Ultra Long Period Cepheids in the HR diagram: new insights from Gaia DR3

Ilaria Musella

Italian National Institute of Astrophysics – Observatory of Capodimonte (Naples)

Ultra long period Cepheids (ULPs)

Properties:

★ Light curves typical of Classical Cepheids

★ P ≥ 80 days (Bird et al. 2009), firstly identified in LMC & SMC (Freedmann et al. 1985)

★ much brighter (M_I from -7 to -9 mag) than 'short period' Cepheids (M_I up to -5 mag)

Ultra long period Cepheids (ULPs)

Properties:

- ⋆ Light curves typical of Classical Cepheids
- ⋆ P ≥ 80 days (Bird et al. 2009), firstly identified in LMC & SMC (Freedmann et al. 1985)
- ⋆ much brighter (M_I from -7 to -9 mag) than 'short period' Cepheids (M_I up to -5 mag)

They should represent "best standard candles" directly observable at cosmological distances (>100Mpc) without using secondary indicators, hence reducing the systematic errors that contribute to the Hubble constant error budget (contribution to understand the Hubble tension)

Ultra long period Cepheids (ULPs)

Properties:

⋆ Light curves typical of Classical Cepheids

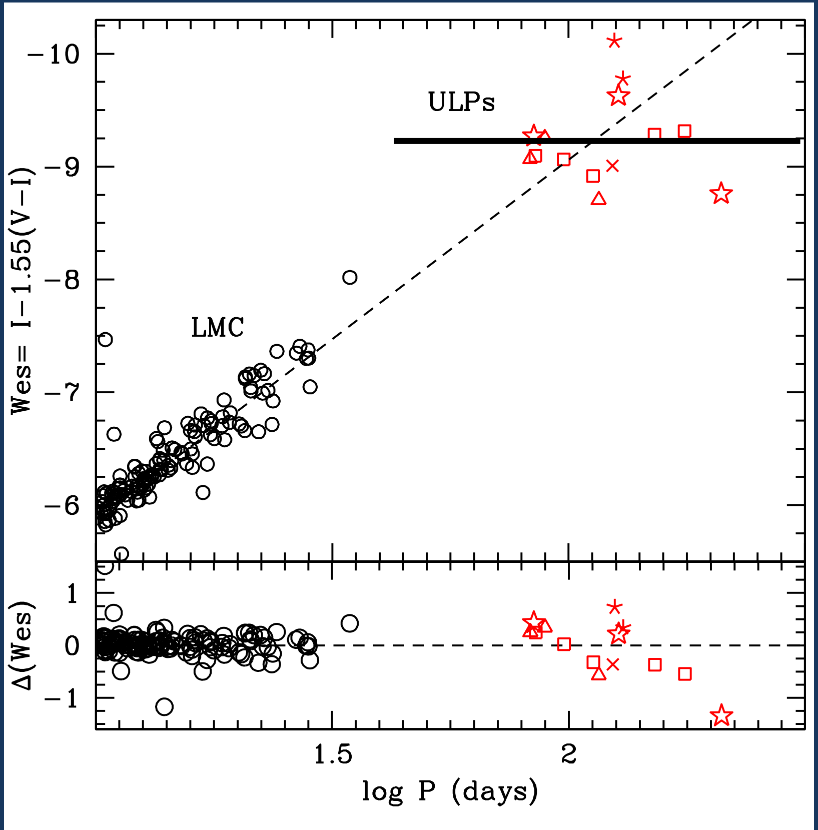
⋆ P ≥ 80 days (Bird et al. 2009), firstly identified in LMC & SMC (Freedmann et al. 1985)

⋆ much brighter (M_I from -7 to -9 mag) than 'short period' Cepheids (M_I up to -5 mag)

They should represent "best standard candles" directly observable at cosmological distances (>100Mpc) without using secondary indicators, hence reducing the systematic errors that contribute to the Hubble constant error budget (contribution to understand the Hubble tension)

Important to verify they are the extension of Classical Cepheids to higher luminosity or a different class and understand their role as "standards candles"

Reddening Free Wesenheit

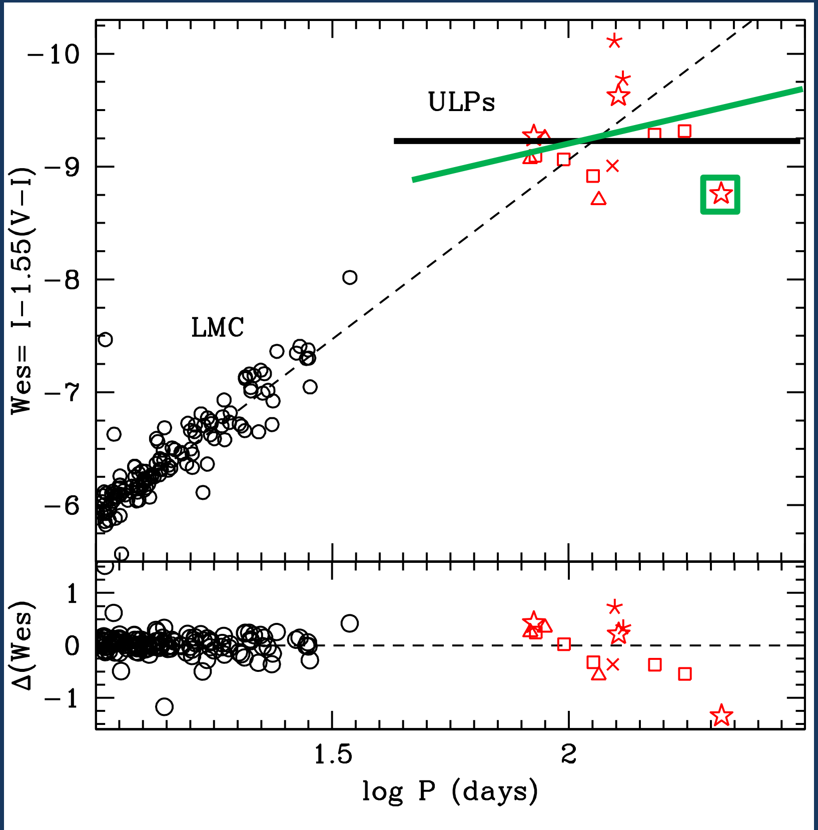


Bird+09

- 16 ULPs in nearby star forming galaxies: LMC, SMC, NGC6822, NGC55, NGC300
- 2 ULPs in the Blue compact dwarf galaxy IZw18 observed by HST: the most metal poor Z=0.0004 and the brightest ones

