Gaia parallaxes versus updated pulsation model predictions

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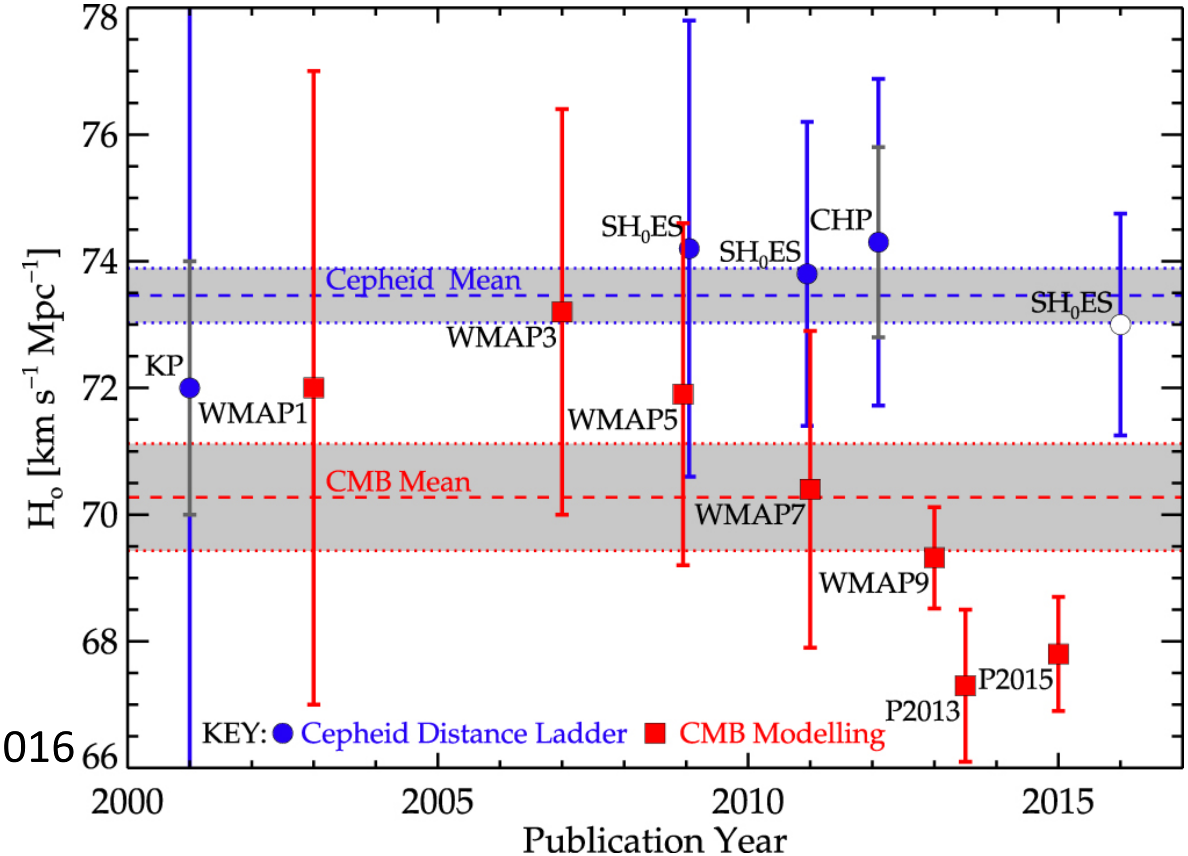
Outline

- The H_0 tension problem and Cepheid distance scale
- Theoretical project: the new dataset of non-linear convective Cepheids pulsation models
- First results from Galactic Cepheids
- Comparison with Gaia DR2 parallaxes
- Conclusions and outlook

The Hubble constant tension



Beaton et al. 2016

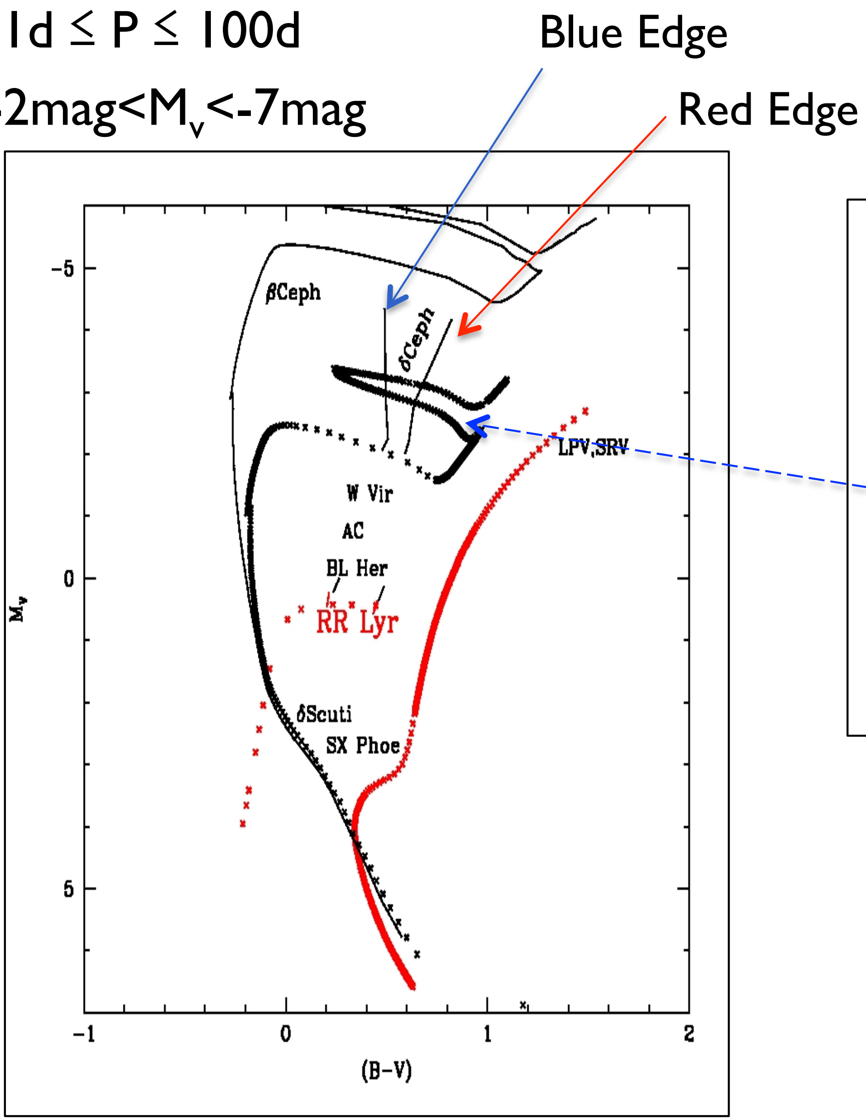
Comparison of recent determinations of Hubble constant (H_0) using the Cepheid distance ladder (circles) and CMBR results (squares) as a function of publication year, with the recent value by Riess et al. (2018) (open circle).

