Pulsating stars as stellar population tracers from OGLE, VISTA, VVV, Gaia and VST data

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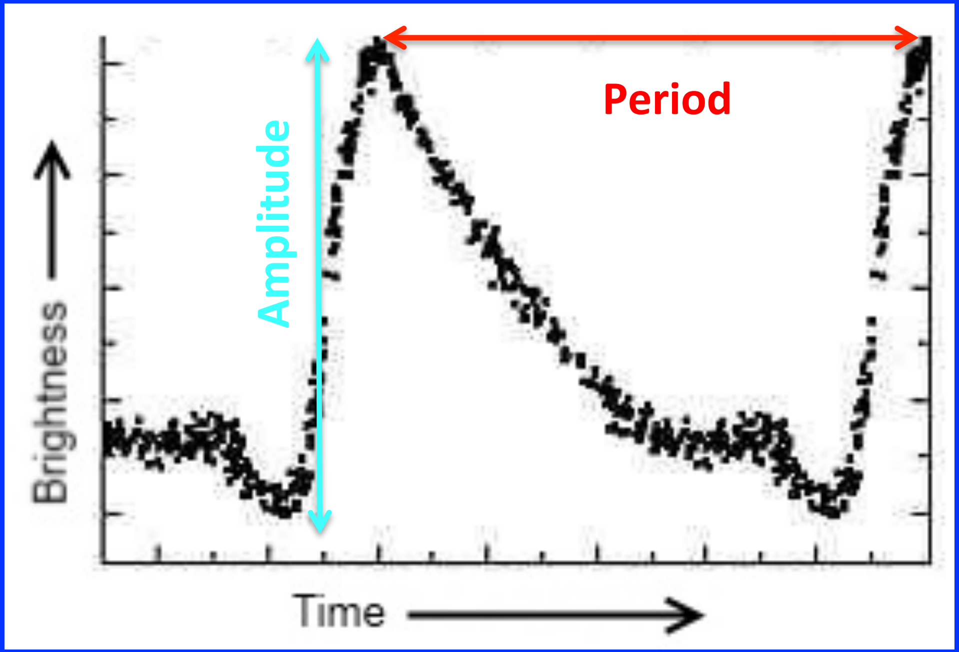
Outline

- Key properties of pulsating stars as stellar population tracers
- Recent results for Classical Cepheids and RR Lyrae
- Perspectives and Future developments

Key properties of pulsating stars



- **“easily” recognized thanks to the light variations**
- **Periods and amplitudes are unaffected by distance and reddening**

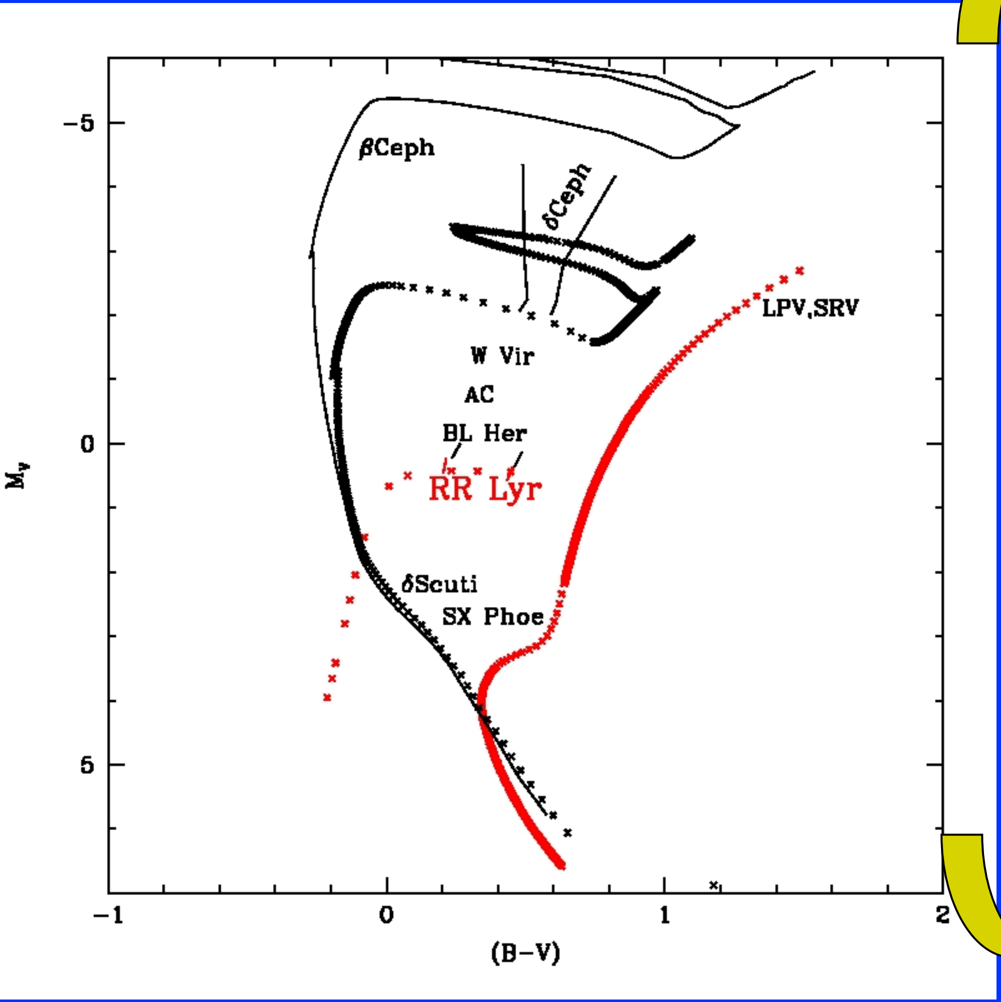
Moreover $P\sqrt{\rho} = cost$

but for Stephan-Boltzman law $L = 4\pi\sigma R^2 T_e^4$

$\Downarrow$

P=P(L,M,Te) → PLC, PL… → distances

Pulsating stars trace different stellar populations



Tracers of stellar populations in galaxies

- **old (> 10 Gyr)**

RR Lyrae, Pop II Cepheids, SX Phoenicis

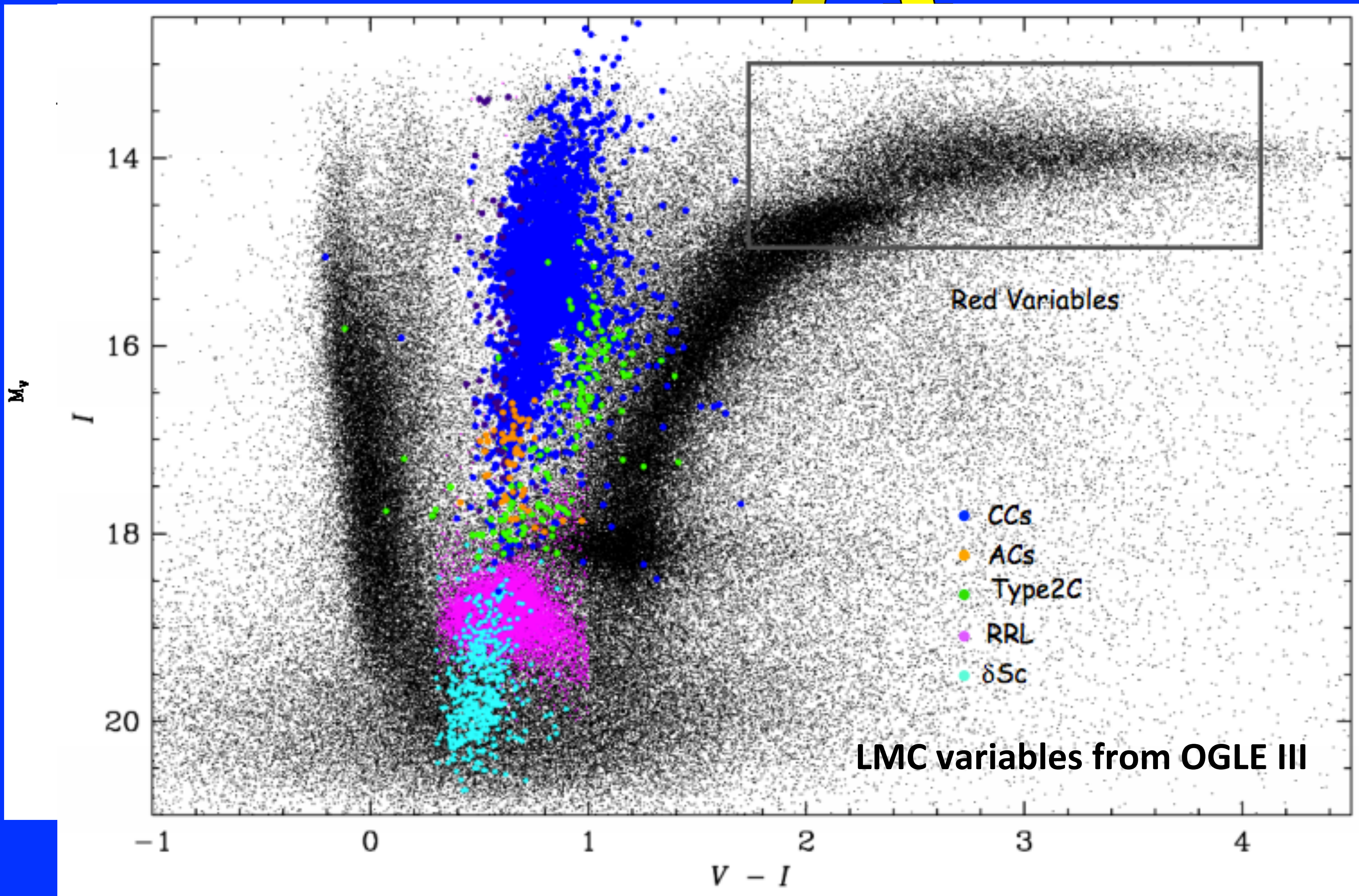
- **intermediate age (1-5 Gy)**

Anomalous Cepheids

- **young (t< 100 Myr)**

Classical Cepheids

Pulsating stars trace different stellar populations



Gy)

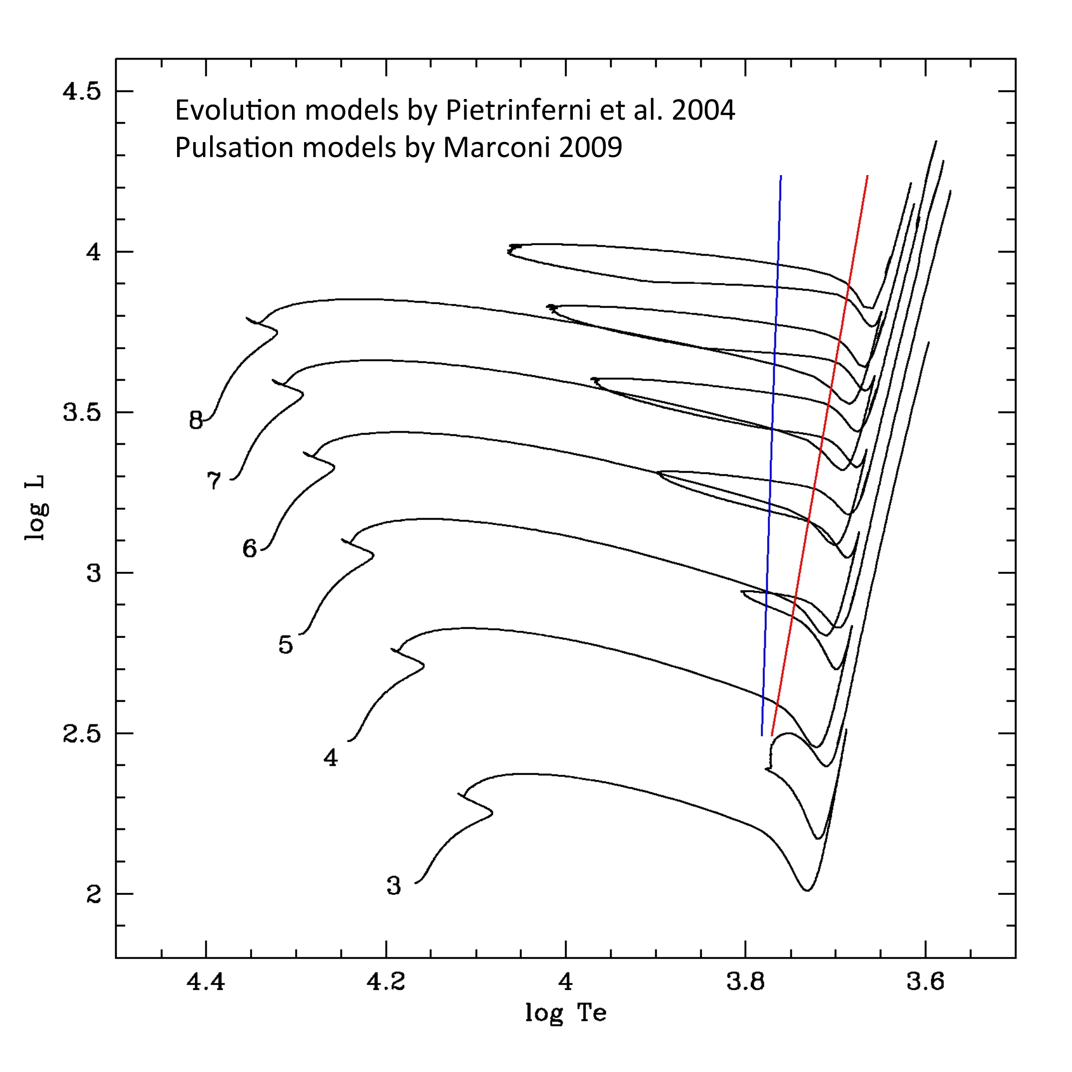
Classical Cepheids as tracers of Pop I stars

Classical Cepheids are yellow supergiant stars

1d ≤ P ≤ 100d
M_V from -2 to -7 mag.

Pulsation in three radial modes: Fundamental (F), First Overtone (FO) and Second Overtone (SO)

Associated to the so called ***blue loop*** → evolutionary phase of intermediate mass stars corresponding to their central Helium burning.