18 ULPs: rms=0.36

Reddening Free Wesenheit



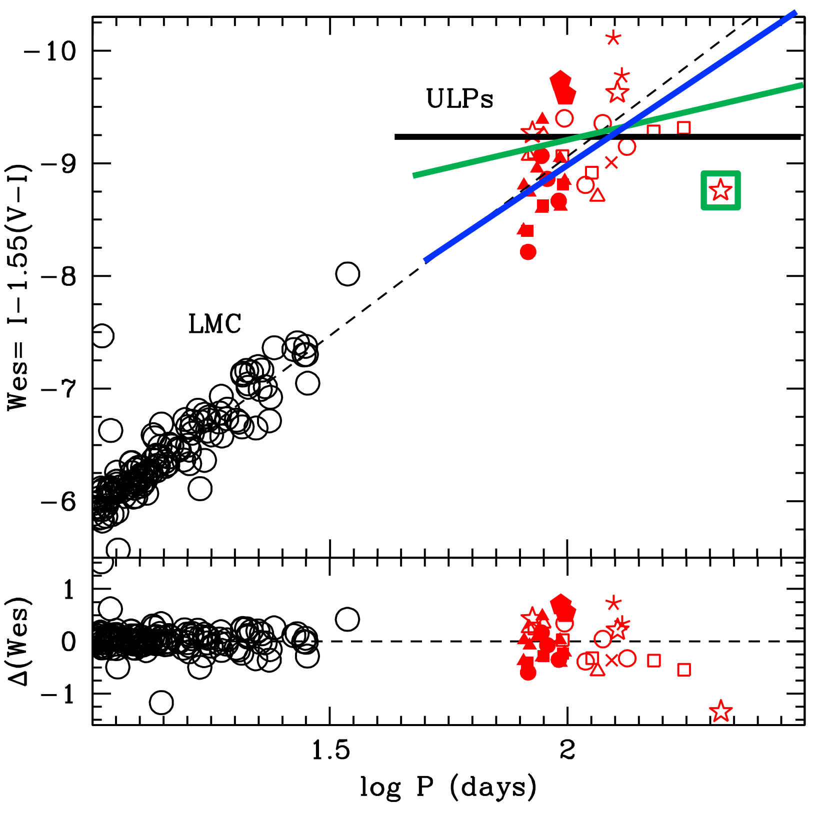
Bird+09

- 16 ULPs in nearby star forming galaxies: LMC, SMC, NGC6822, NGC55, NGC300
- 2 ULPs in the Blue compact dwarf galaxy IZw18 observed by HST: the most metal poor Z=0.0004 and the brightest ones

18 ULPs: rms=0.36

17 ULPs: rms=0.34

Reddening Free Wesenheit



Bird+09

- 16 ULPs in nearby star forming galaxies: LMC, SMC, NGC6822, NGC55, NGC300
- 2 ULPs in the Blue compact dwarf galaxy IZw18 observed by HST: the most metal poor Z=0.0004 and the brightest ones

18 ULPs: rms=0.36

17 ULPs: rms=0.34

Fiorentino+12/13

- 2 ULPs in M81 (Gerke+11)
- 17 ULPs (SH0ES, Riess+09) in NGC 1309, NGC 3021, NGC 3370, NGC 4536, NGC 5584, NGC 4038 and NGC 4258

36 ULPs rms=0.38

Reddening Free Wesenheit

Large dispersion can be due to:

Intrinsic properties

Poor statistics
- long periods → long time baseline
- Very bright → often saturated

Non homogeneous photometry

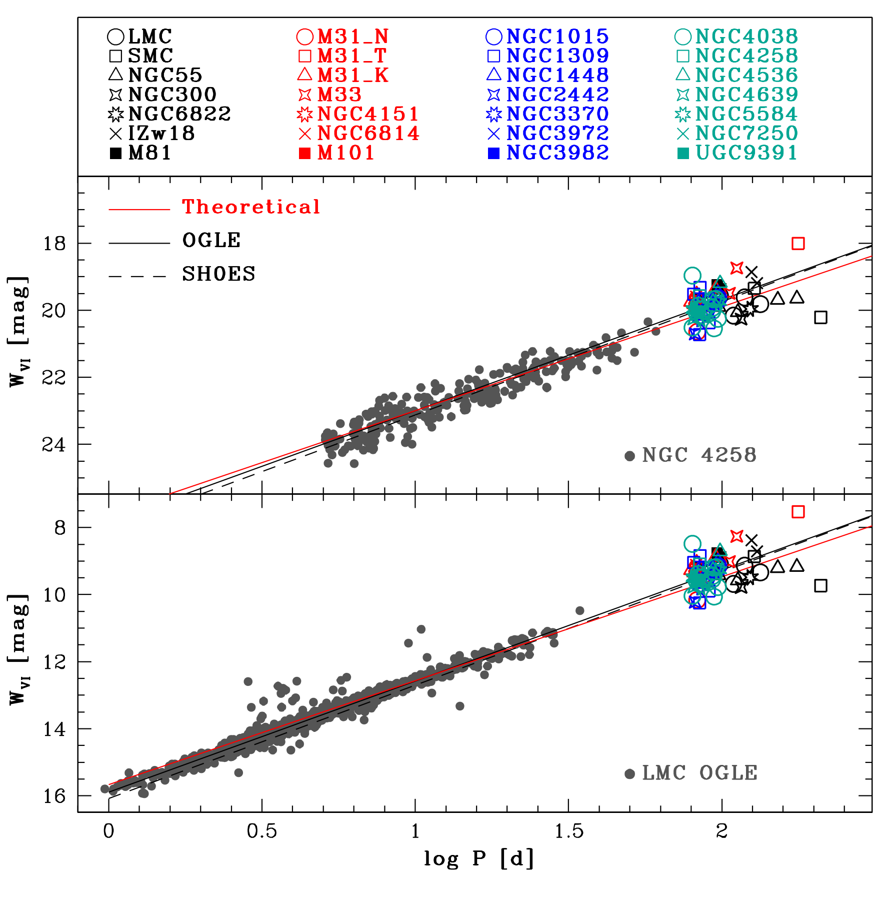
New Sample

New sample by Musella+21/22:

- **Bird sample (18)**
- **2 M81 ULPs (Gerke+11)**
- **New SH0ES sample (Riess+16 and Hoffman+16): 40 ULPs observed in 14 galaxies** (all the Cepheid samples were reanalyzed to obtain a new and homogeneous photometric calibration. Not all the previous ULPs were confirmed and for many of them the new period was different then previous one)
- **6 M31 ULPs (Ngeow+15, Kodric+18, Taneva+20)**
- **2 M33 (Pellerin and Macri 2011)**
- **1 NGC4151 (Yuan+20)**
- **2 NGC6814 (Bentz+19)**