Classical Cepheids

Classical Cepheids are yellow supergiants pulsating stars with:

$1d \lesssim P \lesssim 100d$

$-2mag < M_v < -7mag$



Classical Cepheids lie within the pulsational instability strip in the H-R diagram

Classical Cepheids are associated to the so called '**blue loop evolutionary phase**' of intermediate mass stars corresponding to their central Helium burning.

Cepheid relations

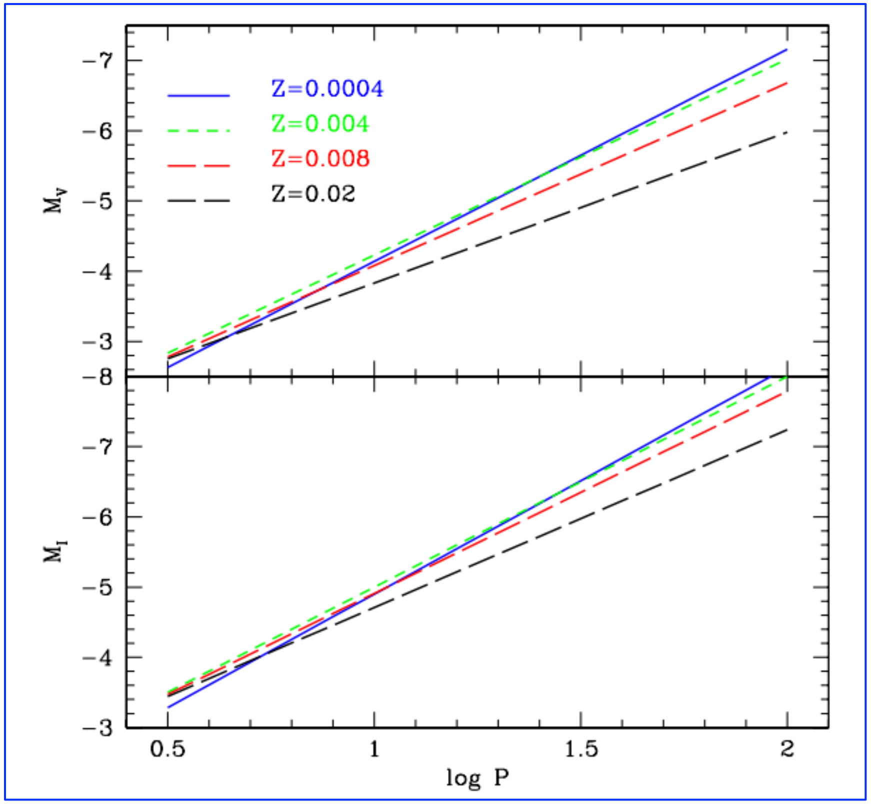
Classical Cepheids show linear period-luminosity-color (P-L-C) and period-luminosity (P-L) relations

$$\bar{M}_J = a + b \log P$$

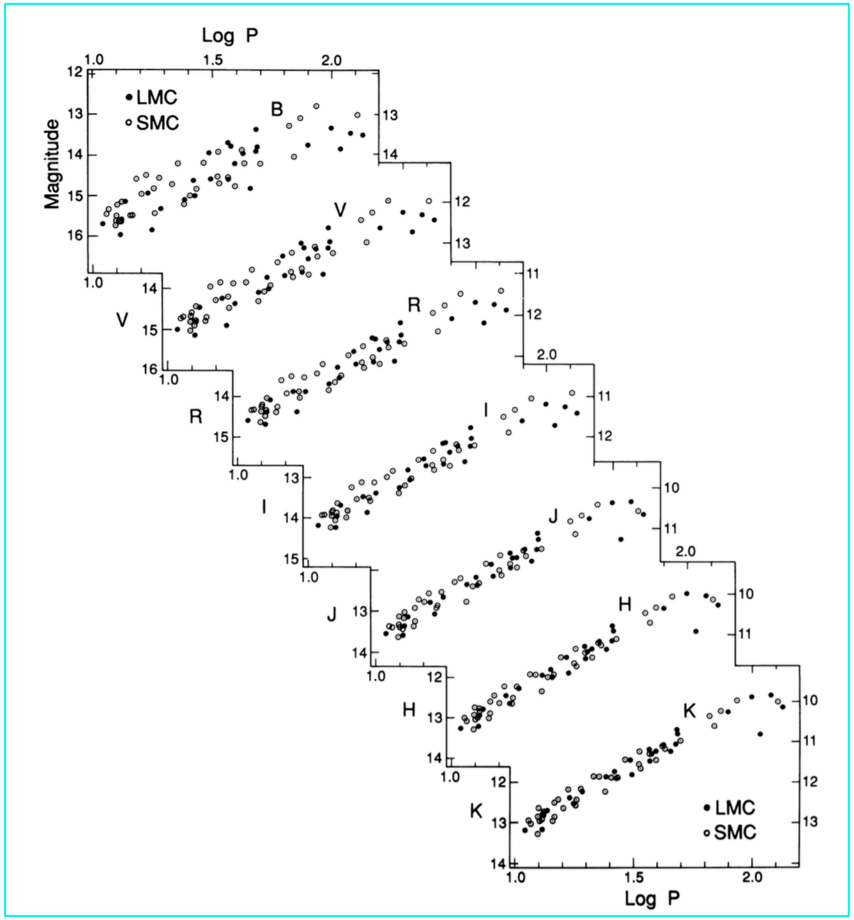
$$\bar{M}_J = \alpha + \beta \log P + \gamma \, [CI]$$

Several systematic effects on optical PL relation

- Intrinsic dispersion of the PL relation (finite instability strip)
- Metallicity dependence on the PL relation
- Possible non-linear effects of PL