Cepheids as distance indicators → 3D structure

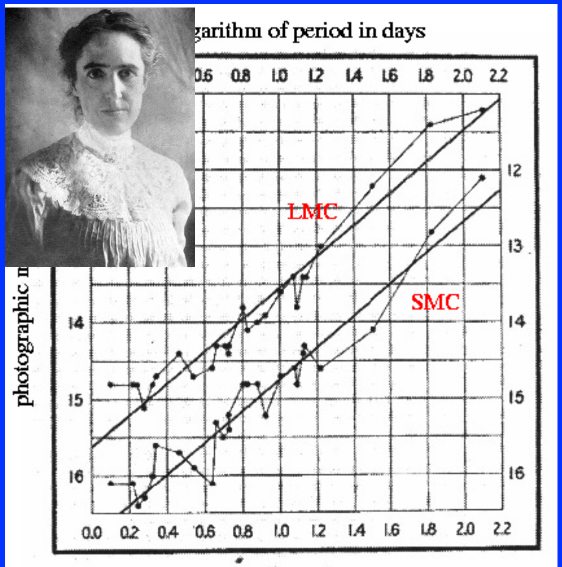
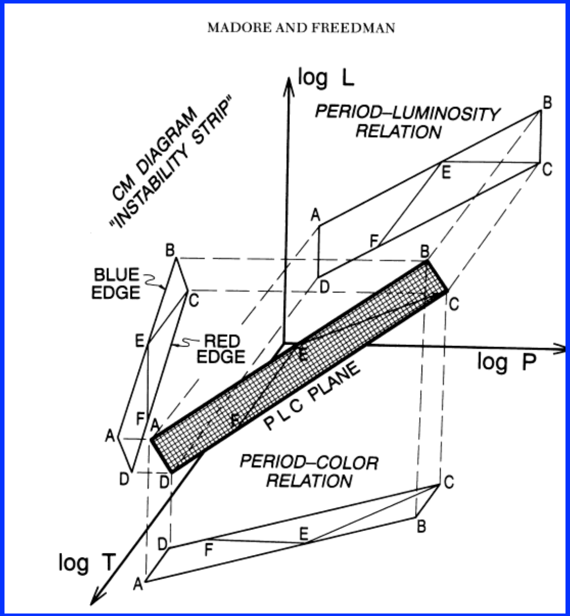


FIG. 2.

Since the discovery by Miss Leavitt (1908, 1912) in the Small Magellanic Cloud, Classical Cepheids are known to obey to a Period-Luminosity (P-L) relation.

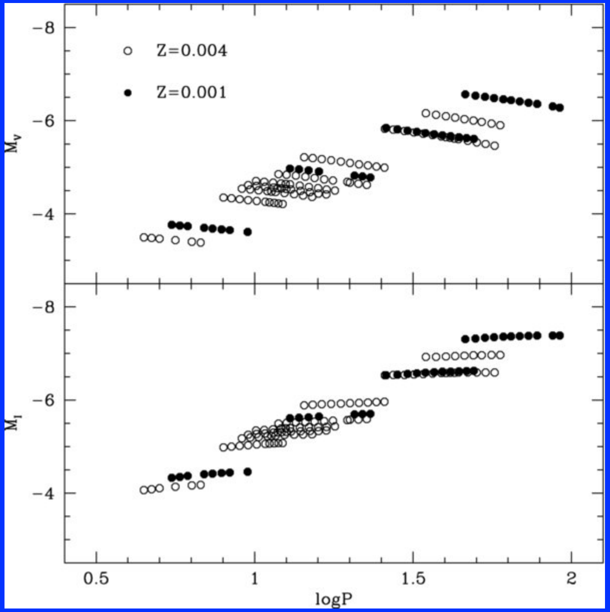
→ Calibration of the extragalactic distance scale

But the strip has a finite width → the PL relation is obtained from averaging over the color extension of the strip or,
as early suggested by Madore & Freedman (1991) the PL is the projection of the PLC relation onto the PL plane.



The PL is a statistical relation !!

Nonlinear convective pulsation models confirm that the topology of the instability strip reflects into the PL

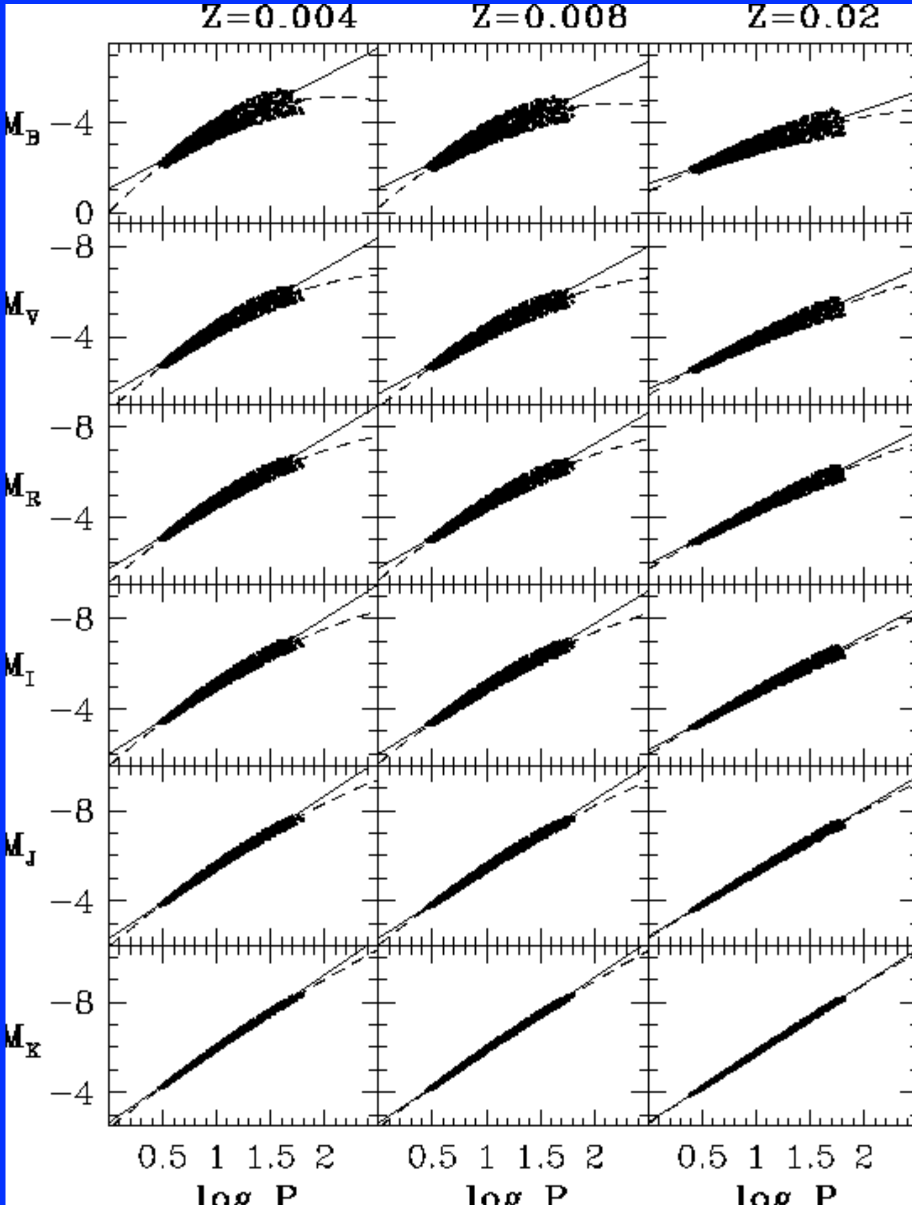


Synthetic multifilter PL relations

The effect reduces when moving towards longer wavelenghths

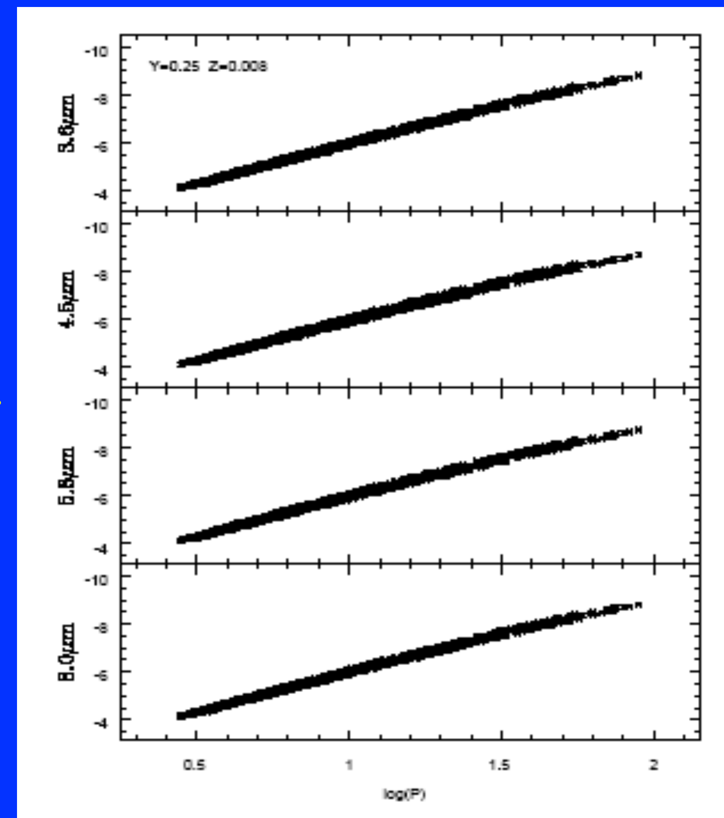
OPTICAL

Near-Infrared



Caputo et al. 2000 A&A

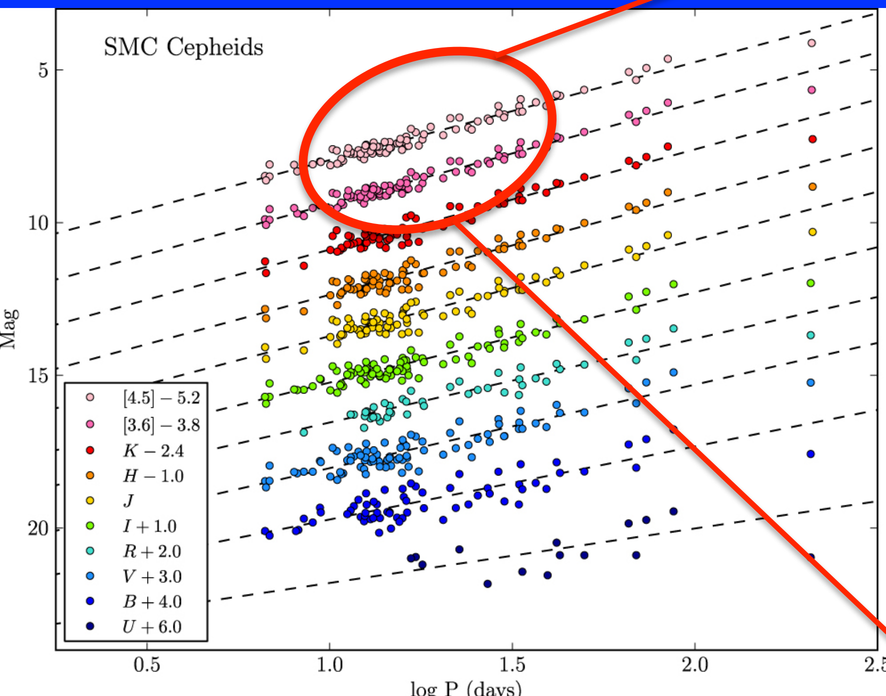
Mid-Infrared



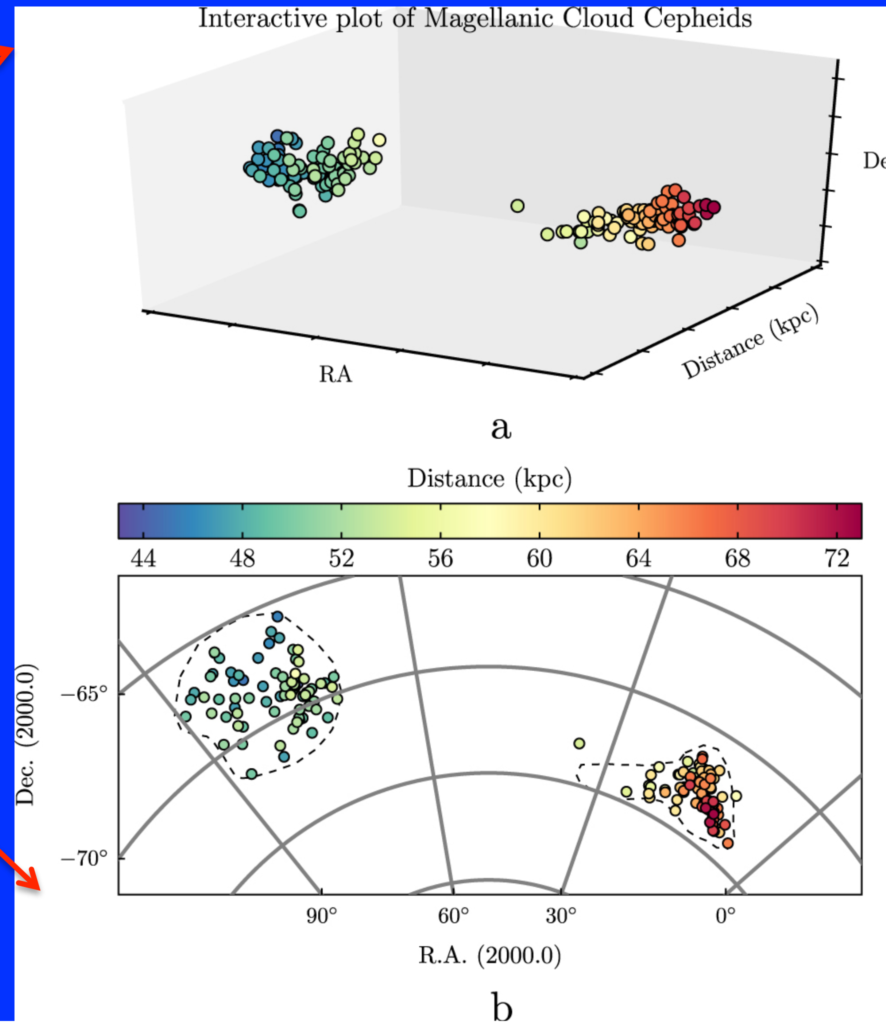
Ngeow et al. 2012 ApJ

3D Structure of the Magellanic Clouds from MIR Cepheid data

Using the Spitzer PL relations



Scowcroft et al. 2016 ApJ 816 49



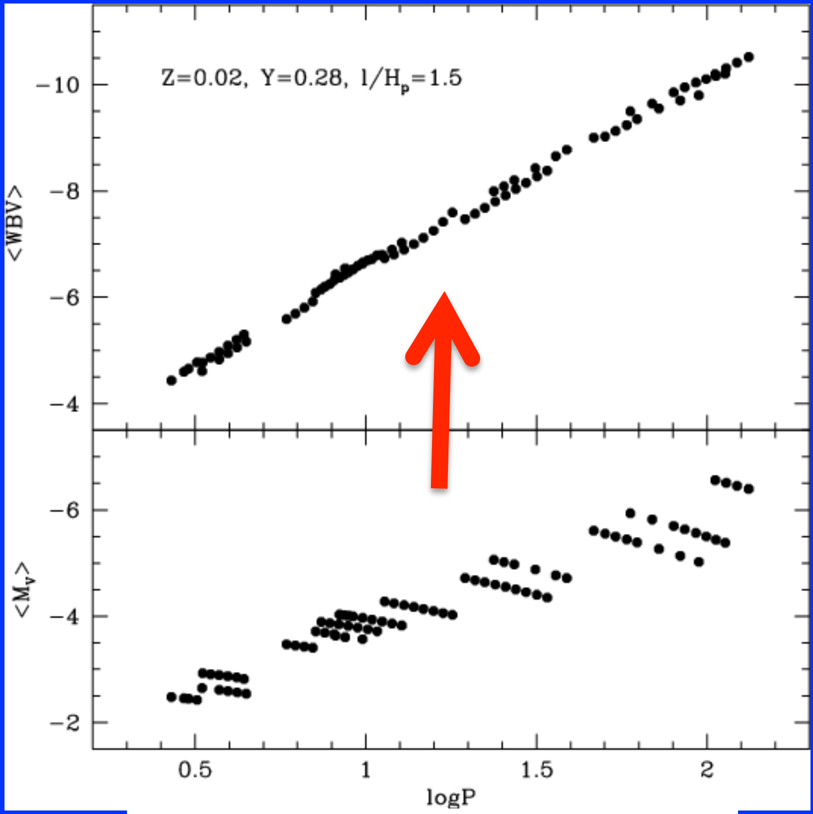
→ confirmed that the galaxy is tilted and elongated (eastern side up to 20 kpc closer than the western side), in agreement with the results from red clump stars and dynamical simulations.