For a total of 72 ULPs

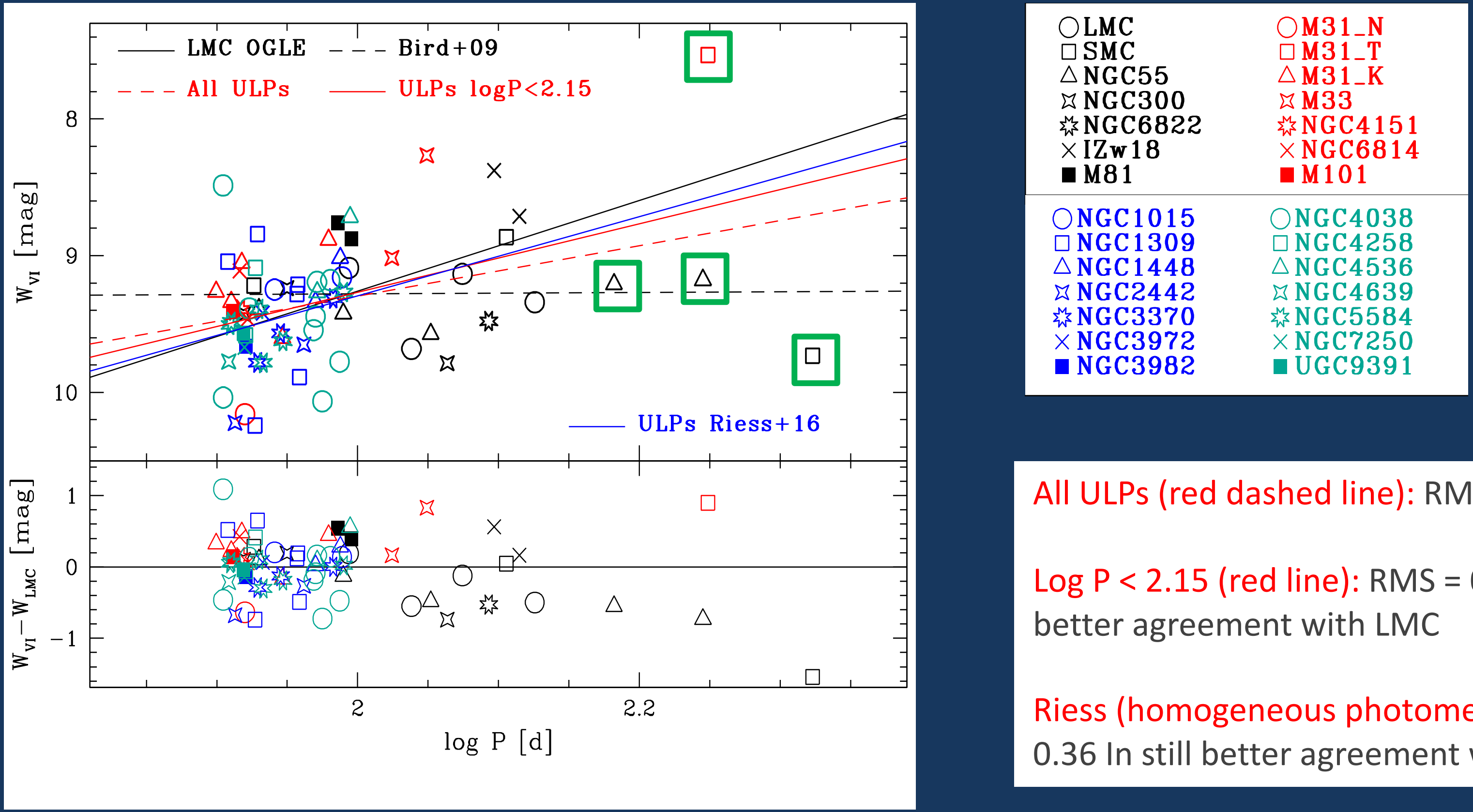
New Sample: Wesenheit



NGC4258 is part of the SH0ES project and is adopted as alternative anchor for the extragalactic distance scale

Dispersion much larger than for LMC but more similar to NGC4258 shorter period Cepheids