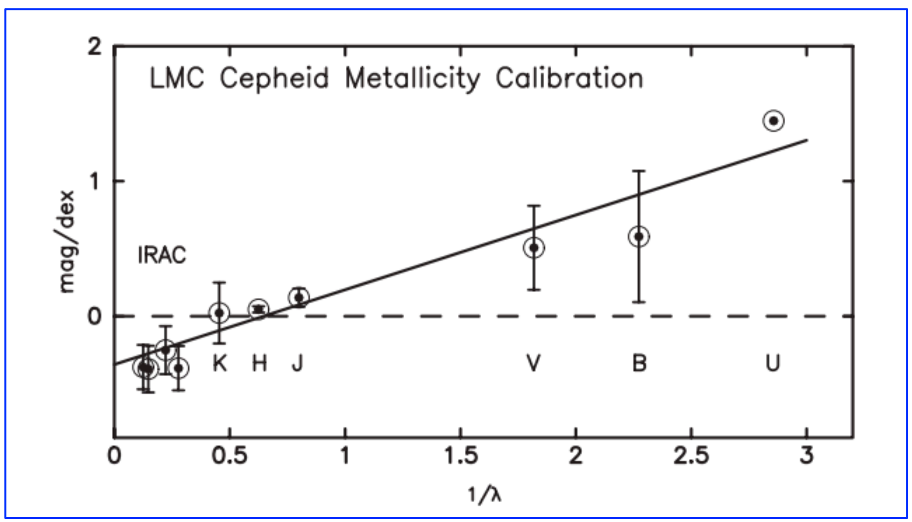
Marconi et al. 2010

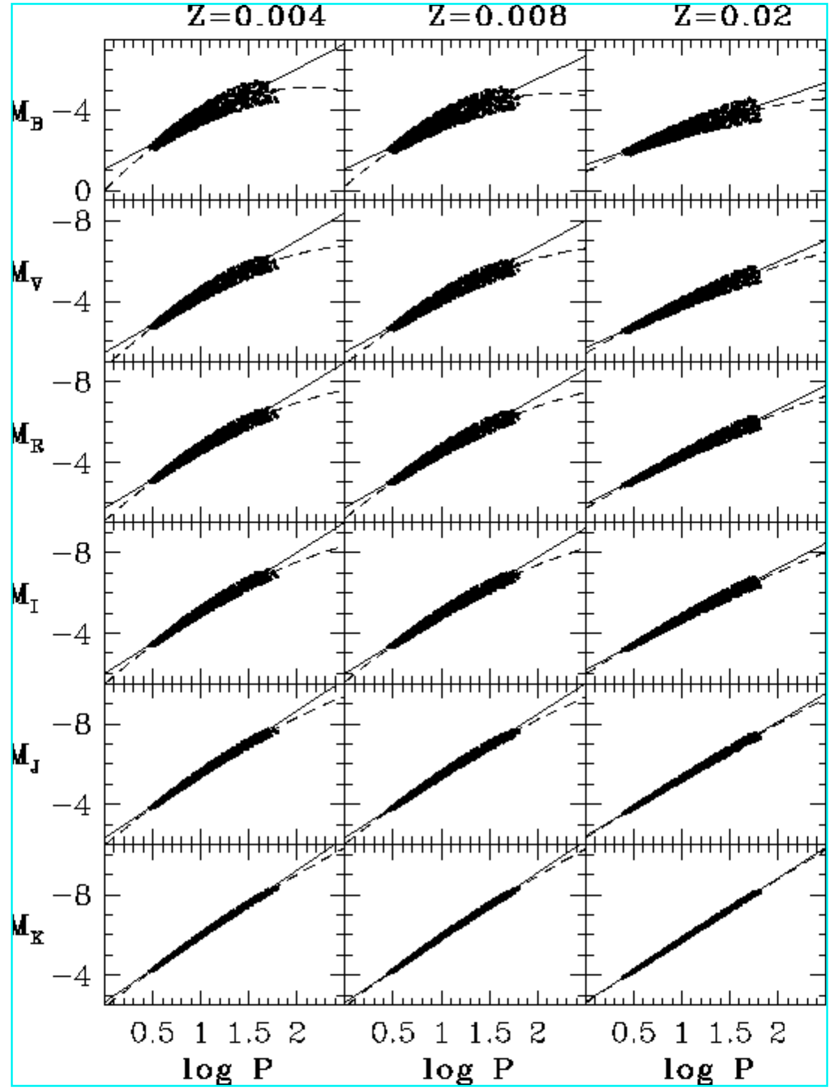


Madore et al. 1991

How to reduce these effects?(1)

- MOVE TO NEAR OR MID INFRARED FILTERS





Optical

Near Infrared

How to reduce these effects?(11)

- THE PERIOD-WESENEHEIT RELATION:

A Period luminosity colour relation reddening free by definition

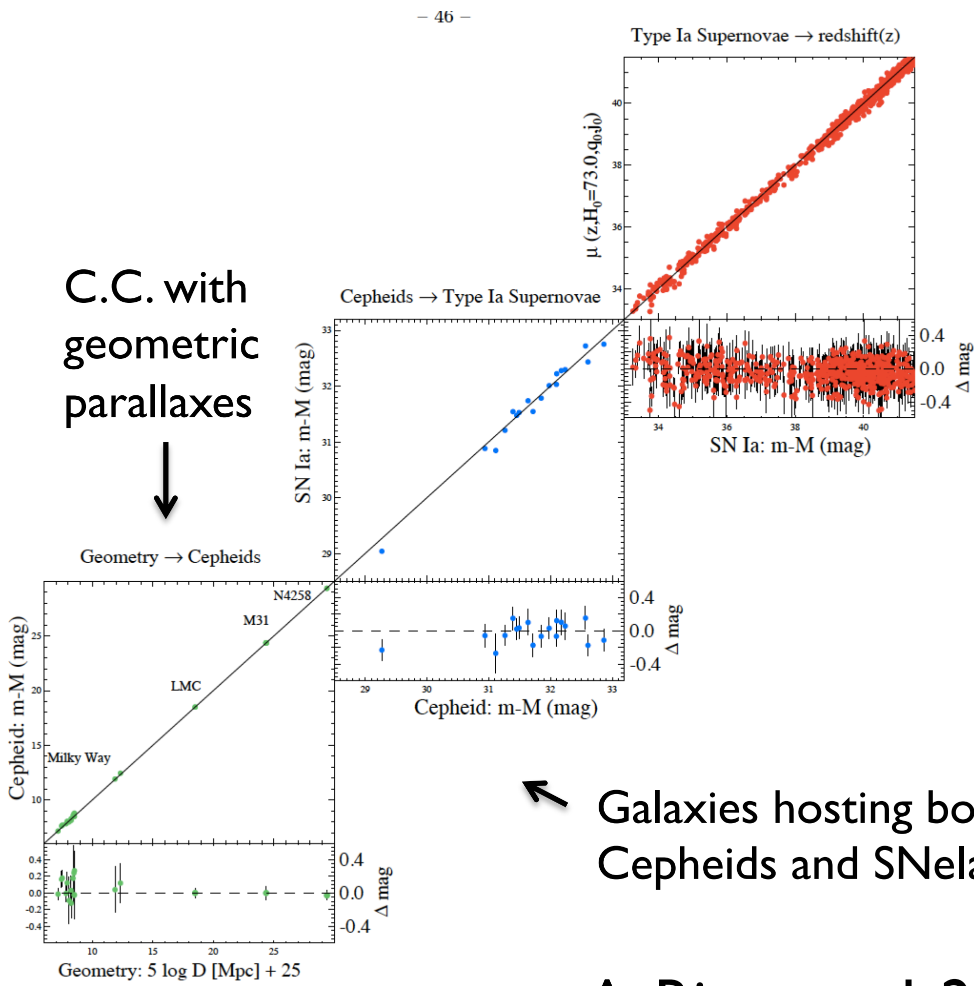
Its formulation in B-V colour is

↓

$$W(B-V) = V - \gamma(B-V)$$

$$\gamma = \frac{A_V}{E(B-V)}$$

The SHOES program



$H_0 = 73.53 \pm 1.62$ Km s^{-1} Mpc^{-1}

2.2% of total uncertainty

C.C. with geometric parallaxes

Galaxies hosting both Cepheids and SNeIa

A. Riess et al. 2018

Other effects

- Dependence of the extinction law on the environment
- Dependence on the metal content
- Dependence on the ML relation (mass loss, overshooting rotation)
- Dependence on the efficiency of convection

WE NEED TO HAVE:

GAIA FINAL DATA RELEASE

A VERY DETAILED DATASET OF NON-LINEAR CONVECTIVE PULSATION MODELS
(extension of Bono et al. 2010 , Marconi et al. 2010)

New dataset of non linear convective Cepheids pulsation models

Based on Stellingwerf's hydrodynamical code (see Bono, Marconi and Stellingwerf, 1999 ApJS)

Expected results:

- Light curves
- Instability strips
- Period-radius relations
- Multi-band Period-Luminosity relations
- Multi-band Period-Luminosity-colour relations

Test for:

- Systematic effects on H_0
- The physics of the stellar models
- The efficiency of convection

Different dataset

LMC $Z=0.008$ $Y=0.25$

- $3 < M_{\odot} < 13$ $\Delta_M = 0.5$
- $4700<T_e(K)<6100$ $\Delta_T = 50K$
- $1.5< \alpha < 2.1$ $\Delta_\alpha = 0.1$

12000 expected models

SMC $Z=0.004$ $Y=0.25$

- $3 < M_{\odot} < 13$ $\Delta_M = 0.5$
- $4700<T_e(K)<6100$ $\Delta_T = 100K$
- $1.5< \alpha < 2.1$ $\Delta_\alpha = 0.2$

12000 expected models

IZw18 $Z=0.0004$ $Y=0.25$

- $3 < M_{\odot} < 13$ $\Delta_M = 0.5$
- $4700<T_e(K)<6100$ $\Delta_T = 50K$
- $1.5< \alpha < 2.1$ $\Delta_\alpha = 0.1$

12000 expected models

M31 $Z=0.03$ $Y=0.25$

- $3 < M_{\odot} < 13$ $\Delta_M = 0.5$
- $4700<T_e(K)<6100$ $\Delta_T = 50K$
- $1.5< \alpha < 2.1$ $\Delta_\alpha = 0.1$

12000 expected models

MILKY WAY $Z=0.02$ $Y=0.28$

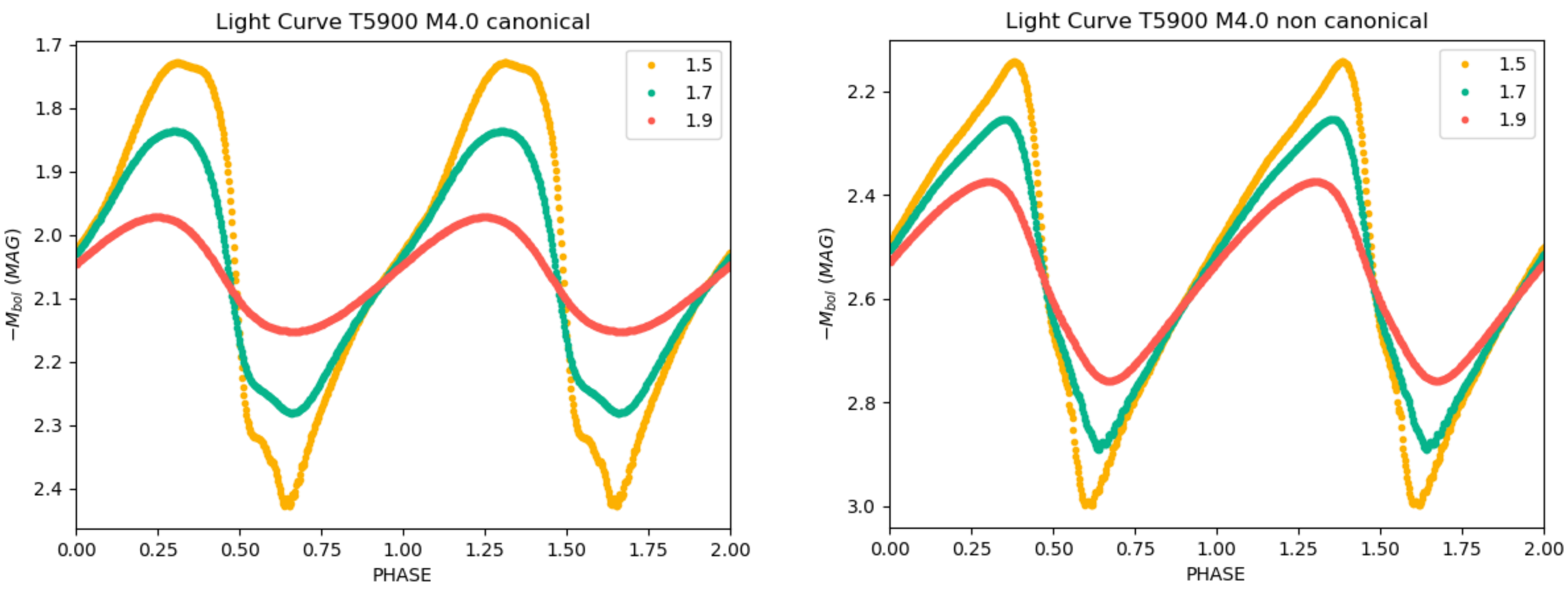
- $3 < M_{\odot} < 11$ $\Delta_M = 1$
- $3700<T_e(K)<6100$ $\Delta_T = 100K$
- $1.5< \alpha < 1.9$ $\Delta_\alpha = 0.2$
- $\text{Log}(L/L_{\odot})= 0.90 + 3.35\log10(M/M_{\odot}) + 1.36\log10(Y) - 0.34\log10(Z) + x$
- $0<x<0.2$ $\Delta_x= 0.2$

1350 expected Cepheids pulsation models

The atlas of light curves

For now we have found around 300 Cepheid pulsation models.

