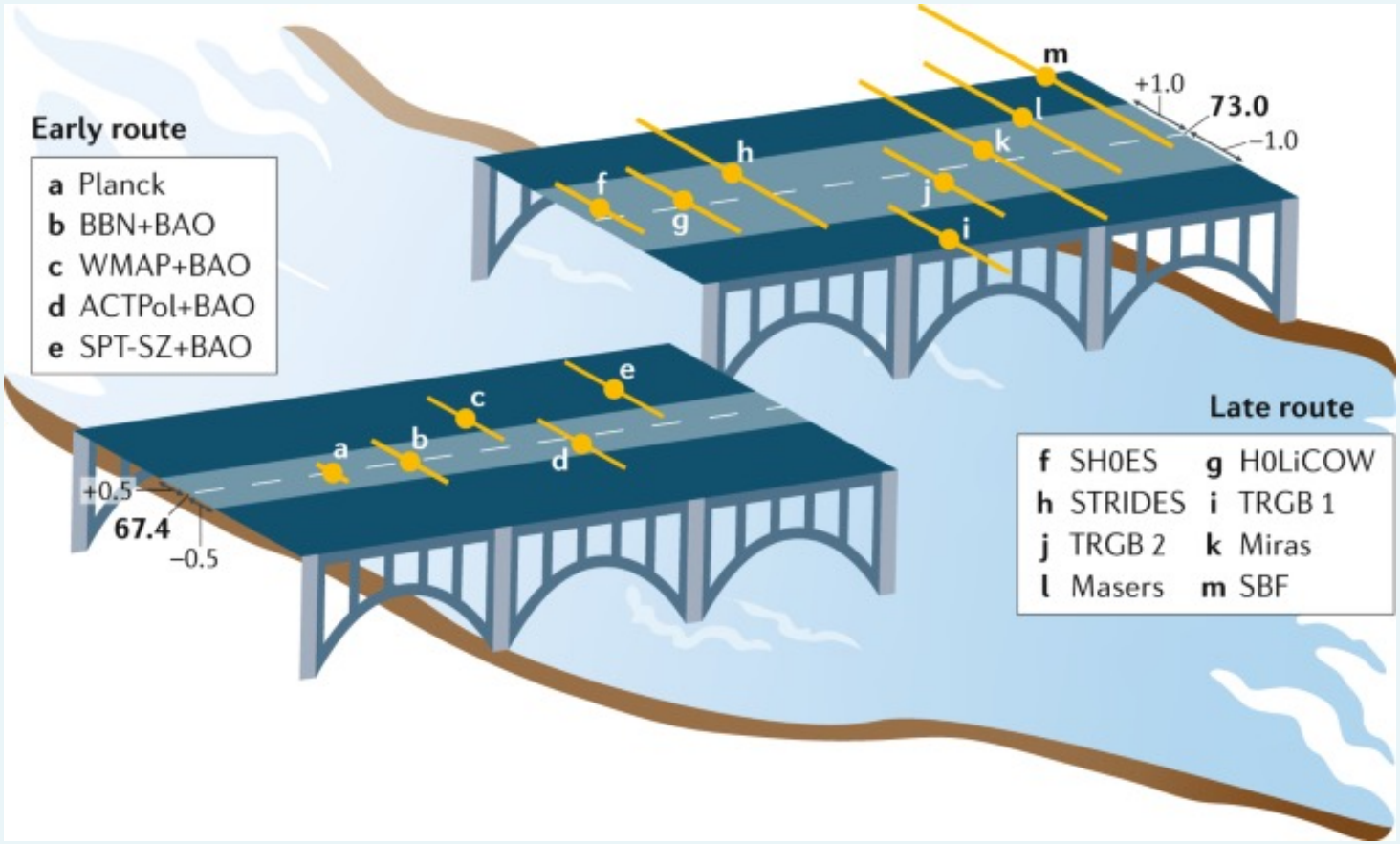
Stellar solutions to the Hubble constant tension: an observational and theoretical challenge