Cepheids as distance indicators → 3D structure

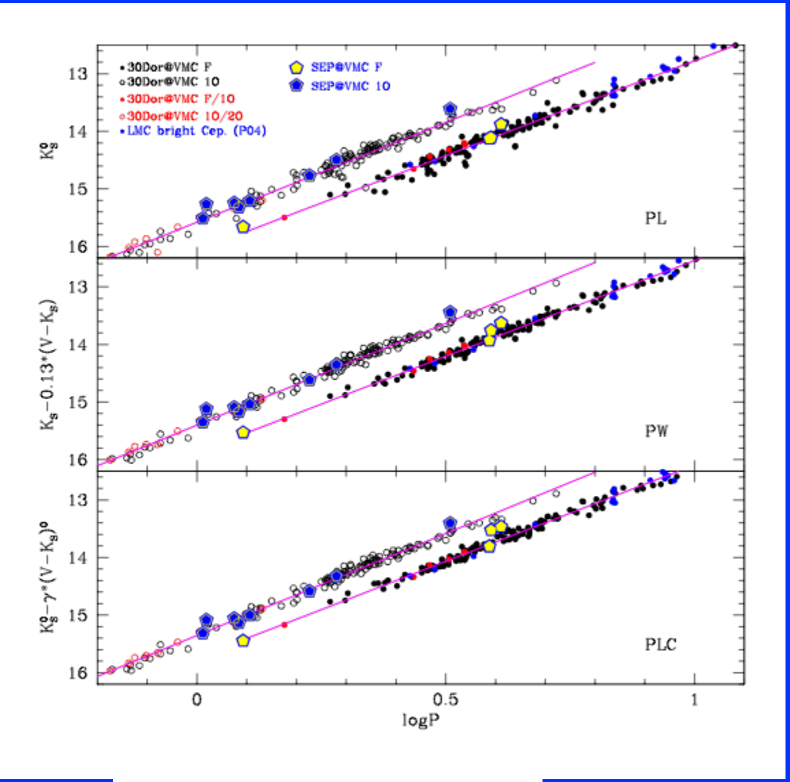
The PLC relation holds for each individual Cepheid: measuring the period and the color, one infers the absolute magnitude and in turn the individual distance.

The Period-Wesenheit (PW) relation is not as rigorous as the PLC but is reddening free by definition.

$$\langle WBV \rangle = V - \gamma(B-V) \qquad \gamma = A_V/E(B-V)$$



Fiorentino, Marconi et al. 2007, A&A



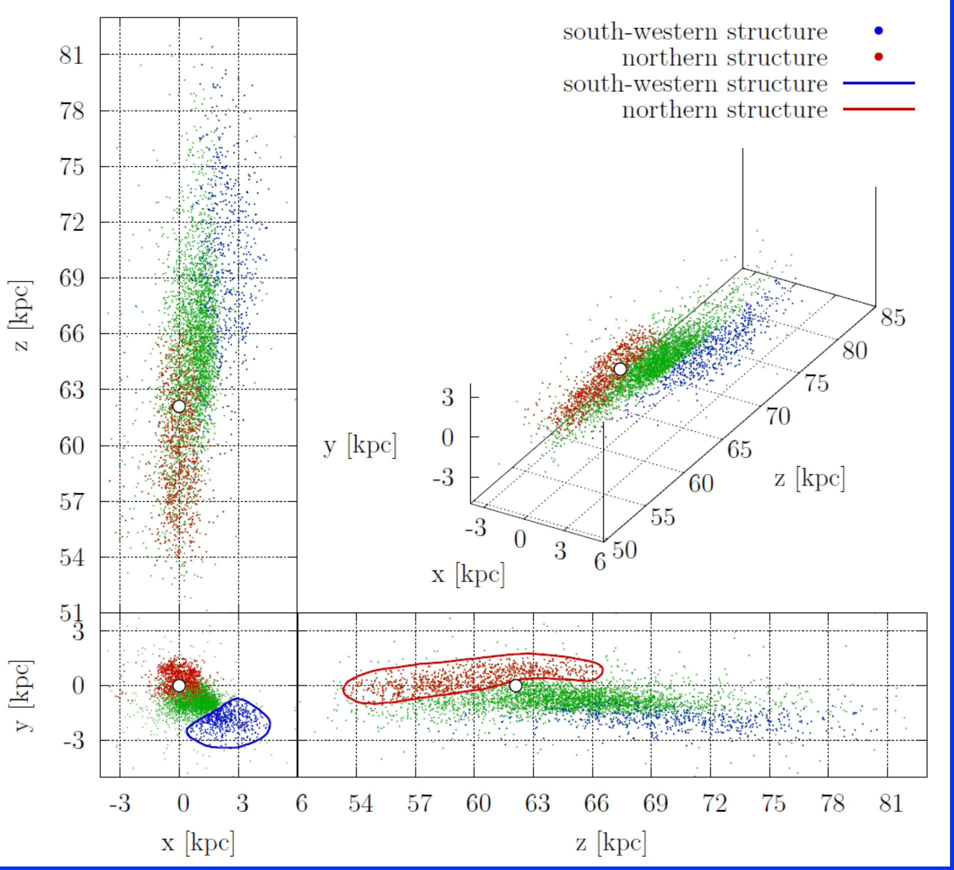
Ripepi et al. 2012 MNRAS

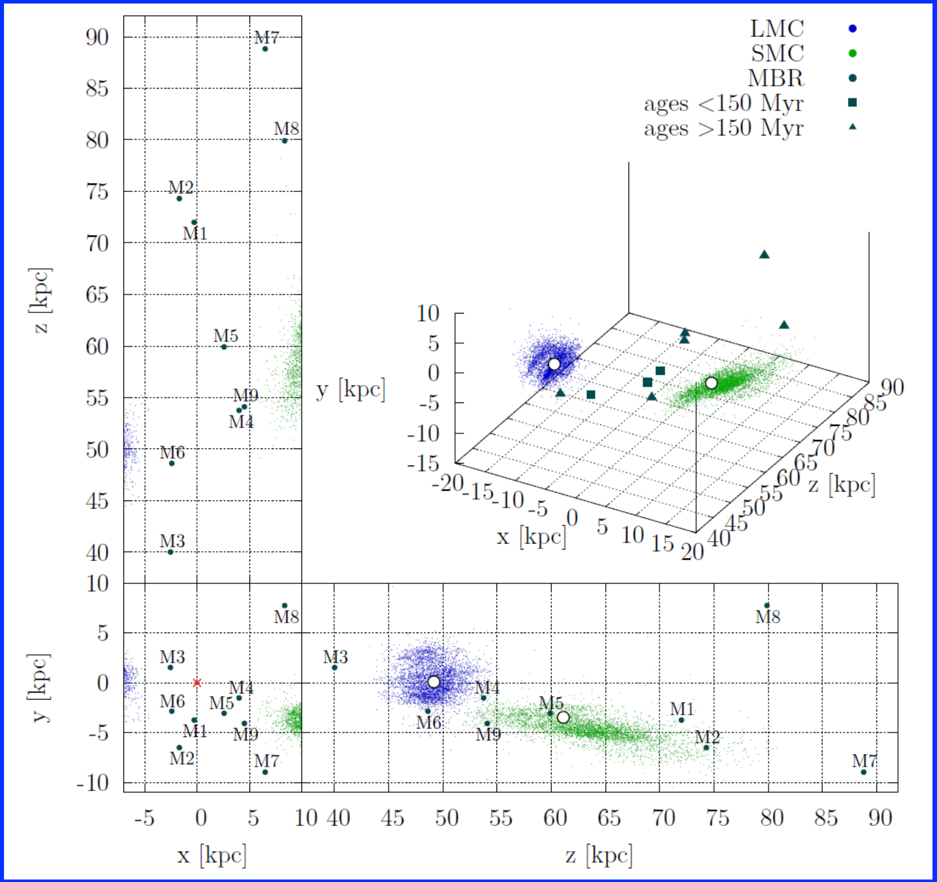
Cepheids as distance indicators → 3D structure

Using the PW(VI) relation

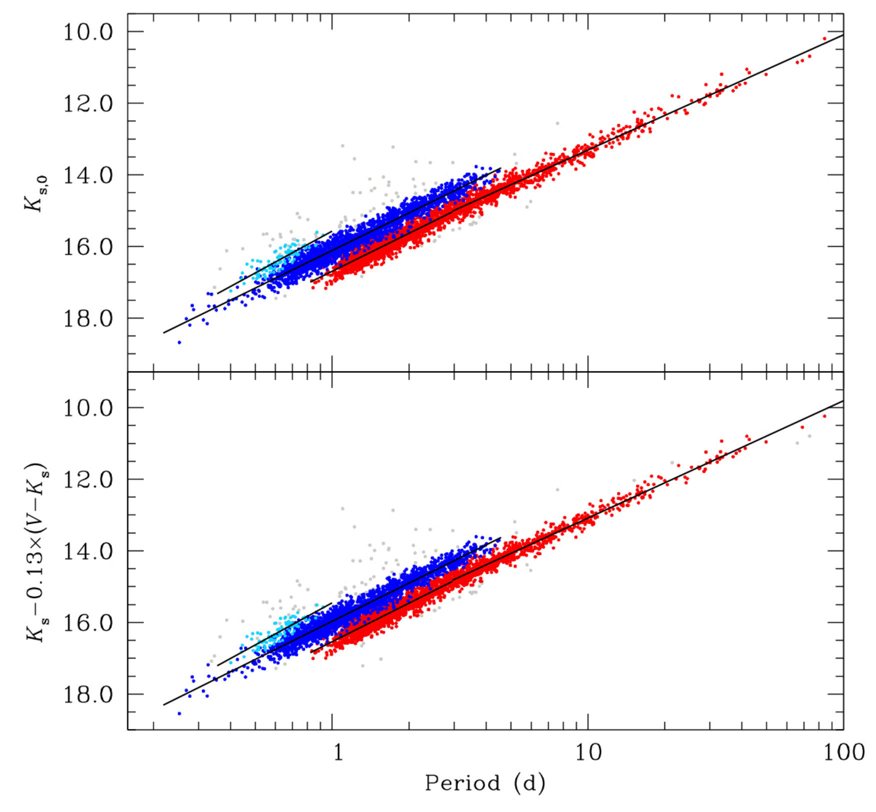
3D structure of the SMC

3D structure of the Bridge





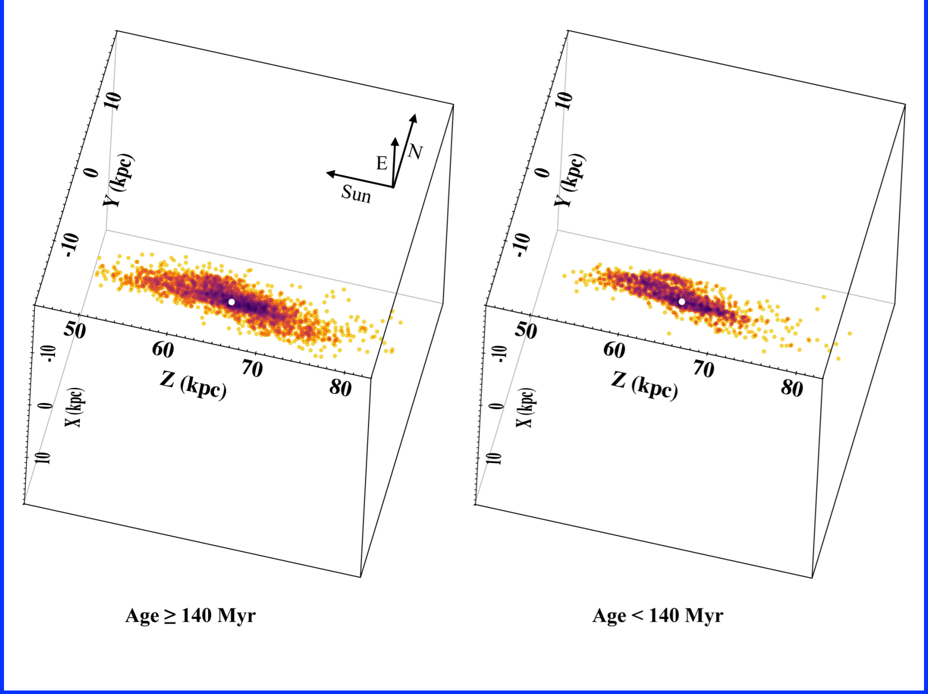
Jacyszyn-Dobrzenieckaet al. 2016



Application to SMC Cepheid VMC@VISTA data (Ripepi et al. 2017 MNRAS in press)

Individual distances from PW(VK) → 3D structure

Ripepi et al. 2017 MNRAS



→The Cepheid distribution is not planar but significantly elongated over more than 25-30 kpc approximately in the E/NE towards SW direction.