New Sample: Wesenheit

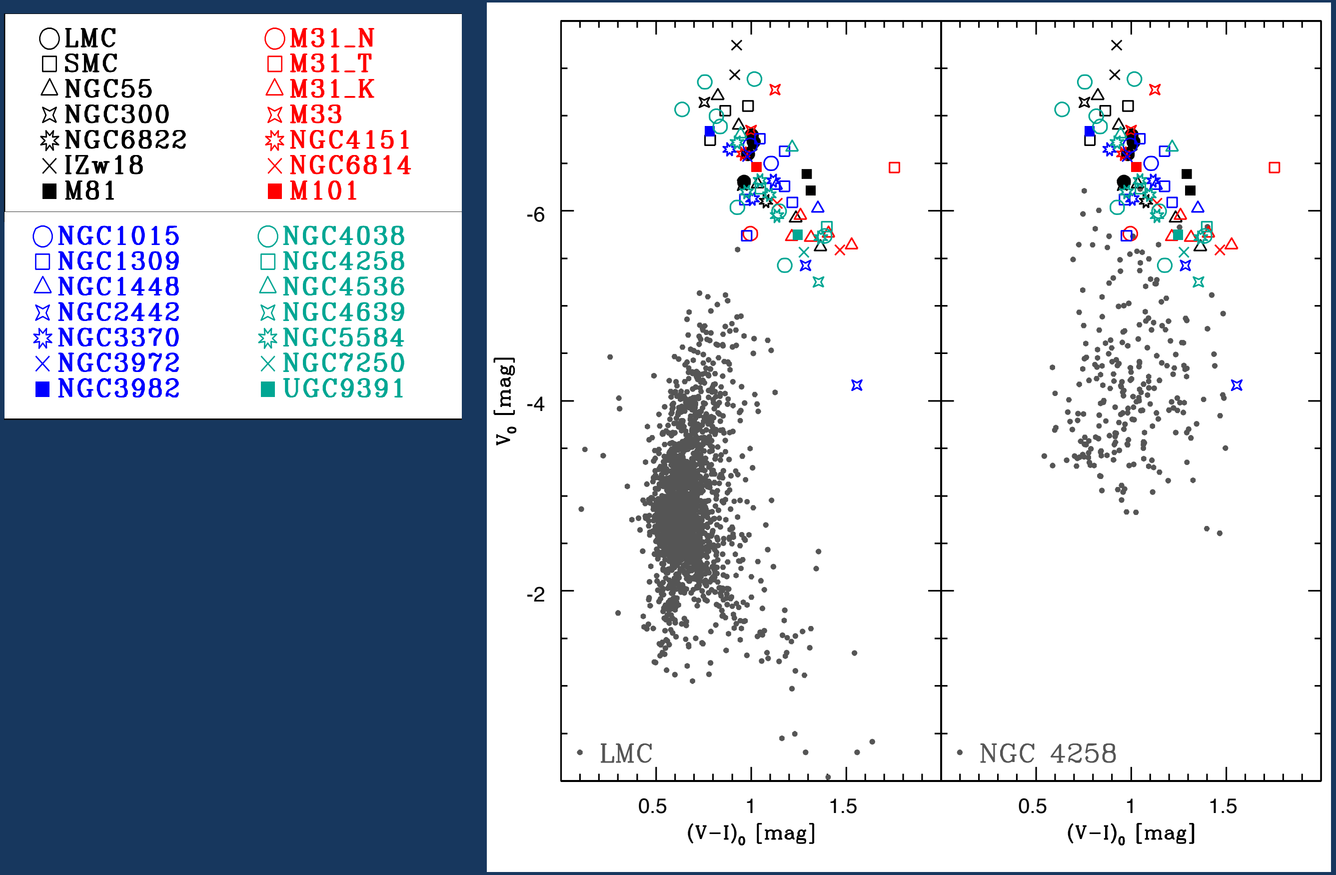


All ULPs (red dashed line): RMS=0.42

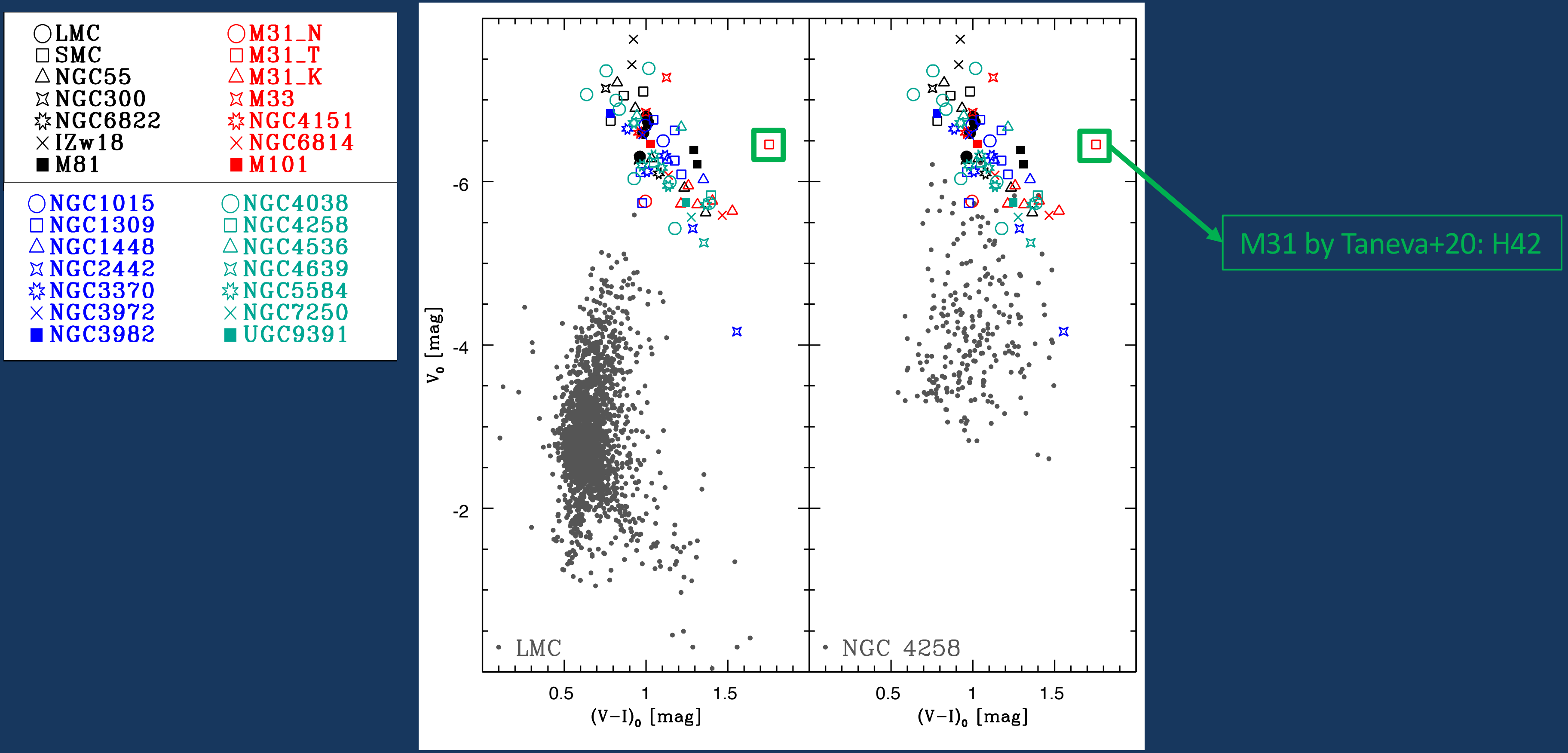
Log P < 2.15 (red line): RMS = 0.38 in better agreement with LMC