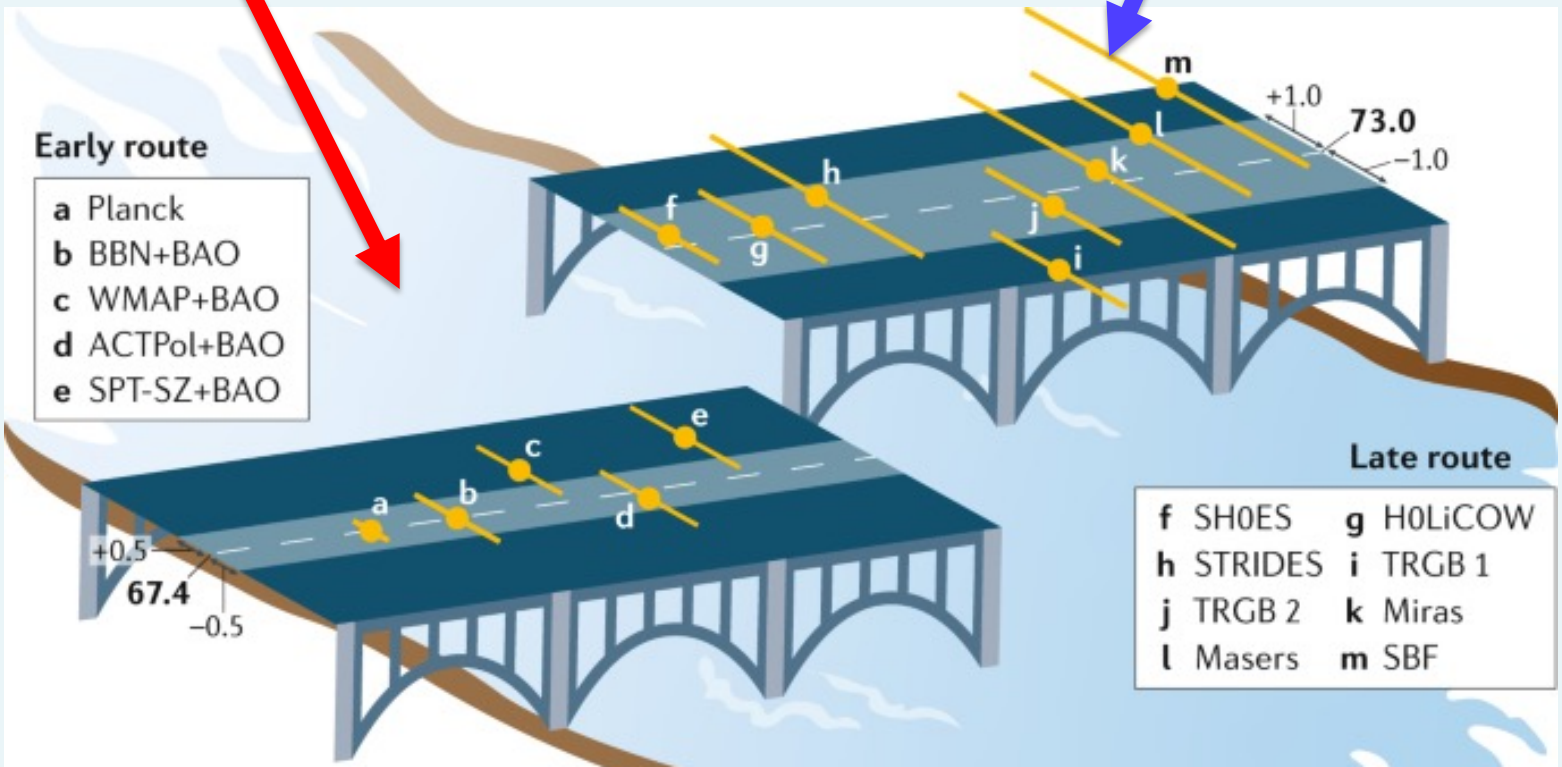
Marcella Marconi

INAF-Osservatorio Astronomico di Capodimonte

Giornate INAF 2-5 Maggio 2023 INAF-Osservatorio Astronomico di Capodimonnte

4-5 sigma difference between Hubble constant values based on

early universe determinations and extragalactic distance scale calibration (e.g. Cepheid+SNIa)



A very debated problem

An incomplete list of meetings since 2020:

ESO Conference: H0 "Assessing Uncertainties in Hubble's Constant Across the Universe" 2020

Hybrid in-person/virtual workshop on the Hubble Tension at MIAPP 2021

Workshop on Tensions in Cosmology – Corfù 2022

ISSI project: SHoT: The Stellar Path to the Ho Tension in the Gaia, TESS, LSST and JWST Era - Bern 2022