Cepheids as age indicators

P√ρ = cost

↓ Stefan-Boltzmann
ML relation

PLC relation

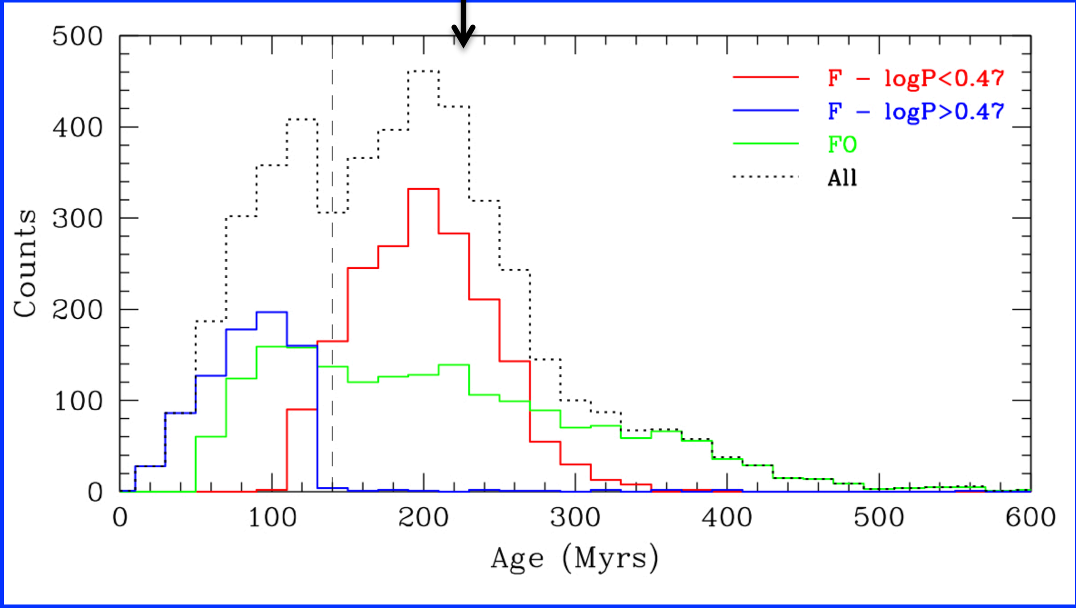
↓ ML relation
Mass-Age relation

Period-Age-Color (PAC) relation

↓ Average over the col. width of the IS

Period-Age (PA) relation

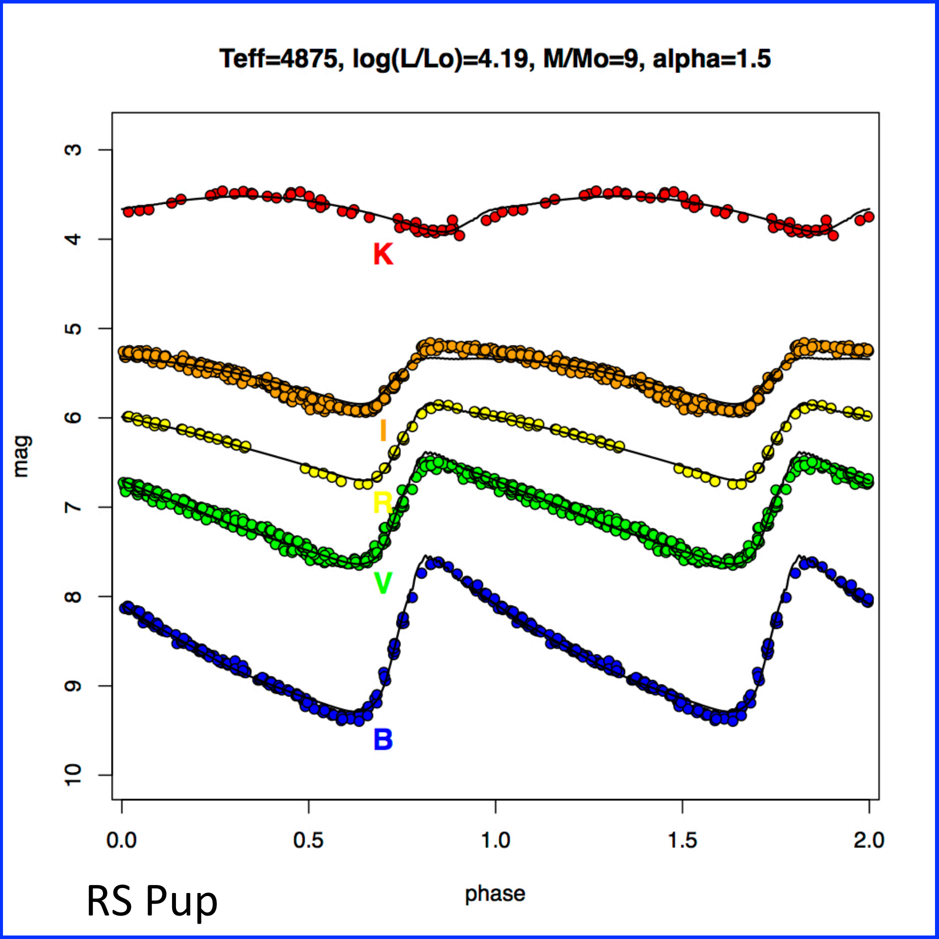
The age distribution of SMC Cepheids based on theoretical PA and PAC and OGLE optical +VMC@VISTA NIR data



Ripepi et al. 2017 MNRAS

Bimodal, with two peaks at 120±10 and 220±10 Myr

All the parameters can be simultaneously constrained through the model fitting technique that is being tested with Gaia



P ≈ 41.5 d, known to be surrounded by a circumstellar nebula reflecting the light from the central star (Kervella 2008)

→ independent geometric parallax:
π_{K08}= 0.502±0.007 mas

→ Gaia DR2 parallax
π_{Gaia}=0.584±0.026 mas

→ Theoretical model fitting parallax
π_{FIT}= 0.58±0.03 mas
in excellent agreement with Gaia estimate.

For the light curves literature optical data, mainly Groenewegen, Fernie, Ngeow… + 2MASS

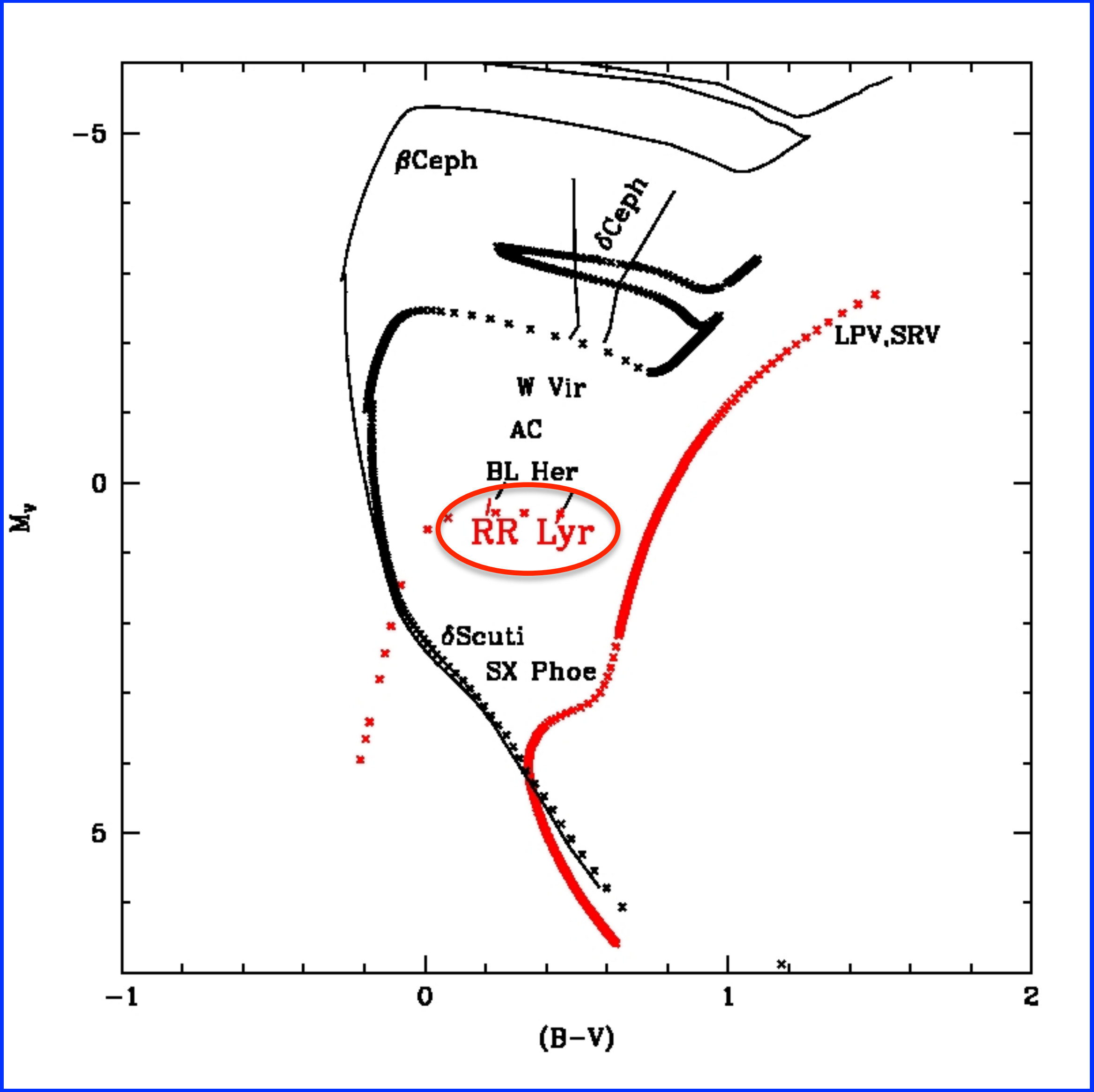
Power of Gaia and future LSST observations:

If accurate distances are available from these missions and metallicities are known from complementary spectroscopic surveys…

Through comparison with theory →
- Light curve model fitting
- Wesenheit relations
- IS, PL relations

→ information on the Mass-Luminosity, Helium content, and in turn on the $\Delta Y/\Delta Z$, extinction law…

RR LYRAE



RR Lyrae are low mass Helium burning stars, on the so called ***Horizontal Branch (HB)*** in the HR diagram.

Most abundant class of pulsating stars in the Milky Way found both in the field and in *GCs*

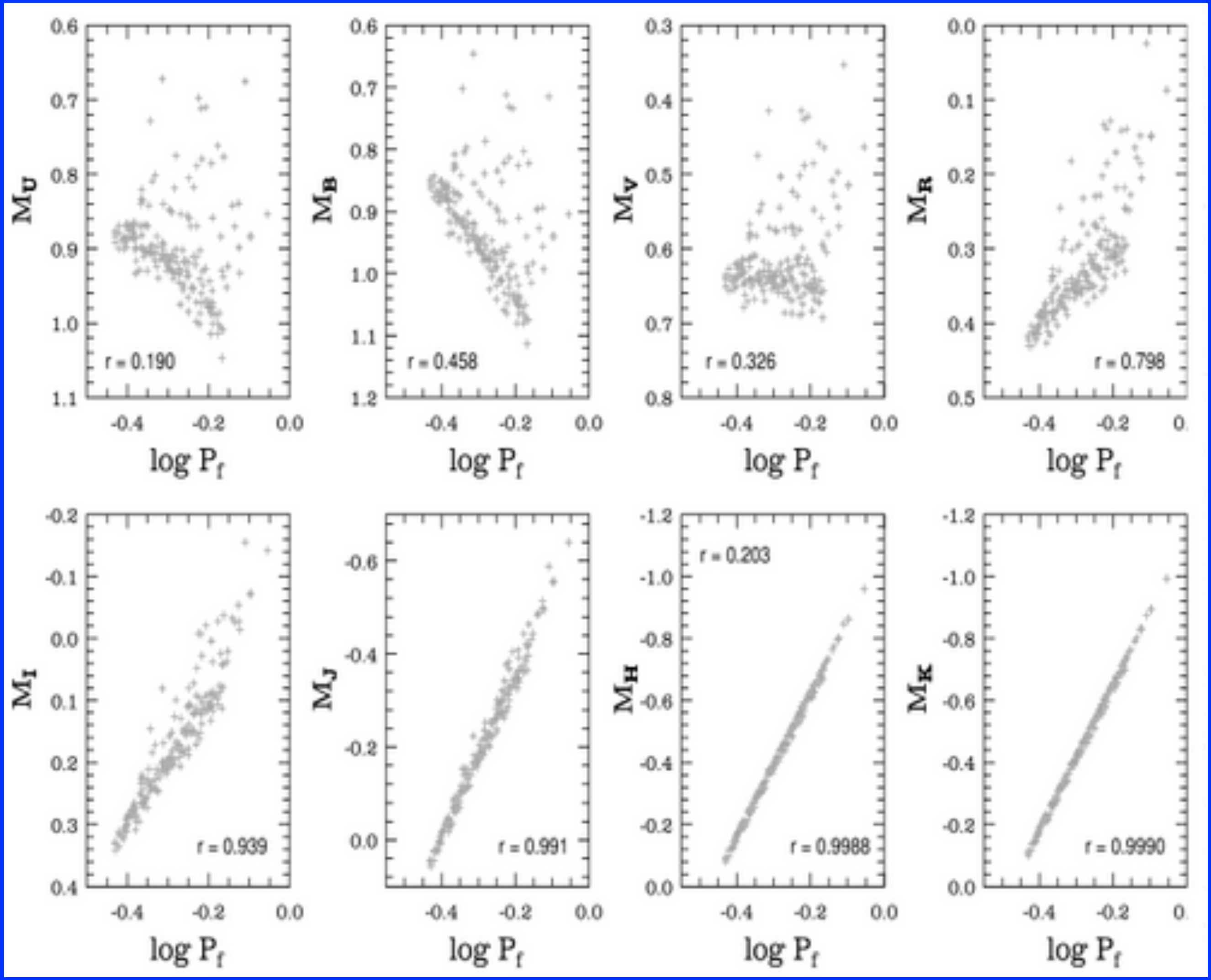
P from ~ 0.3 d to ~ 1.0 d

A_V from ~ 0.2 to ~ 1.8 mag

Tracers of the chemical and dynamical properties of old stellar populations

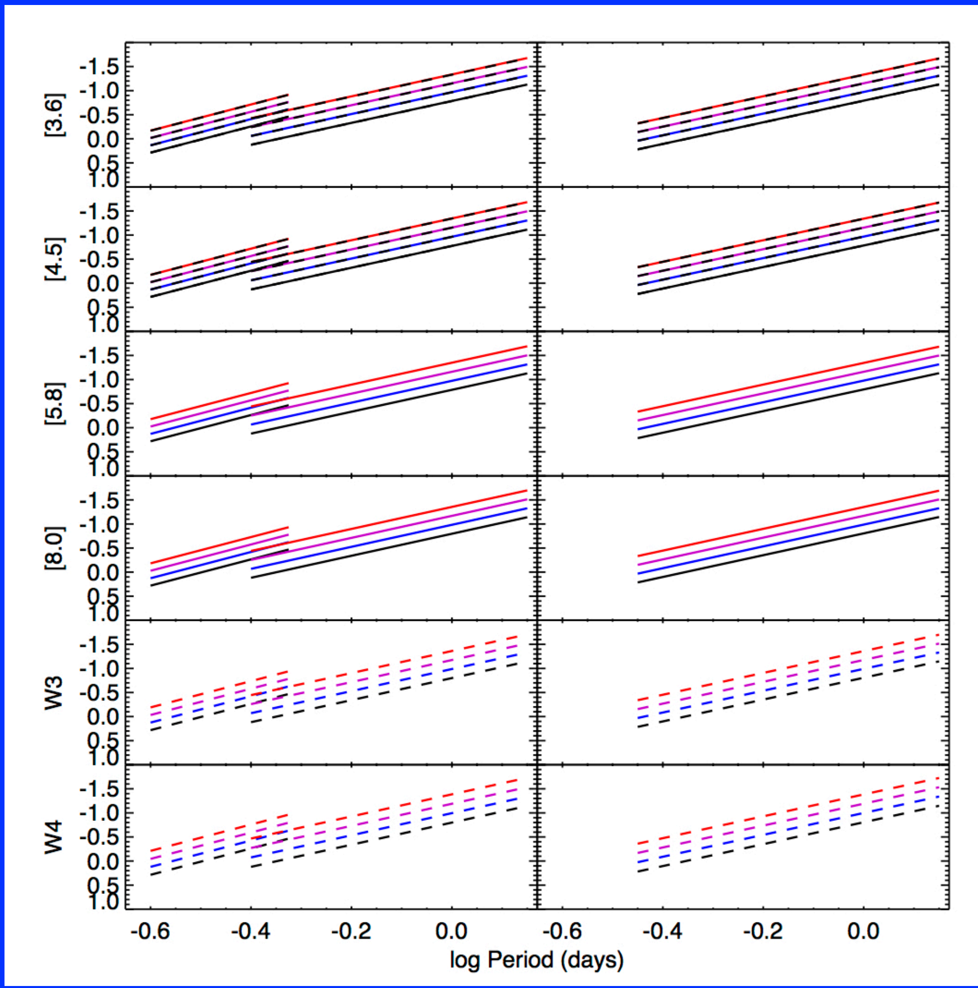
RR Lyrae as distance indicators PL relation: only in the NIR

