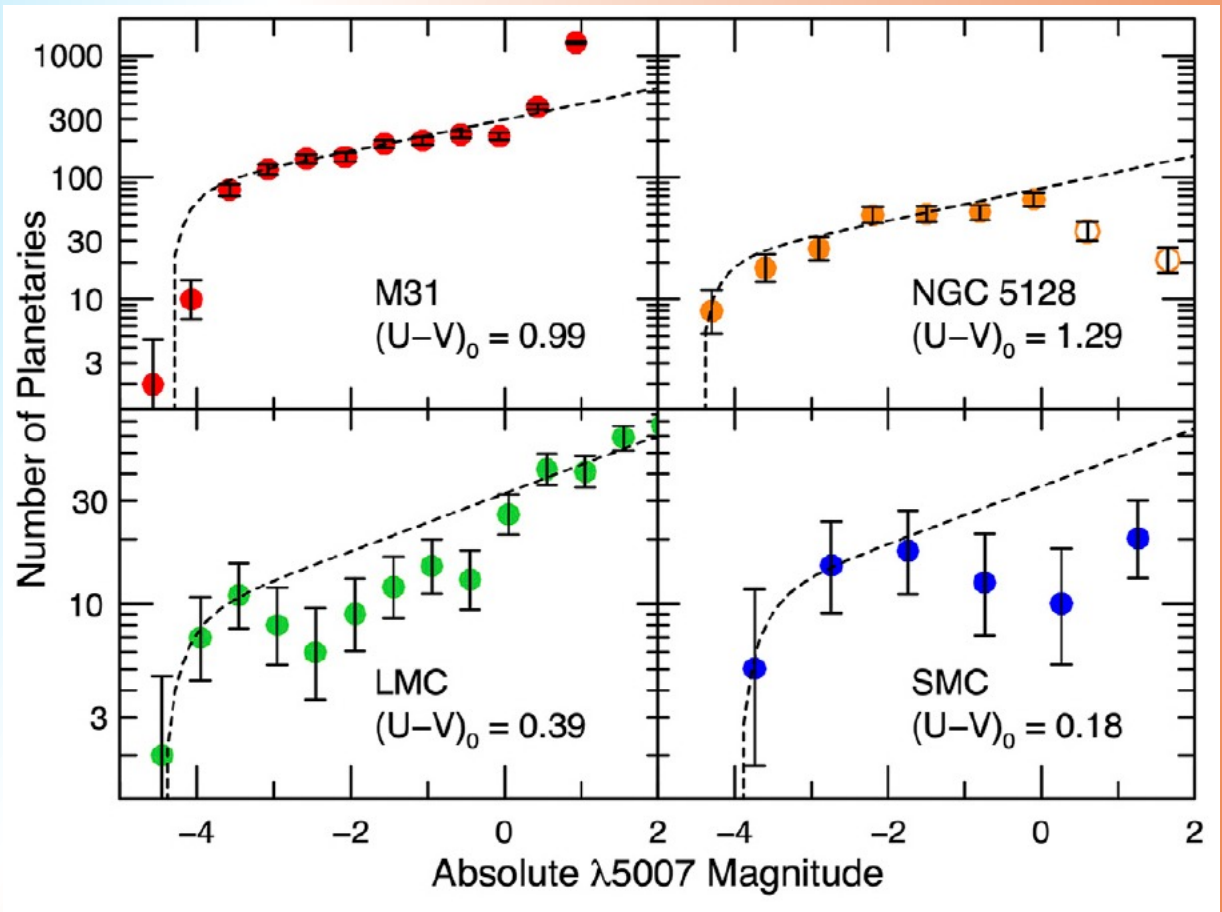
- Ciardullo et al. 1989 improved the PNLF
  - Used nebulae in M31 and the Leo I Group

$$N(M) \propto e^{0.307M}(1 - e^{3(M^* - M)})$$

  - $M^* = -4.53$
- Adopted distance of 710 kpc from Cepheids
- Utilizes distance modulus to calculate distance