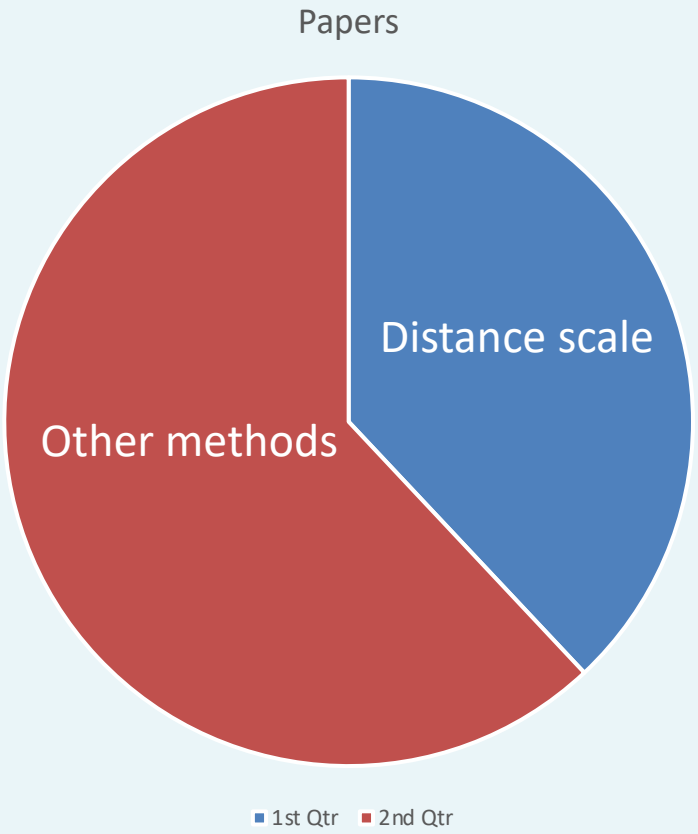
ISSI project: SHoT: The Stellar Path to the Ho Tension in the Gaia, TESS, LSST and JWST Era - Bern 2023

The KEK-PH + KEK-Cosmo + QUP joint lectures and workshops 2023 on "Hubble Tension 2023"

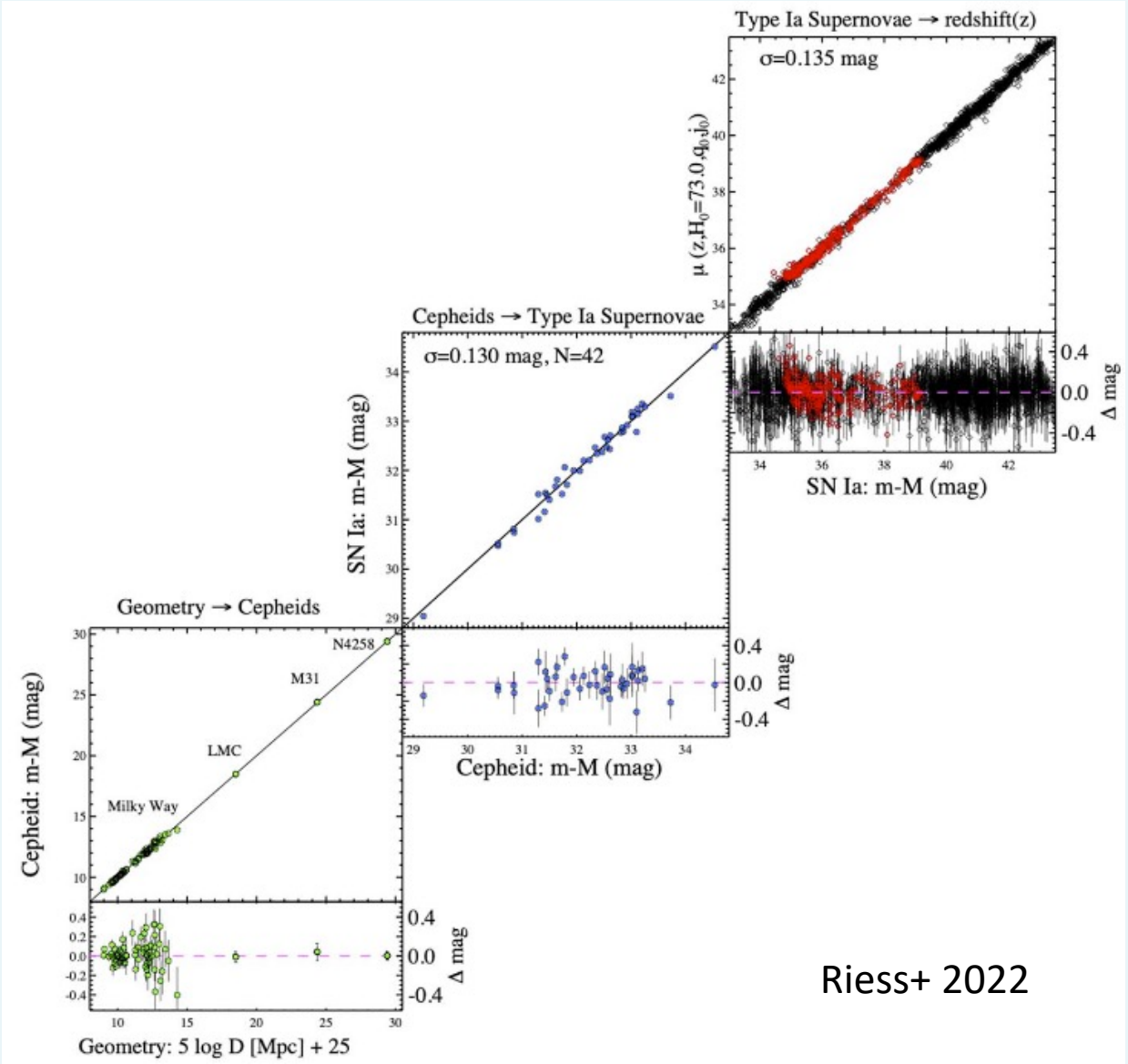
THE EXTRAGALACTIC DISTANCE SCALE AND COSMIC EXPANSION IN THE ERA OF LARGE SURVEYS AND THE JAMES WEBB SPACE TELESCOPE – MIAPP 2023

