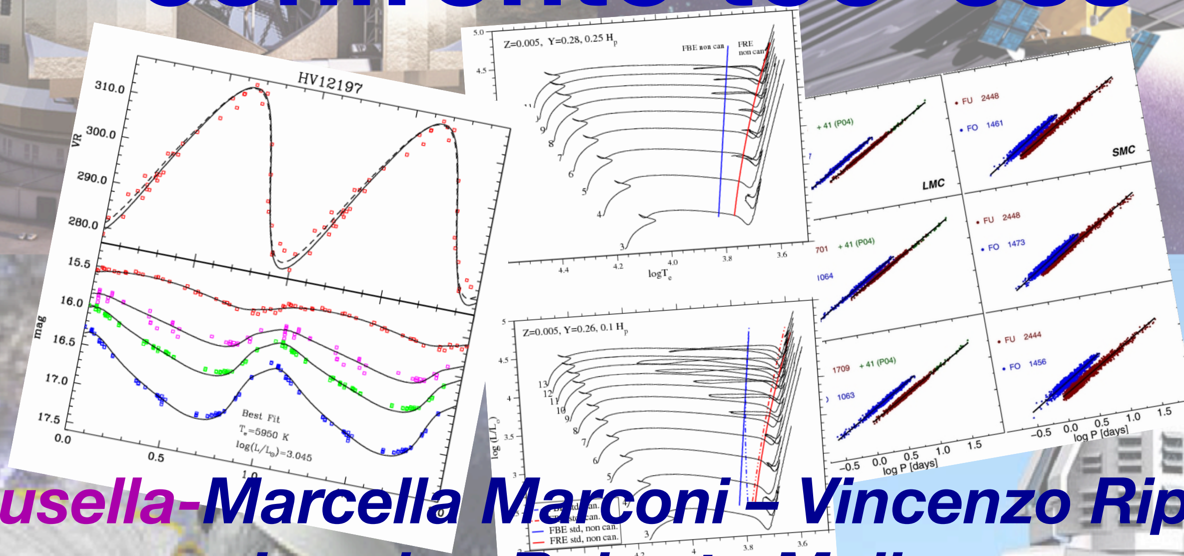
Stelle pulsanti: traccianti, indicatori distanza confronto teo-oss



Ilaria Musella-Marcella Marconi – Vincenzo Ripepi – Silvio Leccia - Roberto Molinaro

INAF-OABO: Gisella Clementini – Felice Cusano – Giuliana Fiorentino – Alessia Garofalo – Tatiana Muraveva

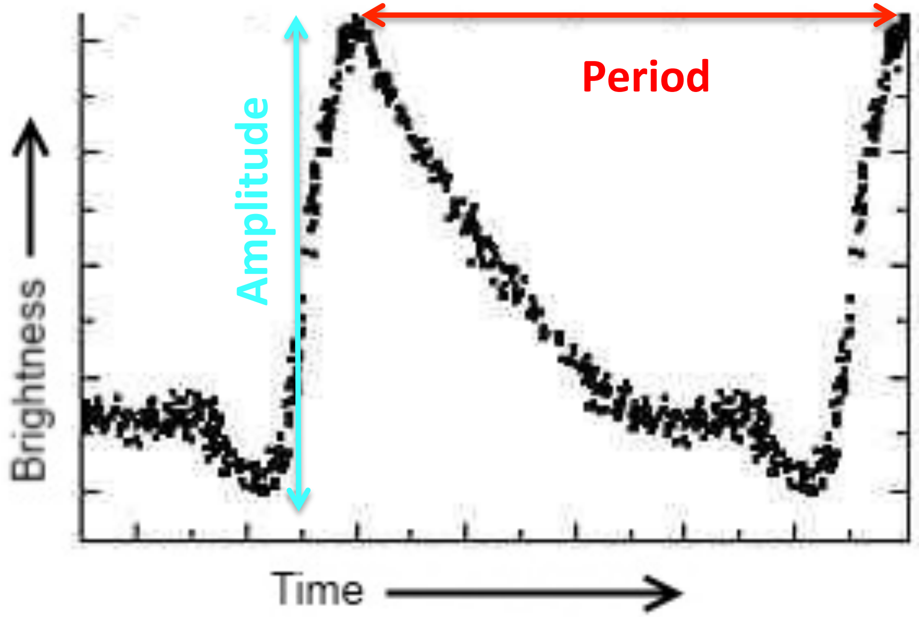
INAF-OAR: Enzo Brocato – Roberta Carini - Marcella Di Criscienzo

INAF-OACT: Adriano Pietrinferni - Gabriella Raimondo

Univ. Torvergata: Giuseppe Bono - Vittorio Braga

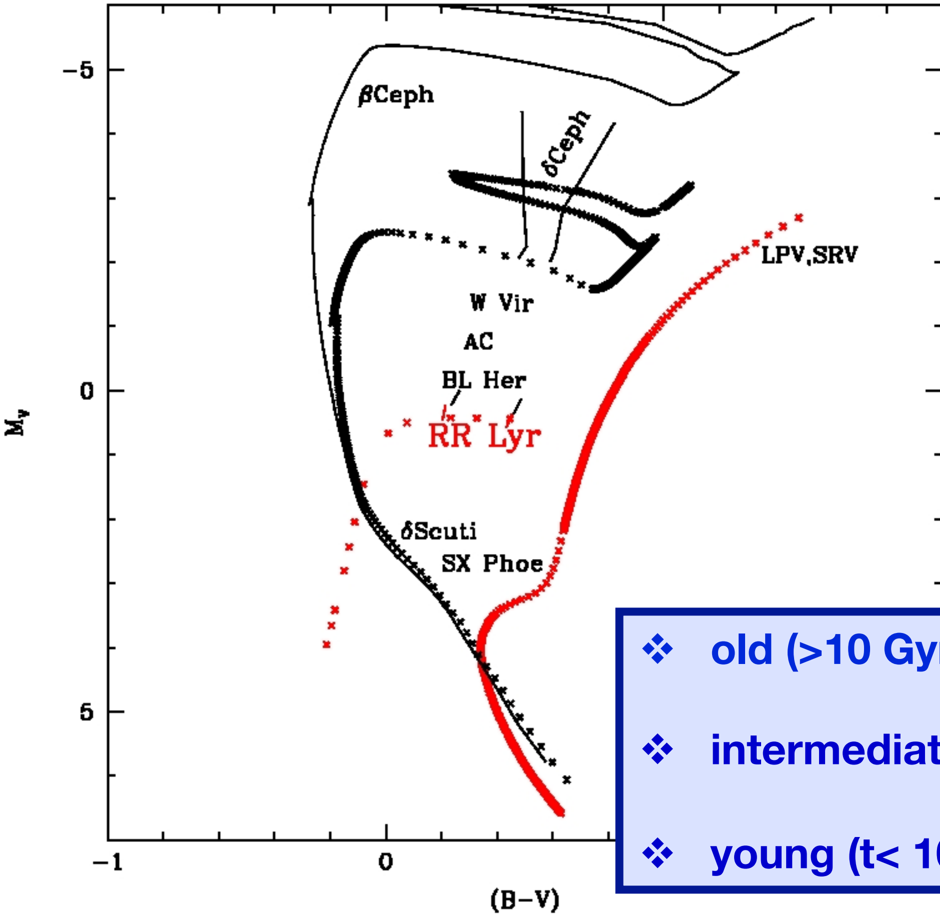
Why investigating Pulsating Variable stars (I)

- “easily” recognized thanks to the light variation
- periods and amplitudes are unaffected by distance and reddening



Why investigating Pulsating Variable stars (II)

Pulsating stars in the instability strip

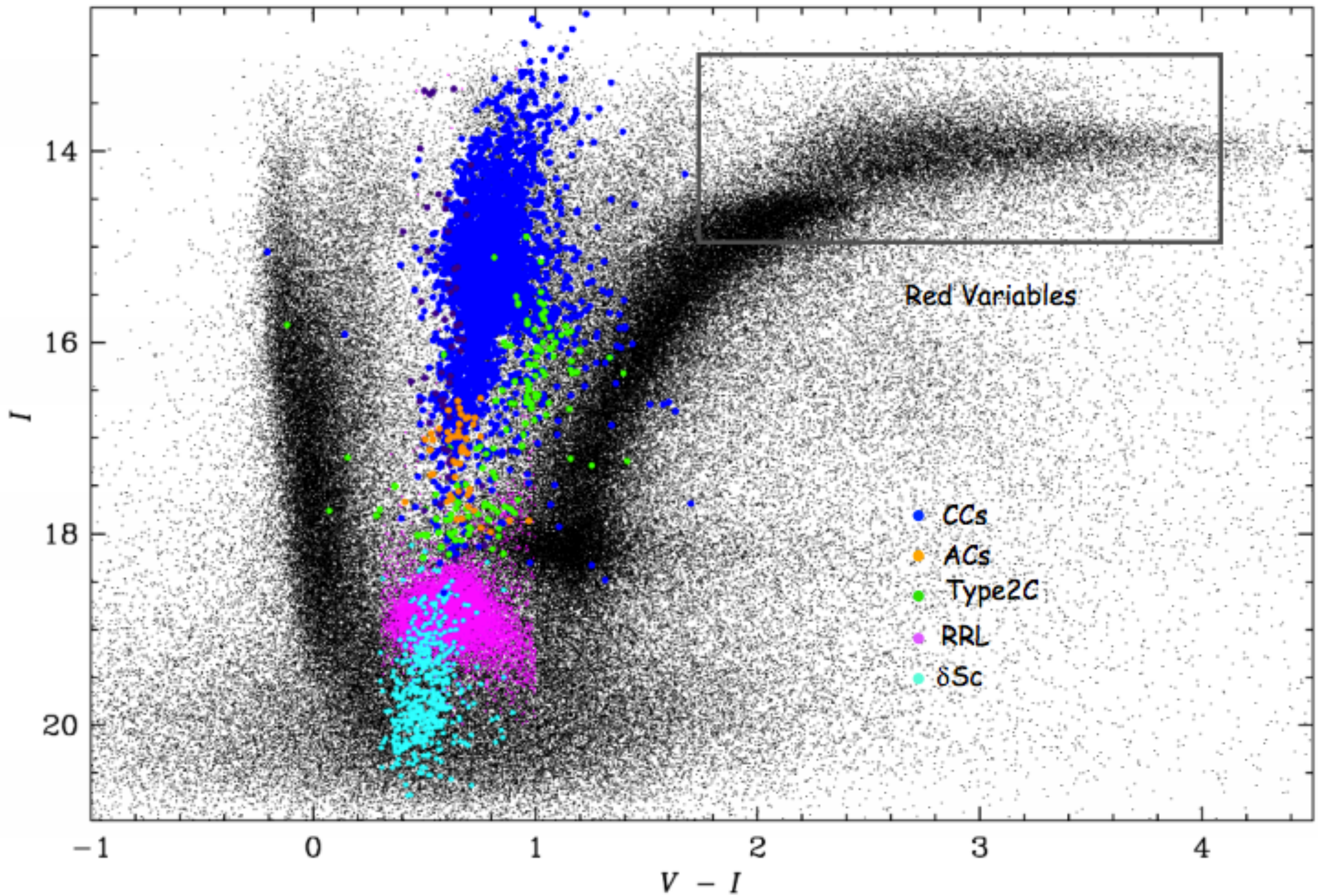


The various classes of pulsating stars map different evolutionary phases (and a wide range of periods)

They can trace stellar populations of different age in the same system

- **old (>10 Gyr)**: RR Lyrae, Pop II Cepheids, SX Phoenicis
- **intermediate age (1-5 Gy):** Anomalous Cepheids
- **young (t< 100 Myr):** Classical Cepheids

LMC variables from OGLE III



Soszynski et al. 2009

Why investigating Pulsating Variable stars (III)

A theoretical and observational study of the pulsating stars properties

Constraints on stellar intrinsic parameters (M, L,....)

Trace stellar population of different age and chemical composition

Set the astronomical distances and the distance scale

map 3D structure, radial trends, haloes, streams

Trace stellar generation in different stellar systems

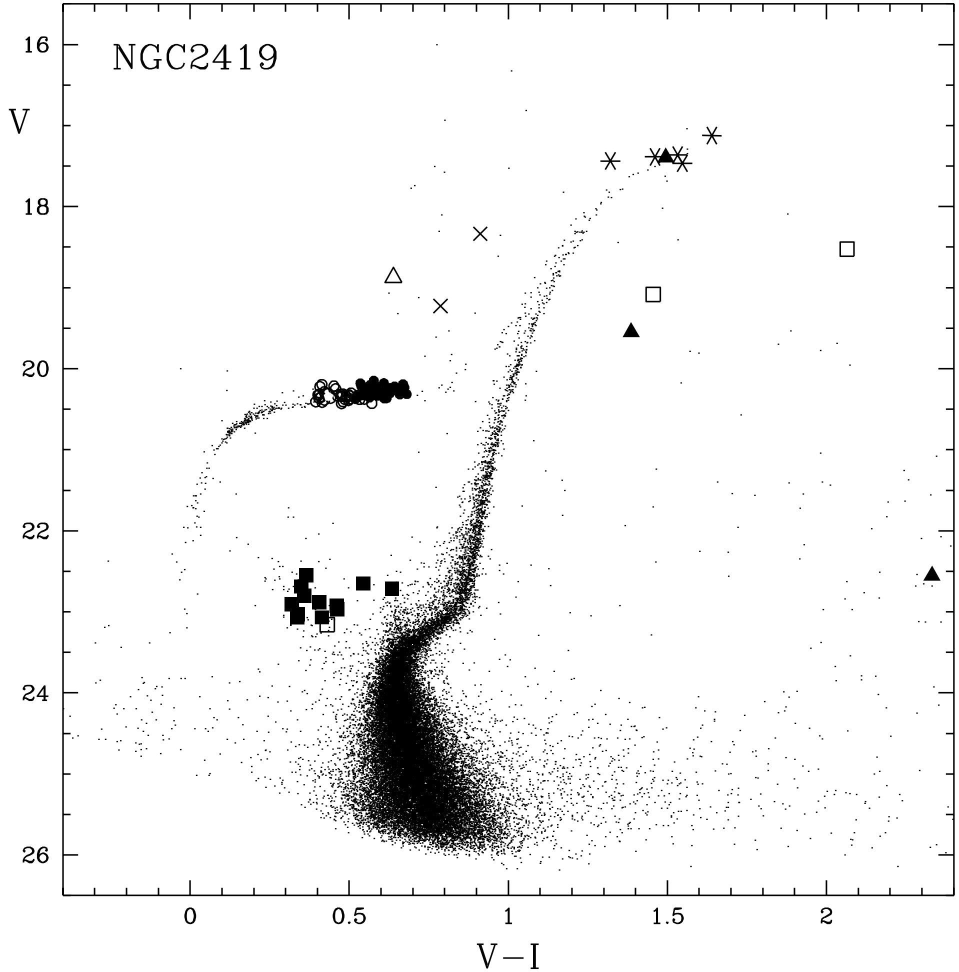
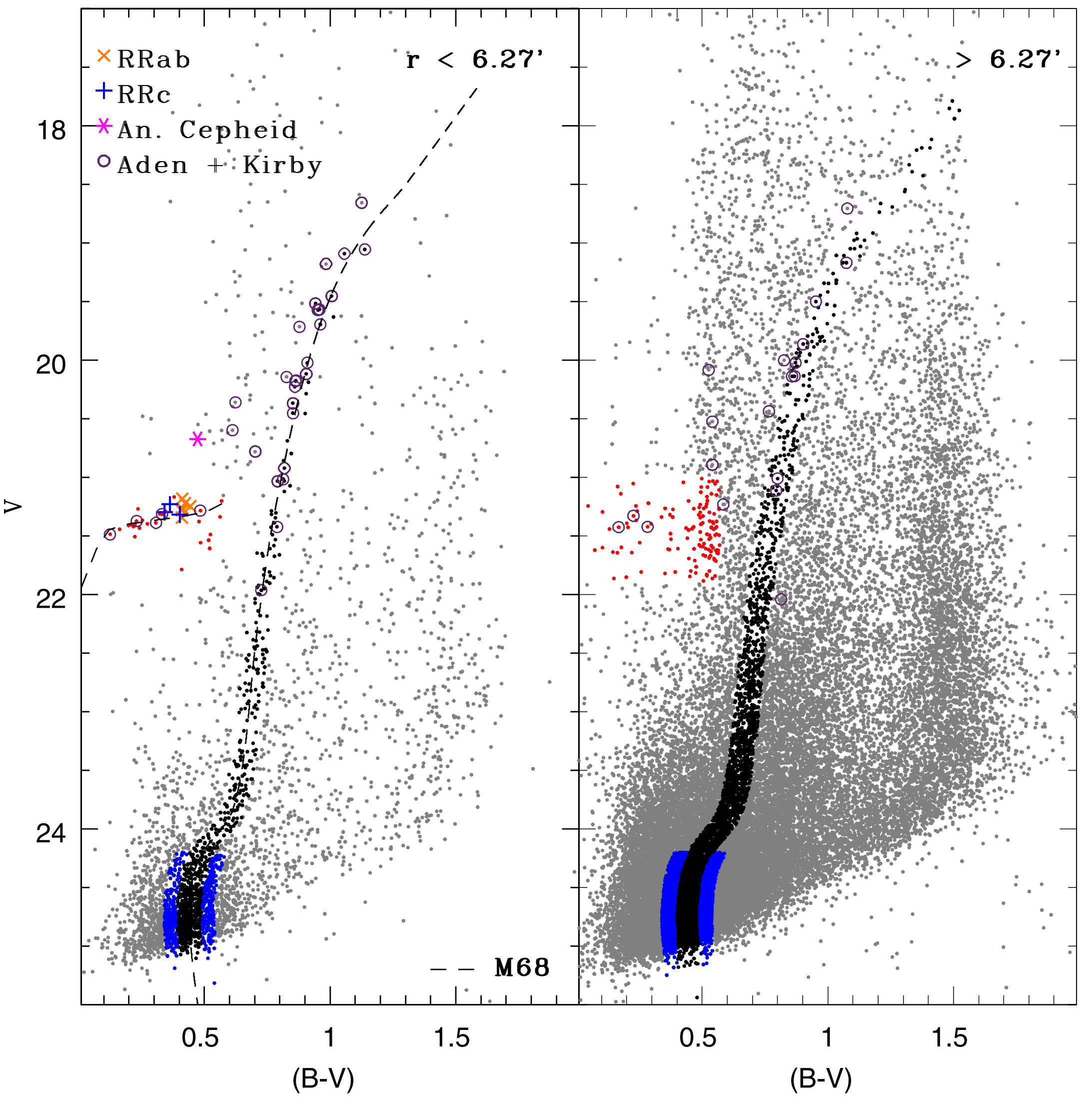


Figure 2. *V* vs. *V* − *I* CMD of NGC 2419 from the Subaru data set, with the cluster variables plotted according to their intensity-averaged magnitudes and colors, and using different symbols for the various types of variables. Filled circles: *ab*-type RR Lyrae stars (RRab); open circles: first-overtone (RRc) RR Lyrae; pentagon: double-mode (RRd) star; open triangle: Population II Cepheid; filled squares: SX Phoenicis stars; open squares: binary systems; asterisks: long-period and semiregular variables; crosses: δ Scuti stars; filled triangles: variable stars with non-reliable classification of type (NC).