Modern Use of PNLF

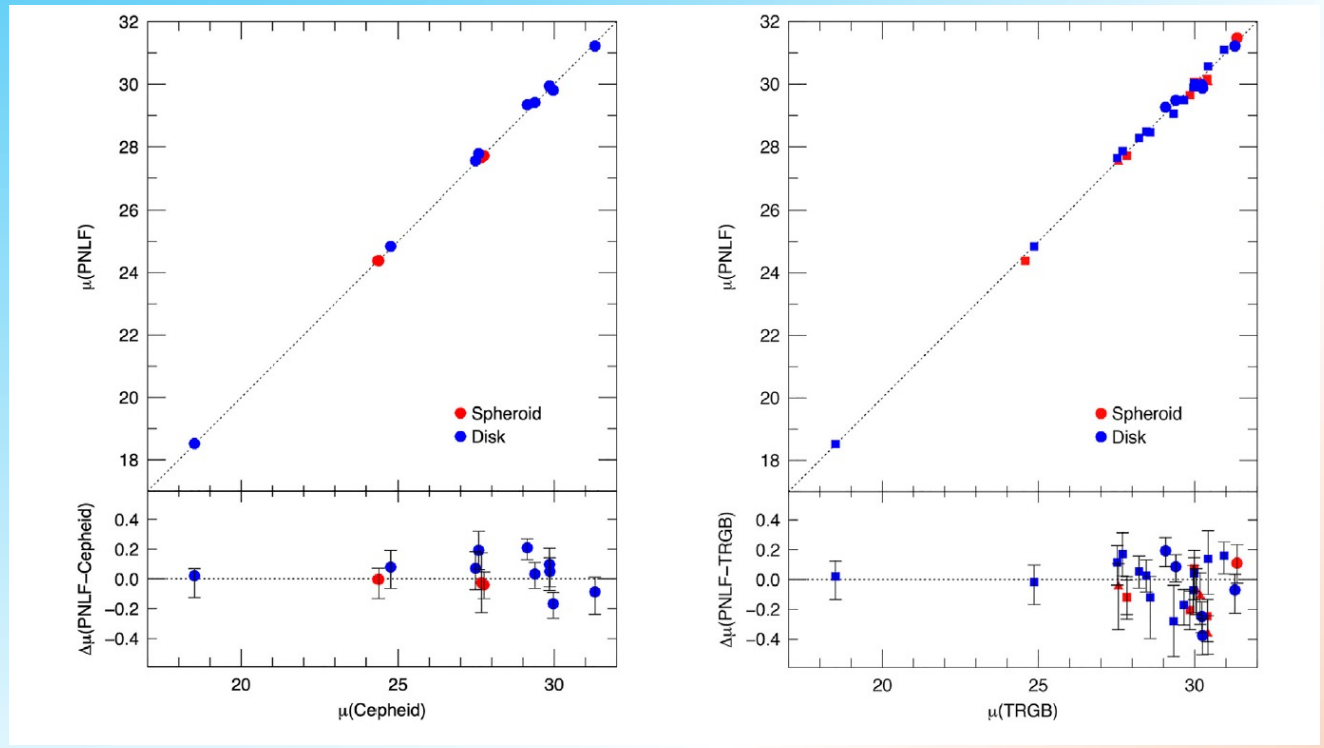
- Thanks to IFUs, PNLF is coming back into popularity
- Modified PNLF with c_2 term
  - To accommodate faint-end slope
- Can be stretched out to 40 Mpc
  - With ~10% error
- Also used to verify distance to galactic center
  - 8.1 kpc (Reid 1989)