A very debated problem

An incomplete count (~500 in total) of papers on the Hubble constant tension since 2020



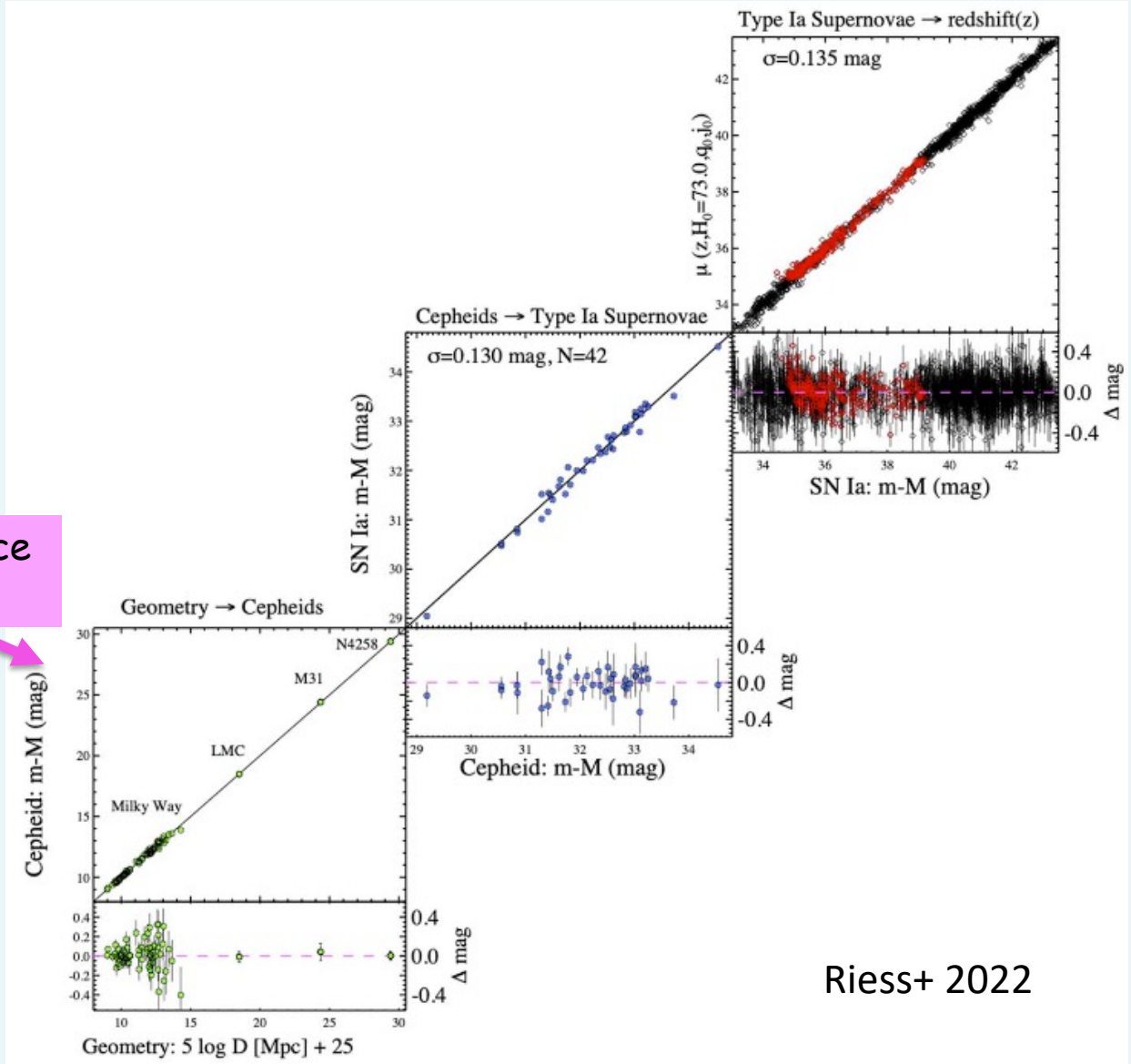
The stellar route in 3 steps



Riess+ 2022