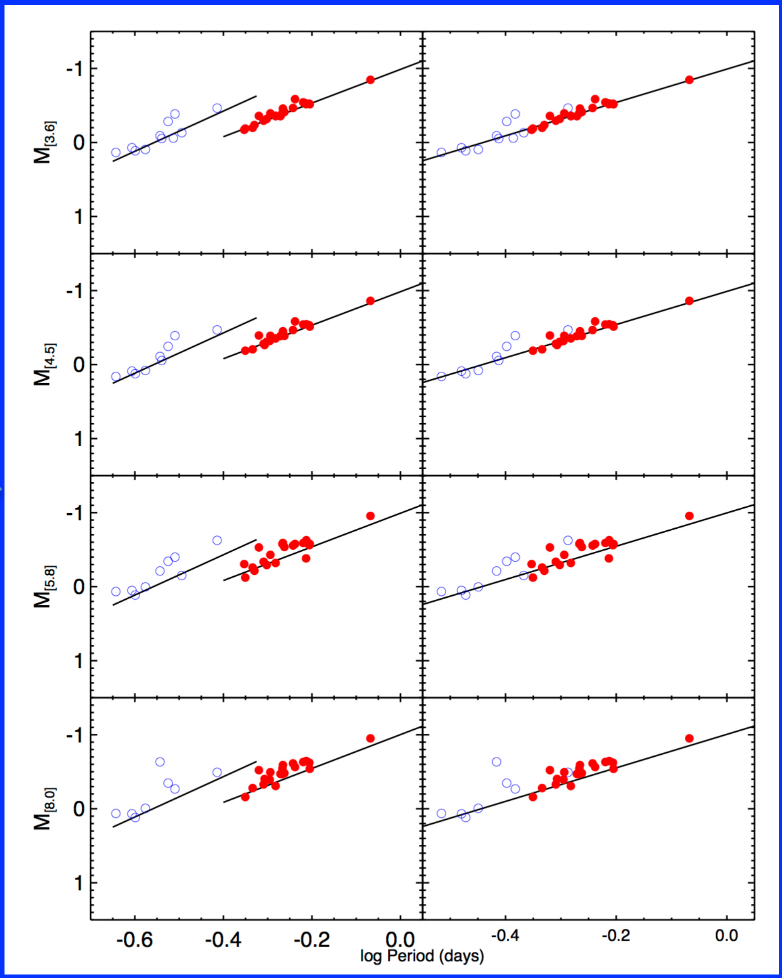
(since the pioneering investigations by Longmore et al. 1986, 1990 MNRAS)



Catelan 2004

RR Lyrae as distance indicators
Theoretical MIR PLZ relations: application to M4 RR Lyrae



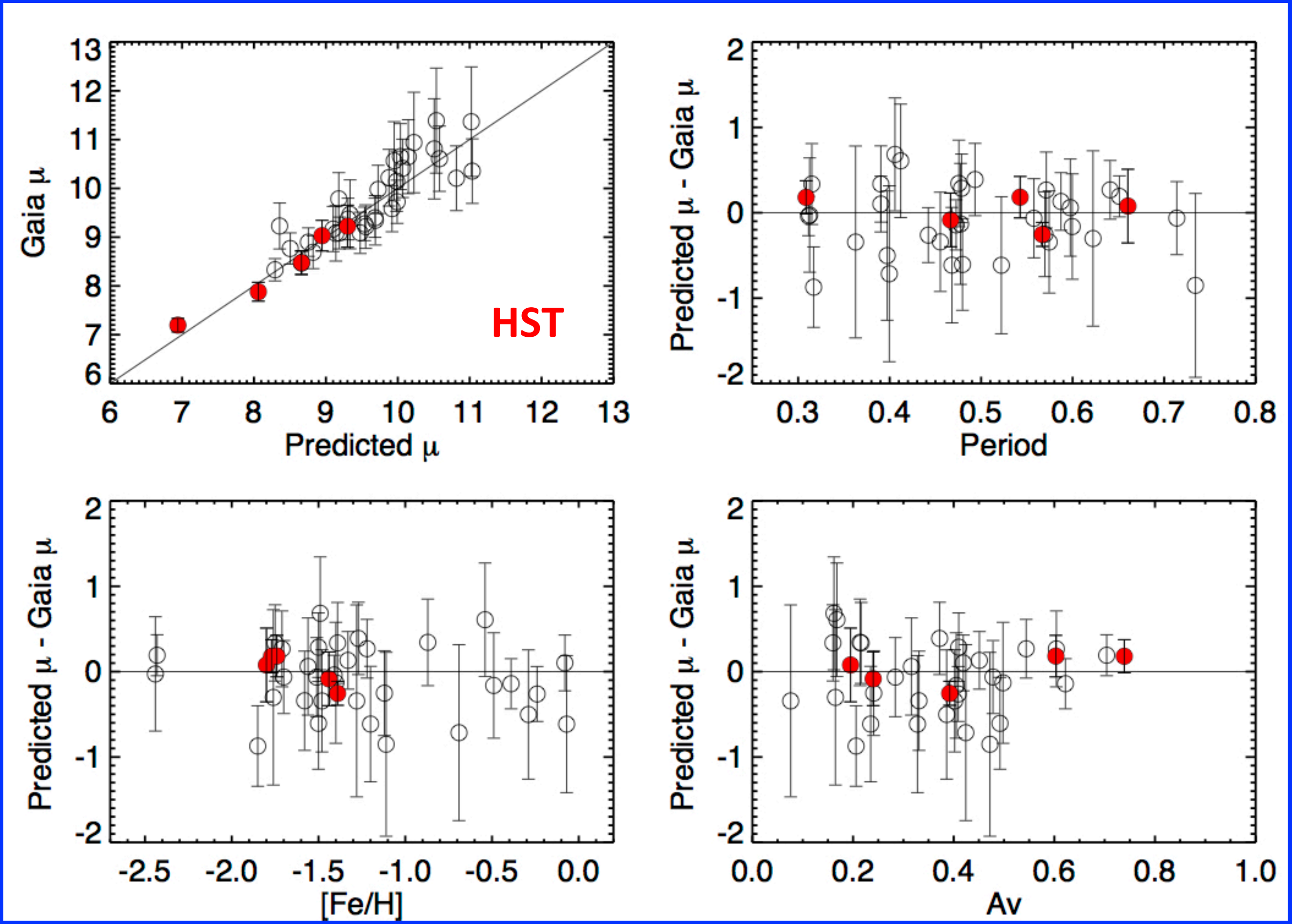


μ_0=11.257 ±0.035 mag

Neeley et al. 2017 ApJ

Comparison between predicted and Gaia distances

41 Galactic RR Lyrae

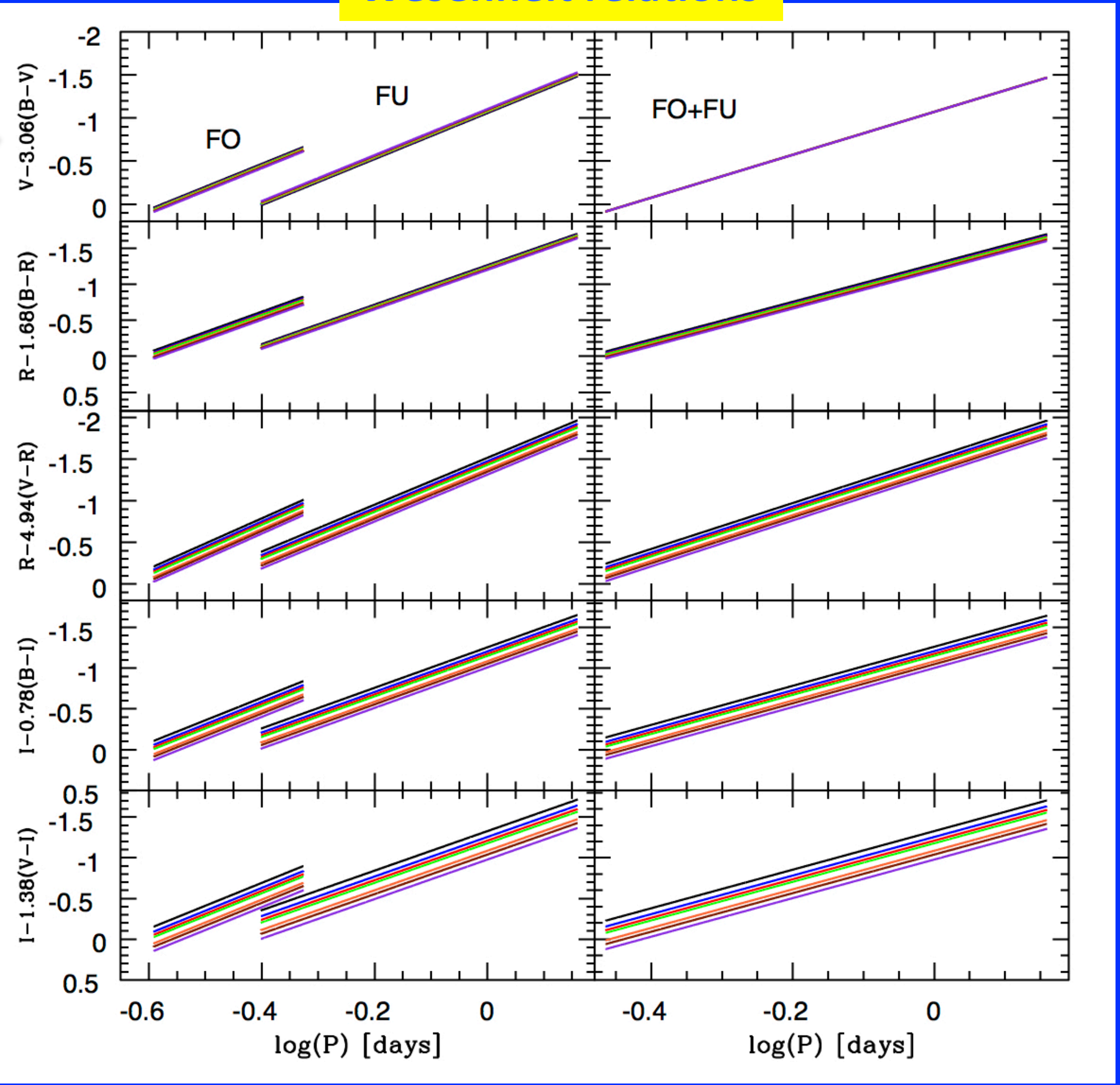


Neeley et al. 2017 ApJ

The theoretical metal-dependent WESENHEIT relations

B,B-V Wesenheit is **not** sensitive to metallicity !!!

Wesenheit relations



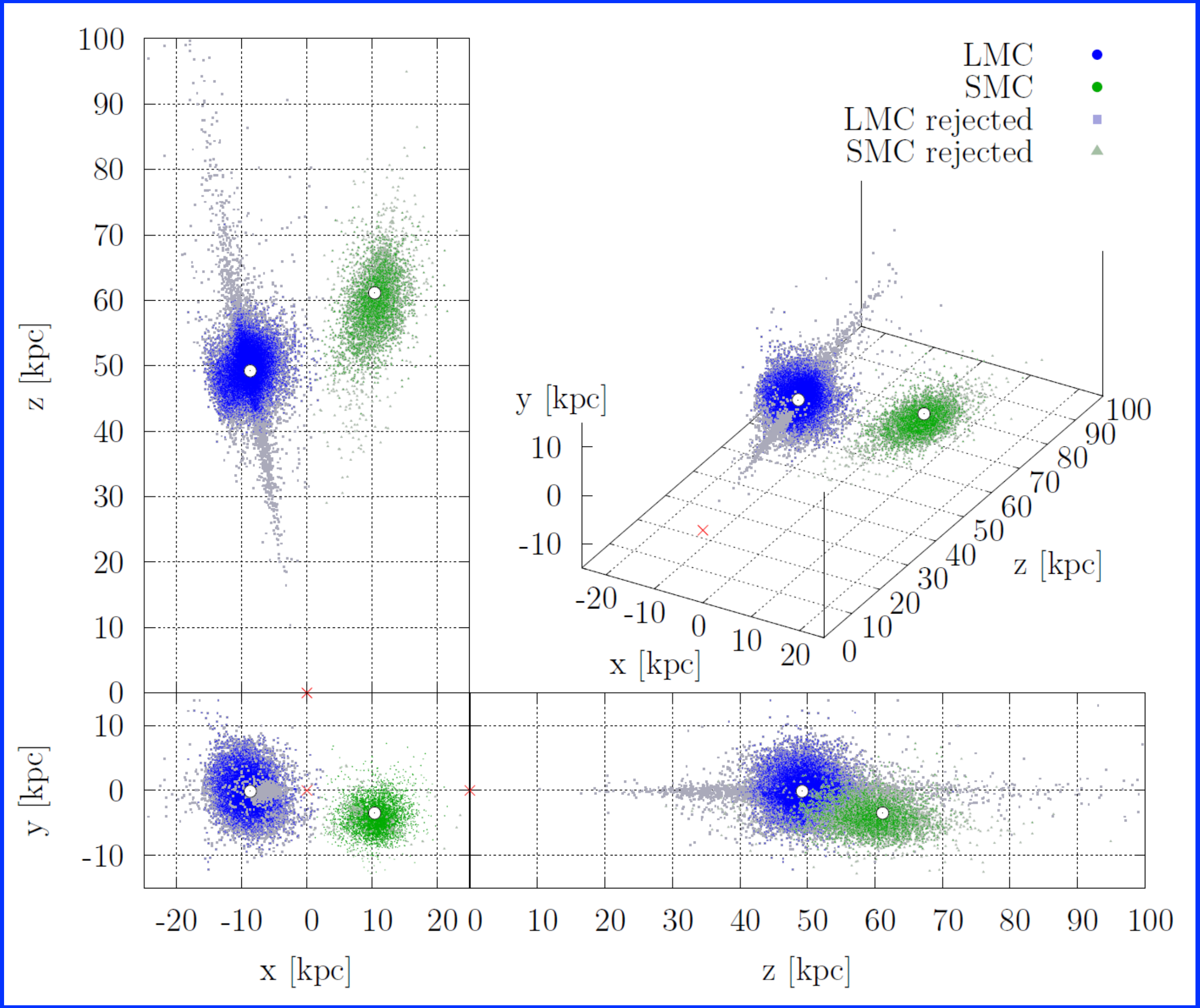
Z=0.0001, 0.0003, 0.0006, 0.001, 0.004, 0.008, 0.02

M_{ZAHB} $\log L_A = \log L_{ZAHB}$
$\log L_B = \log L_{ZAHB} + 0.1$ dex
$\log L_D = \log L_{exhaustion}$

M lower by 10%
$\log L_C = LOG_{LZAHB} + 0.2$ dex

Marconi et al. 2015 ApJ

Three-dimensional analysis of a sample of 22 859 type ab RR Lyrae stars in the Magellanic System from the OGLE-IV Collection of RR Lyrae stars.