$$N(m) \propto e^{c_2 m}\left\{1 - e^{3(m^* - m)}\right\}$$

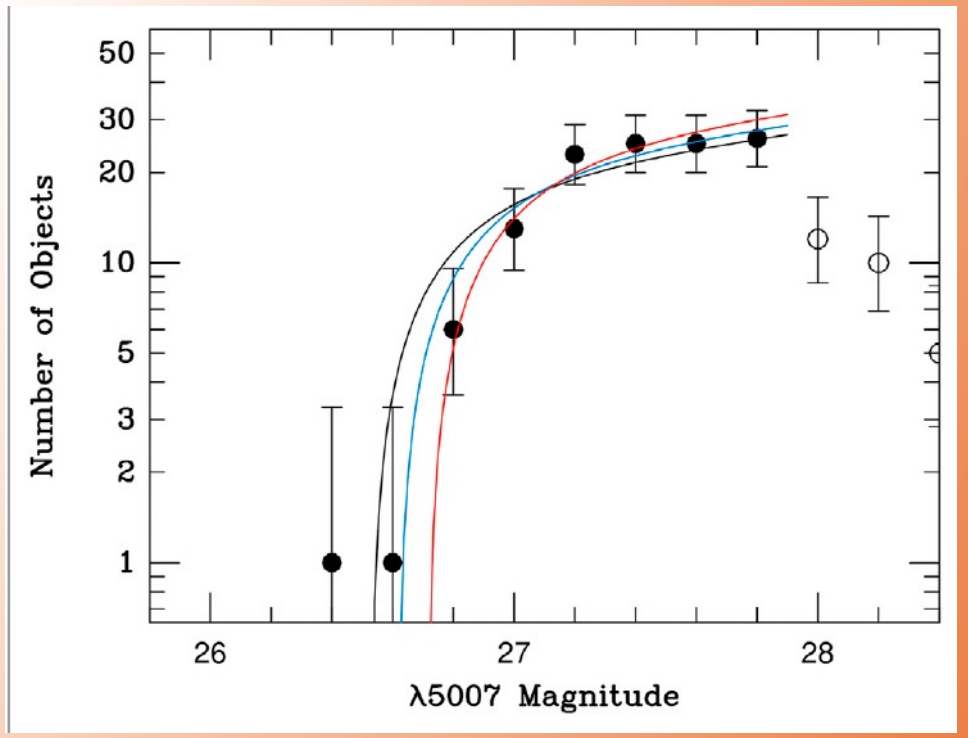
PNLF Advantages and Shortcomings

- PNLF does not depend strongly on stellar population
- Effective up to 40 Mpc



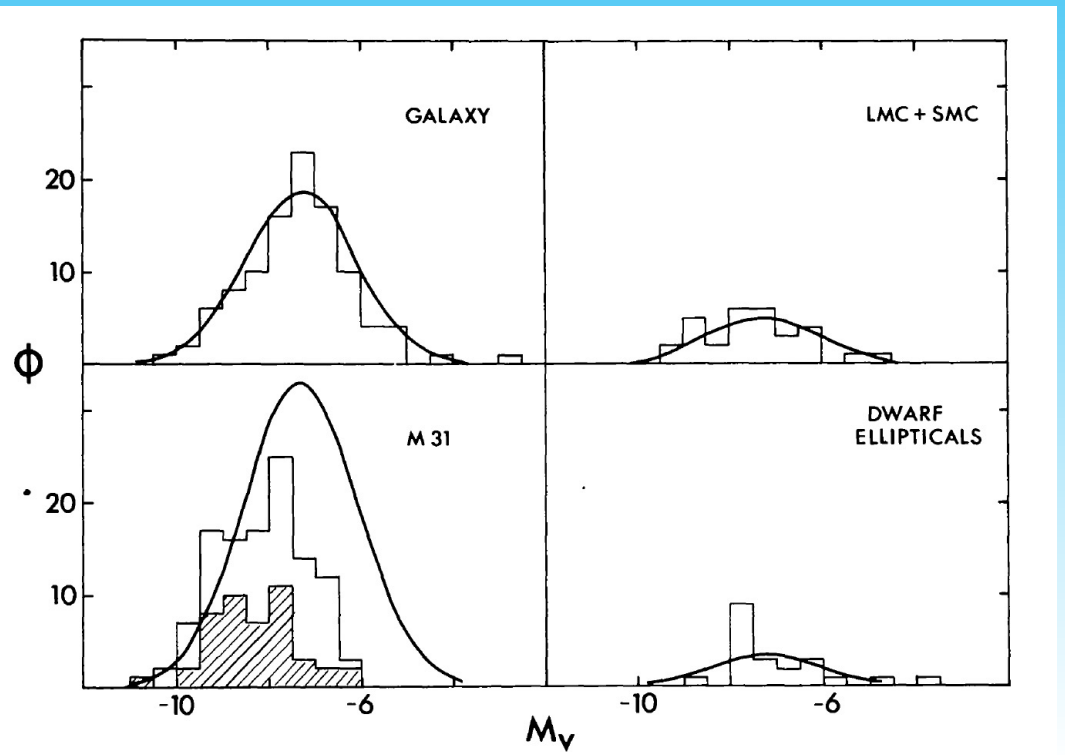
Ciardullo 2022

- PNe are relatively dim
- Galaxies in different clusters are slightly different slopes at the faint end