Riess (homogeneous photometry) RMS = 0.36 In still better agreement with LMC

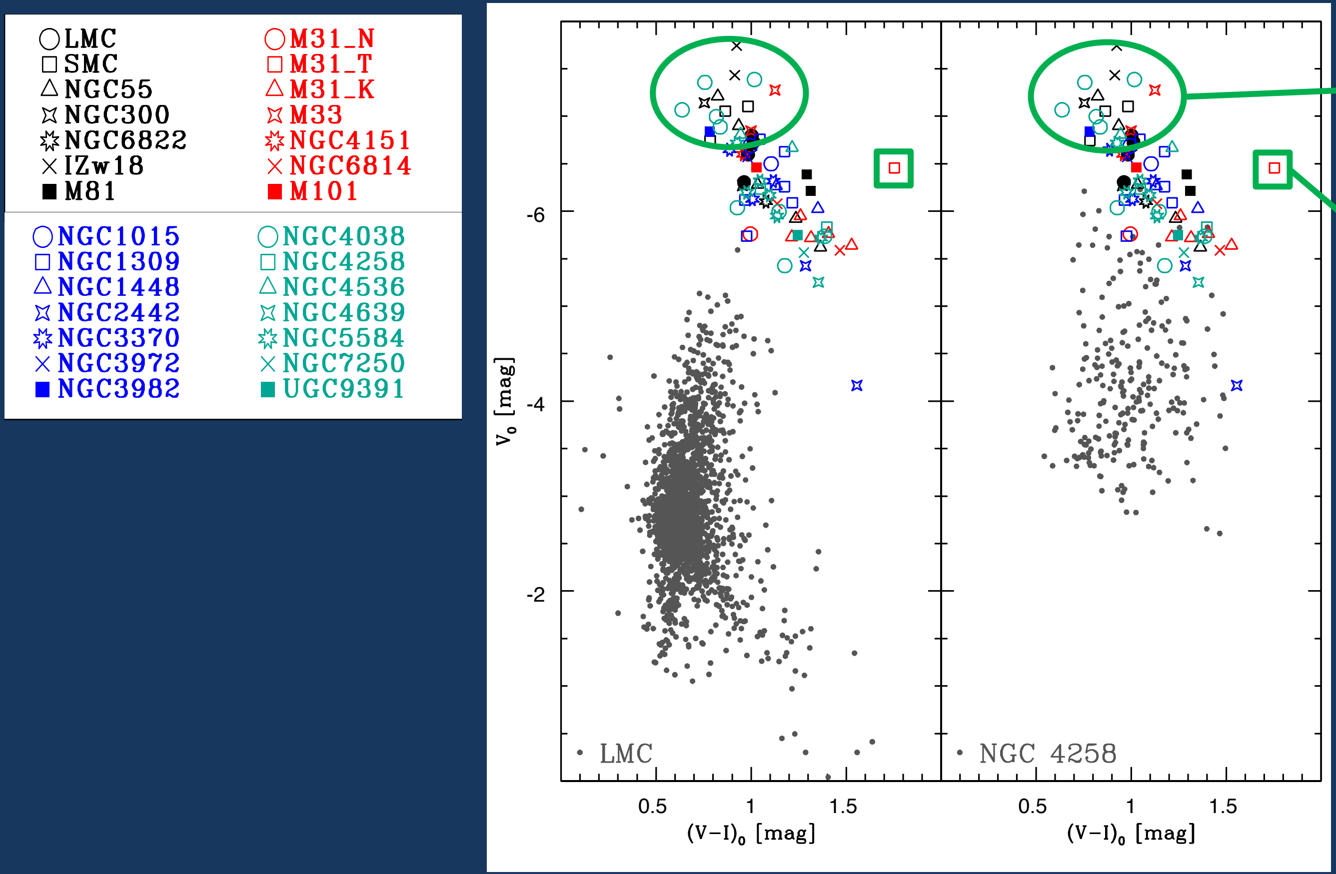
New Sample: CMD



New Sample: CMD



New Sample: CMD



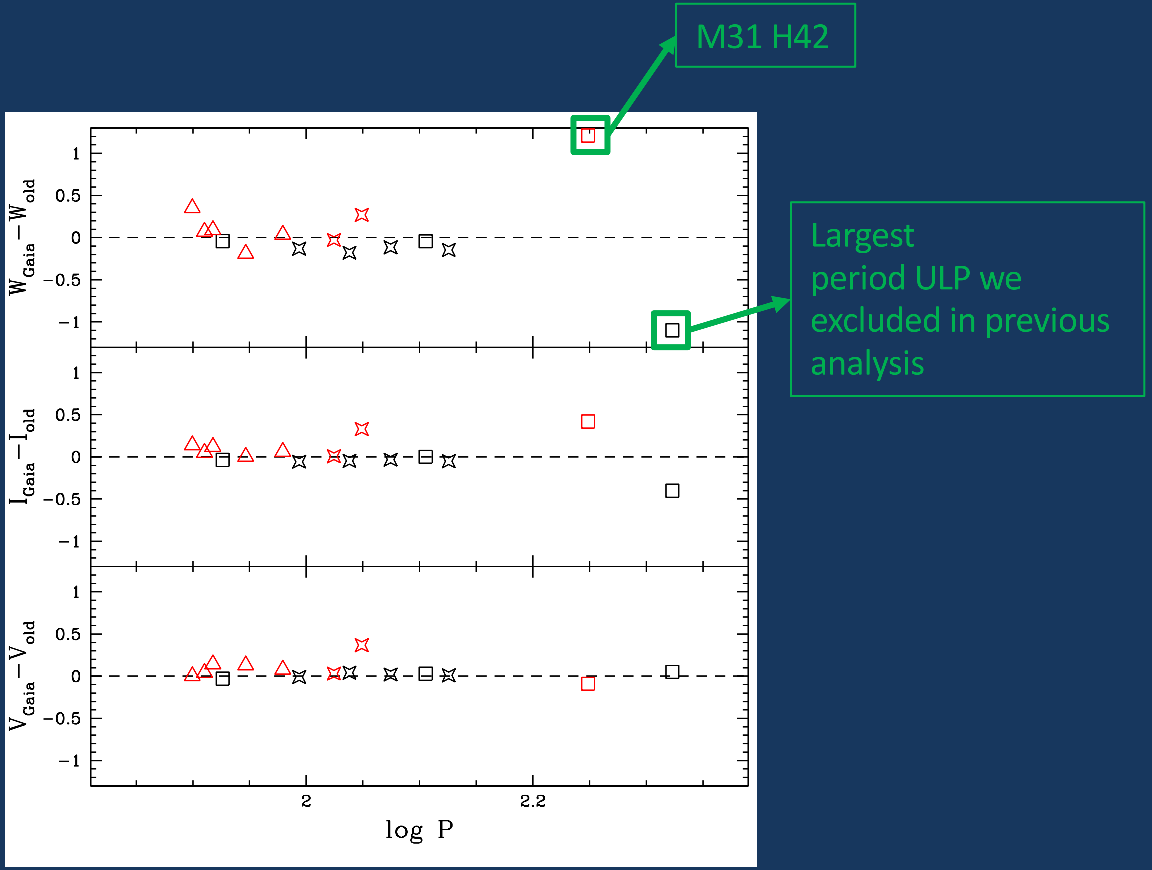
Higher luminosity ULPs seems to be bluer then expected

M31 by Taneva+20: H42

Gaia DR3 data

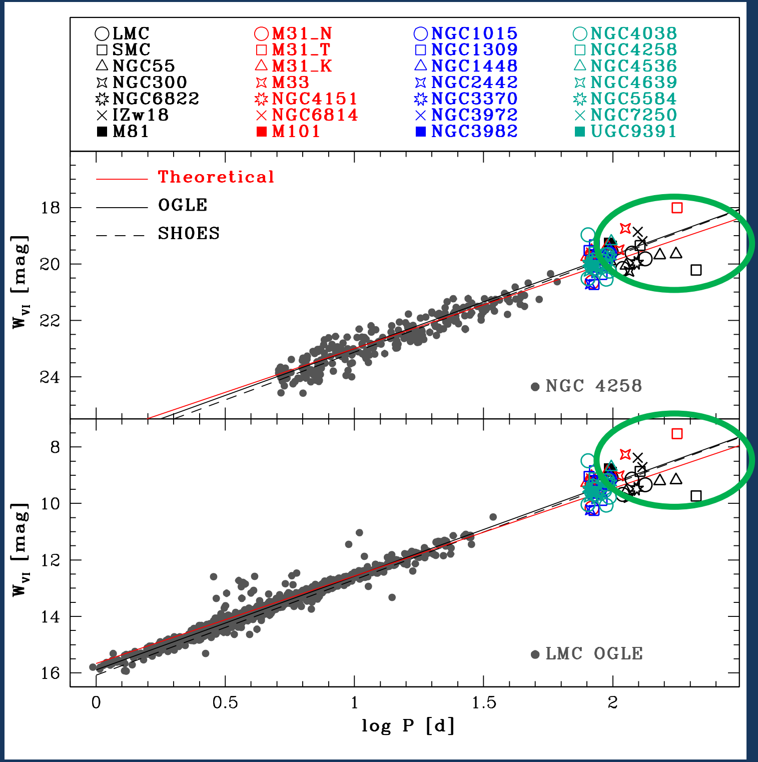
14 ULPs with accurate and homogeneous photometry:

- All the known ULPs in LMC, SMC and M33
- 5 ULPs in M31 (including H42)