The stellar route in 3 steps

Geometric distance to Cepheids



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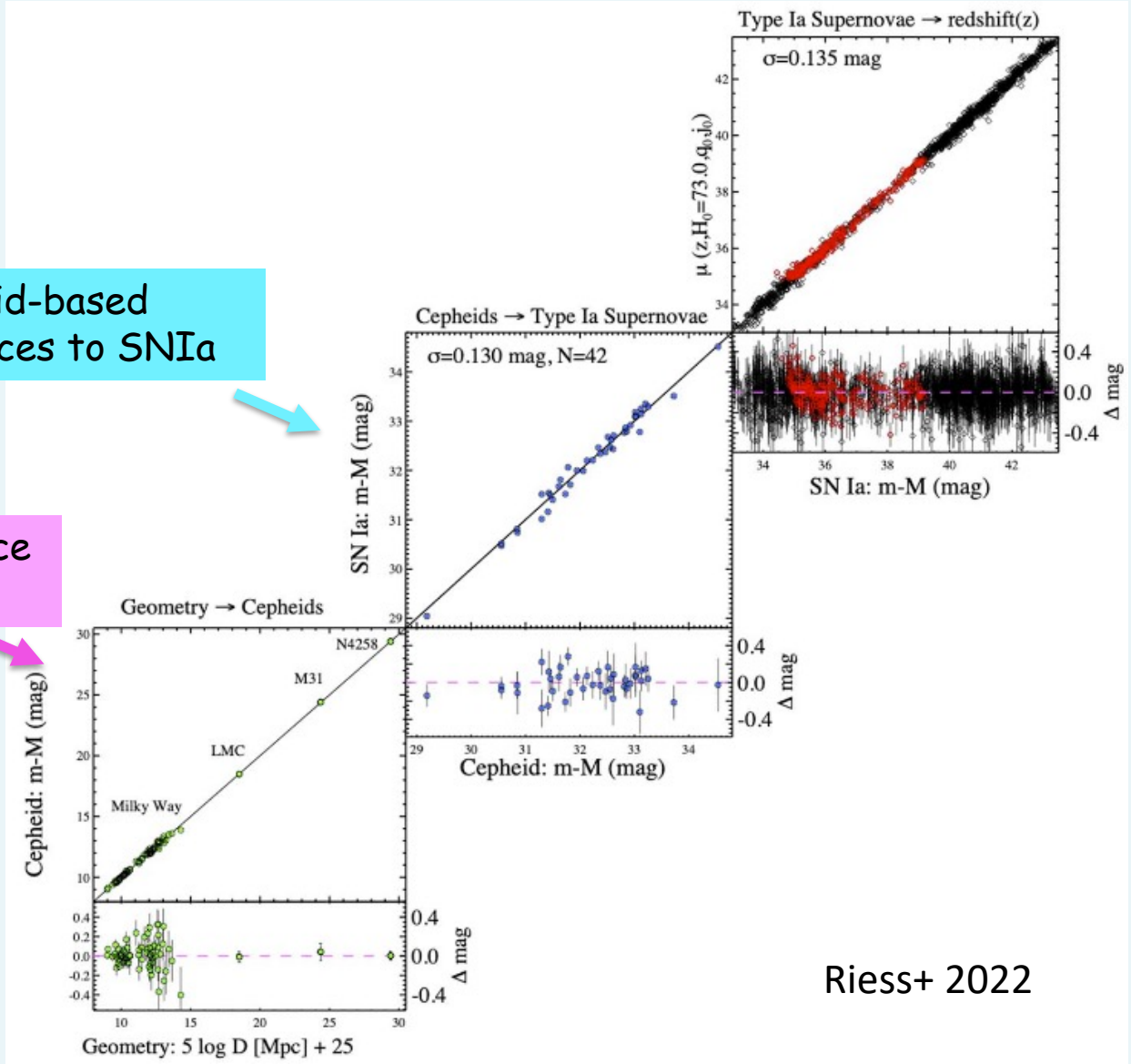
Cepheid-based distances to SNIa