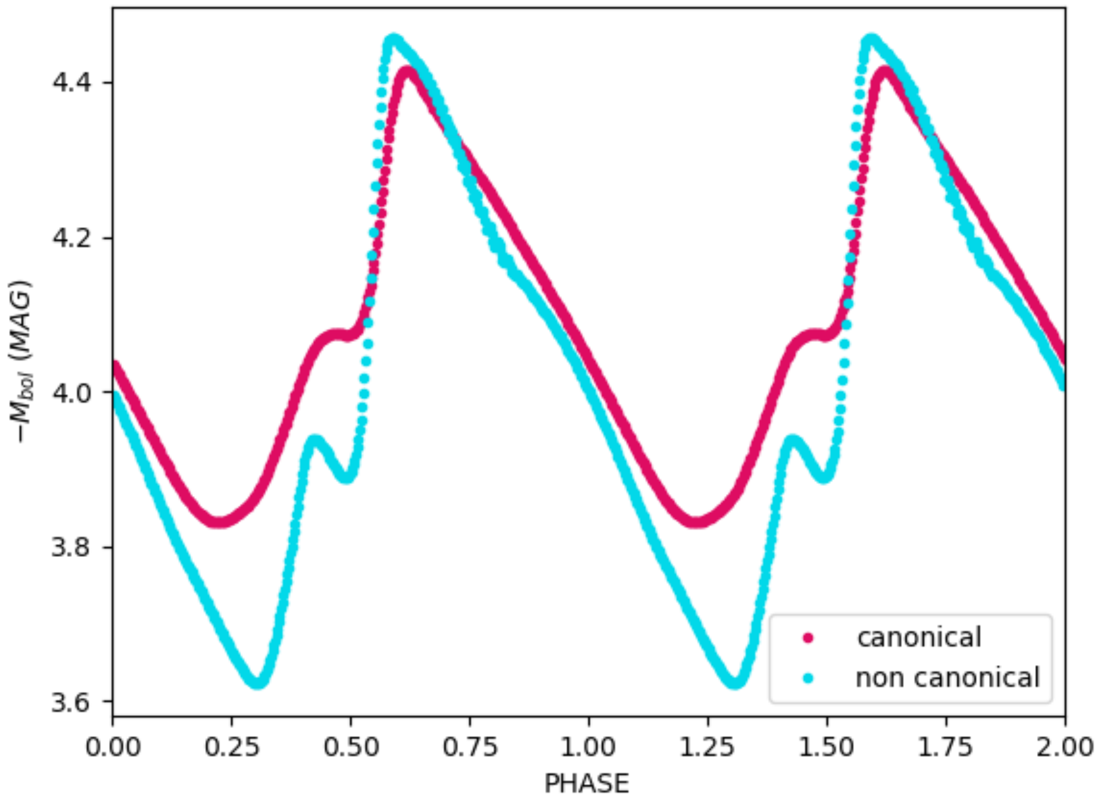
Light curves: effect of convective efficiency



Increasing the efficiency of convection the amplitude of light curves decreases and morphology gets smoother

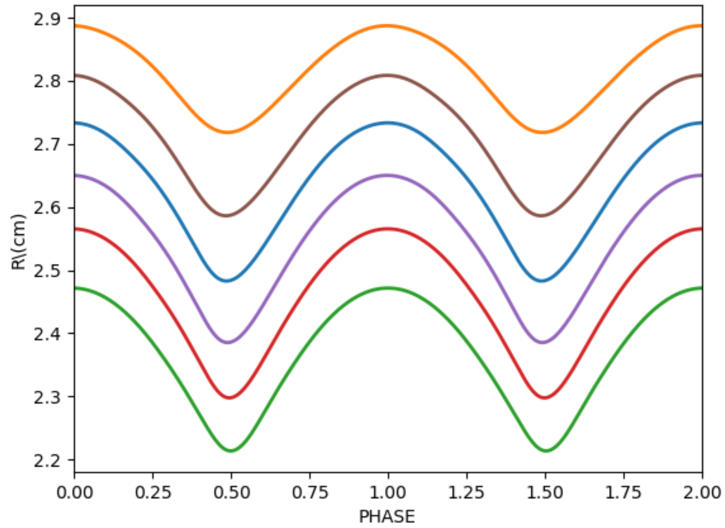
Light curves: effect of the assumed M-L relation

Comparison between two models with the same period and luminosity but different mass



Both the morphology and the amplitude of the light curves depends on the assumed mass-luminosity relation