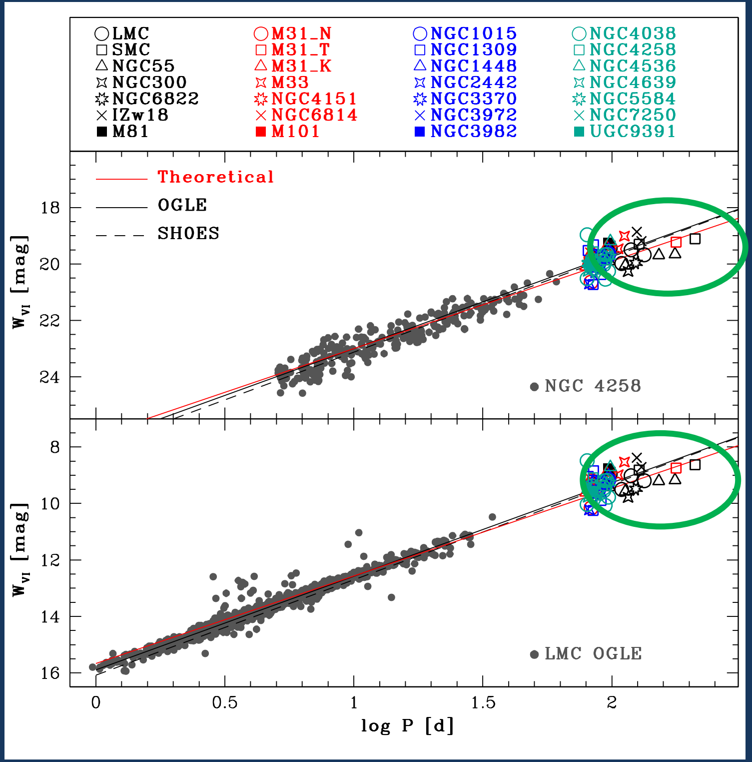


Wesenheit

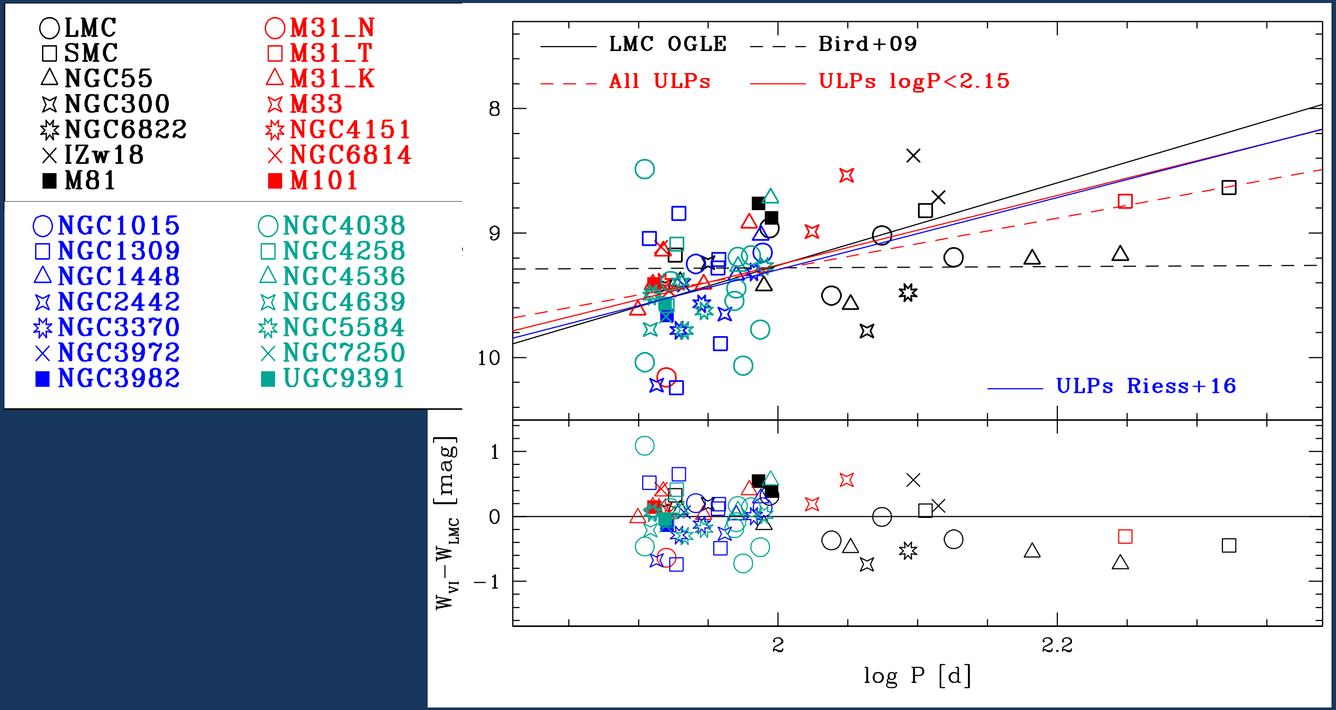
Before DR3



After DR3



Wesenheit

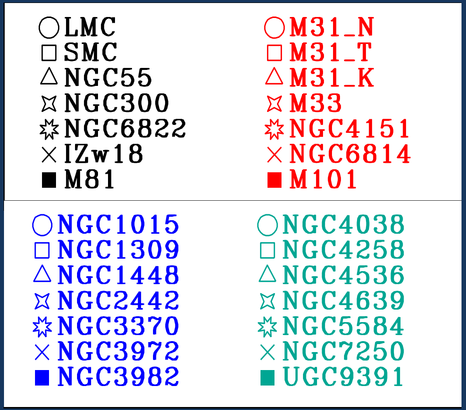


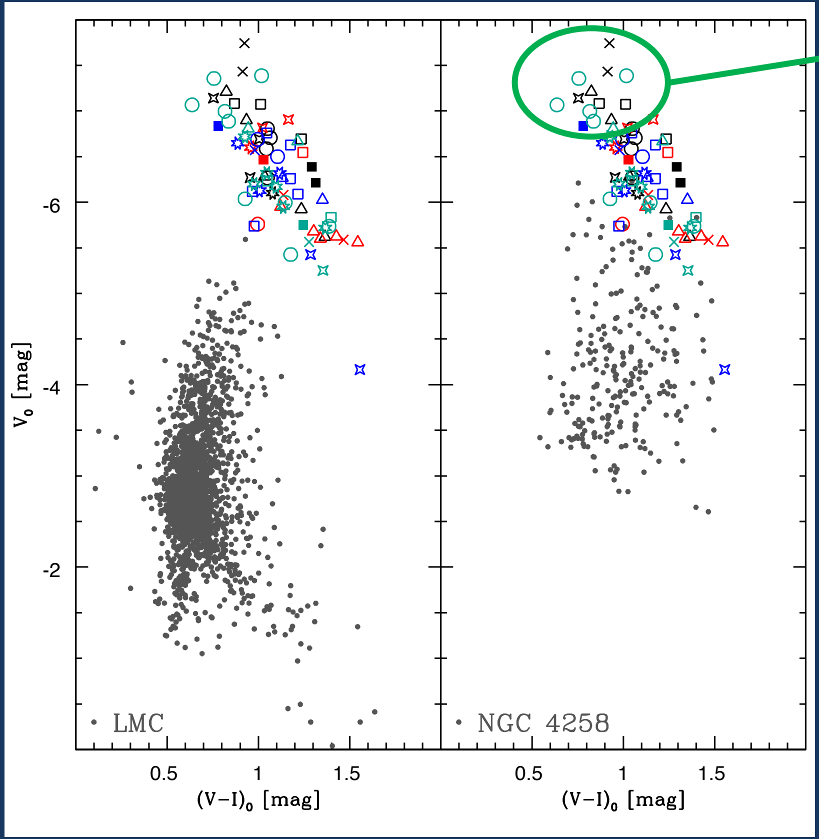
All ULPs RMS=0.42 → 0.36

Log P < 2.15 RMS = 0.38 → 0.36

in perfect agreement with the result from the homogeneous Riess sample and in very good agreement with the LMC one