Di Criscienzo et al. 2011

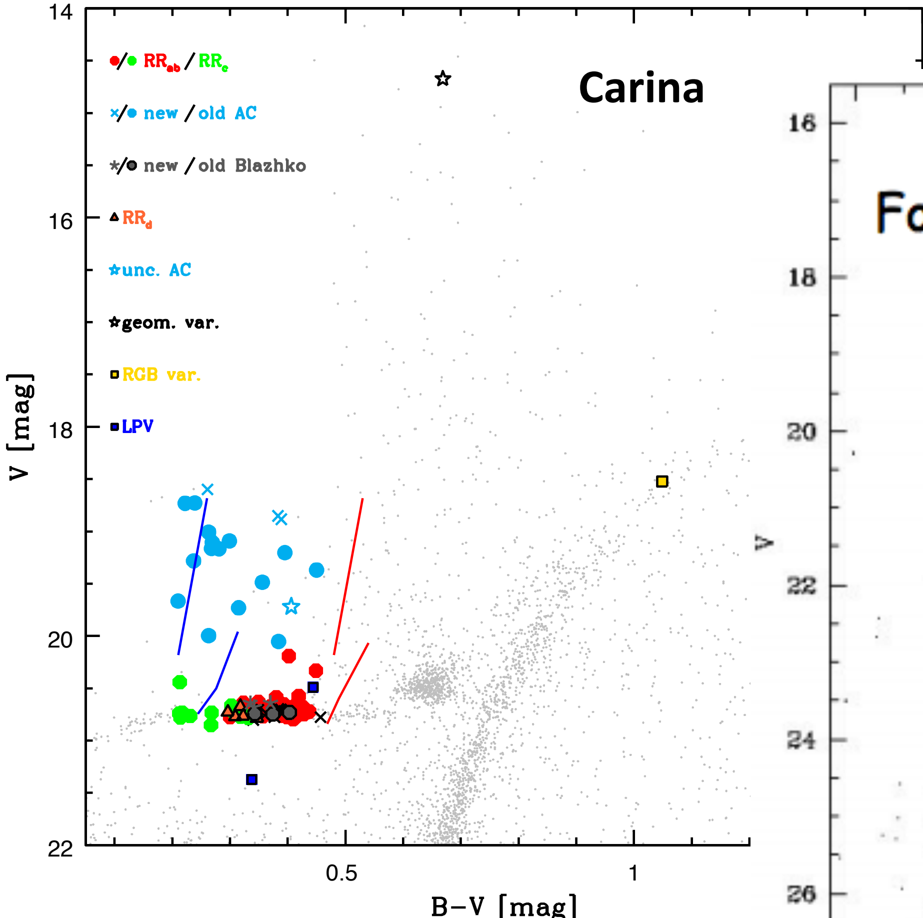
Trace stellar generation in different stellar systems



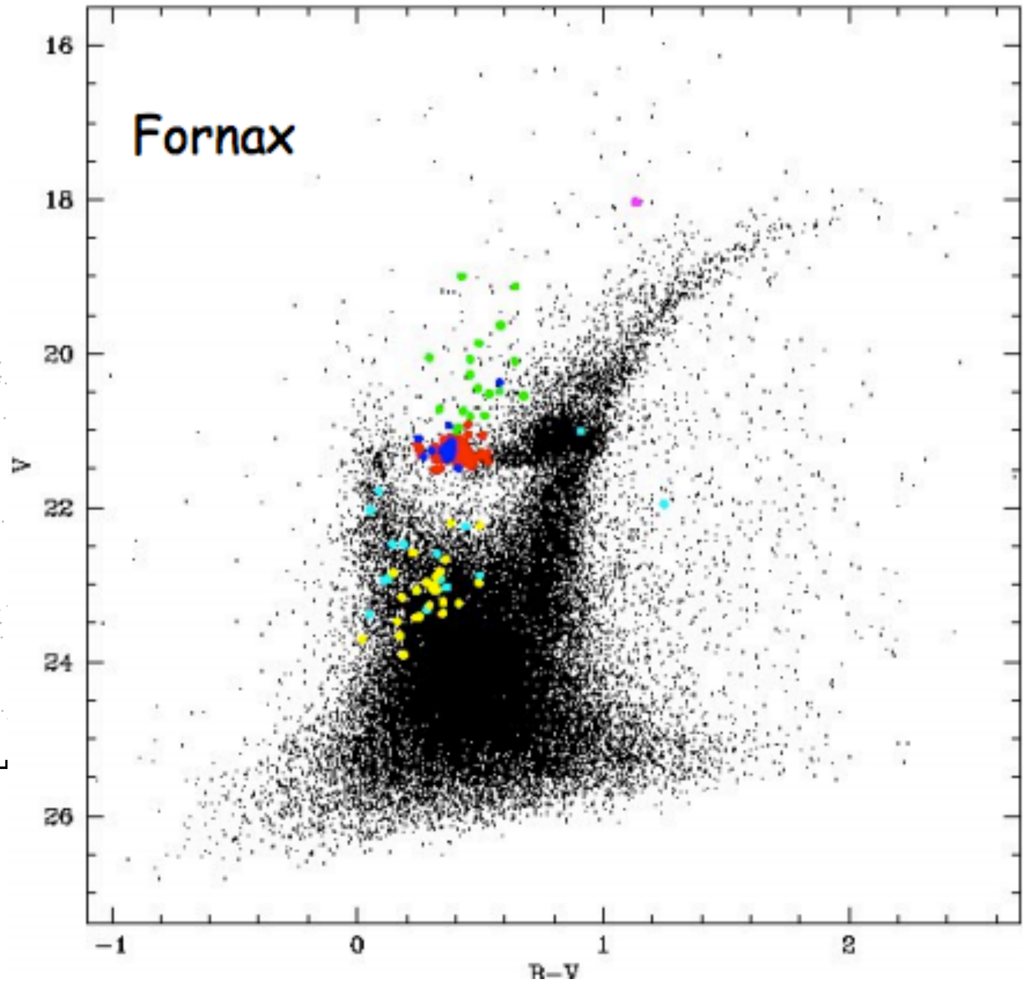
Hercules UFD

Musella et al. 2012

Trace stellar generation in different stellar systems

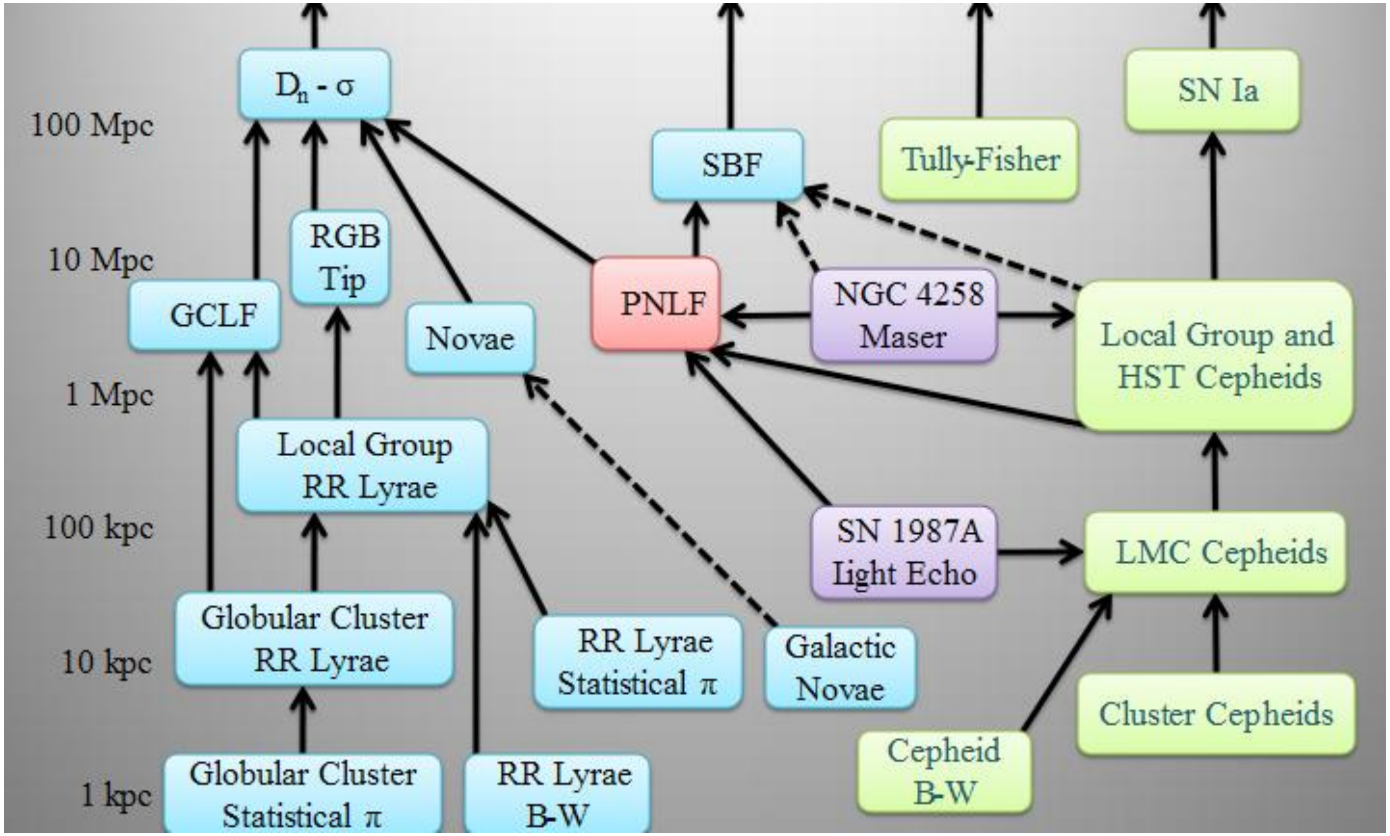


Coppola et al. 2015



Greco et al. 2007

Cosmic distance ladders



The cosmic distance scale is largely based on the Classical Cepheids and RR Lyrae stars.

One or more secondary distance indicators are needed to get to *cosmologically significant* distances and estimates H_0

Cepheids as distance indicators

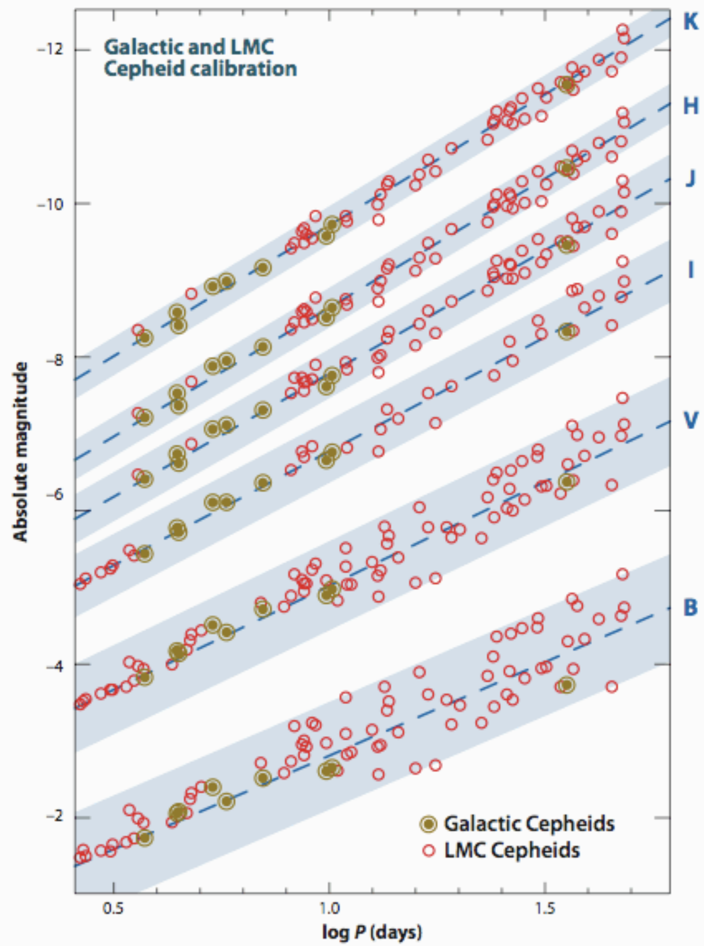


Figure 3

Composite multiwavelength period-luminosity (PL) relations (Leavitt Laws) for Galactic (*circled filled dark yellow dots*) and Large Magellanic Cloud (LMC) (*open red circles*) Cepheids from the optical (BVI) through the near-IR (JHK). There is a monotonic increase in the slope, coupled with a dramatic decrease in total dispersion of the PL relations as one goes to longer and longer wavelengths.

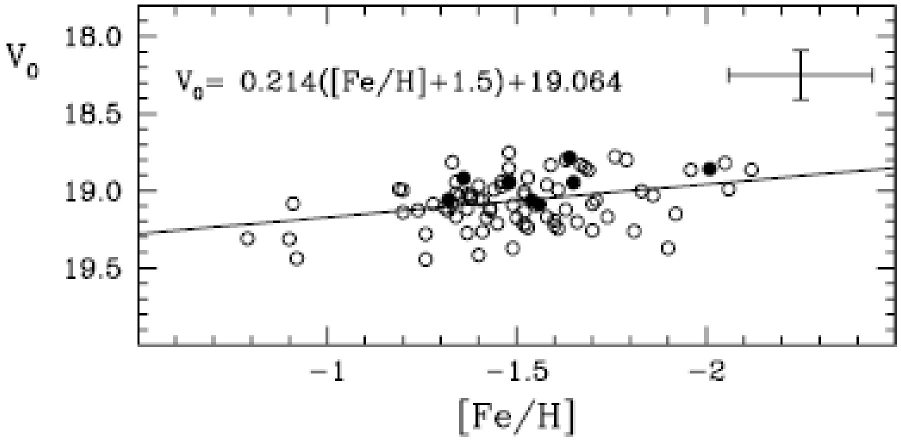
For Classical Cepheid, we ha a Period-Luminosity relation in all the bands and the dispersion decrease moving from optical to NIR bands

Slopes and zero-points are dependent on the host galaxy chemical composition

RR Lyrae as distance indicator (I)

The visual magnitude versus metallicity relation

$$M_V(RR) = a\,[Fe/H] + b$$



For LMC RR Lyrae (Gratton et al. 2004)

$0.13 < a < 0.30$ $0.5 < b < 1.0$

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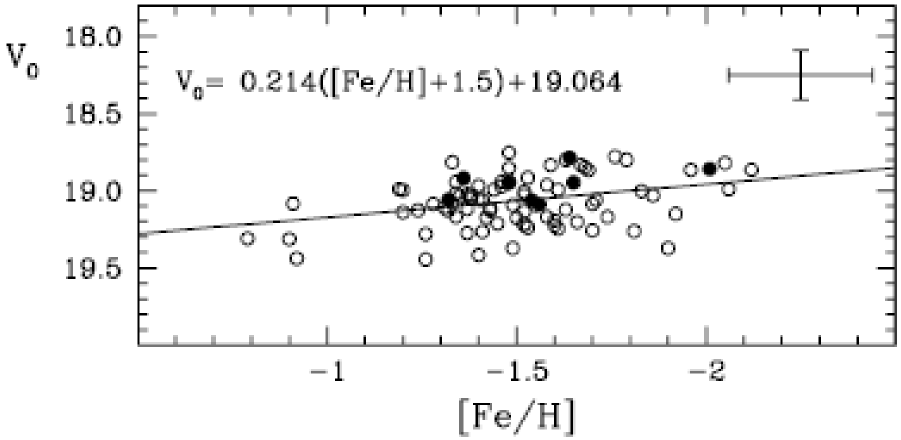

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Distances to Globular Clusters and nearby galaxies containing RR Lyrae if the metal abundance is known or measurable.