From radius curves to Period-Radius relations



M 5.0 canonical α = 1.5

From non linear models we obtain radius curves

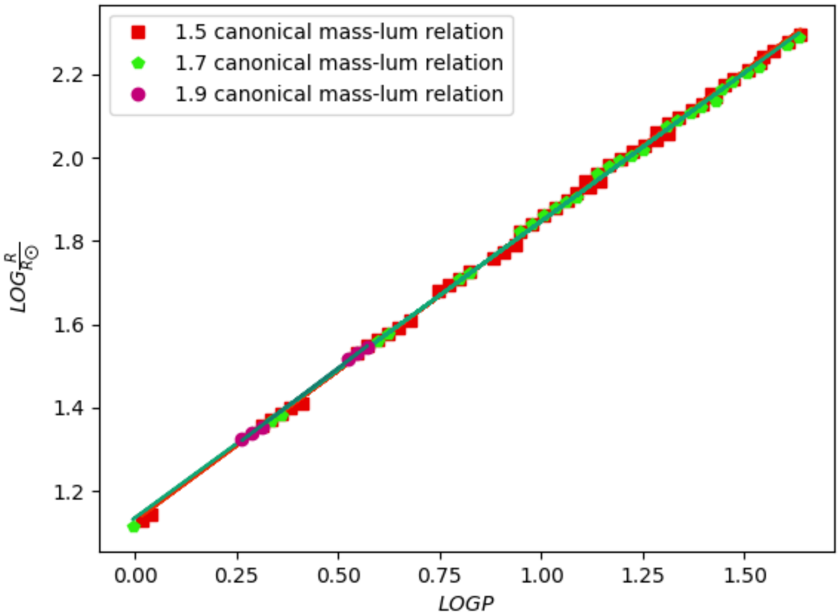
↓

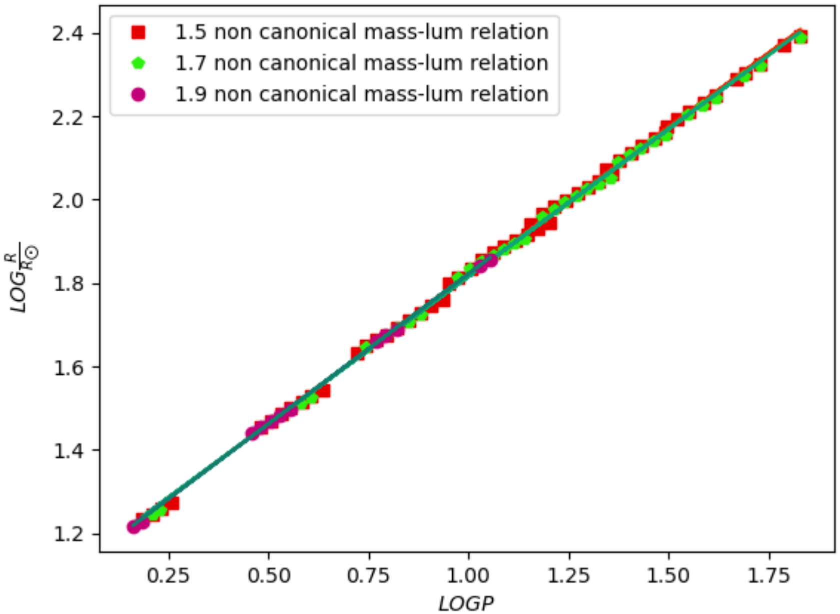
mean radii

↓

P-R relations

Period-radius relations: effect of convective efficiency

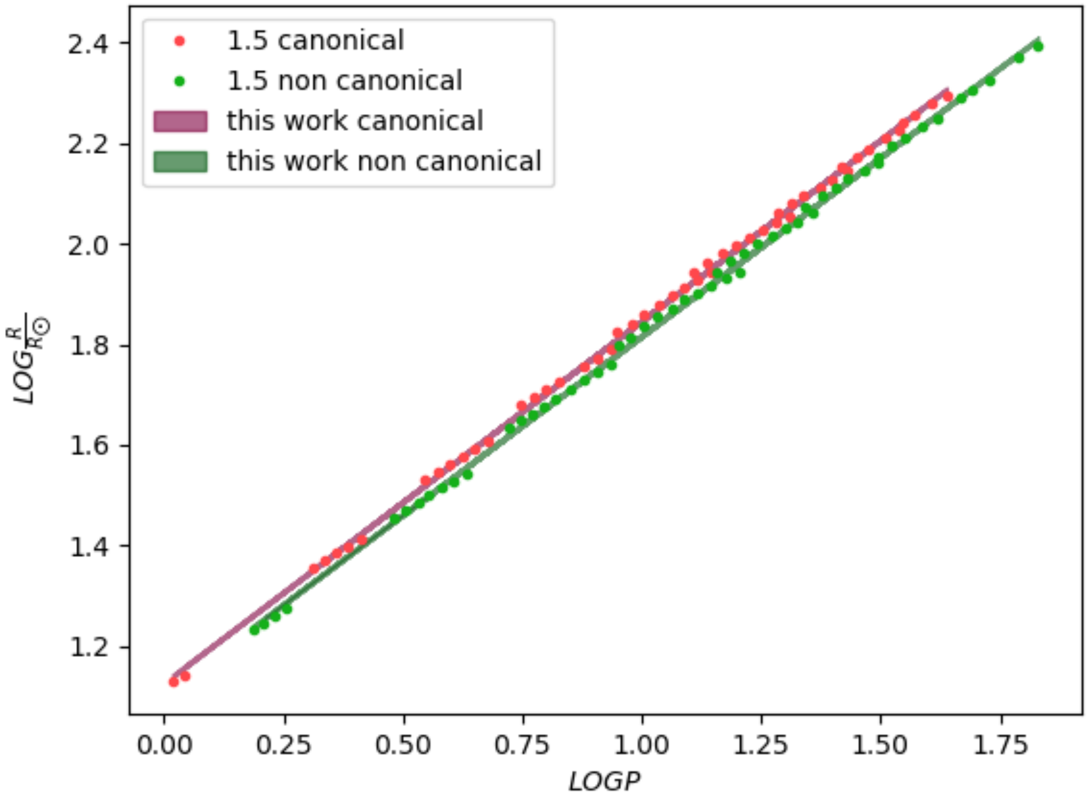




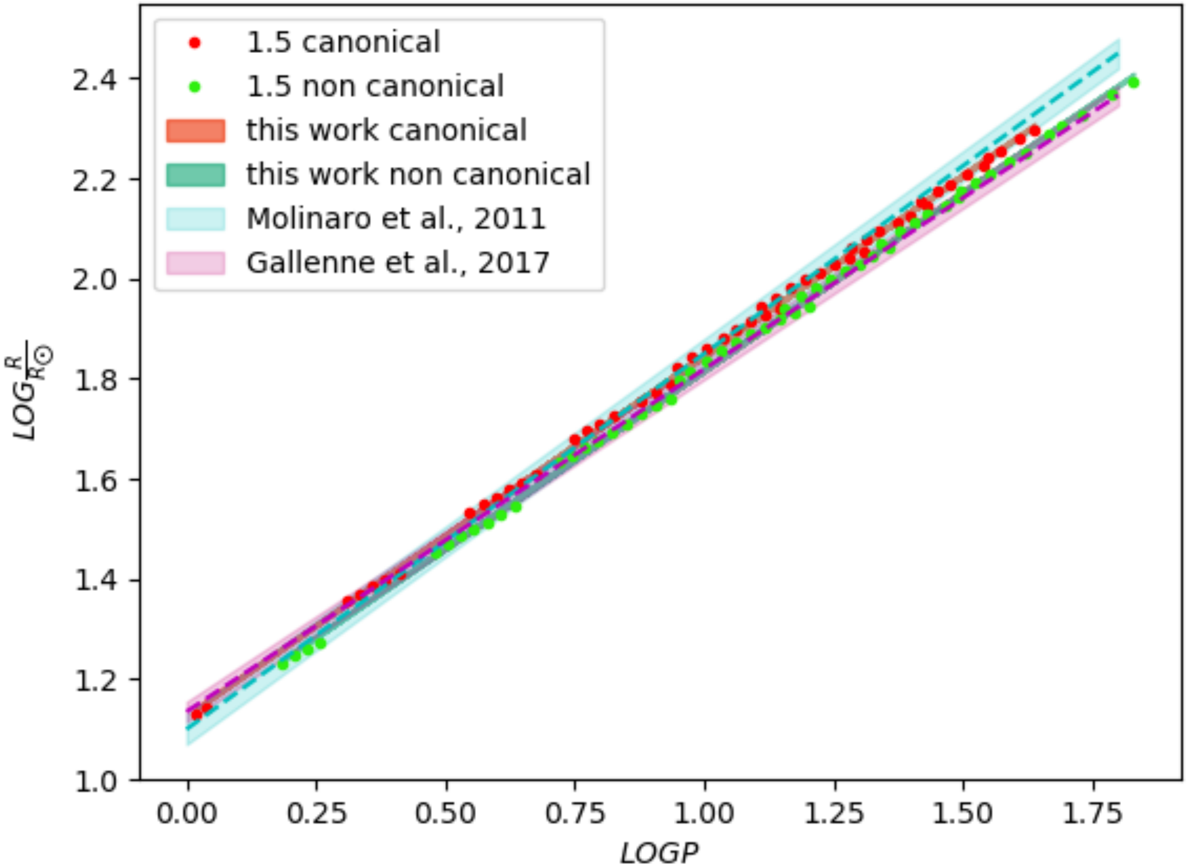
The period-radius relation does not vary considerably with the efficiency of convection