CMD

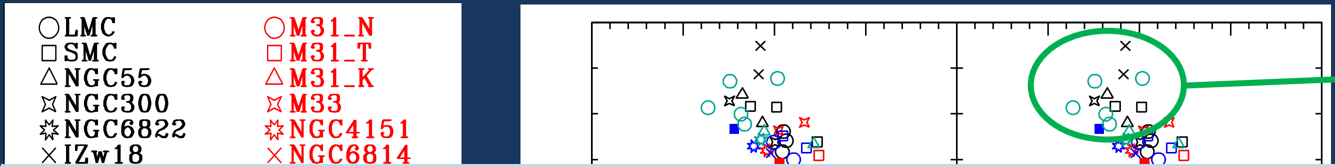




Higher luminosity ULPs are also bluer then expected

Large range in colour

CMD

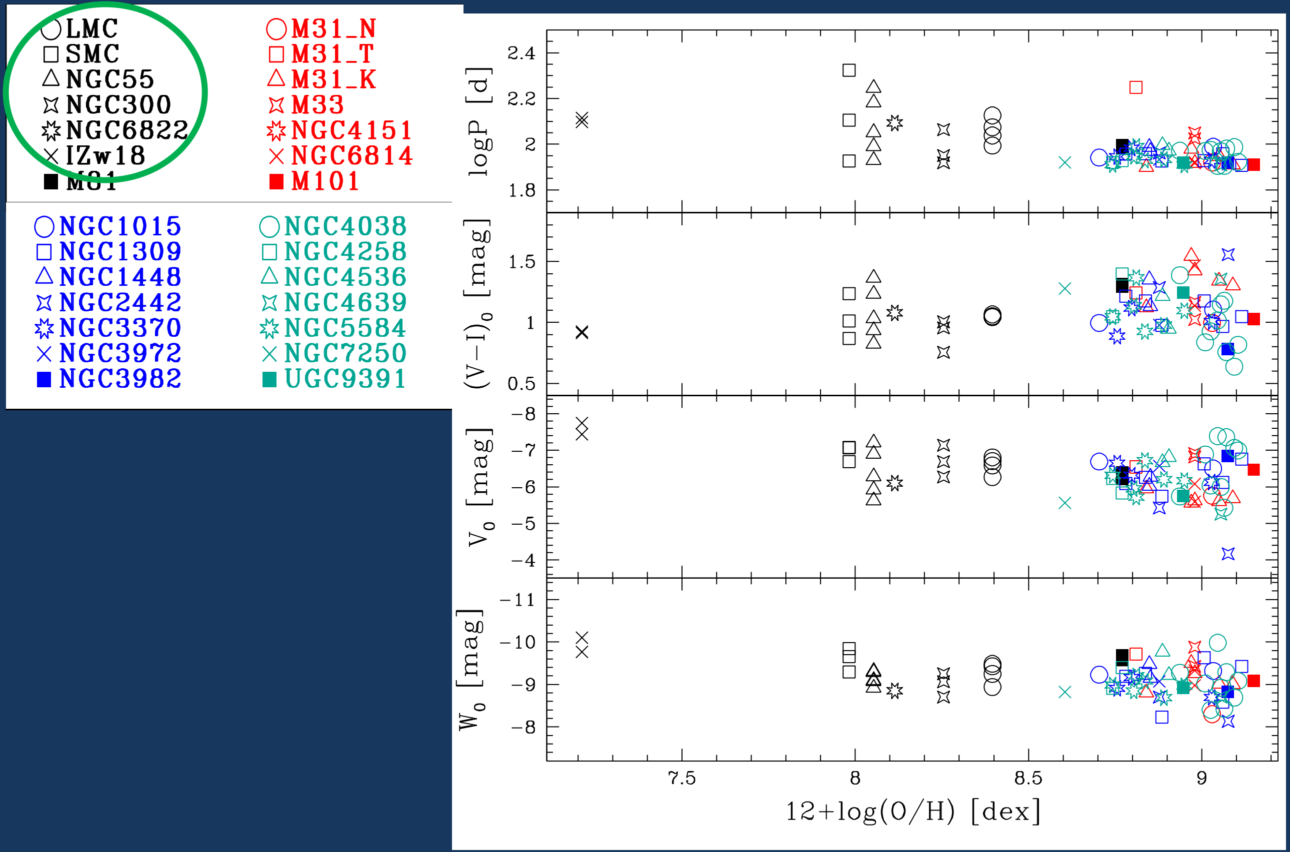


Higher luminosity ULPs seems to be bluer then expected

large distribution in colour and behaviour of the higher luminosity ULPs

- **Intrinsic property**
- **Unhomogeneity of photometries (we have seen the example of the Riess and DR3 Gaia homogeneous dataset)**
- **Wrong Period determination (due to the needed long time baseline)**
- **Dependence on Metallicity**
- **Adopted Reddenings and/or moduli**

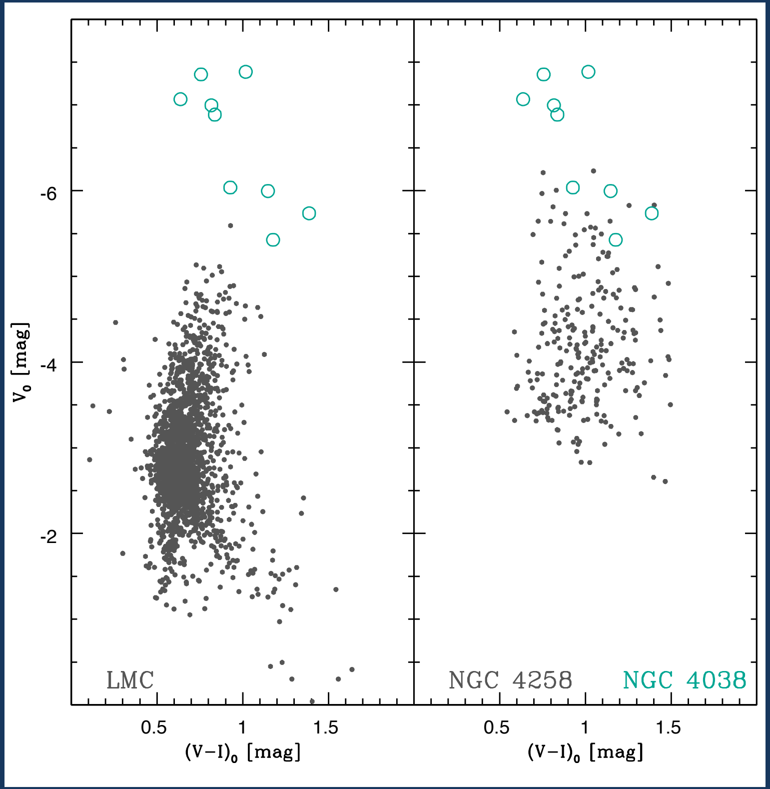
Dependence on the metallicity?