Geometric distance to Cepheids



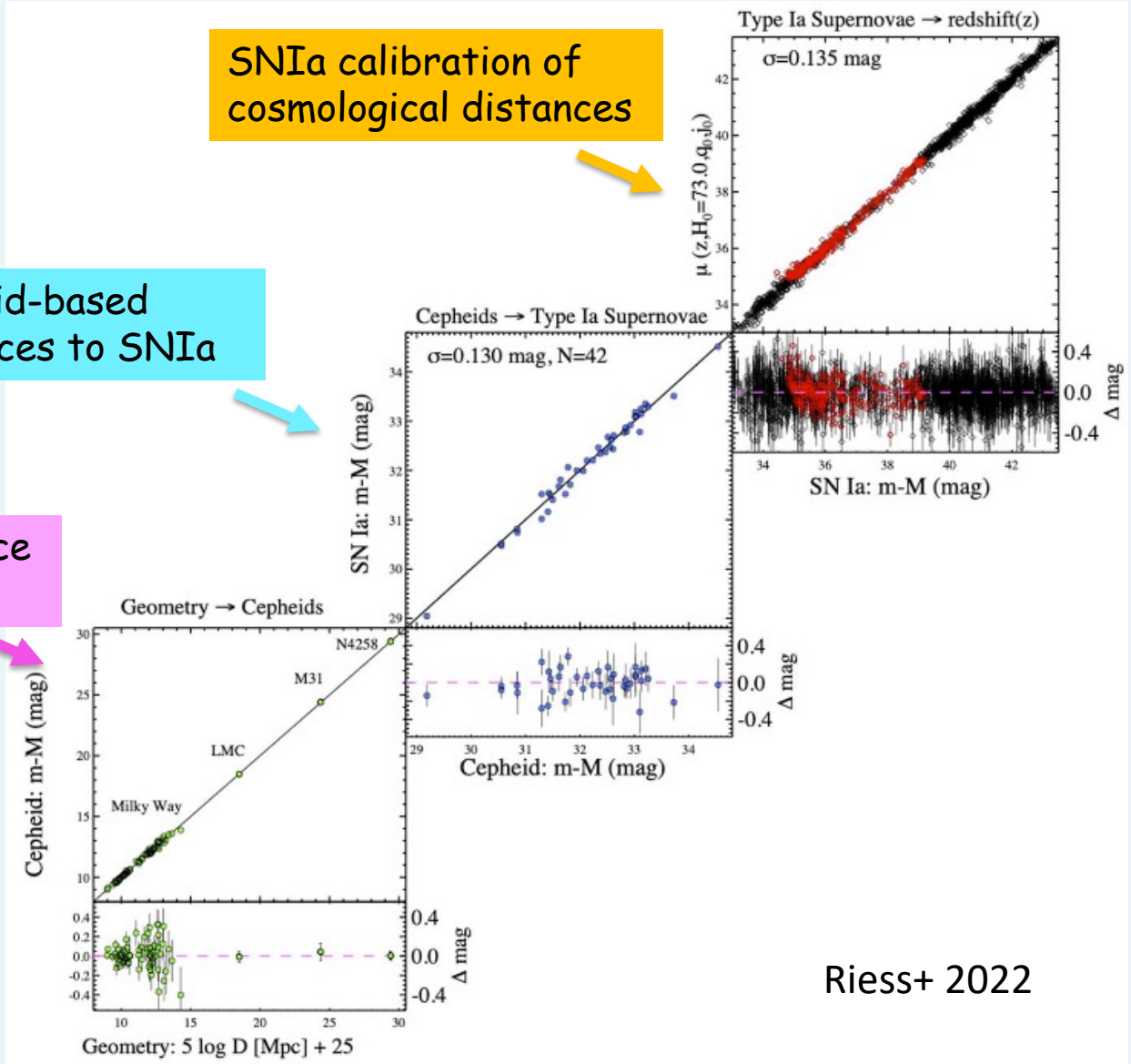
Riess+ 2022

The stellar route in 3 steps

SNIa calibration of cosmological distances

Cepheid-based distances to SNIa

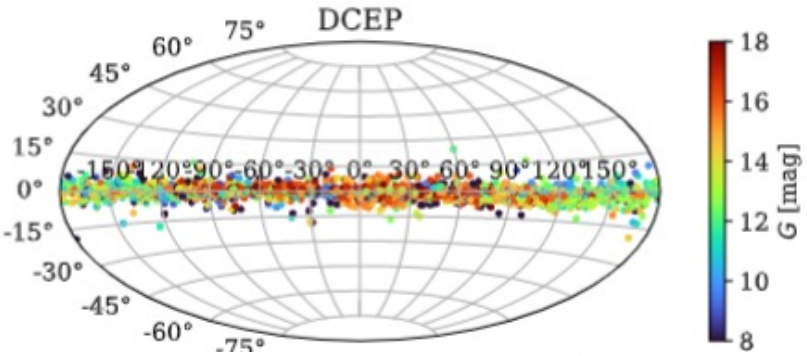
Geometric distance to Cepheids