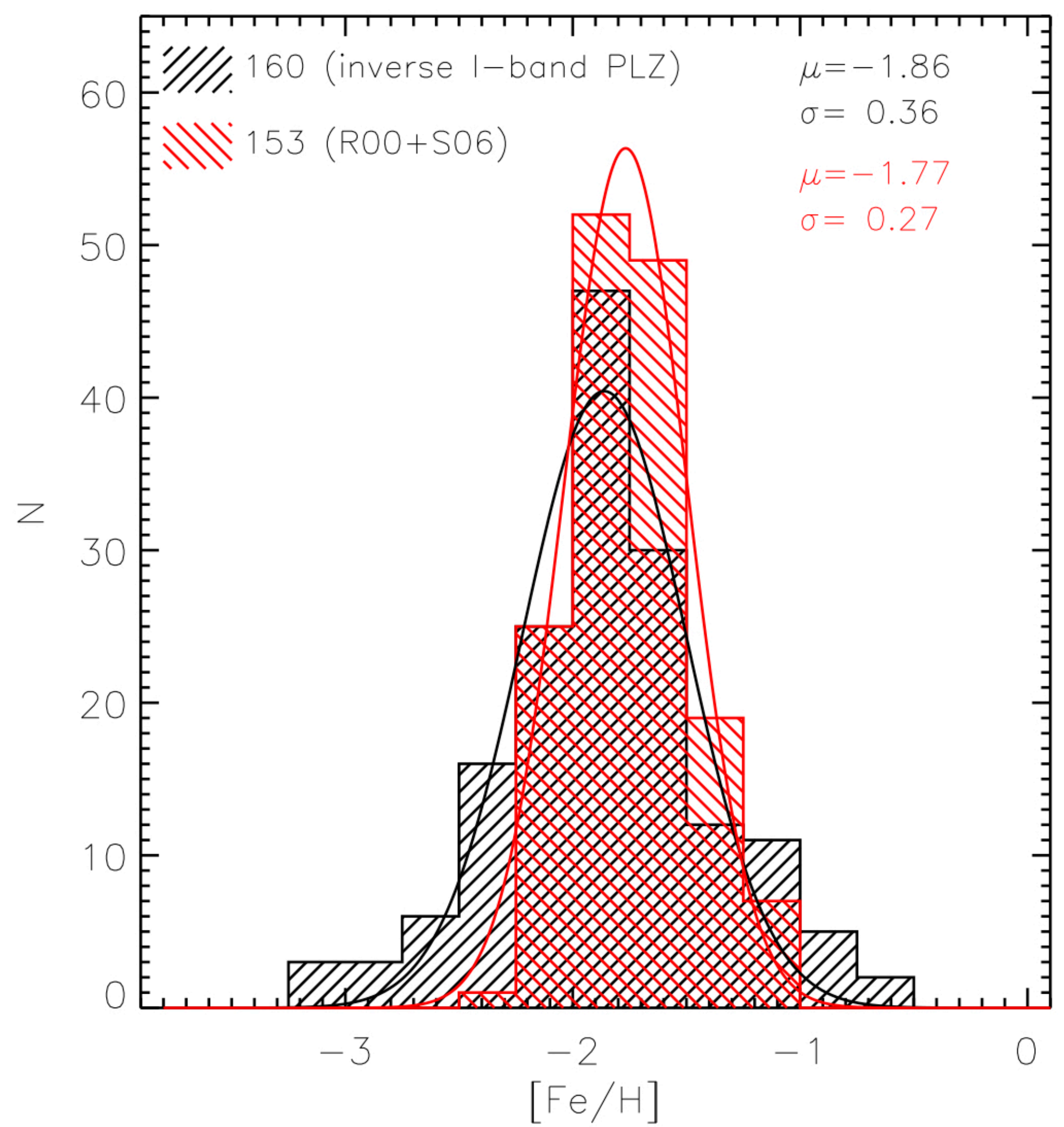


Jacyszyn-Dobrzenieckaet al. 2017

Dependence of RR Lyrae properties on Z → metallicity distribution

The case of ω Cen: application of the M_I-logP-Z relation

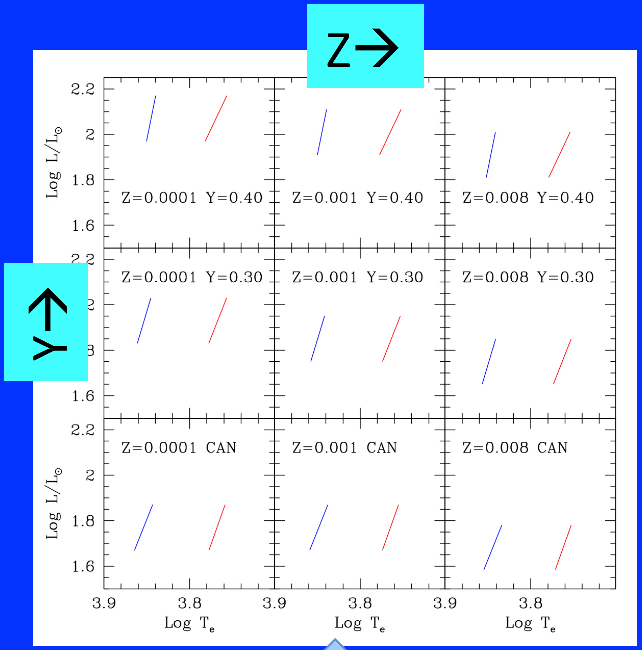
By inverting the metal dependent PL(I) relation → **metallicity distribution**

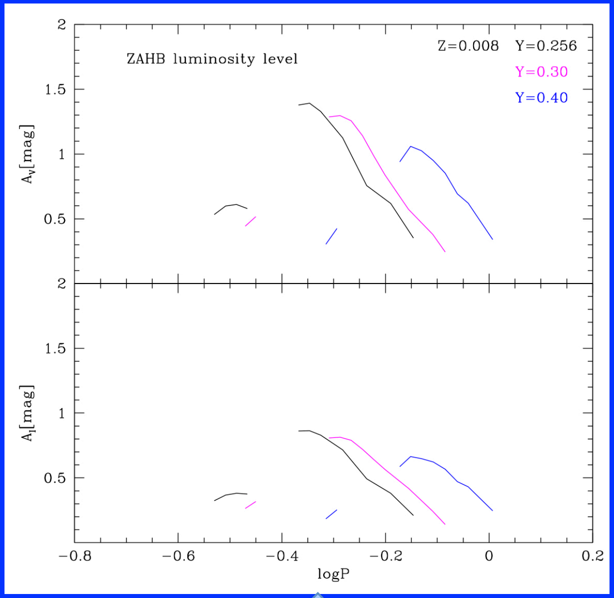


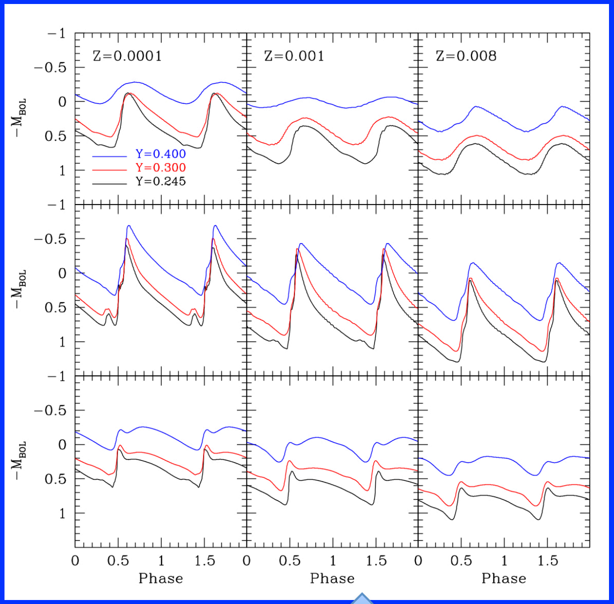
Braga et al. 2016 ApJ

Dependence of RR Lyrae properties on Y → He enhancement

→ Pulsation observables depend on the helium content







Width of the IS is almost unaffected.

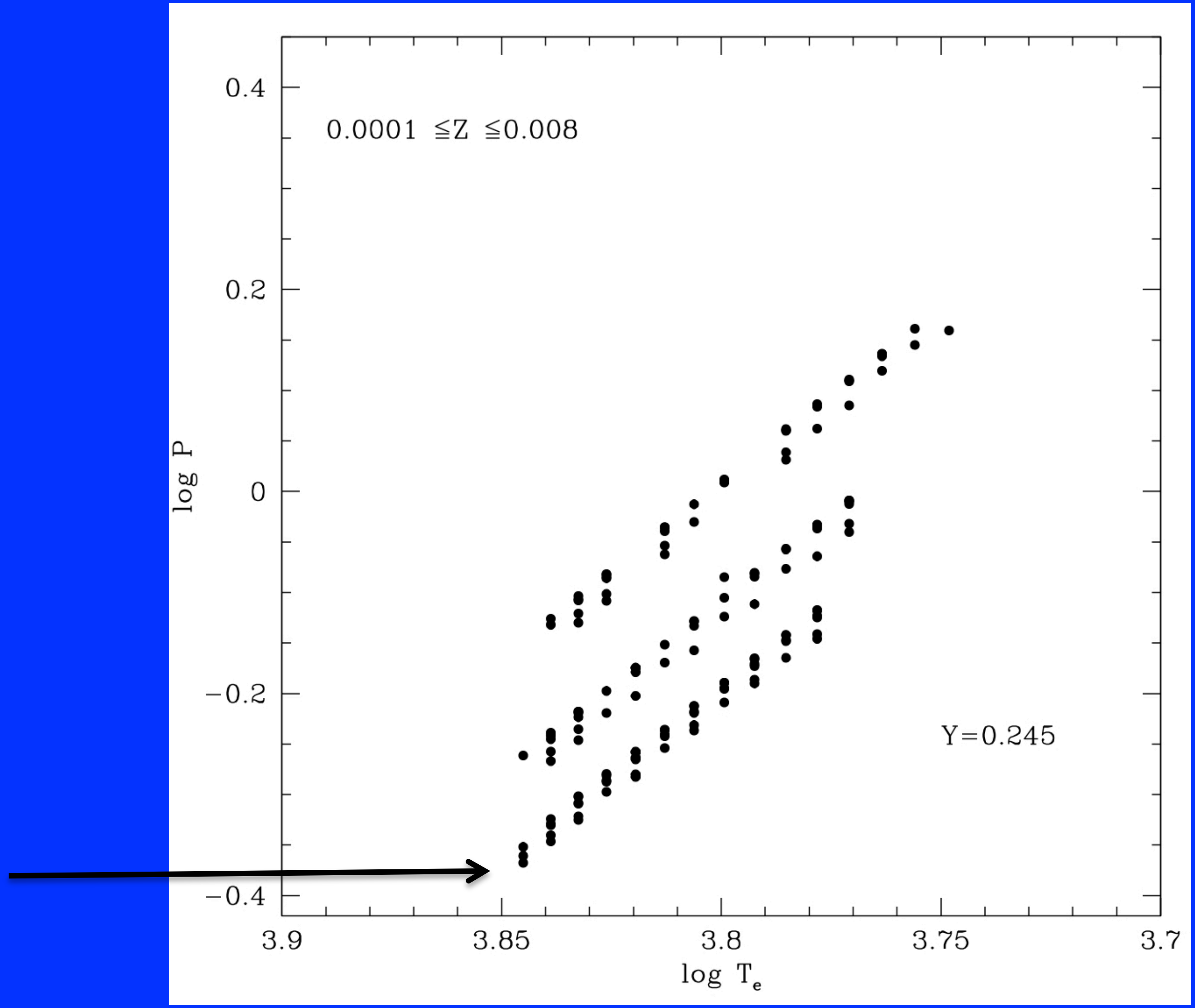
The most important effect due to the increase of the corresponding luminosities

Periods increase with Y

Amplitudes decrease

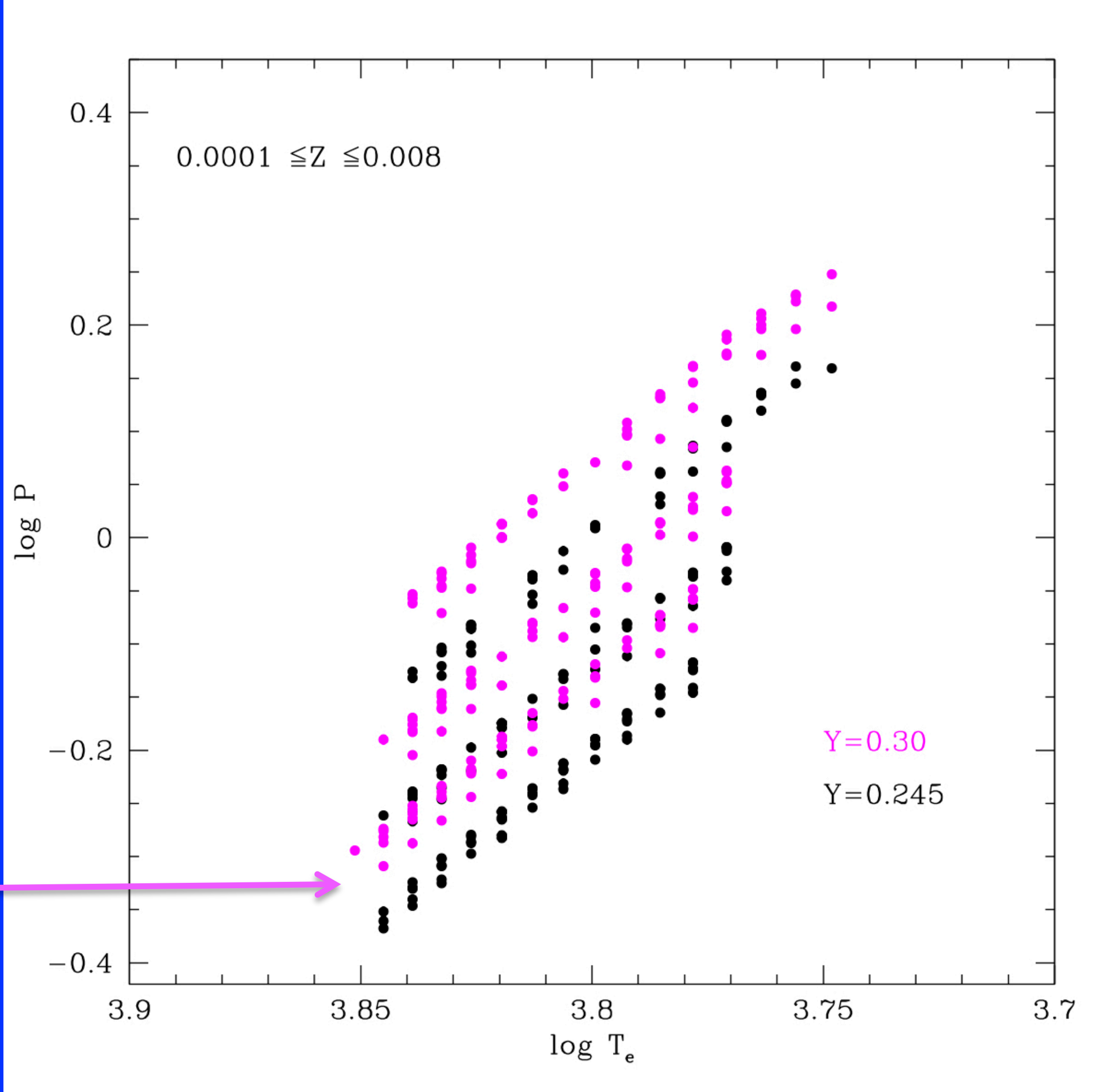
Given the same position in the strip, morphology is similar but with smaller amplitudes.