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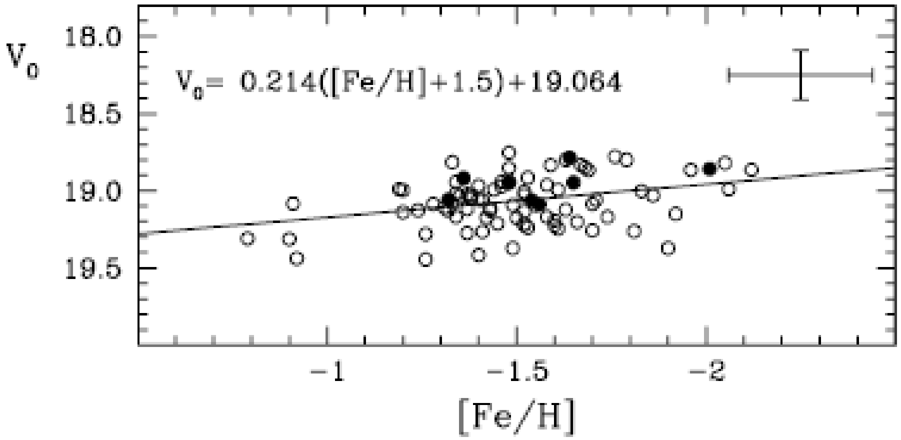

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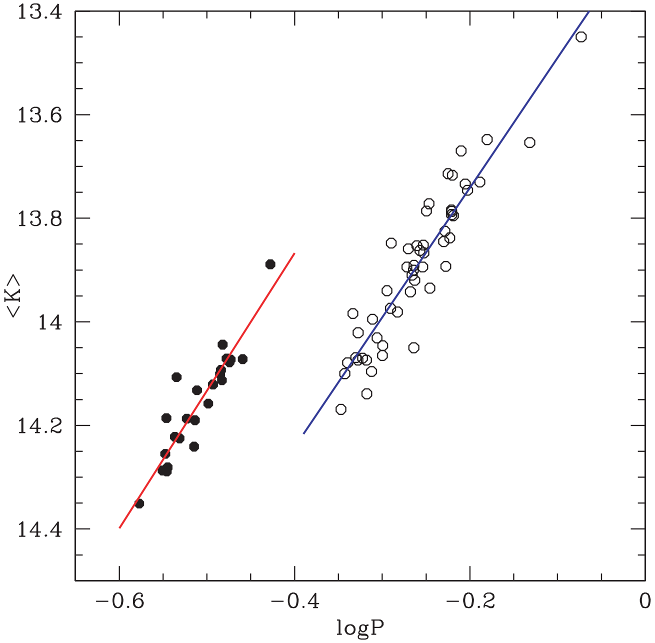
$0.13 < a < 0.30$ $0.5 < b < 1.0$

- **Distances to Globular Clusters and nearby galaxies containing RR Lyrae if the metal abundance is known or measurable.**
- **The slope and the zero point of the relation $M_V = a + b\,[Fe/H]$ can give information on the relative and absolute ages of globular clusters respectively.**

RR Lyrae as distance indicator (II)

The Period-Luminosity relation in the K (2.2μm) band

(since Longmore 1986, 1990)



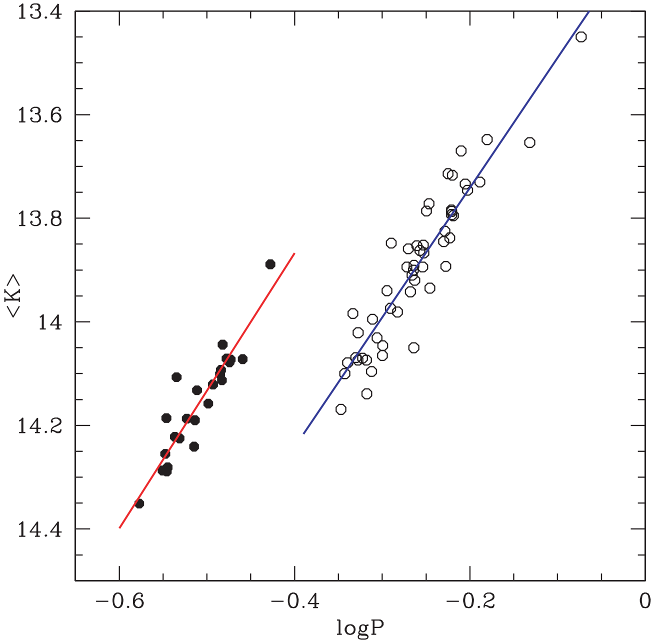
M5

Coppola et al. 2011

RR Lyrae as distance indicator (II)

The Period-Luminosity relation in the K (2.2μm) band

(since Longmore 1986, 1990)



M5

Coppola et al. 2011

The reddening effect on the NIR bands is much smaller than in V

RR Lyrae as distance indicator (II)

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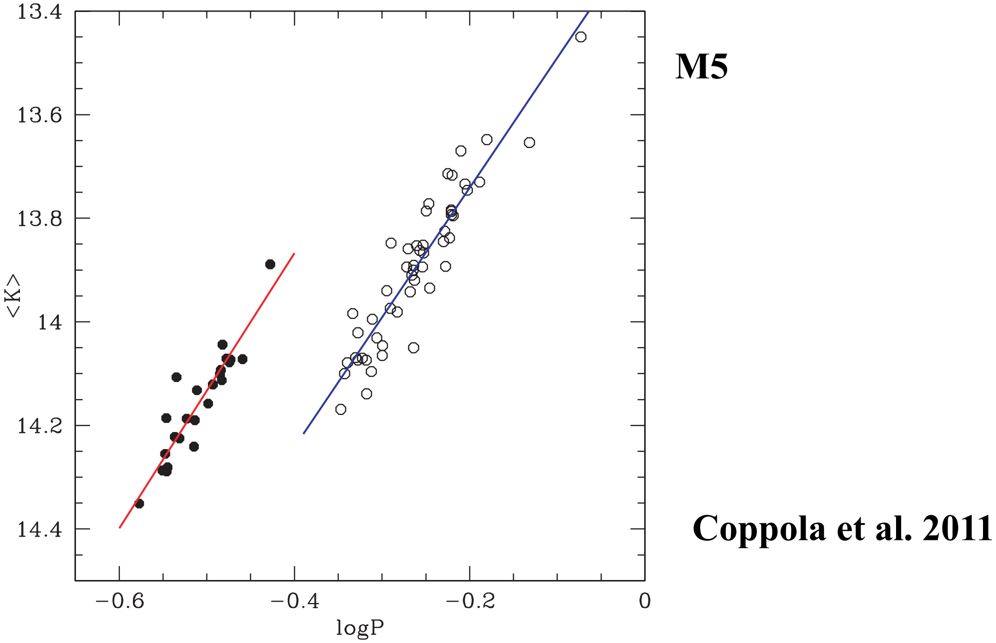

➡ **The reddening effect on the NIR bands is much smaller than in V**

➡ **Period is a very solid parameter: if apparent magnitudes are measured and the metallicity effect is small, the application of a PL(K) gives the distance of the investigated stellar system**

Derivations of the PL_KZ relation

Tight PLZ_K relation (σ~0.05 mag) but…..

M_K=-2.101 logP+0.231[Fe/H] – 0.77 (Bono et al. 2003)

M_K=-2.353 logP+0.175logZ – 0.597 (Catelan et al. 2004)

M_K=-2.38 logP+0.08[Fe/H] – 1.07 (Sollima et al. 2008)

➔ Significant uncertainty on the coefficients and in particular on the metallicity term (!)

Open problems

- Dependence of the Cepheid Period-Luminosity relations and of the RR Lyrae Period-Luminosity in the K band on the chemical composition of the host galaxy
- Systematic effects on secondary distance indicators
- Consistency between Cepheids and RR Lyrae distance scales

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↓

and in turn on the Ho determination

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↓

and in turn on the Ho determination

To address these issues is fundamental to have a theoretical scenario

we need accurate pulsation models to reproduce and interpret the observational properties (and to calibrate the Cosmic distance scale problem)

Theoretical constraints to the Cepheid and RR Lyrae based estimates of the Hubble constant

Extensive sets of nonlinear convective pulsation models for variables (Cepheids, RR Lyrae, Anomalous Cepheids…) at varying chemical composition (Z and Y).
(*see e.g.Bono, Marconi, Stellingwerf 1999, Fiorentino et al. 2002, Marconi et al. 2003, Di Criscienzo et al. 2004, Marconi, Musella, Fiorentino 2005, Marconi et al. 2010*)

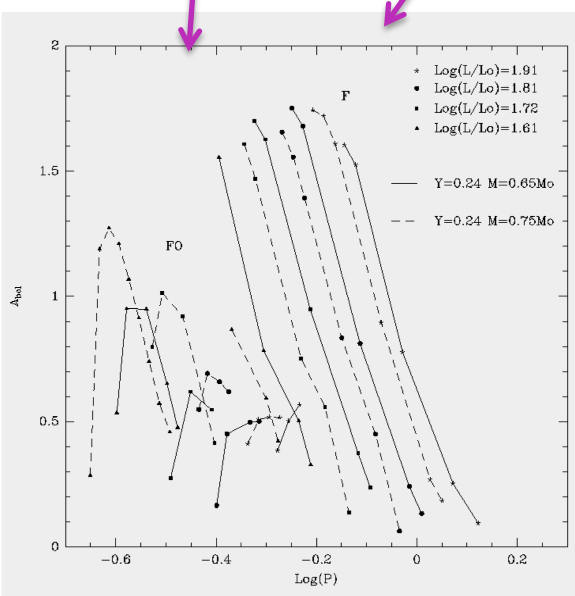
↓

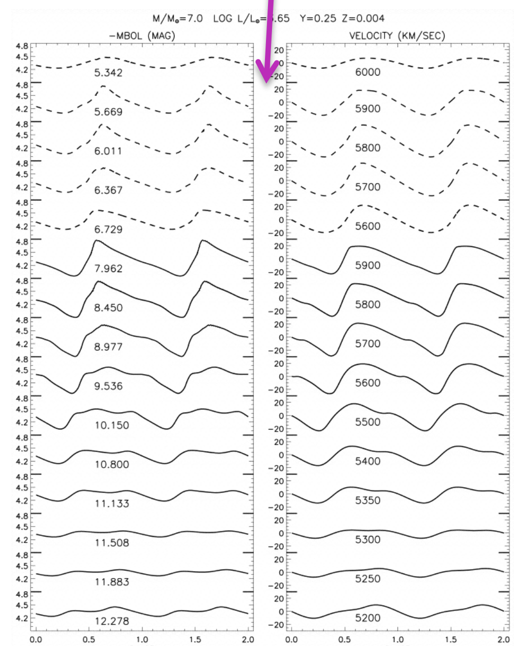
Interpretation of the observed pulsation properties, theoretical calibration of the extragalactic distance scale and of its dependence on chemical composition.
(*see e.g. Caputo, Marconi, Musella 2000, Fiorentino et al. 2007, Bono et al. 2008, 2010, Marconi et al. 2010, Marconi et al. 2011, Fiorentino, Musella, Marconi 2013, Marconi et al. 2015)*

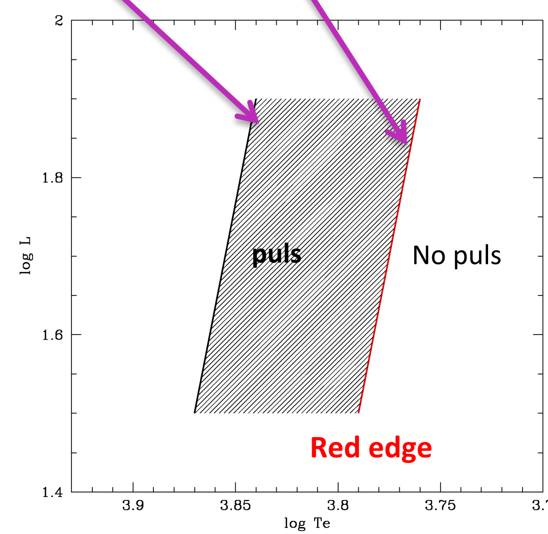
Theoretical approach to the study of pulsating stars

NON linear convective approach *(Gehmeyr et al. 1990, Bono & Stelingwerf 1994, Bono, Marconi Stellingwerf 1999, Szabo et al. 2000, 2004)* allow to have

⟹ **Periods, amplitudes, lightcurves, blue and red edges**

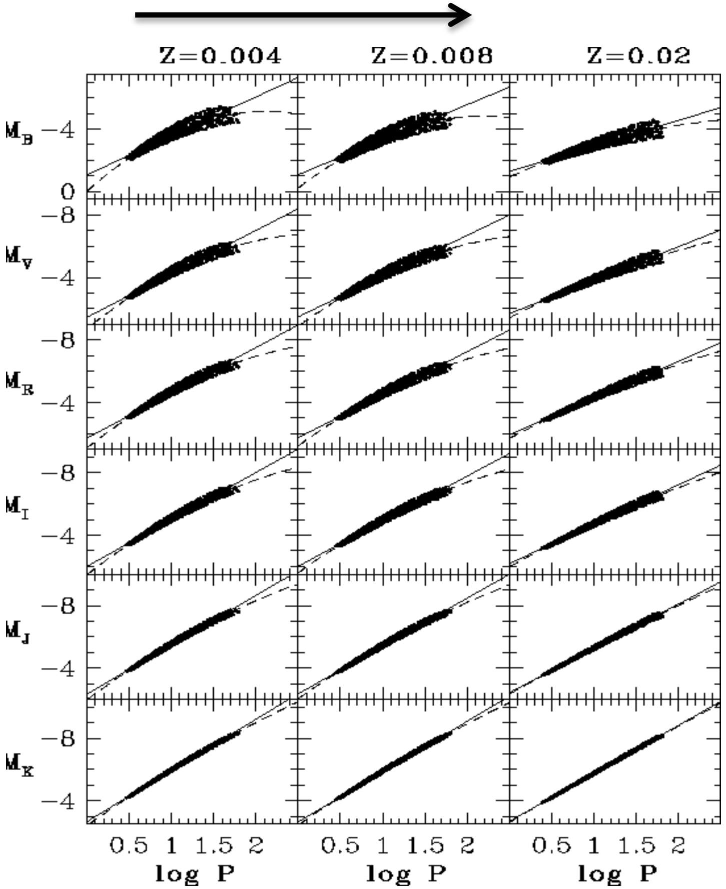






Cepheid PL relations

As Z increases the PL gets flatter !!