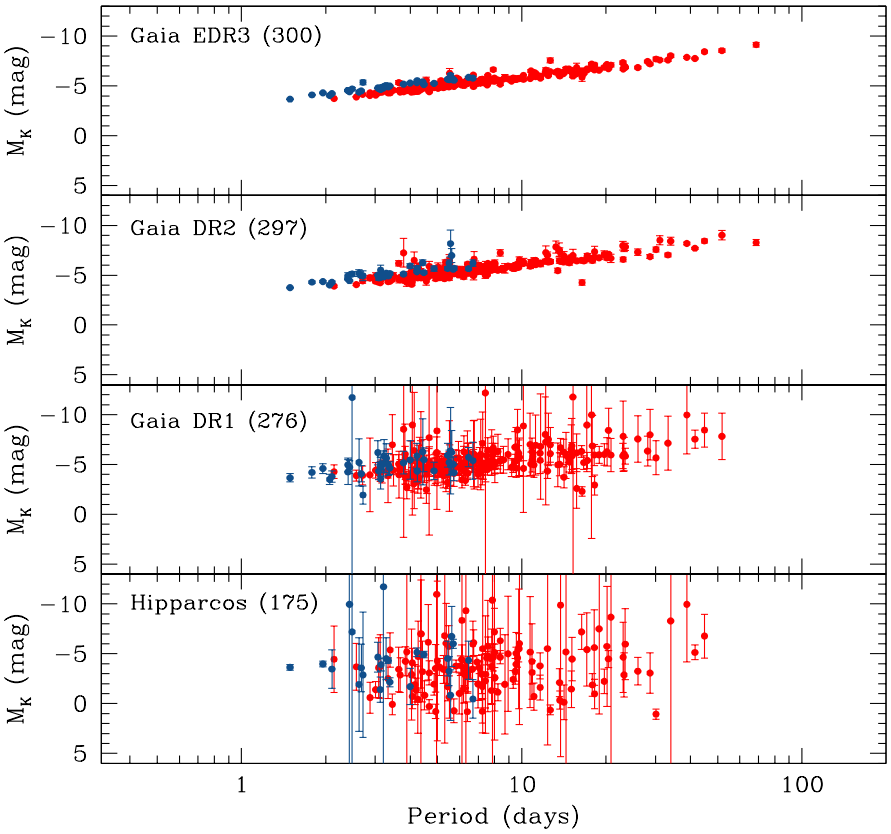


Riess+ 2022

The first step: the impact of Gaia

3,434 MW **Classical Cepheids** in Gaia DR3
→ largest homogeneous dataset





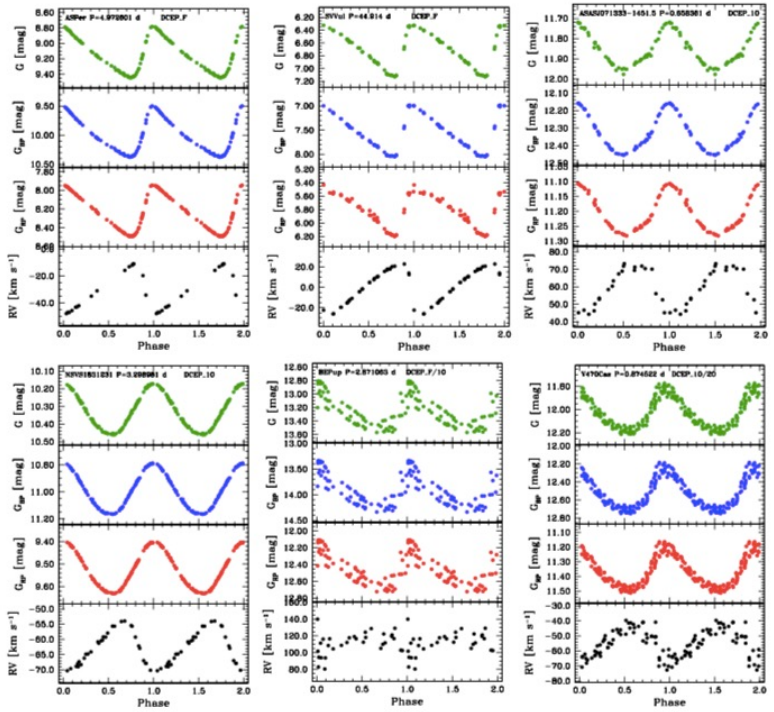
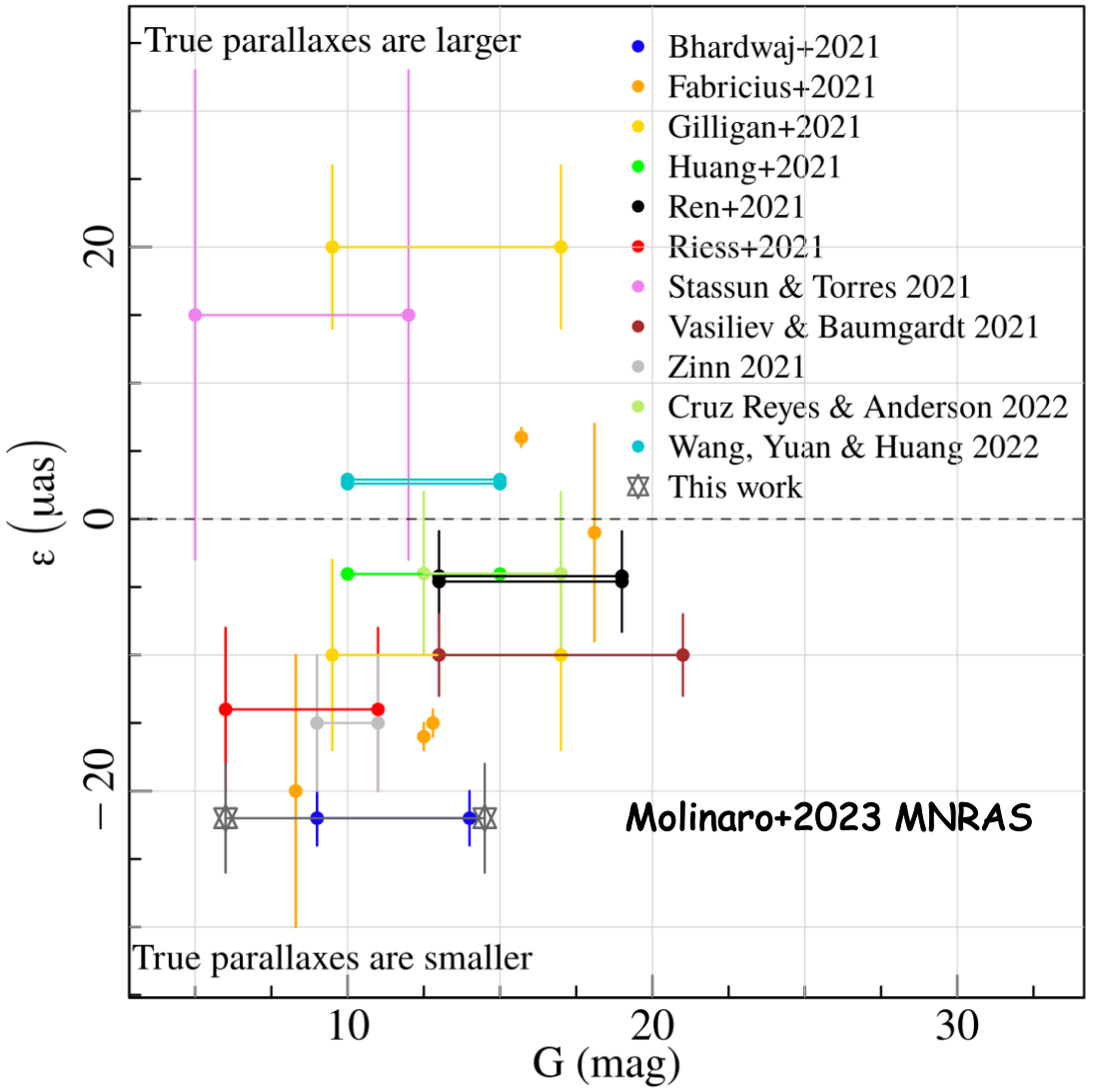