Marconi et al. 2018 in prep



Marconi et al. 2016 CoKon

The minimum period of RR_{ab} is predicted to increase with Y



Marconi et al. 2016 CoKon

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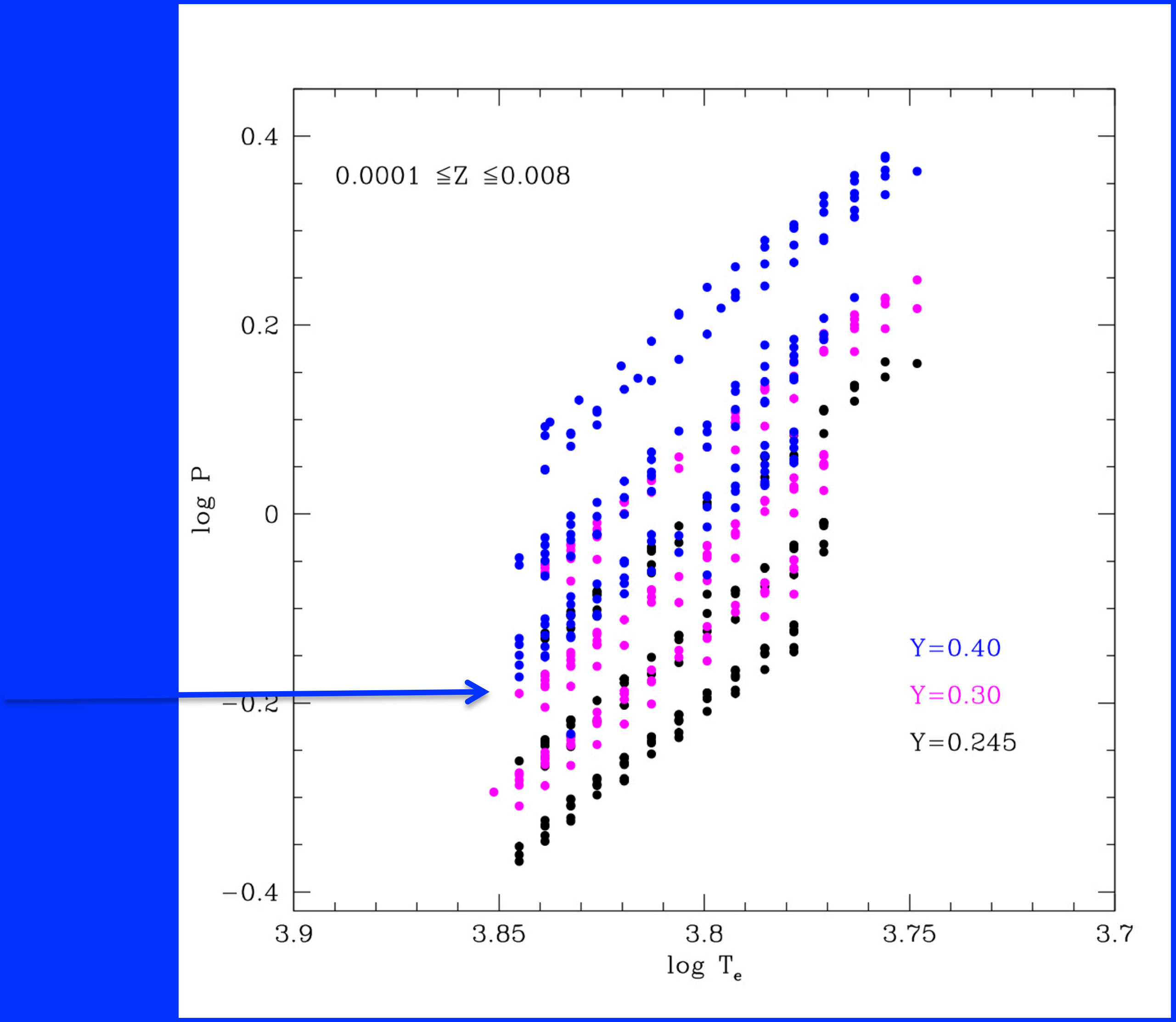


Marconi et al. 2016 CoKon

The minimum period of RR_{ab} is predicted to increase with Y

Application to Bulge RR Lyrae

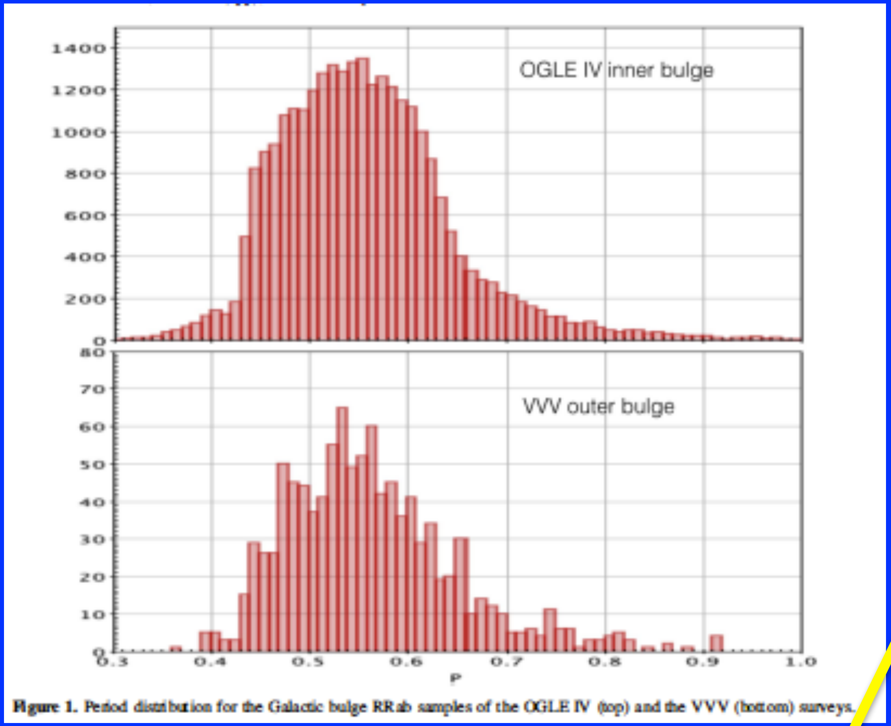
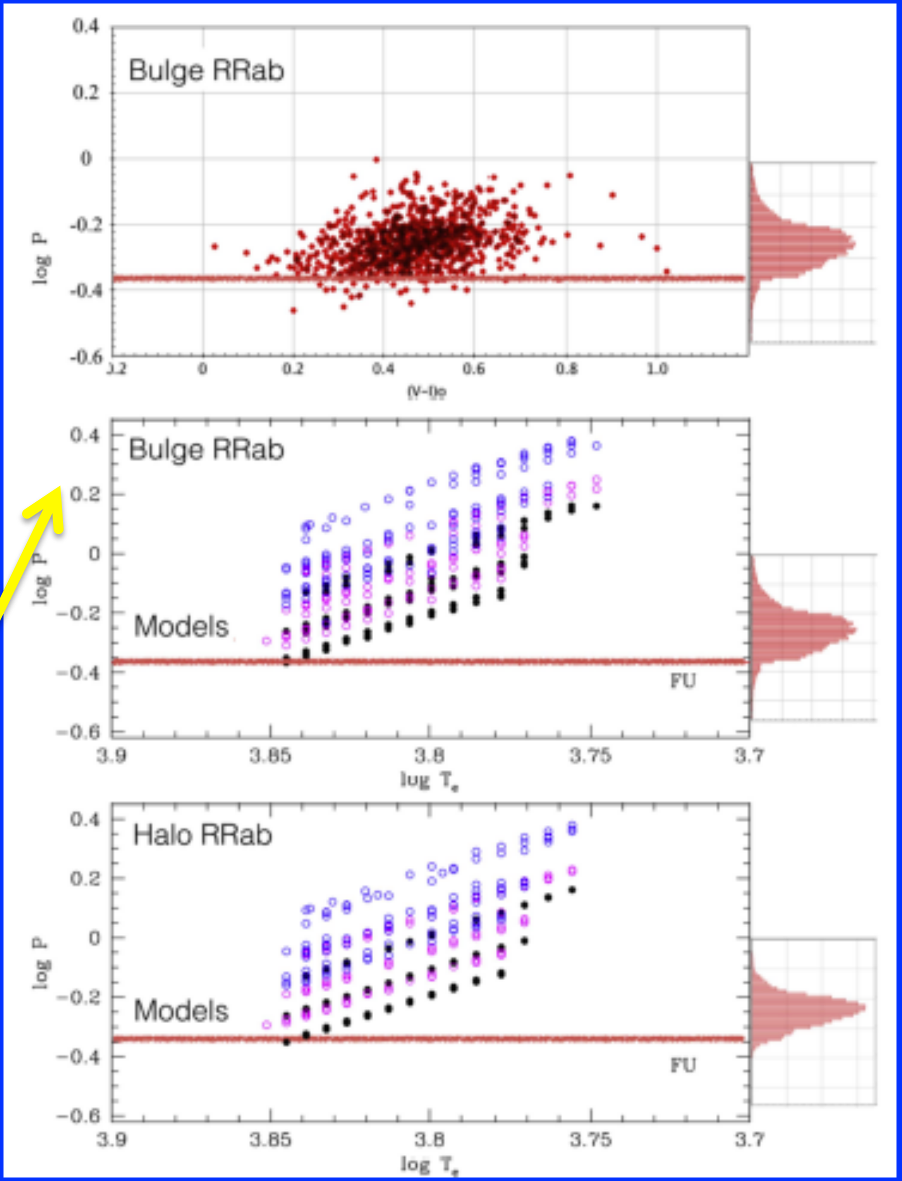


Figure 1. Period distribution for the Galactic bulge RRab samples of the OGLE IV (top) and the VVV (bottom) surveys.

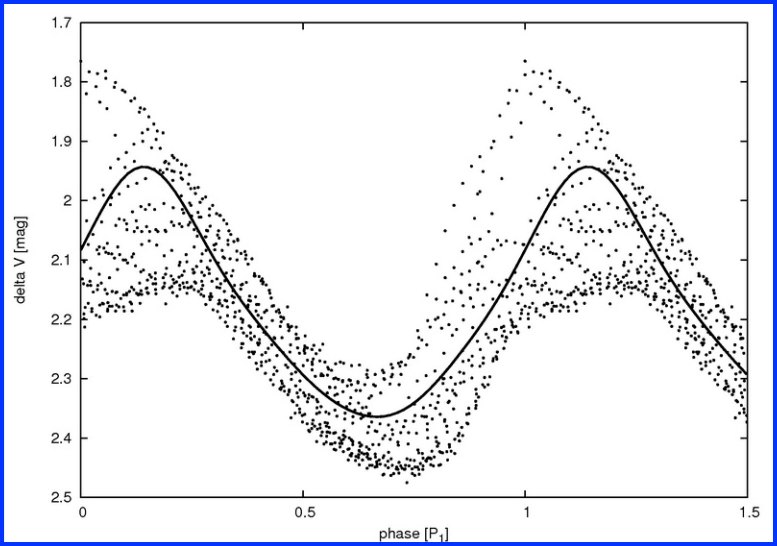


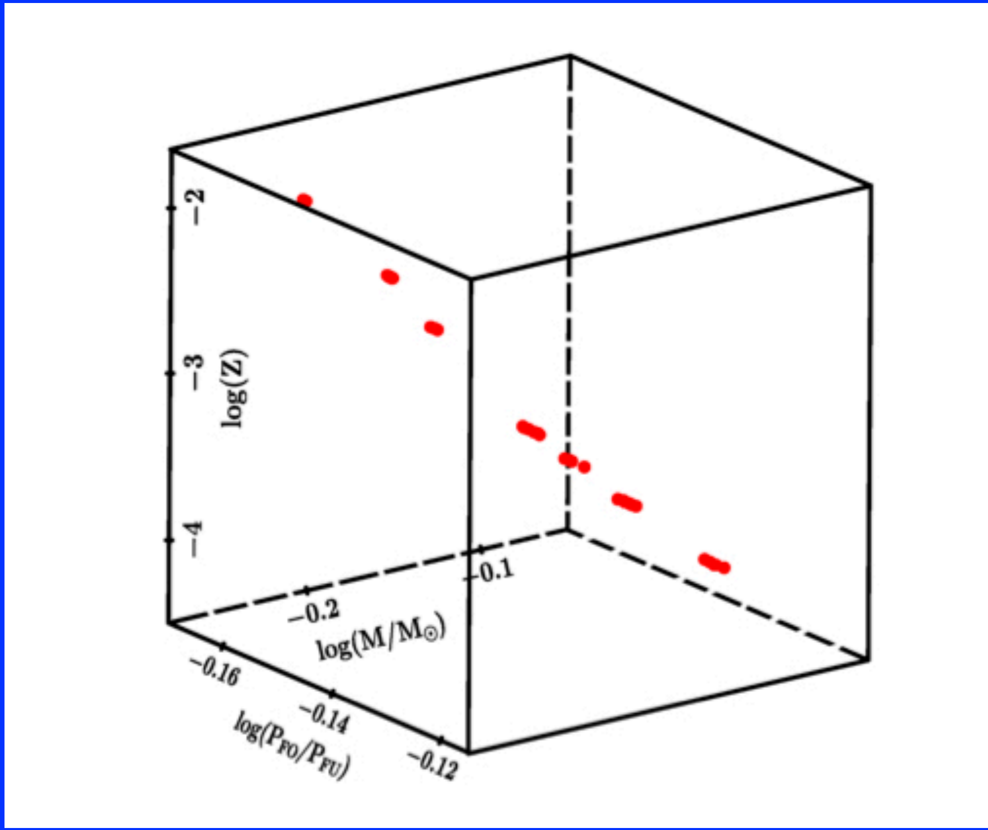
The bulk of the bulge ab-type RR Lyrae are consistent with primordial He abundance Y = 0.245, ruling out a significant He-enriched population, at variance with results based on red clump giants.