Period-radius relations

Period-radius relation for canonical and non canonical M-L relation



Period-radius relations: comparison with literature



General good agreement with Molinaro et al. 2011 and Gallenne et al. 2017

From multi-filter light curves to individual distances

From non linear models we obtain multi-filter light curves

↓

Mean magnitudes and colours

↓

PL, PLC, PW relations

↓

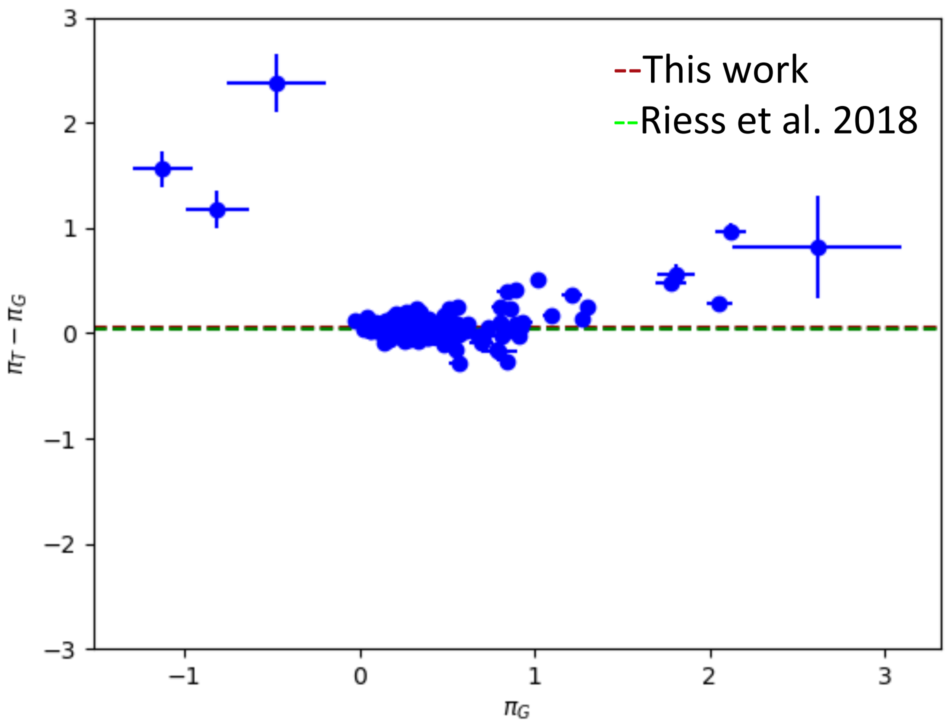
Theoretical distances and parallaxes

Comparison between theoretical PW(BV colour) based and Gaia DR2 parallaxes

-- Riess et al. 2018 $<\Delta\pi>_w = 0.047 \pm 0.013$(mas)

-- This work $<\Delta\pi>_w = 0.047 \pm 0.025$(mas)

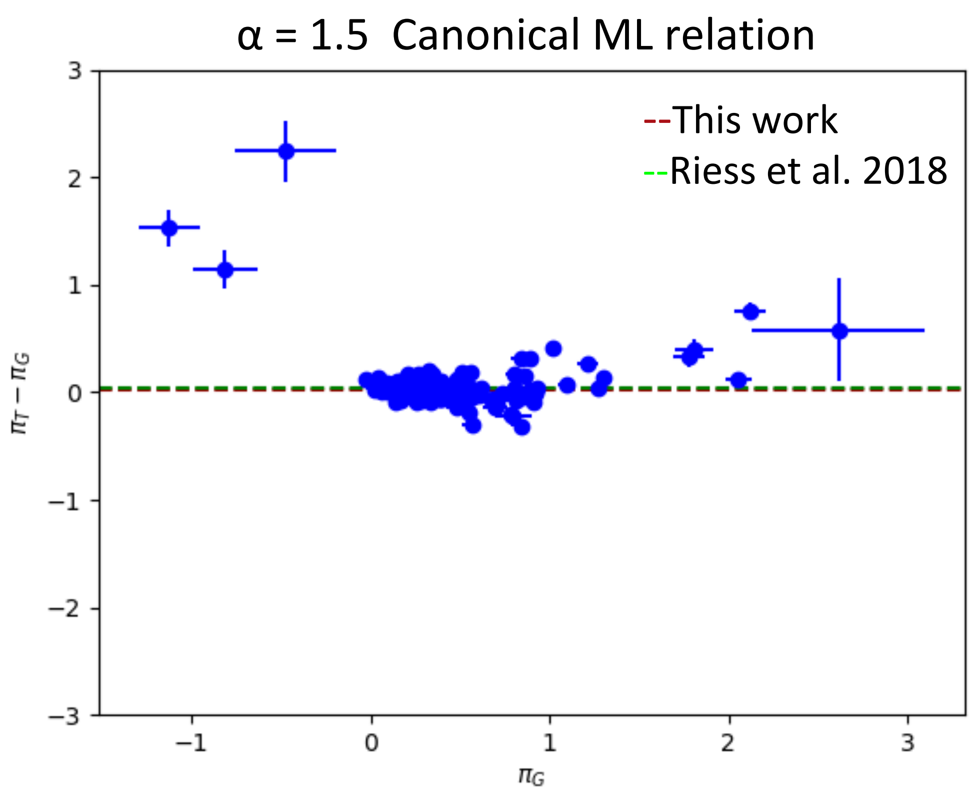
α = 1.5 Non Canonical ML relation



Comparison between theoretical PW(BV colour) based and Gaia DR2 parallaxes

-- Riess et al. 2018 $<\Delta\pi>_w = 0.047 \pm 0.013$(mas)