Caputo, Marconi, Musella 2000, A&A

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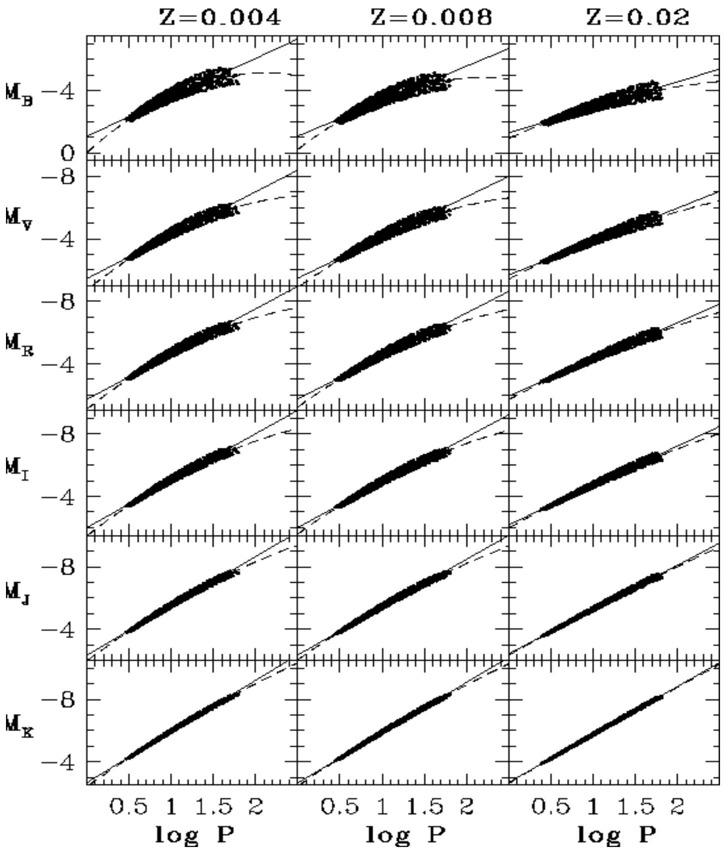
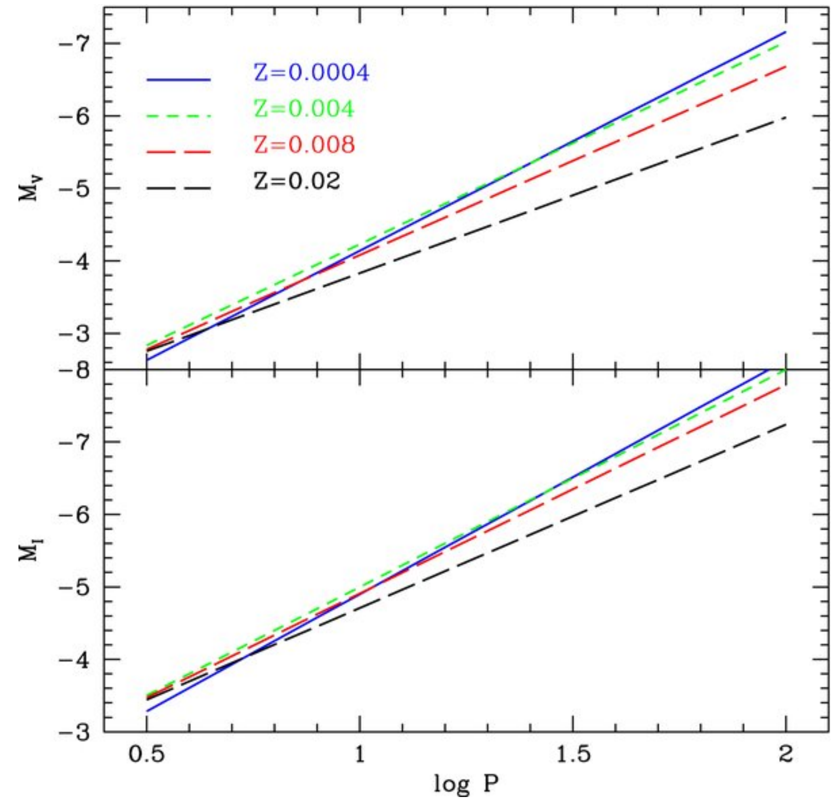


Caputo, Marconi, Musella 2000, A&A

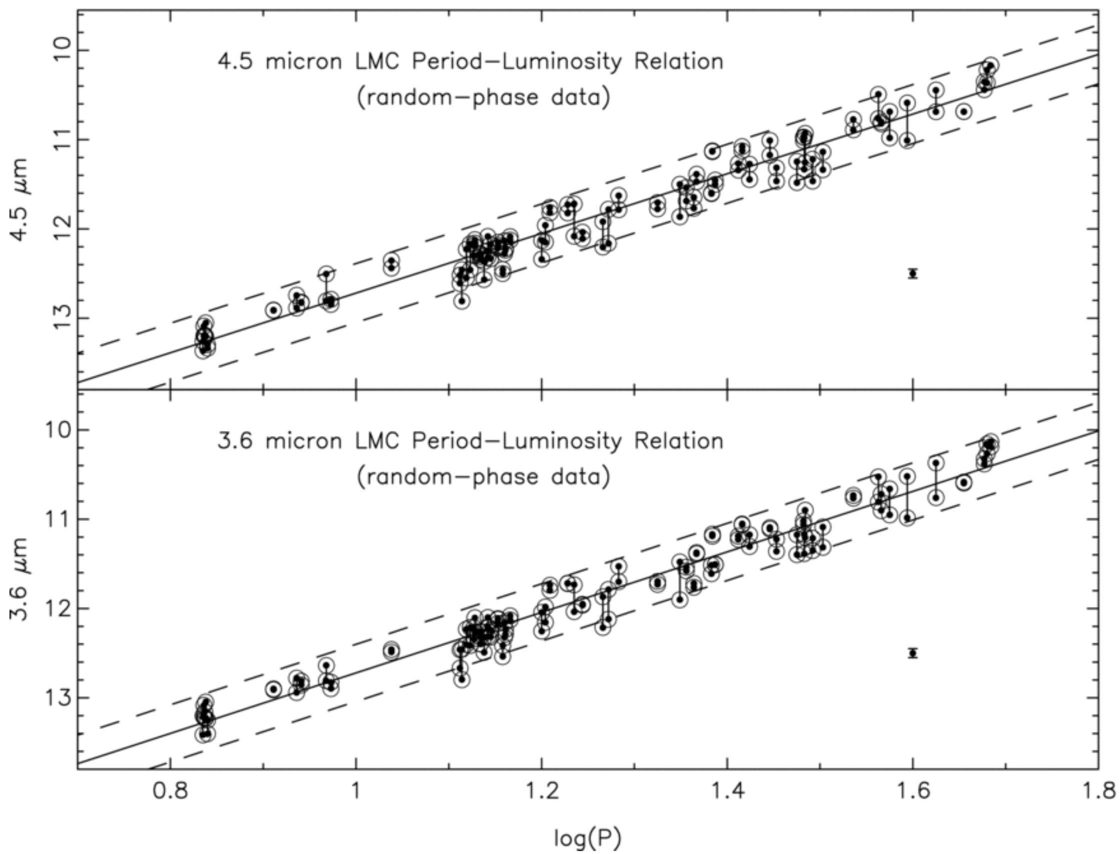
At very low metallicity
the effect saturates



Recent observations confirm this result
(Pietrzynski et al. 2006, 2007)

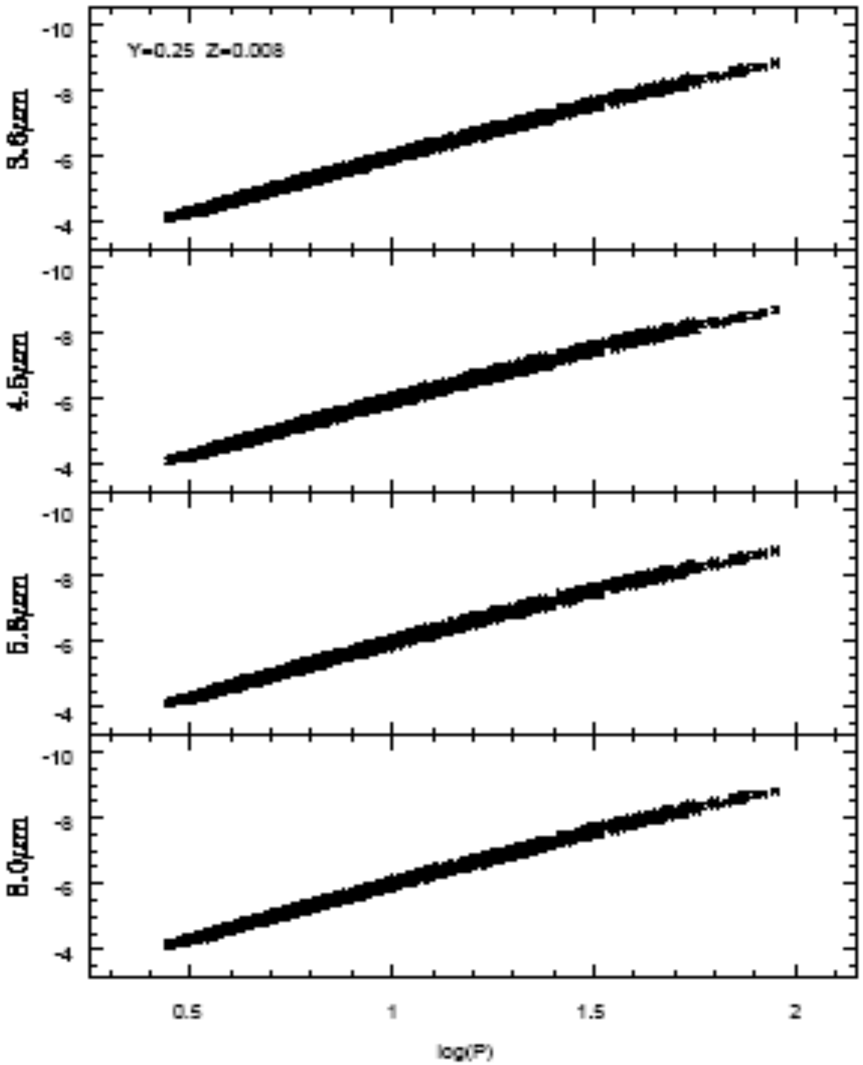
MIDinfrared Cepheid PL relations

The mid-infrared Cepheid PL relation will be important in the JWST (James Webb Space Telescope) era, as it holds the promise of deriving the Hubble constant at the 2% level (Freedman & Madore 2010).



→ the Spitzer's IRAC band (3.6μm, 4.5μm, 5.8μm & 8.0μm) P-L relations were derived for Cepheids in our Galaxy (*Marengo et al. 2010*), in the LMC (*Freedman et al. 2008; Ngeow & Kanbur 2008; Madore et al. 2009; Ngeow et al. 2009*) and in the SMC (*Ngeow & Kanbur 2010*).

Theoretical MIDinfrared PL relations



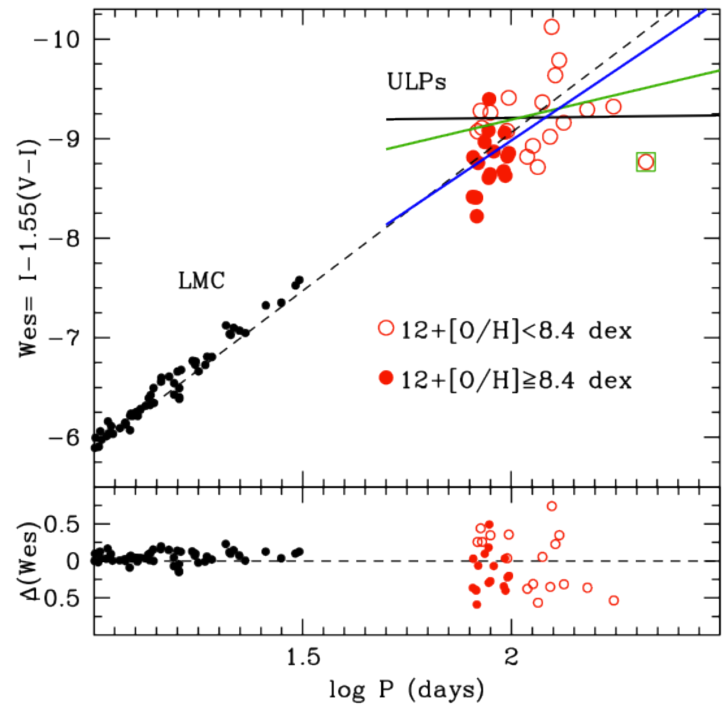
The dispersions of the PLs in these bands are negligible

Ngeow et al, 2012, ApJ

Ultra long Period variables

ULPs identified in nearby star forming galaxies (Bird et al. 2009) with P>80 d

- ⋆ much brighter (M_I from -7 to -9 mag) than 'short period' Cepheids
- ⋆ HST is able to observe them up to 100 Mpc
- ⋆ Metal poor: NGC 6822(Pietrzynski et al. 2004), NGC 55 (Pietrzynski et al. 2006), NGC 300 (Gieren et al. 2004), IZw18 (Fiorentino et al. 2010)
- ⋆ Metal rich: NGC 1309- NGC 3370- NG3021 (Riess et al. 2009), M81 (Gerke et al. 2011), NGC4852 (7), Antenna (11), N5584 (8) (Riess et al. 2011)



they should represent "best standard candles" to extend the cosmic distance ladder to the 100 Mpc and beyond and GAIA will give direct calibration of LMC ULPs with parallaxes at μarcsec accuracy

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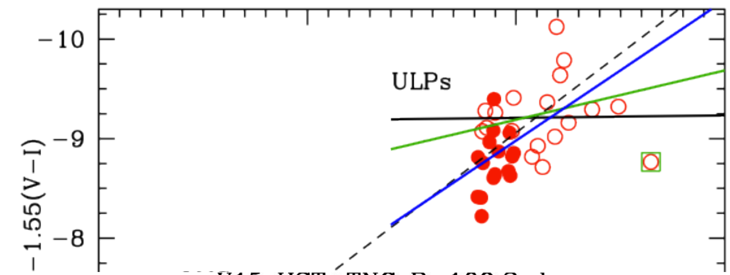
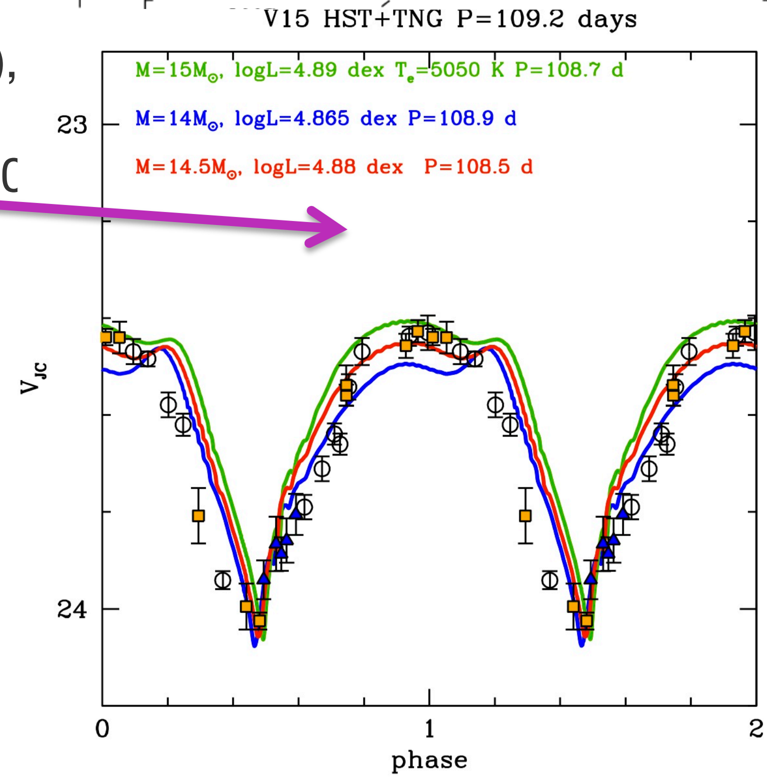




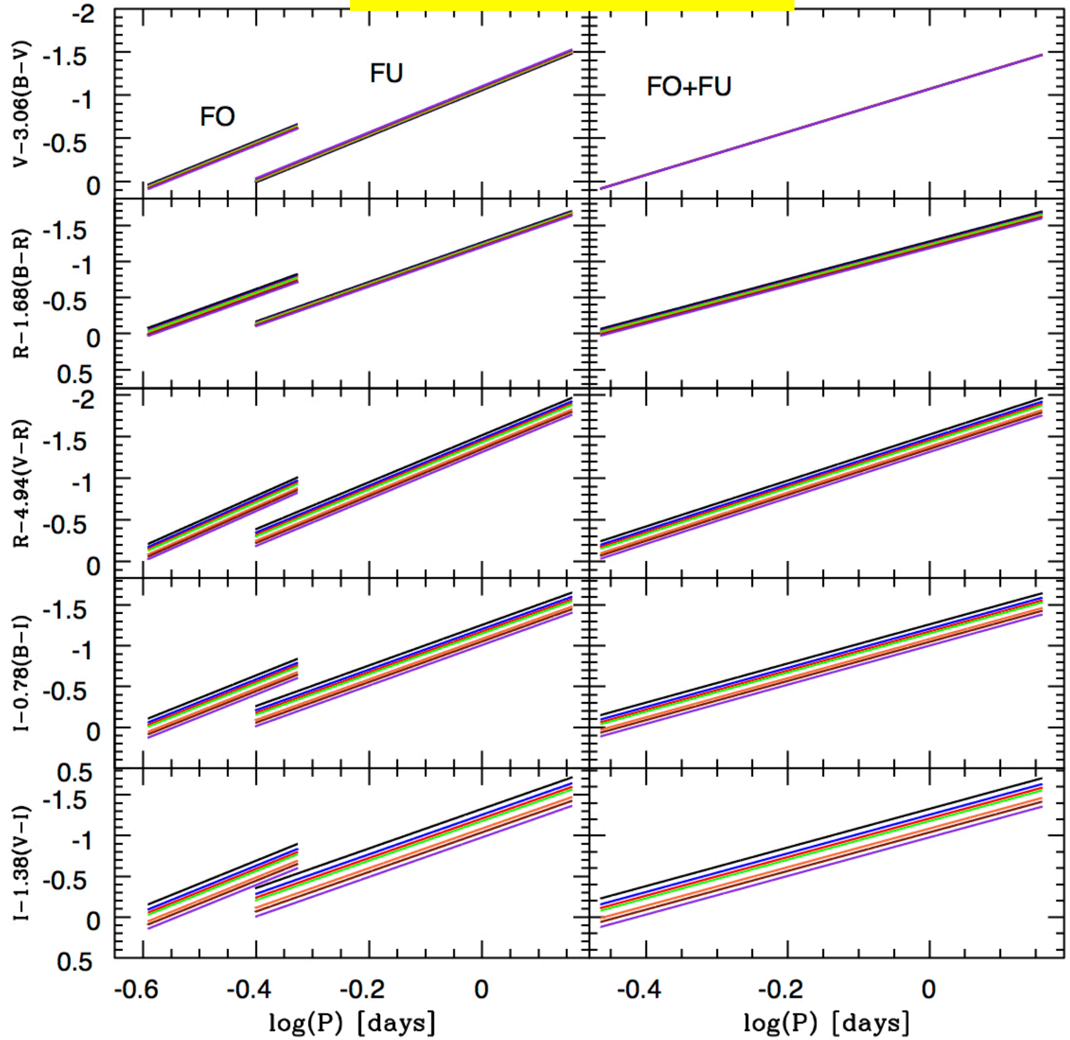
We need to understand the nature of these pulsators

RR Lyrae Wesenheit relation

The new metal-dependent WESENHEIT relations for RR Lyrae:
model predictions and applications to observations

Wesenheit relations

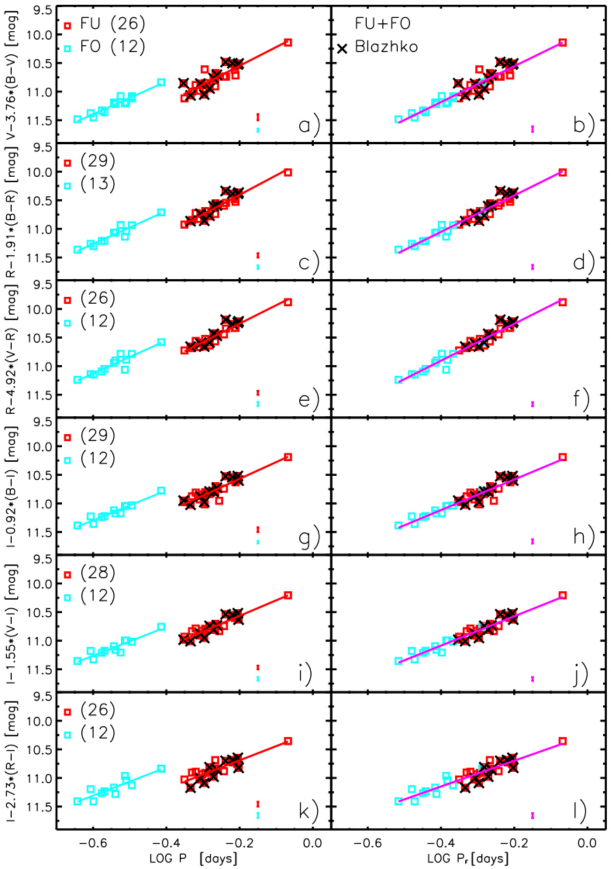
B,B-V Wesenheit is **not** sensitive to metallicity !!!