Marconi & Minniti 2018 ApJL

Double mode RR Lyrae → Pulsational masses

→ an analytical relation to infer the masses as a function of both the period ratio and the metallicity for double mode RR Lyrae





$$\log M/M_{\odot} = -0.85\ (\pm\ 0.05)\ -2.8\ (\pm 0.3)\log P_{FO}/P_F\ -\ 0.097\ (\pm\ 0.003)\log Z$$

Marconi et al. 2015 ApJ

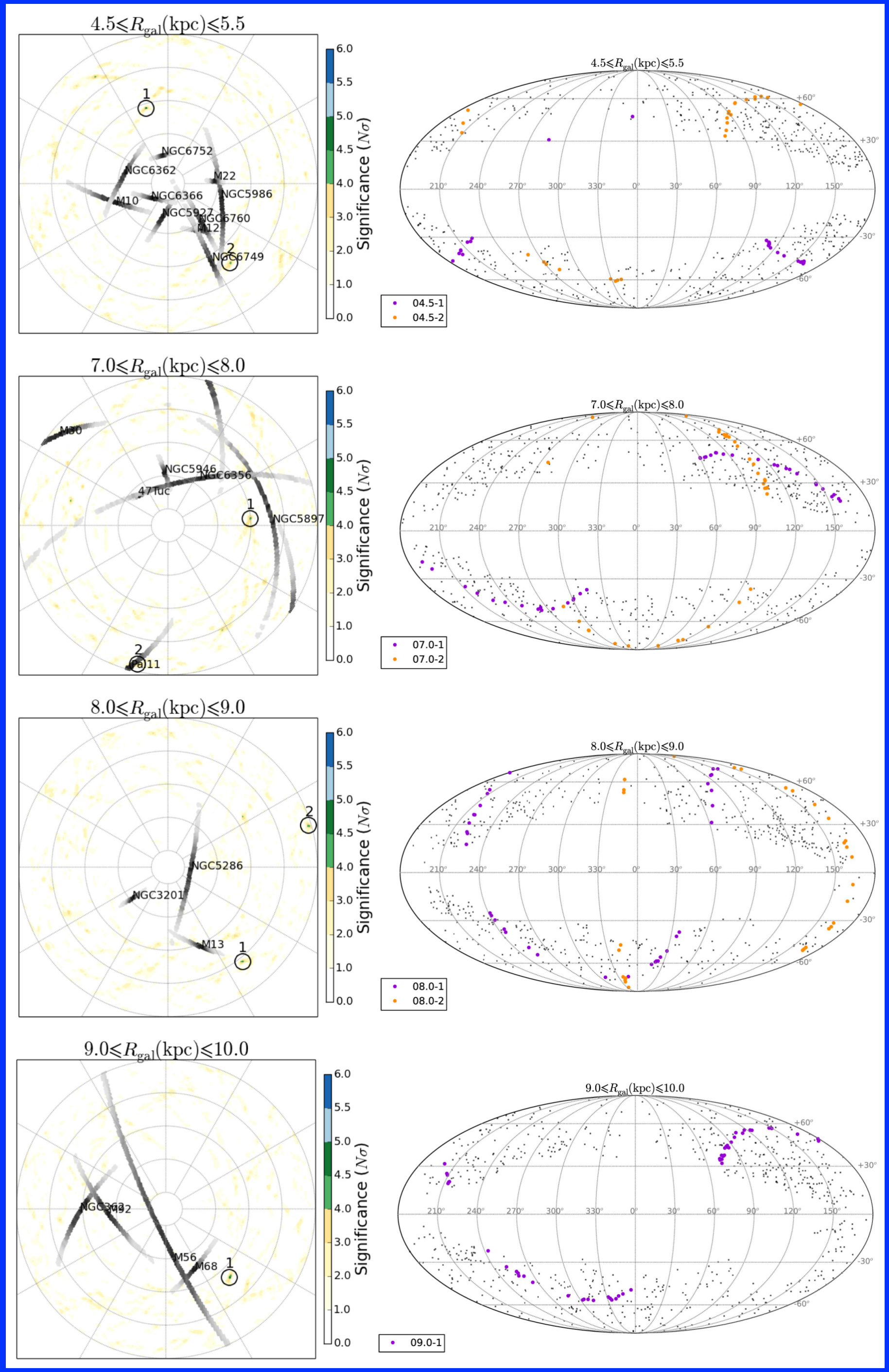
RR Lyrae as tracers of stellar streams

e.g. Mateu et al. 2018 MNRAS

"Fourteen candidate RR Lyrae star streams in the inner Galaxy"

→ RR Lyrae star streams in the Catalina survey

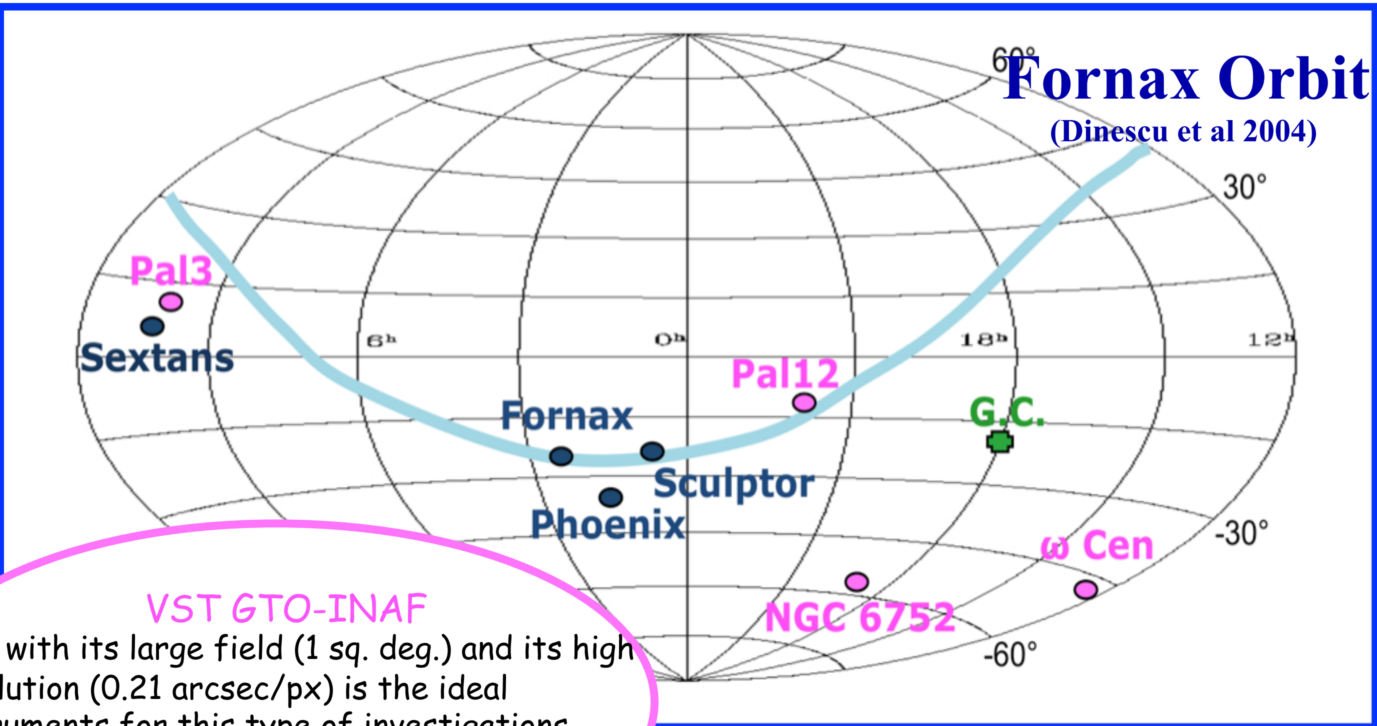
But see also previous results for the Sagittarius stream (Vivas et al. 2005), the Pisces stream (Sesar et al.) and Orphan stream (Hendel et al. 2018)…etc…



STREGA@VST

Tracing tidal tails and halos around stellar clusters and galaxies **to investigate Galactic halo formation mechanisms**

Mapping large areas (at least up to 2-3 tidal radii), in the g, r and i bands, to trace signatures of interaction between selected stellar systems and the Galactic Halo by using **RR Lyrae** and Turn off stars as tracers.



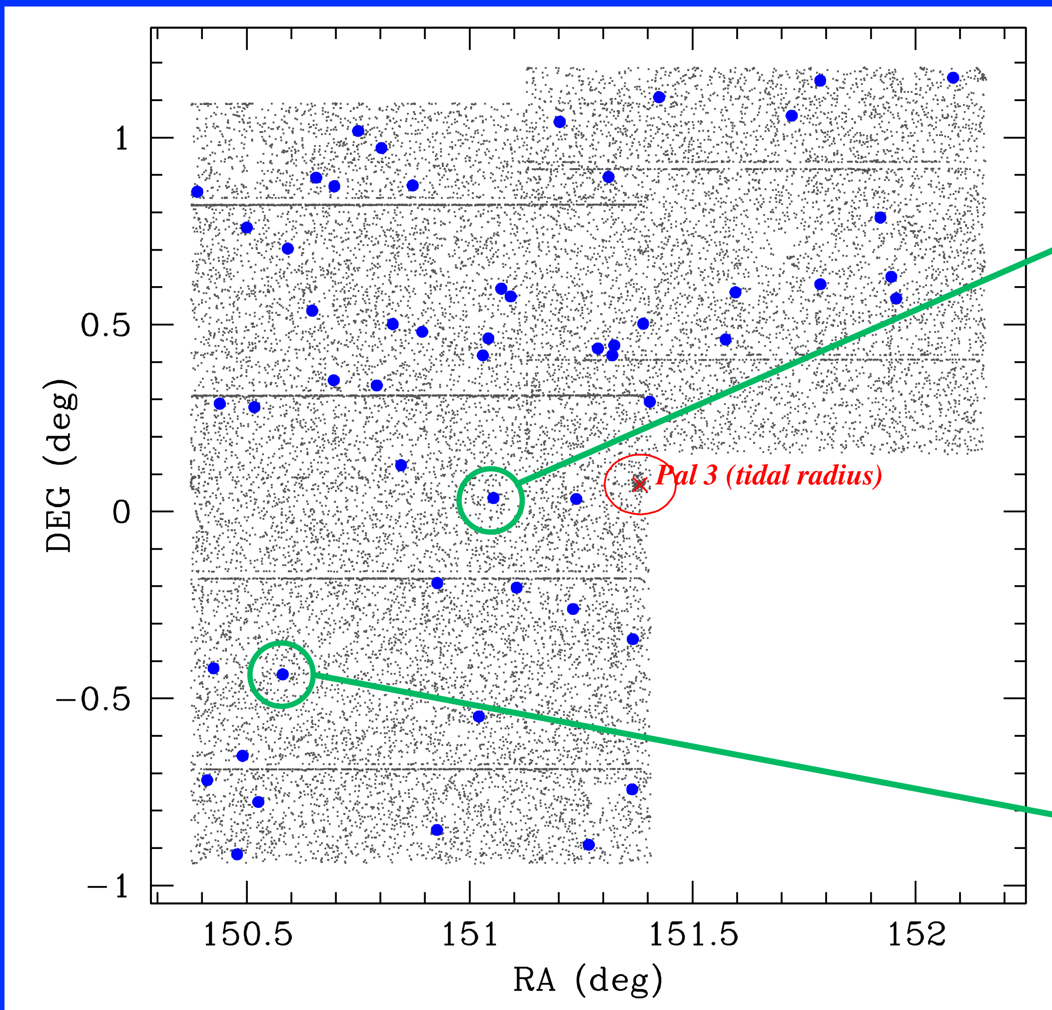
VST GTO-INAF

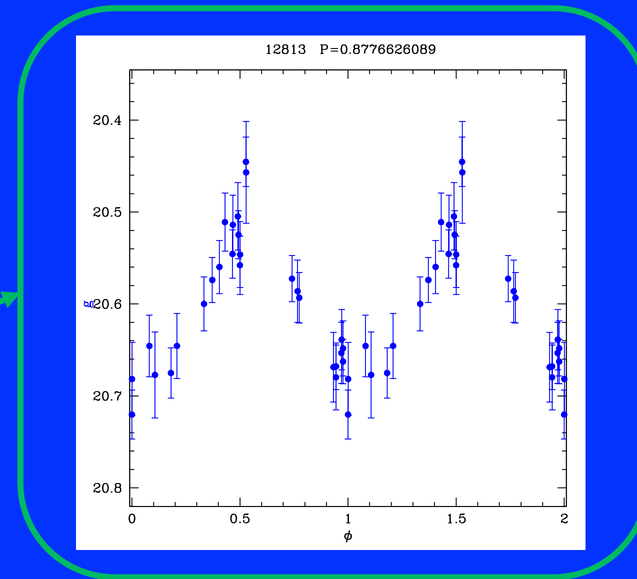
VST with its large field (1 sq. deg.) and its high resolution (0.21 arcsec/px) is the ideal instruments for this type of investigations

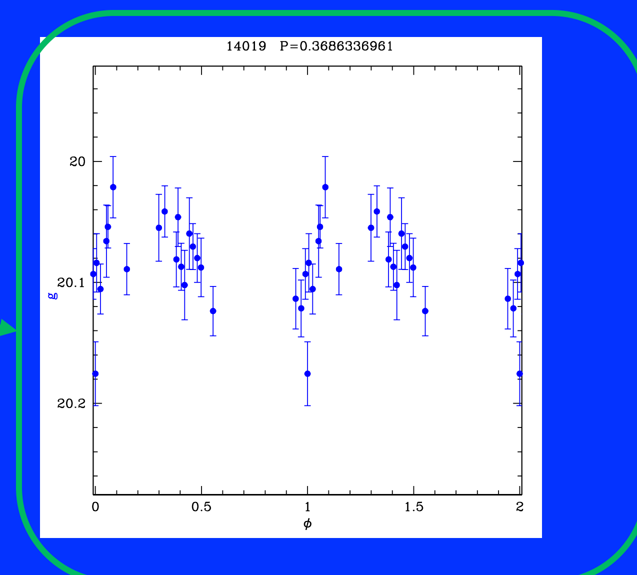
see Ilaria's talk

Pal3 extratidal RR Lyrae

Work in progress







Moretti, M.I. et al. 2018 in prep

Perspectives and Future Developments

Use Gaia data Release 2 (and subsequent ones) distances to constrain the physical assumptions in evolutionary and pulsational models.

Extend this approach to extragalactic pulsating stars with LSST

Complete the RR Lyrae search around Pal 3 and extend it to the fields around Fornax and Sculptor in the context of the STREGA Survey

Thank you !!