Metal poor ULPs appear to be slightly brighter and bluer

Also the photometrically homogeneous Gaia and Riess samples cover a large color range

Reddening, distance and metallicity effect?



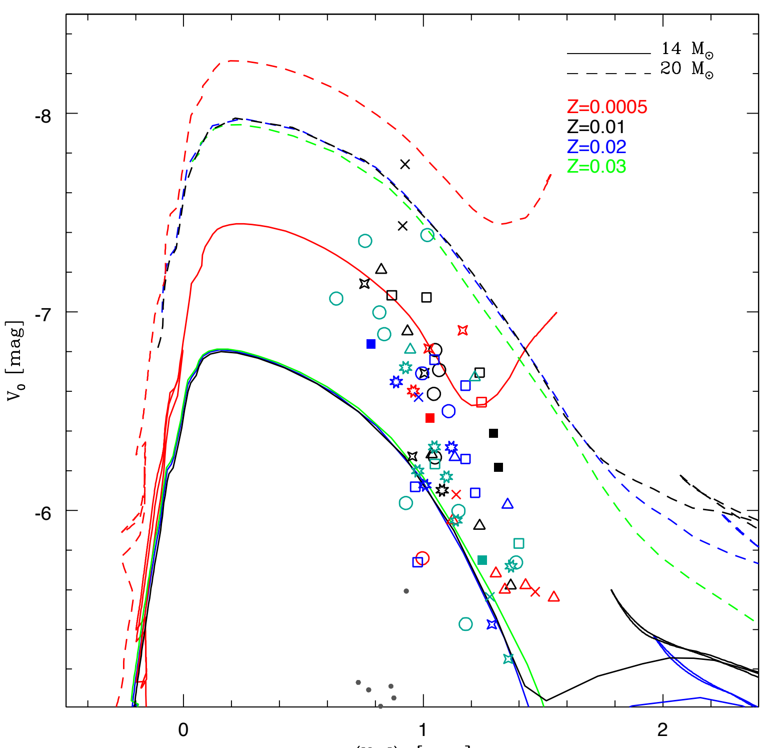
NGC 4038 (SH0ES projects) [9 ULPs]

Large range in color

The 5 brightest NGC 4038 ULPs have solar metallicity confirmed by Lardo+15
So they are bluer then expected but not metal poor

Comparison with evolutionary models

- At these higher masses, unlike what happens for the CCs, the evolutionary models do not predict the blue loop crossing the instability strip.

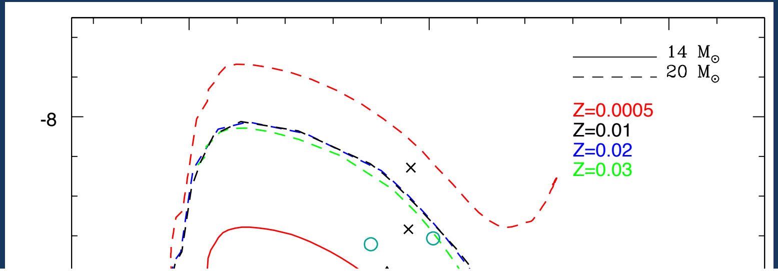


Tracks by Bressan+12

Comparison with evolutionary models

- At these higher masses, unlike what happens for the CCs, the evolutionary models do not predict the blue loop crossing the instability strip.

- In addition, if we apply a period-luminosity.-color-mass relation, in many cases, we find inconsistent results



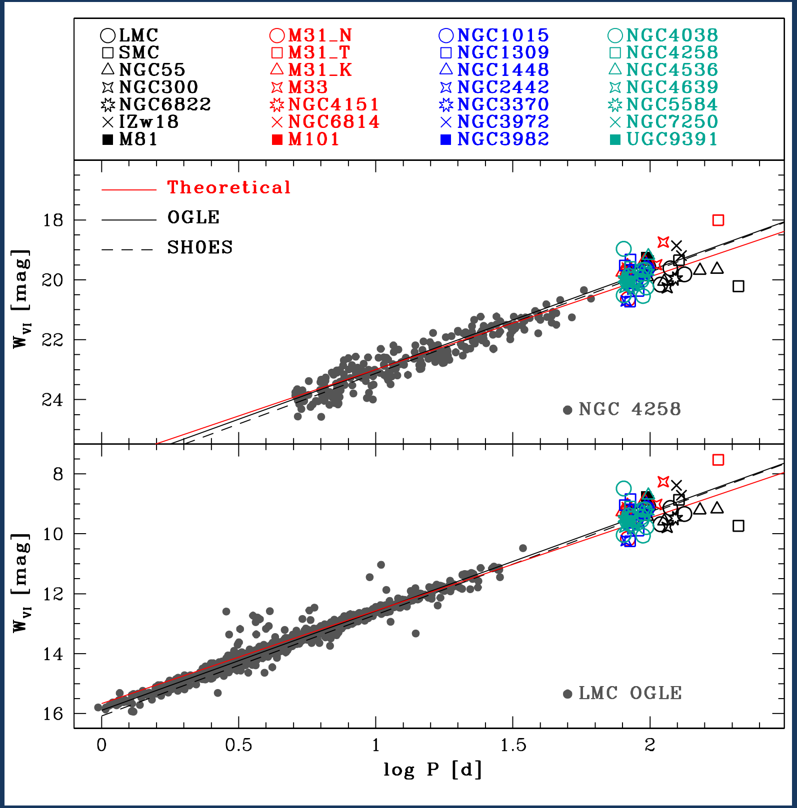
Galaxy	Period	Mass Track	Computed Mass	Computed period Assuming the computed mass
LMC	98.6	~15.6	~15.33	~97.29
LMC	133.6	~13.7	~8	~87
LMC	118.7	~15.6	~12.4	~97.29
M31	81.35	~14	~10	~62
M31	88.45	~14	~9	~62
M31	95.38	~15.6	~14.3	~88.9

Comparison with pulsational models

We compare ULP properties with nonlinear convective pulsation models (Marconi+, De Somma+, Fiorentino+) able to reproduce all the observables (periods, mean magnitudes, light curves, amplitudes…)

- Good agreement with the mean statistical properties obtained for the CCs extended to higher luminosities and periods

- Difficult to perform the light curve fitting (to derive intrinsic stellar parameters and distance and reddenings) also due to the previous described inconsistencies in the PLMC.



Conclusions

These objects represent a challenge both from observational and theoretical point of view to define them as "standard candles":

- ★ Theoretical Evolutionary Framework: evolutionary phase of ULPs
- ★ Theoretical Pulsation Models: extension of pulsational models to highest luminosities
- ★ Statistics and accuracy: improving and increasing the sample (e.g. Rubin-LSST)

Thanks!