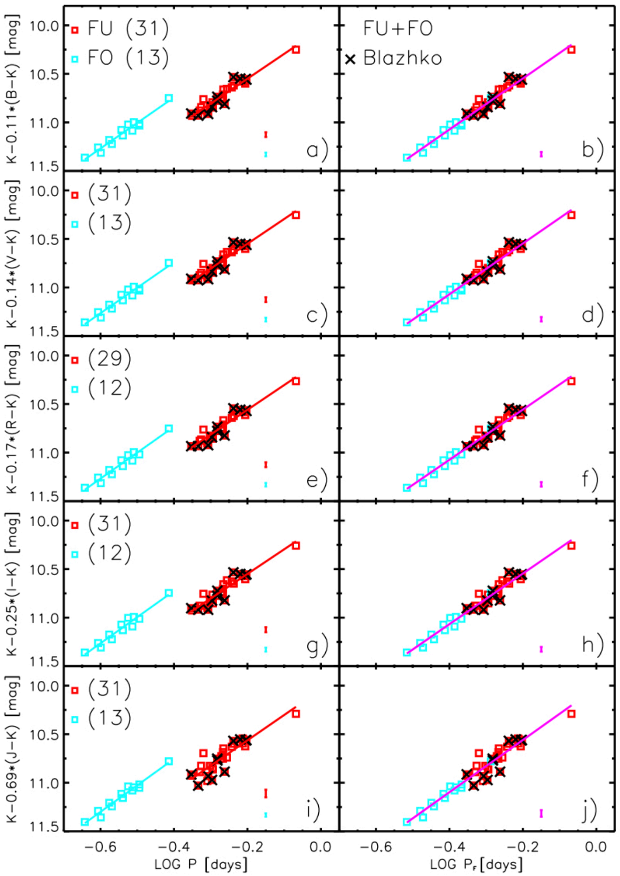


Marconi et al. 2015 ApJ

RR Lyrae Wesenheit relation

The case of M4



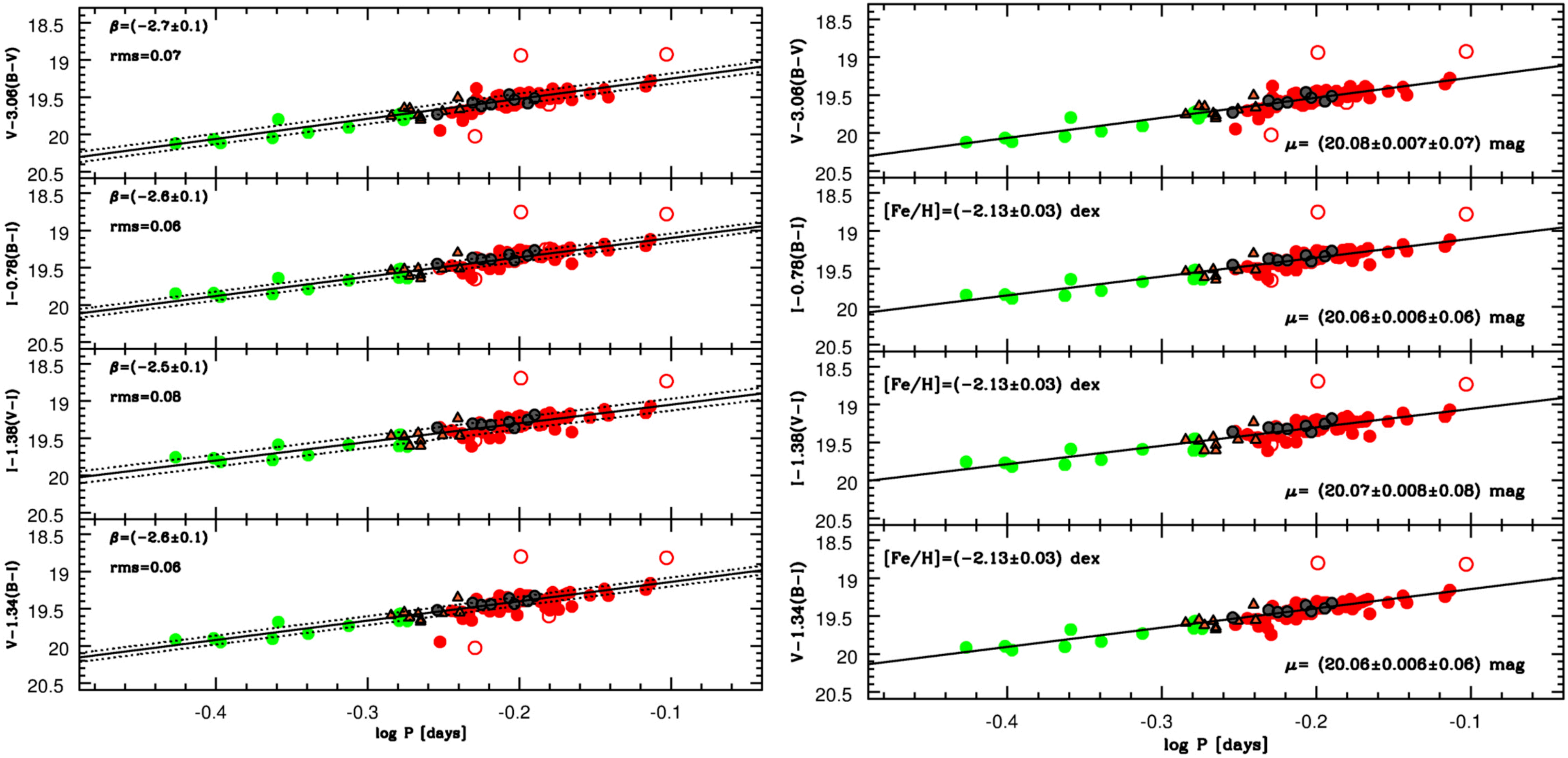


Braga et al. 2015 ApJ

→ distances to globulars hosting RRLs with a precision better than 2%-3%.

RR Lyrae Wesenheit relation

The case of Carina

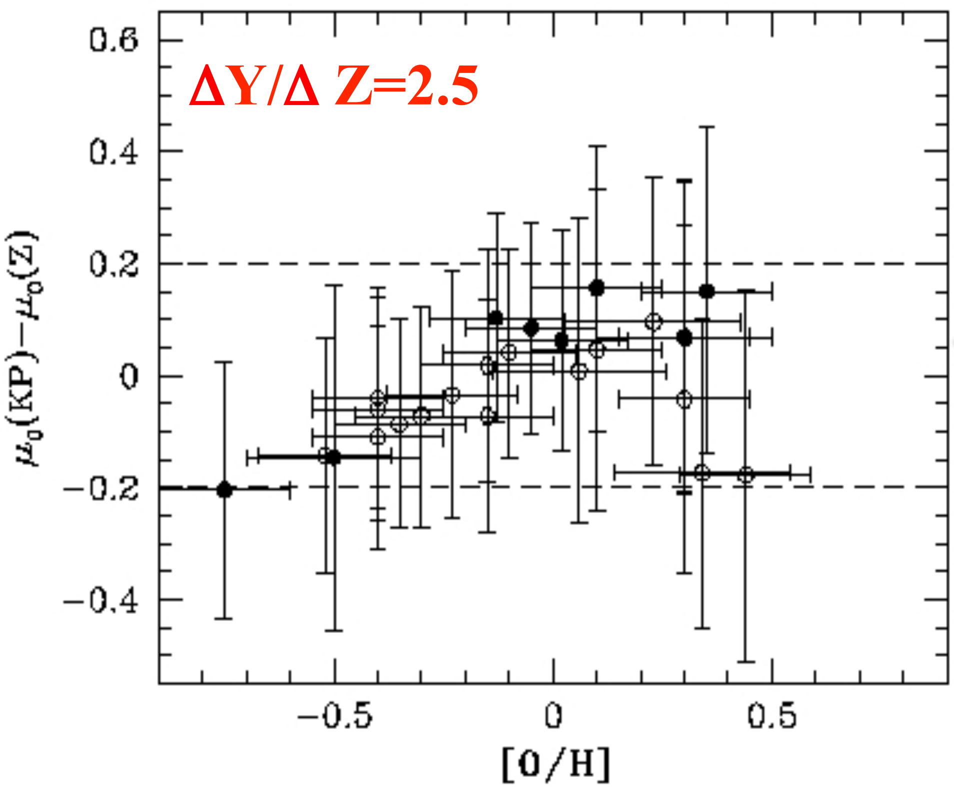


Coppola et al. 2015 ApJ

Metallicity effects on the Cepheid extragalactic distance scale

μ_0(KP) = KP distance modulus adopting LMC slope

μ_0(Z) = distance modulus adopting the theoretical slope corresponding to the host galaxy



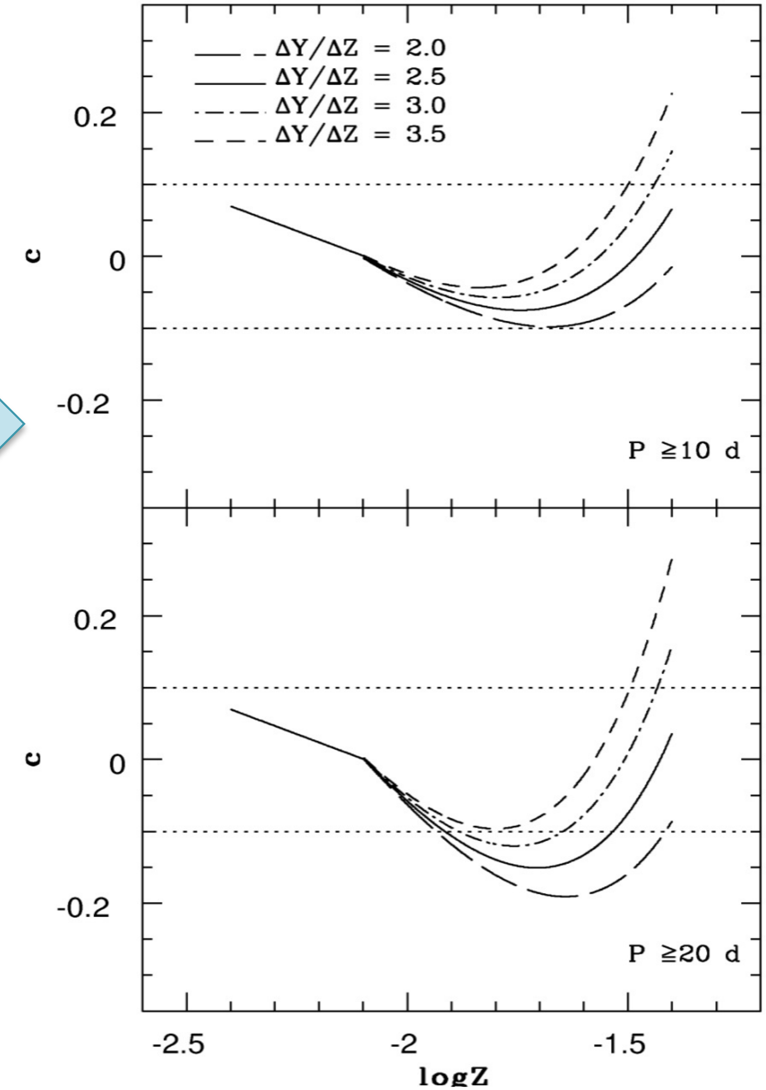
Distance modulus correction when the true metallicity is taken into account

Marconi, Musella & Fiorentino, 2005

Metallicity effects on the Cepheid extragalactic distance scale

Simultaneous effect of Z and Y variations on the instability strip topology and PL relation

Dependence on ΔY/ΔZ



Marconi, Musella, Fiorentino 2005, ApJ

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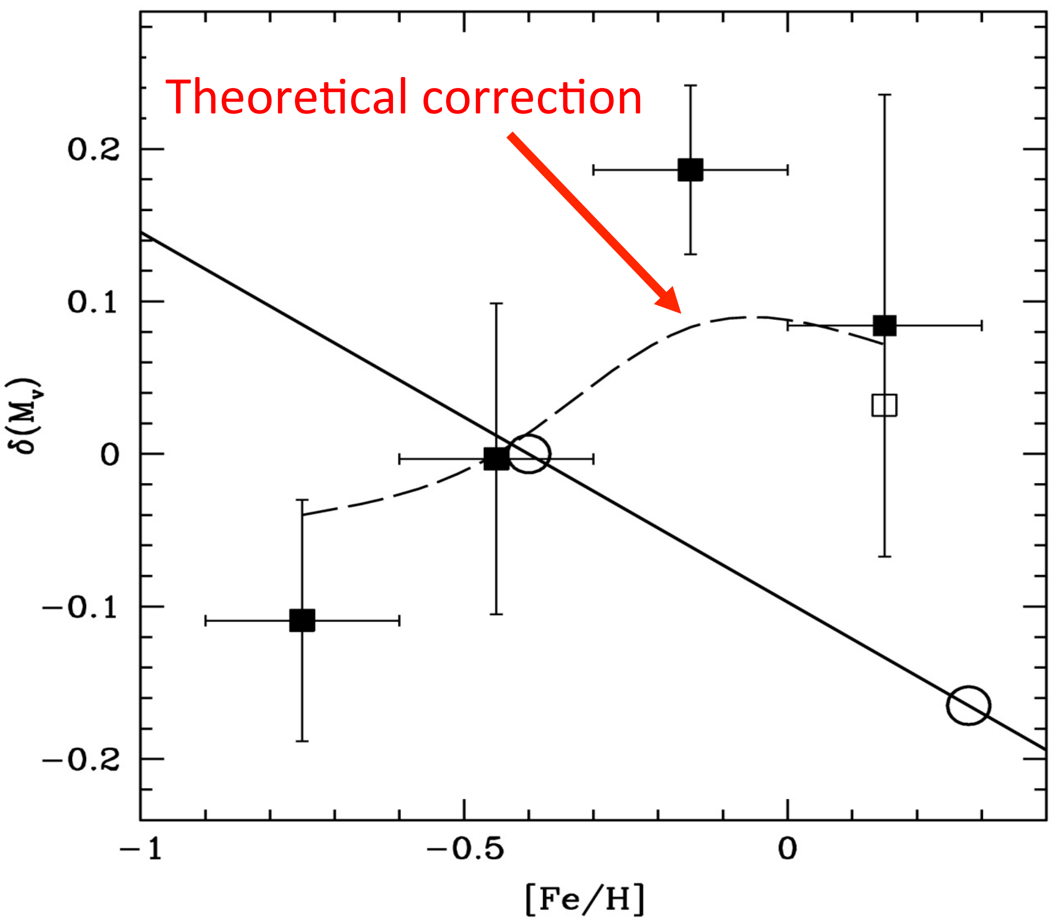
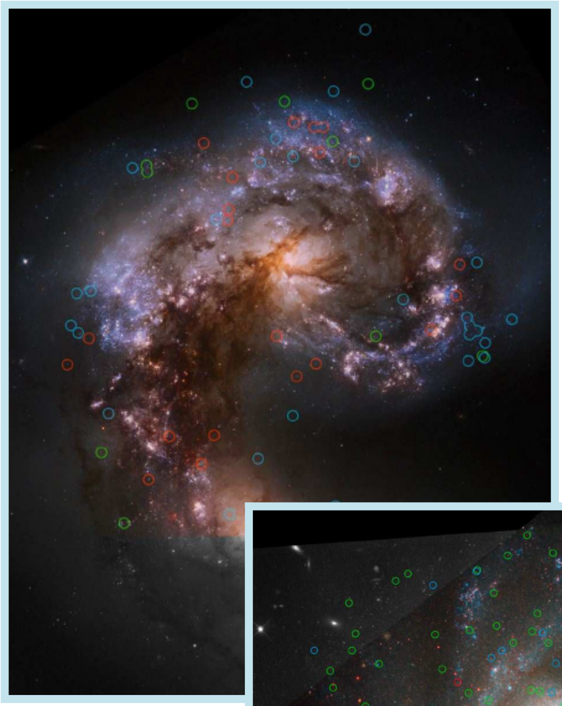
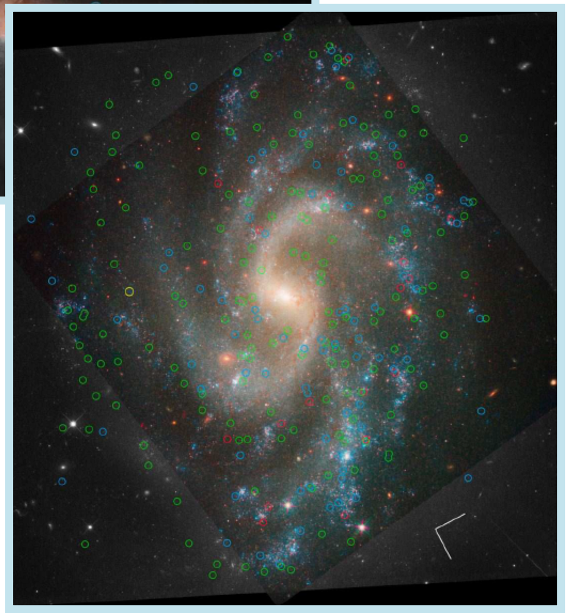