Ciardullo 2022

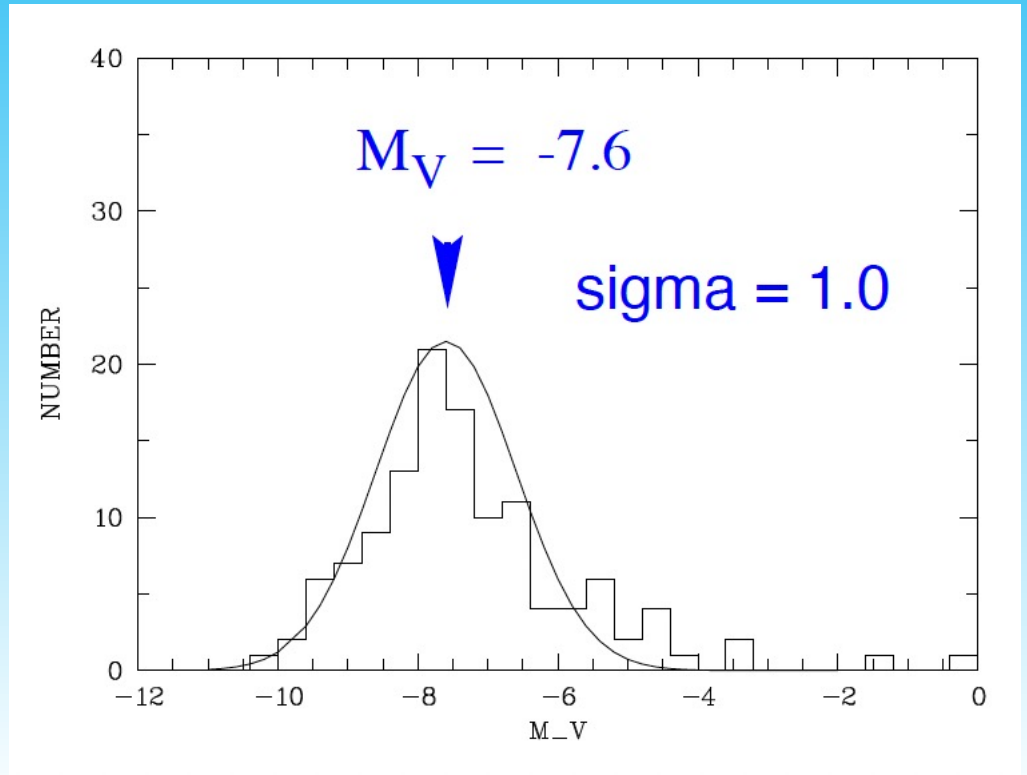
Globular Cluster Luminosity Function



- D.A. Hanes in 1977 was the first to suggest universal turn over magnitude (TOM)
- Gaussians were fit at first to determine TOM
  - t_5 functions fit the data better upon further study
  - Peak at $M_v = -7.66 \pm 0.09$
- Can reach out to ~120 Mpc using HST

Globular Cluster Luminosity Function

- Originally used all GCs in galaxy
- Younger stellar populations cause the TOM to become fainter
  - Impacts distance measurements
- Compare to M31 TOM to get distance modulus



GCLF Advantages and Short Comings

- Can reach to ~120 Mpc
- Good for early type, large ellipticals
- Can be used to approximate Hubble Constant
  - $H_0 = 69 \pm 9$ (Kavelaars et al 2000) or 73 (Harris et al 2009)

- Accurate background subtractions are needed for precise distance moduli
- Need to used old clusters to get correct TOM
- Provides systematically shorter distance modulus, by 0.1 – 0.27 mag, for Virgo and Fornax cluster

Rejkuba 2012

Villegas et al 2010

Luminosity Functions (PNe and GC)

Planetary Nebulae

- Useful up to 40 Mpc
- Might become more popular with IFUs
- Can use all PNe in a galaxy to fit

Globular Cluster

- Useful up to 120 Mpc
- Best for Ellipticals and Lenticulars
- Only for old, metal poor clusters