-- This work $<\Delta\pi>_w = 0.02 \pm 0.02$(mas)

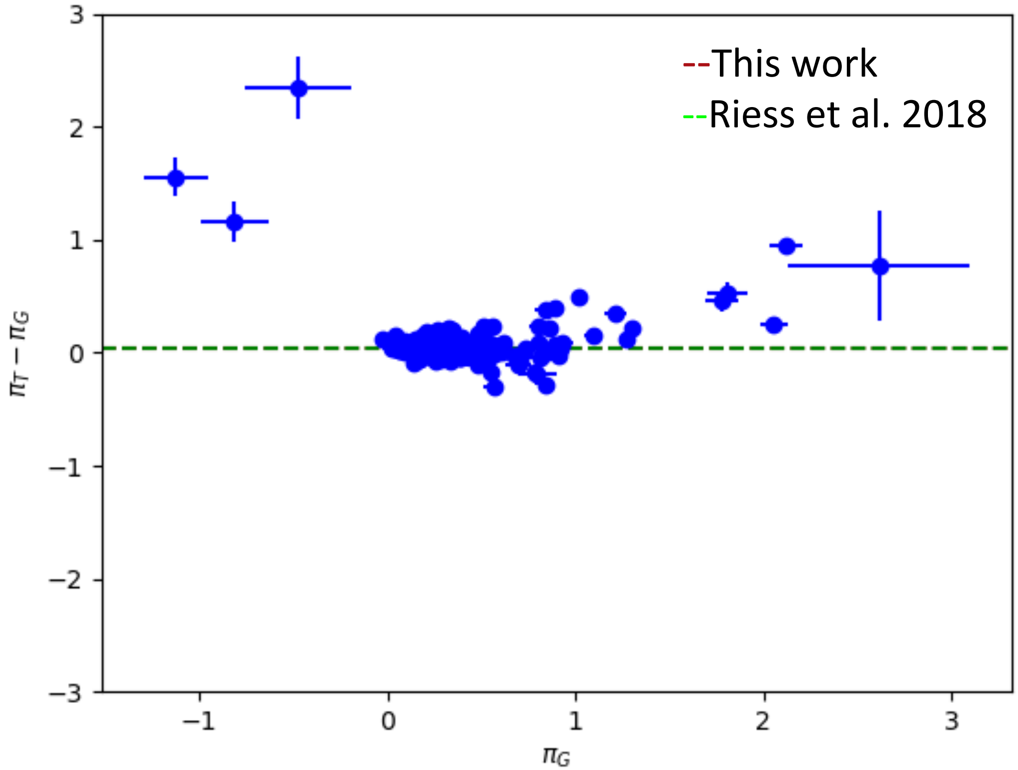


Comparison between theoretical PW(BV colour) based and Gaia DR2 parallaxes

-- Riess et al. 2018 $<\Delta\pi>_w = 0.047\pm0.013$(mas)

-- This work $<\Delta\pi>_w = 0.041\pm0.025$(mas)

α = 1.7 Non Canonical ML relation

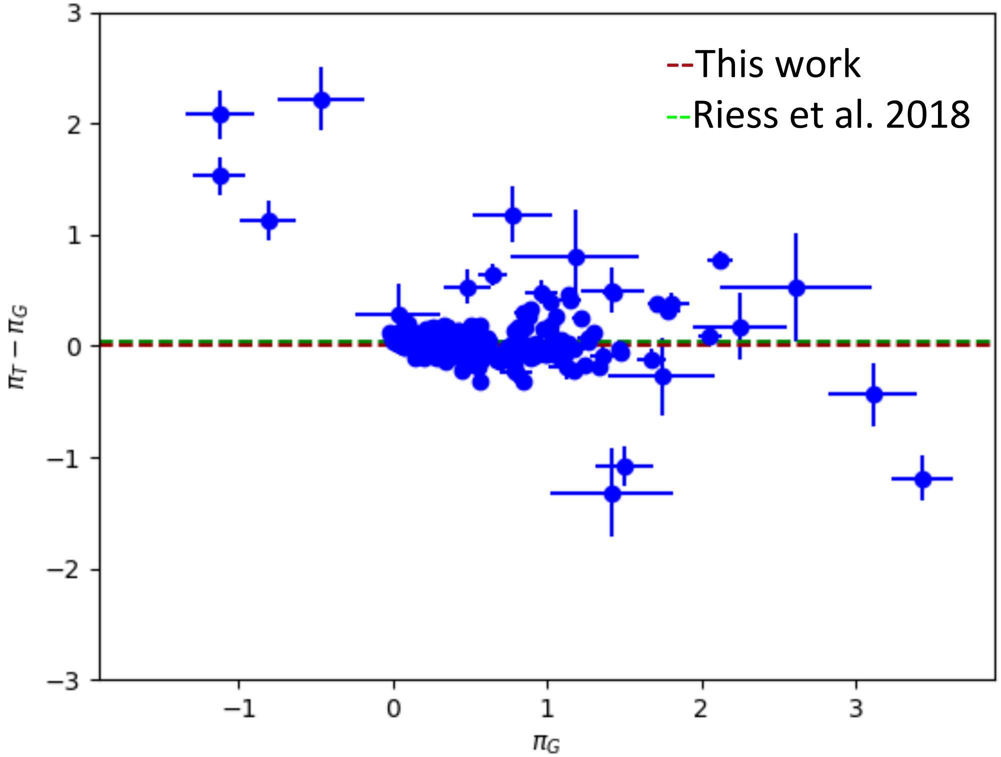


Comparison between theoretical PW(BV colour) based and Gaia DR2 parallaxes

-- Riess et al. 2018 $<\Delta\pi>_w = 0.047 \pm 0.013$(mas)

-- This work $<\Delta\pi>_w = 0.014 \pm 0.025$(mas)

α = 1.7 Canonical ML relation



Conclusions and Outlook

Gaia is going to significantly reduce the contribution to the error budget due to the geometric calibration

Non-linear convective pulsation models allow us to understand residual systematic effects on the Cepheid based cosmic distance scale

These models are being tested against Gaia DR2 parallaxes and the first results suggest a parallax offset for Cepheids consistent with Riess et al. results

Conclusions and Outlook

We plan to:

- To extend the Cepheid pulsation models dataset
- To test alternative Pop II calibrations
- To exploit LSST capabilities
- To evaluate the Hubble constant in one step thanks to Maory+Micado@ELT

Thank you!