Qualitatively in agreement with the results based on spectroscopic [Fe/H] measurements of Galactic Cepheids

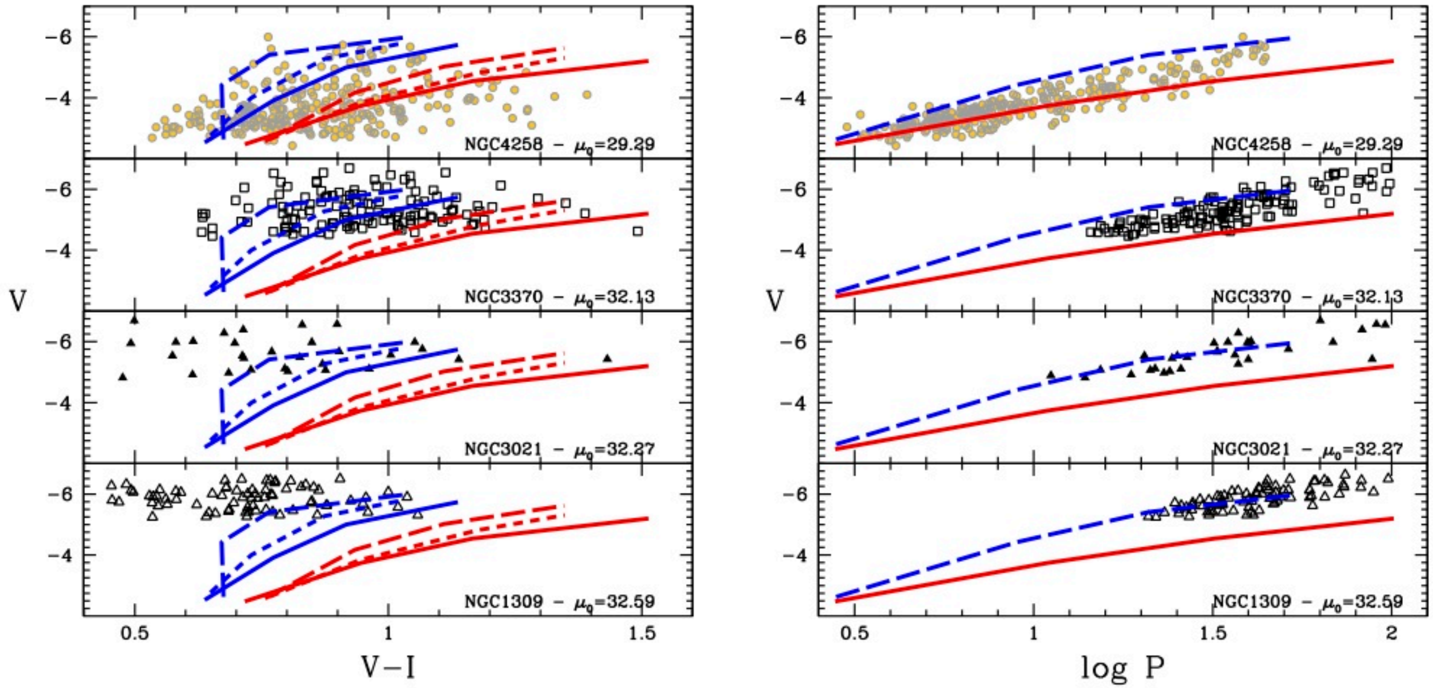
Riess Cepheid sample

Macri et al. 2006, Riess et al. 2009a,b, Riess et al. 2011

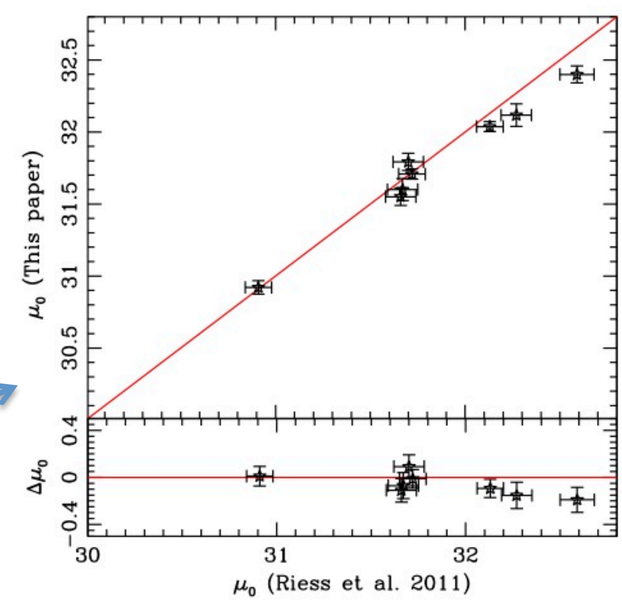




- ACS and WFC3-IR camera (Riess 2011) on board HST Cepheid in 8 SNIa hosting galaxies.
- The zero point anchored to NGC4258 (Z=0.02, d=7.2±0.5 Mpc, Maser geometrical distance)



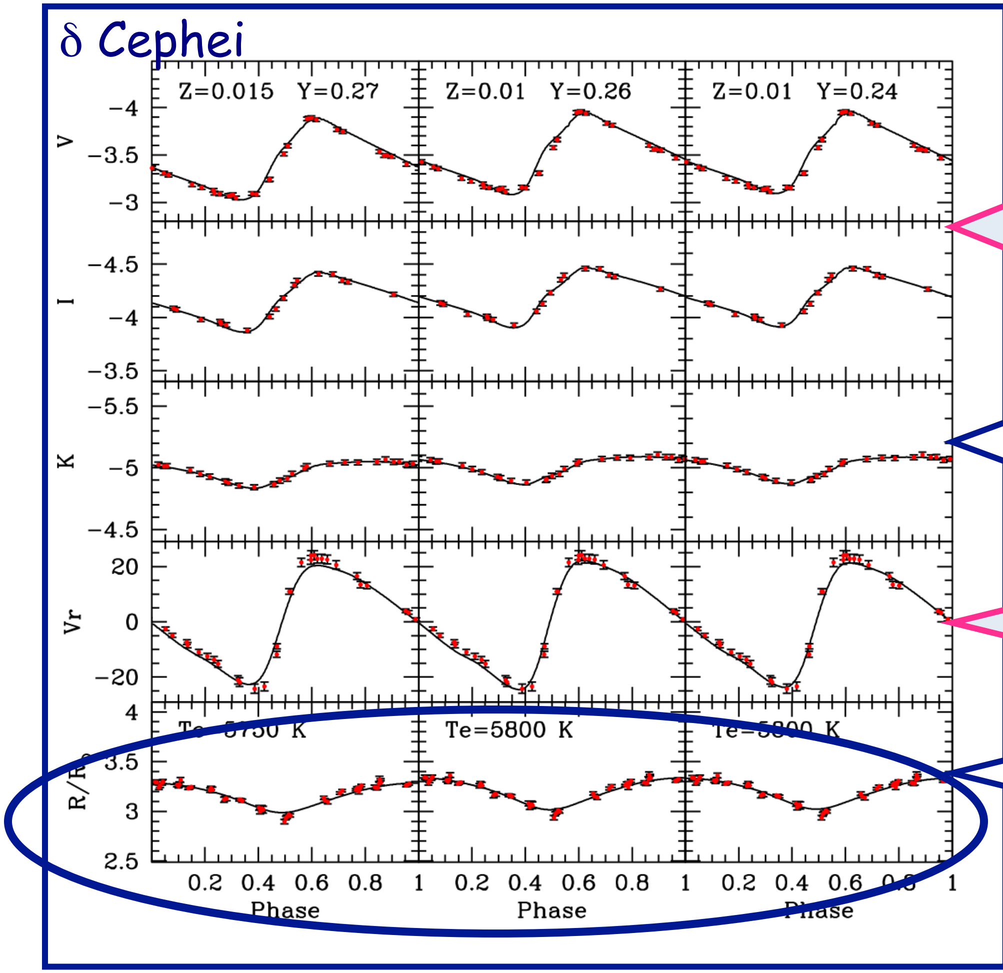
Predicted strip in agreement with observations for NGC4258 but systematically redder than Cepheids in further galaxies.



Theoretical correction to extragalactic distances

Fiorentino, Musella, Marconi 2013 MNRAS

Model fitting of light, radial, velocity curves



(Natale, Marconi, Bono 2008 ApJL)

the shape and the amplitude in the optical bands depend on surface temperature and radius variation,

the dependence on temperature is significantly reduced in the K band

Vrad independent of reddening, but dependent on p factor

Independent of reddening and p-factor

The model fitting of OGLE-LMC-CEP0227

Pietrzyński et al. (2010) ➔ first accurate determination of the dynamical mass of a classical Cepheid in a well-detached, double-lined, eclipsing binary in the LMC (OGLE-LMC-CEP0227).

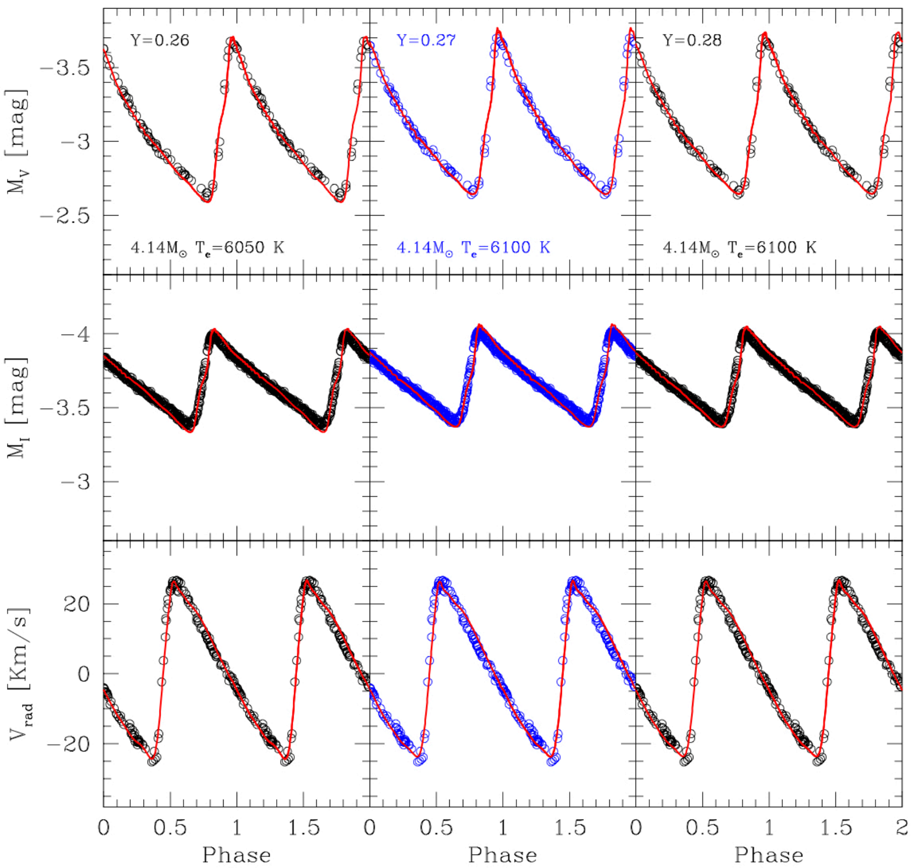
High-quality photometric data set + spectroscopic follow-up + near-perfect system

⬇

Cepheid mass of the pulsator to an unprecedented 1% precision.

Physical Parameter	Primary (A)	Secondary (B)
Mass ($M/M_\odot$)	4.14 ± 0.05	4.14 ± 0.07
Radius ($R/R_\odot$)	32.4 ± 1.5	44.9 ± 1.5
Teff(K)	5900 ± 250	5080 ± 270

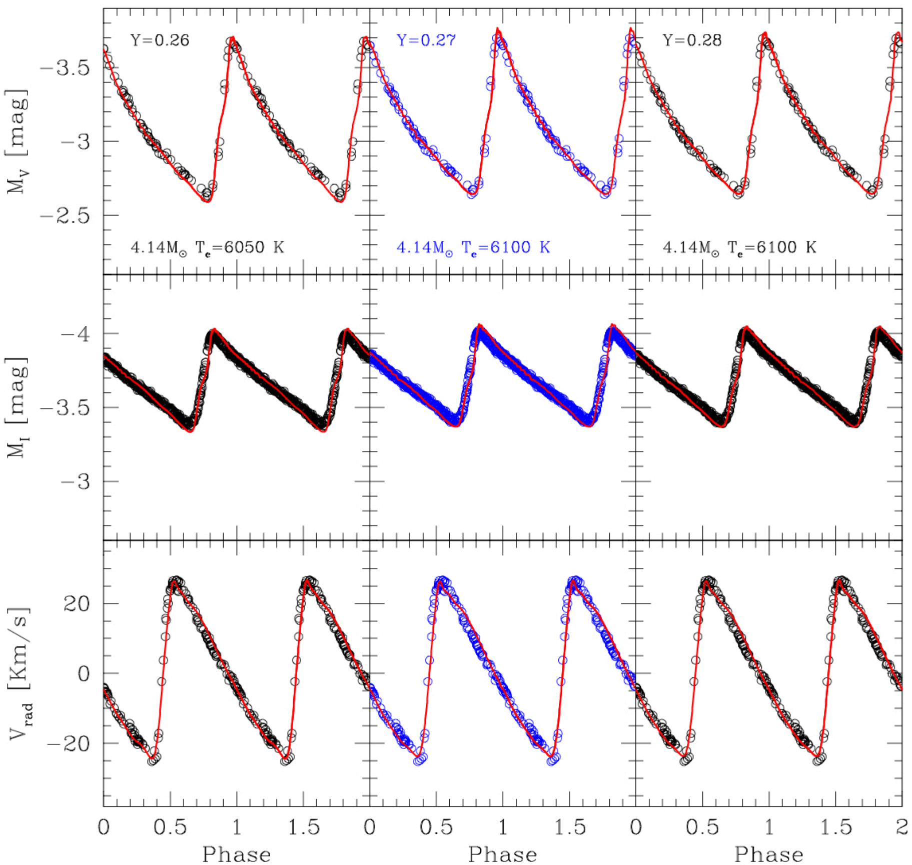
The model fitting of OGLE-LMC-CEP0227



	Model fitting	Dynamical estimate
$M/M_\odot$	4.14	4.14±0.05
$R/R_\odot$	34.3	33.7±1.5
T_e(K)	6100	5900±250

$M_{0(LMC)}$=18.50 mag E(B-V) = 0.1 mag

The model fitting of OGLE-LMC-CEP0227



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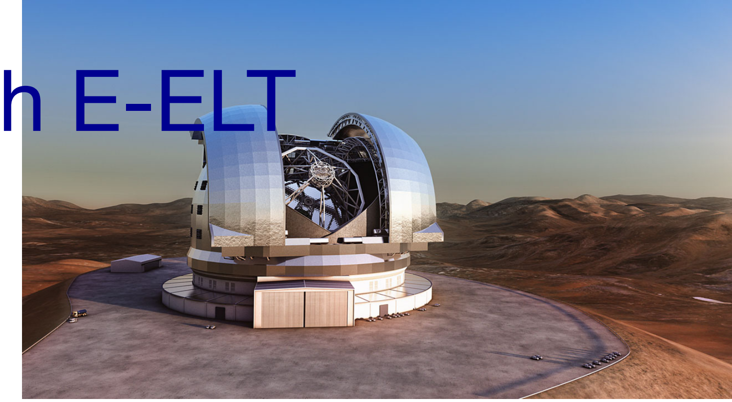
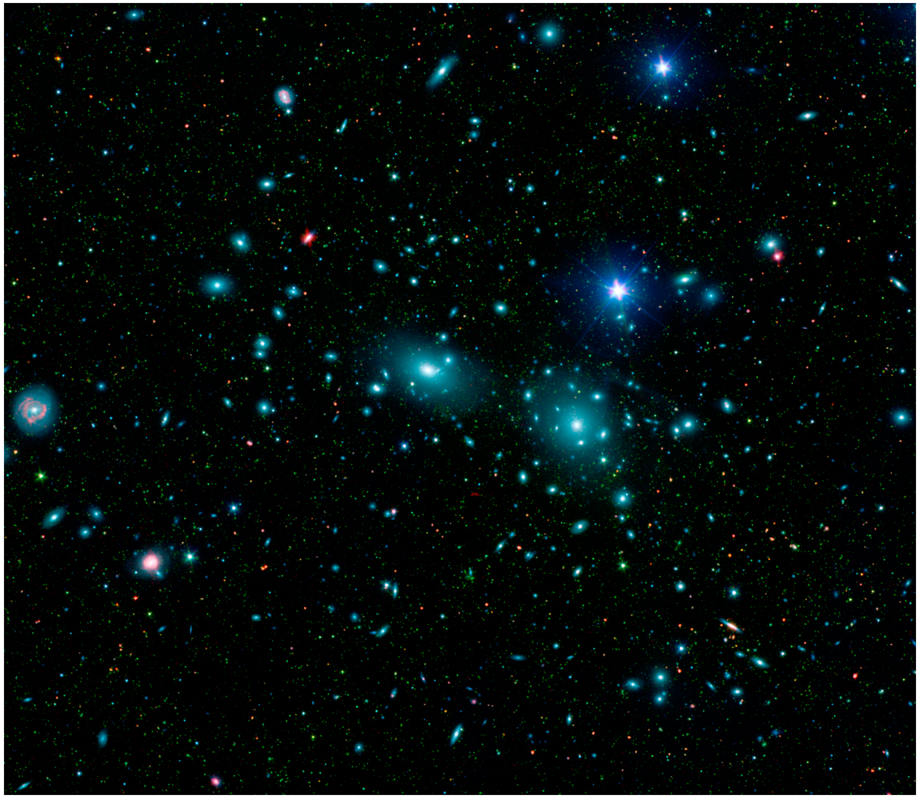
$M_{0(LMC)}$=18.50 mag   E(B-V) = 0.1 mag

Interesting application for GAIA

Perspective for Cepheids with E-ELT





Fix the metallicity issue

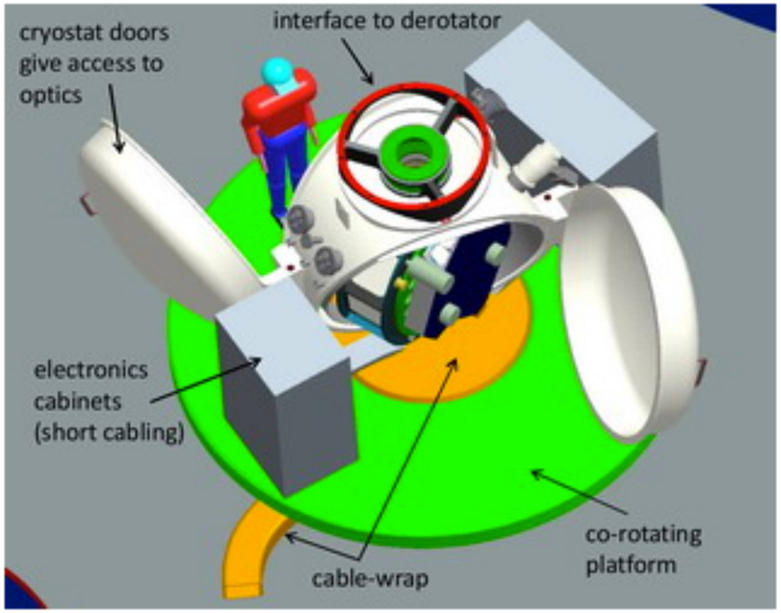
ELT high resolution MOS → spectroscopic characterization (abundances) of large extragalactic Cepheid samples → *metallicity effect on the PL outside the MW*

Reaching COMA in one step:

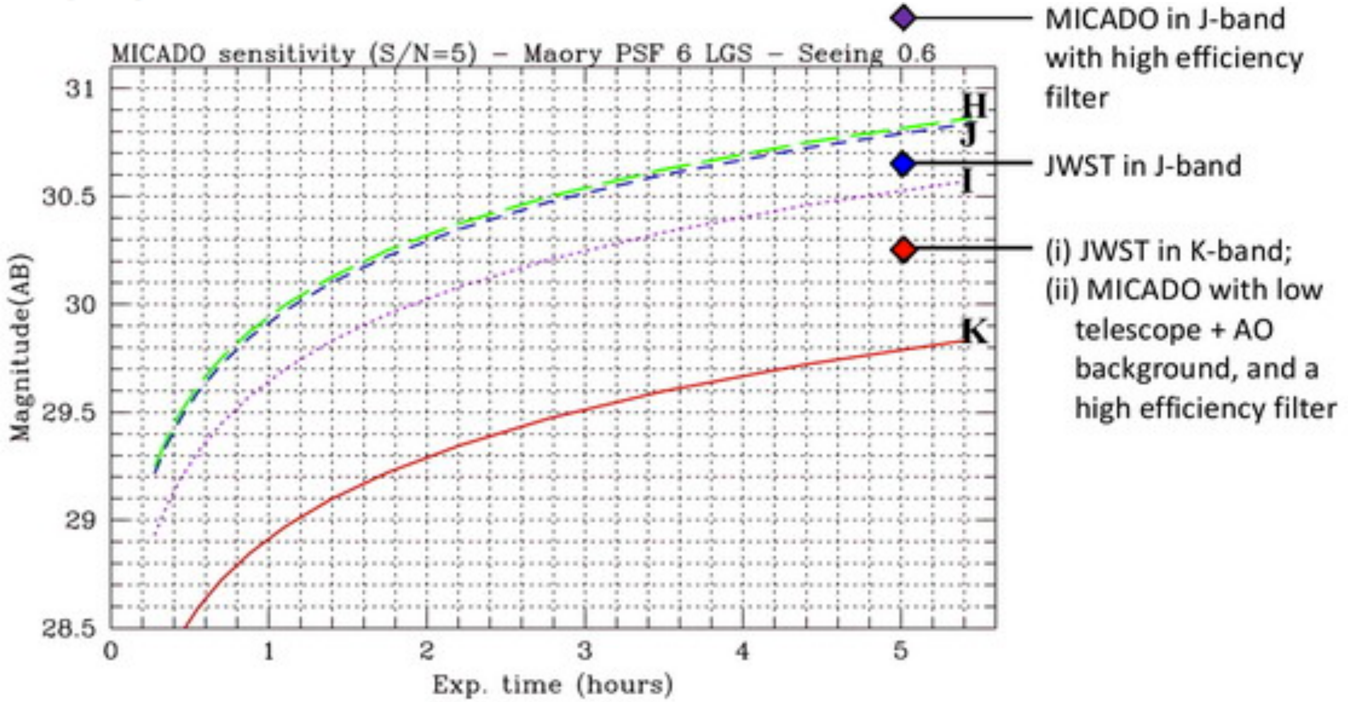
E-ELT CAM (MICADO) → even in crowded fields, opportunity to observe Classical Cepheids in the Coma Cluster, and in turn the ***opportunity to estimate the Hubble constant only using primary distance indicators!!***

E-ELT CAM: MICADO

Plus SCAO + MAO+MCAO

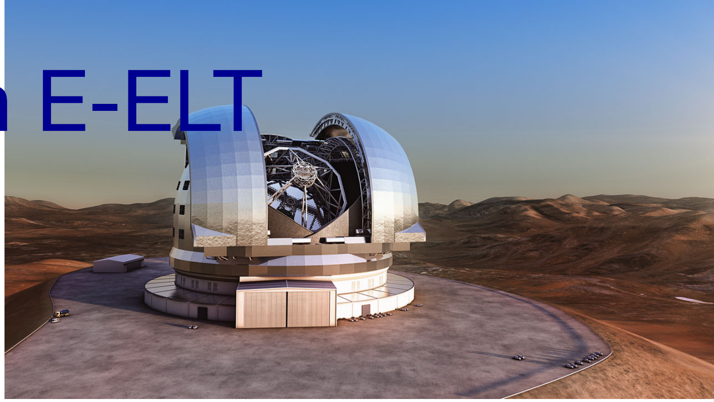


Overview of MICADO



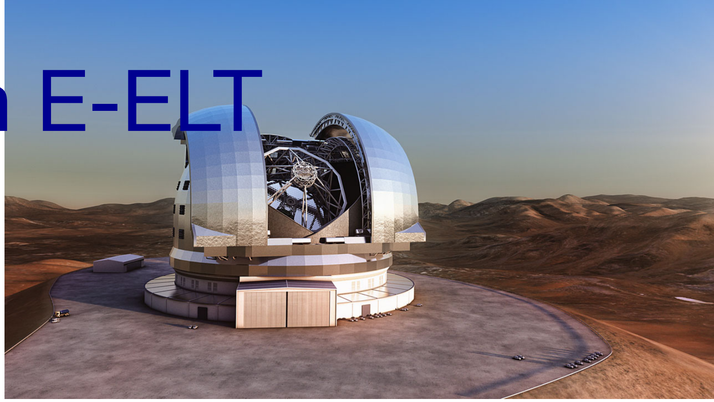
Broadband imaging sensitivity of MICADO as a function of integration time

Perspective for RR Lyrae with E-ELT



To measure the brightness of HB stars with accuracy ~10% within 31-32 mag in the V band, and 28-29 mag in the K band in spiral galaxies and ~36/33 mag (V/K band) in elliptical Galaxies

Perspective for RR Lyrae with E-ELT



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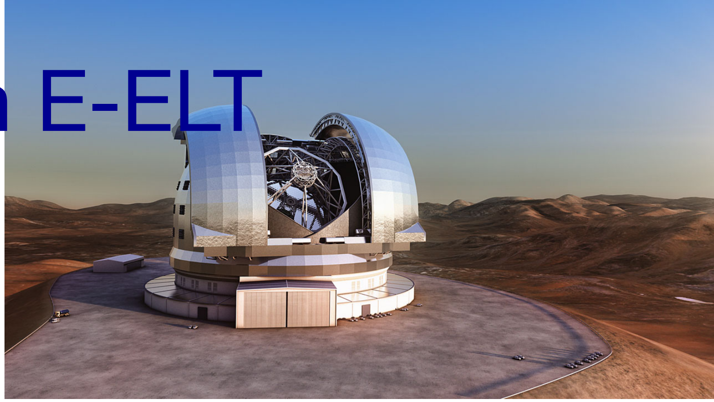
➔detection of HB stars and RR Lyrae variables in several giant spiral and elliptical galaxies in the Virgo cluster

Perspective for RR Lyrae with E-ELT



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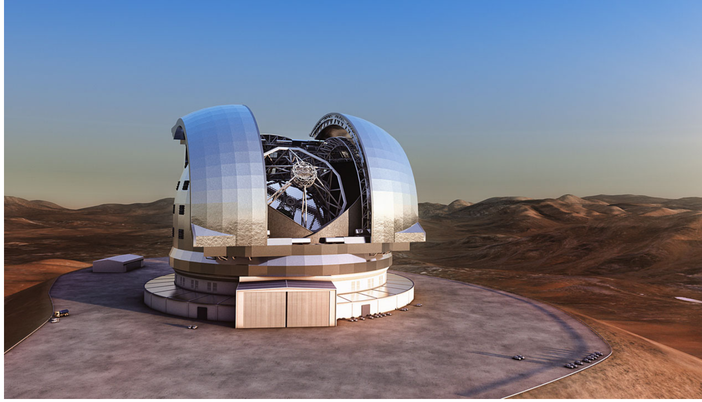
⬇

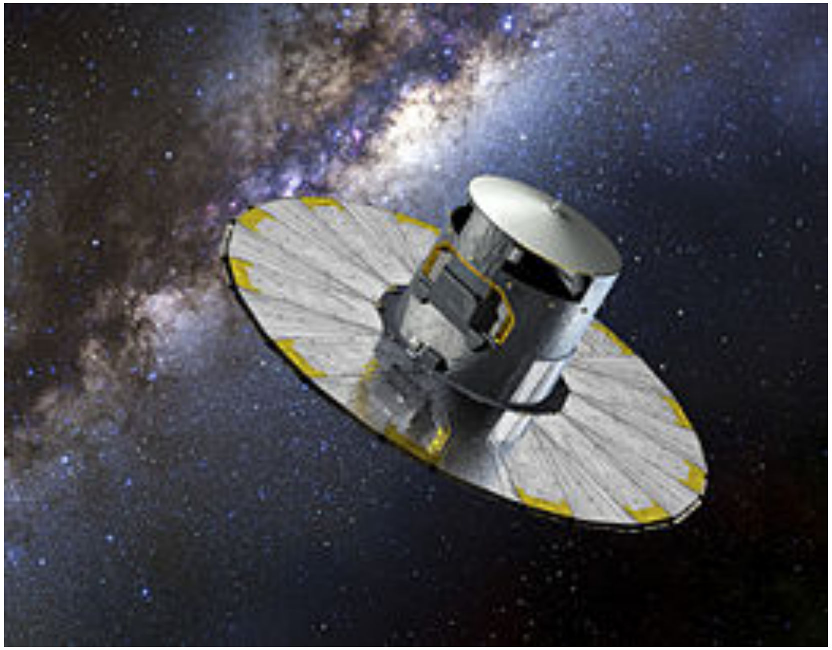
Presence of RR Lyrae stars in both elliptical & spiral galaxies

➔unique opportunity to check of the accuracy of type Ia Supernovae as secondary distance indicators and to constrain quantitatively the dependence of the peak luminosity of SN Ia on the host galaxy



But E-ELT will not perform time-series observations

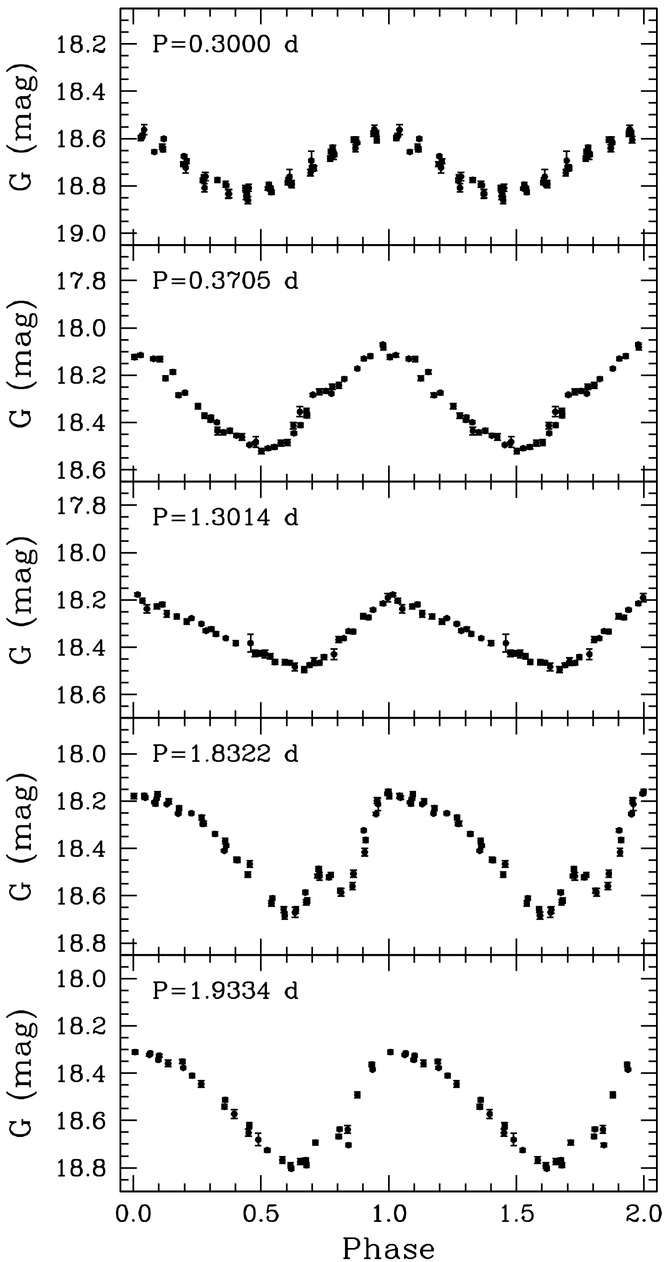
→ Need for specific techniques to use empirical and or theoretical templates, to reconstruct the light curves for both Cepheids and RR Lyrae



GAIA

We will have distances (and metallicity also from complementary survey)

GAIA

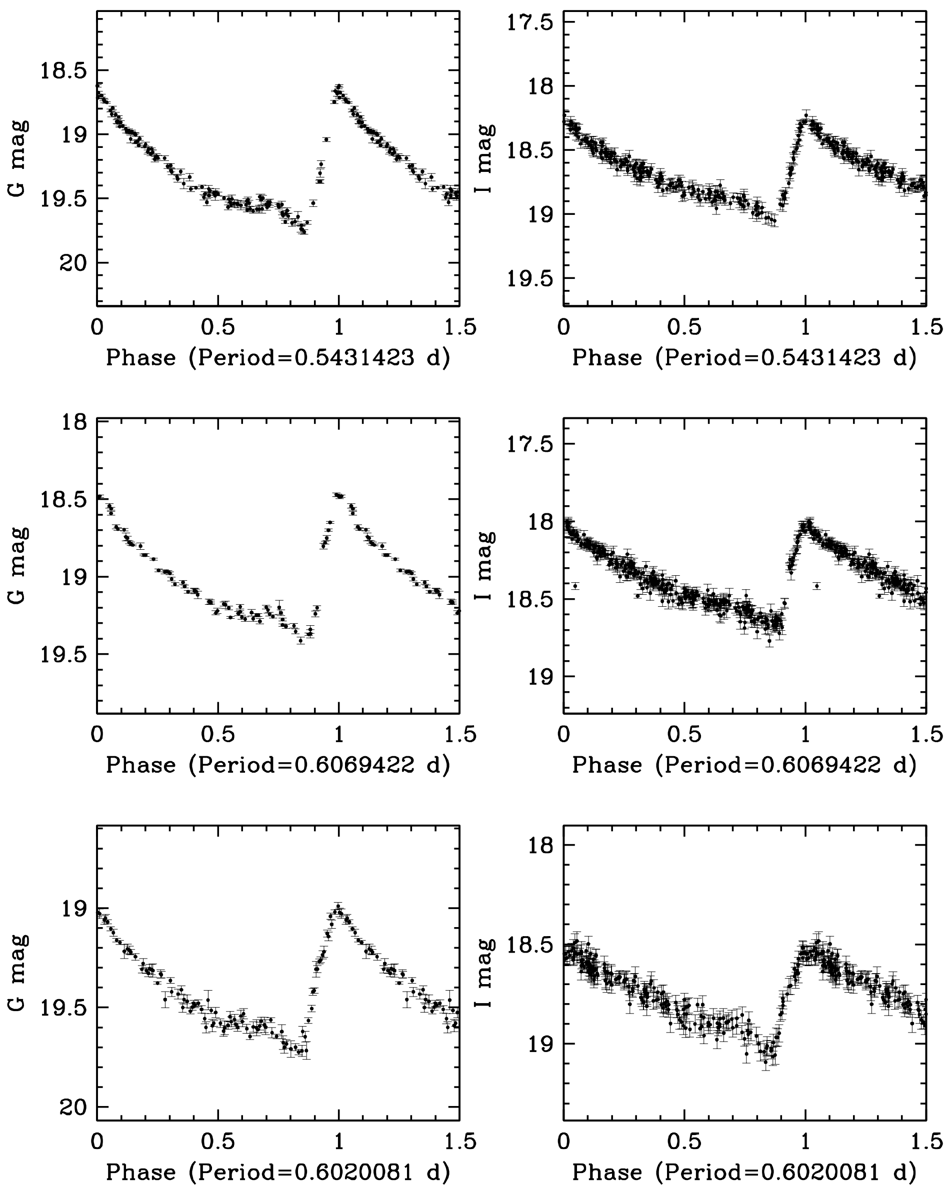


We will have distances (and metallicity also from complementary survey)

GAIA IMAGE OF THE WEEK
(May 28, 2015)

SHORT PERIOD/FAINT CEPHEIDS
IN THE LMC OBSERVED BY GAIA

GAIA



/ill have distances (and
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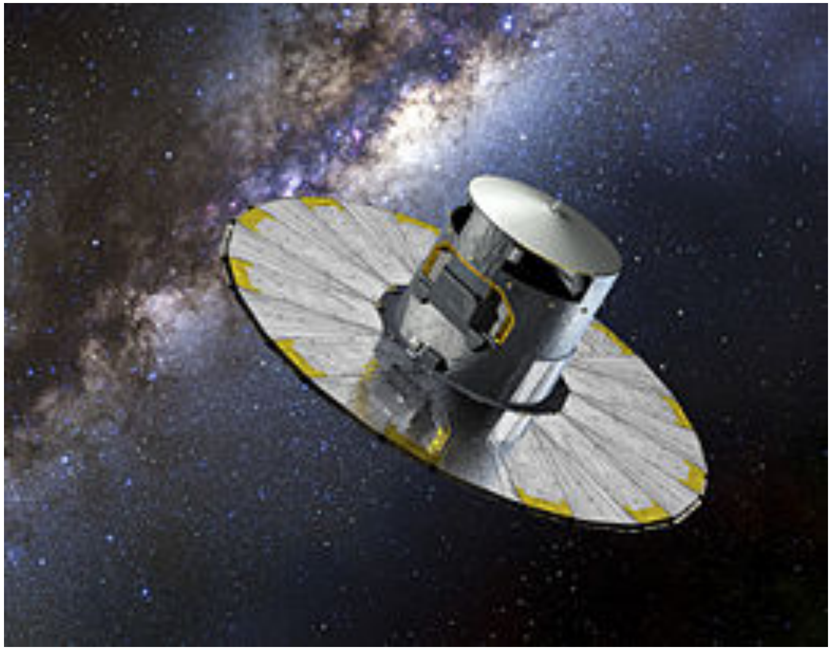
GAIA IMAGE OF THE WEEK
(March 5, 2015)

RR LYRAE IN THE LMC
OBSERVED BY GAIA



GAIA

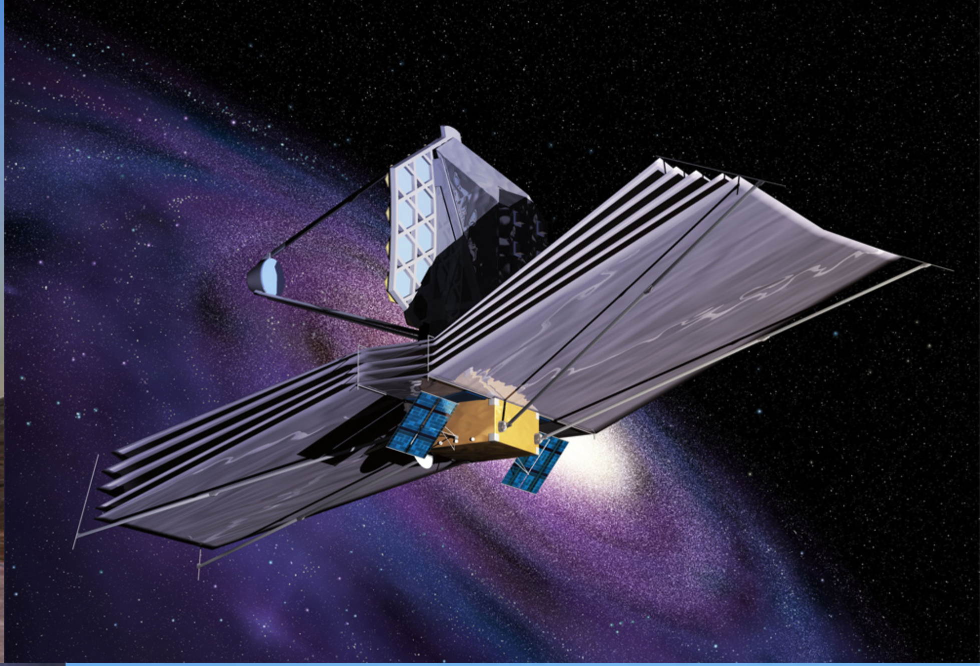
We will have distances (and metallicity also from complementary survey)

- ★ Opportunity to perform theory versus observations for all variable classes
- ★ To set slope and zero point of the Cepheid PL in the MW
- ★ To set the dependence on the metallicty of the RR Lyrae PLK and Mv – [Fe/H] relation
- ★ LMC ULPs parallaxes allow us to calibrate the first step of the extragalactic distance scale
- ★ From the fitting of the light curves, known distance and metallicity, we derive an accurate and independent stellar mass estimate → ML → test of the evolutionary models.

LSST

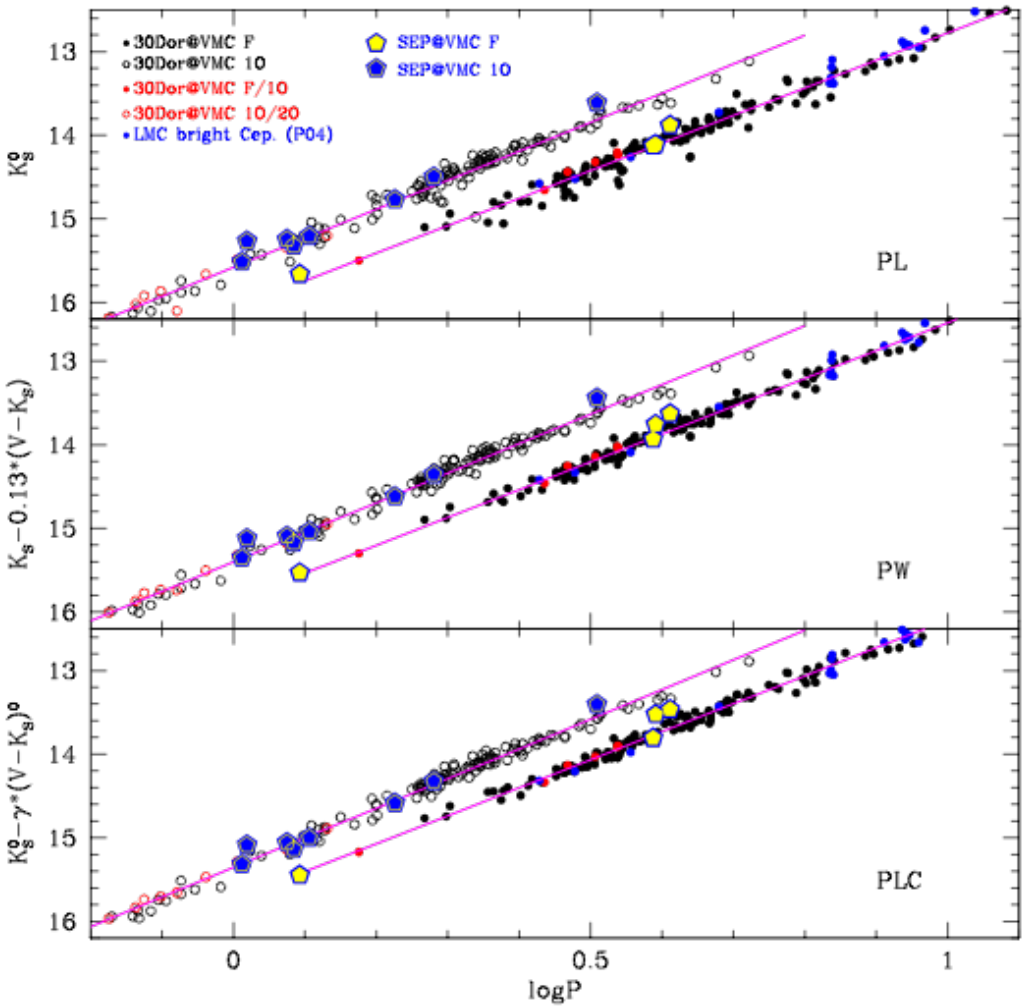
- Time coverage, 5 mag deeper than GAIA → observation of variable stars also in Local Group and external galaxies

GRAZIE

30 Dor and Gaia fields: Cepheid analysis comparison

VMC survey: Ripepi et al. 2012



Gaia field appears to be ~2Kpc closer to the Sun than the 30 Dor Field. In agreement with results from SFH recovery.

Wesenheit appear to work very well to determine the distance of the two region

↓

Ideal to do a 3D map of the MCs

Working in progress to use RR Lyrae and their PLK

Classical Cepheids

Classical Cepheids ha a relevant role for the
extragalactic distance scale and ***stellar evolution***

They obey to a PL relation

Calibration of the extragalactic distance scale (up to 30 Mpc with HST)

H_0 estimate
(e.g. Freedman et al. 2001, Riess et al. 2012)

Important to construct an accurate extragalactic distance scale

ML relations predicted by evolutionary calculations

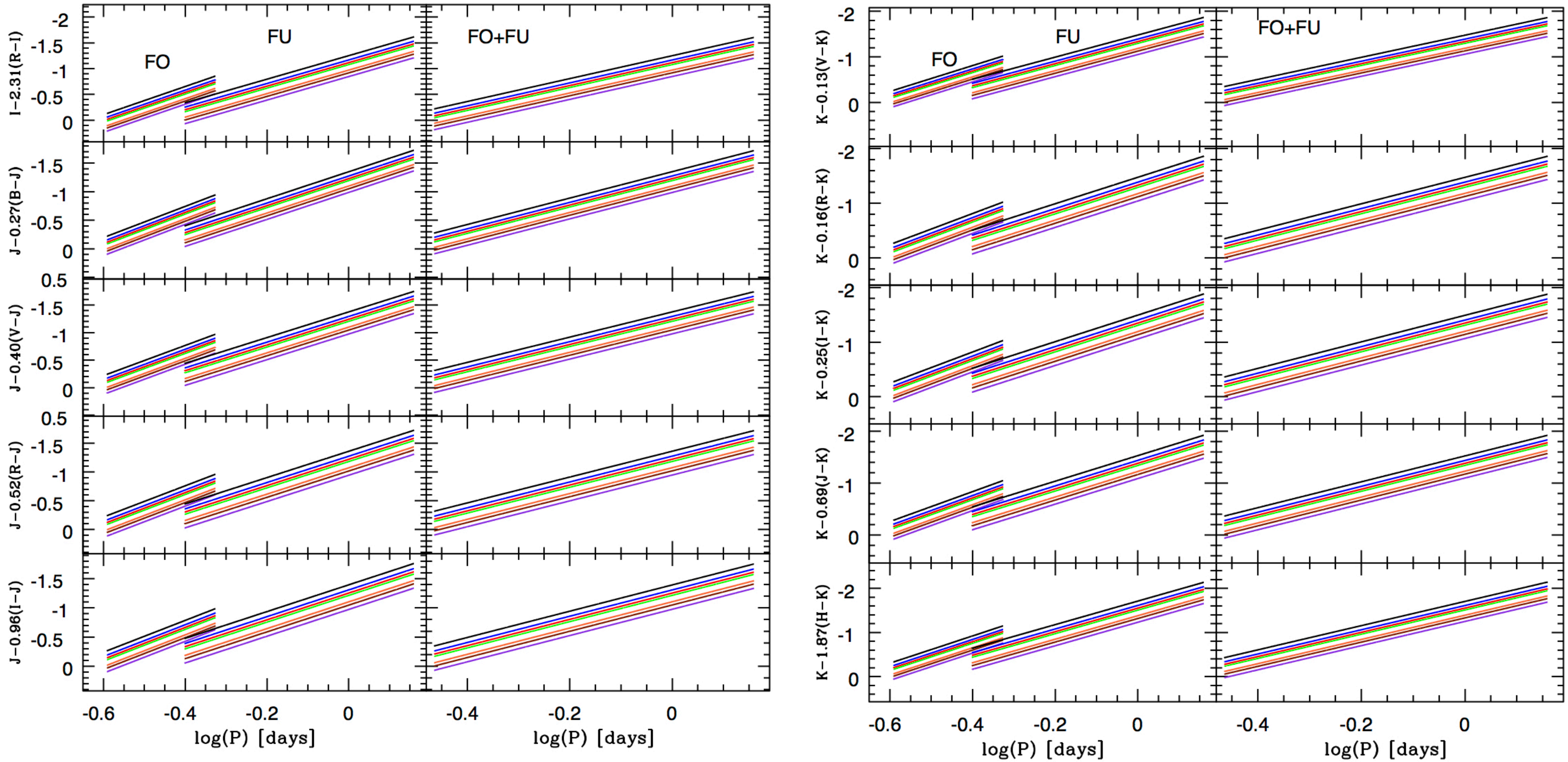
Input to pulsation models

Theory versus observations

Insight into evolutionary and pulsational physics

RR Lyrae Wesenheit relation

Wesenheit relations



Marconi et al. 2015 ApJ

Recent evaluation of Ho

- **Cepheids + TRGB: $63.7 \pm 2.3_{ran} \pm 3.6_{sys}$ Km $s^{-1}Mpc^{-1}$ (Tammann et al. 2013)**

- **TRGB: 73 ± 5 Km s^{-1} Mpc^{-1} (Mould & Sakai 2008)**

- **WMAP+SDSS+SNIa(5 years): 65.6± 2.5 Km s^{-1} Mpc^{-1} (Reid et al.2010)**
- **WMAP(5/7years): 70.4±1.4 Km s^{-1} Mpc^{-1} (Komatsu et al. 2010)**

- **Cepheids + SNIa: 73.8 ± 2.4 Km s^{-1} Mpc^{-1} (Riess et al. 2011)**

- **Cepheids + secondary indicators: 74.3 ± 2.1 Km s^{-1} Mpc^{-1} (Freedman et al. 2012)**

- **Cepheids + models: $76.0 \pm 2.0_{ran} \pm 1.0_{sys}$ Km s^{-1} Mpc^{-1}**