Fig. A.1. Light and RV curves for a selected sample of DCEPs of different modes.

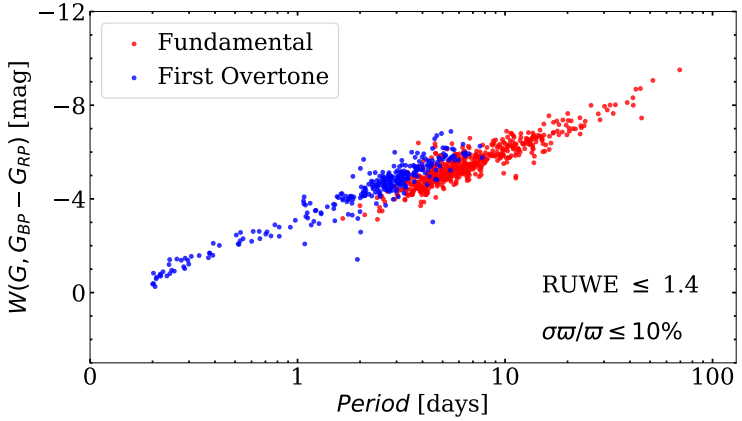
The first step: what needs to be improved

- Better quantify the zero point offset of Gaia parallaxes that is known to depend on the source magnitude, colour and position.

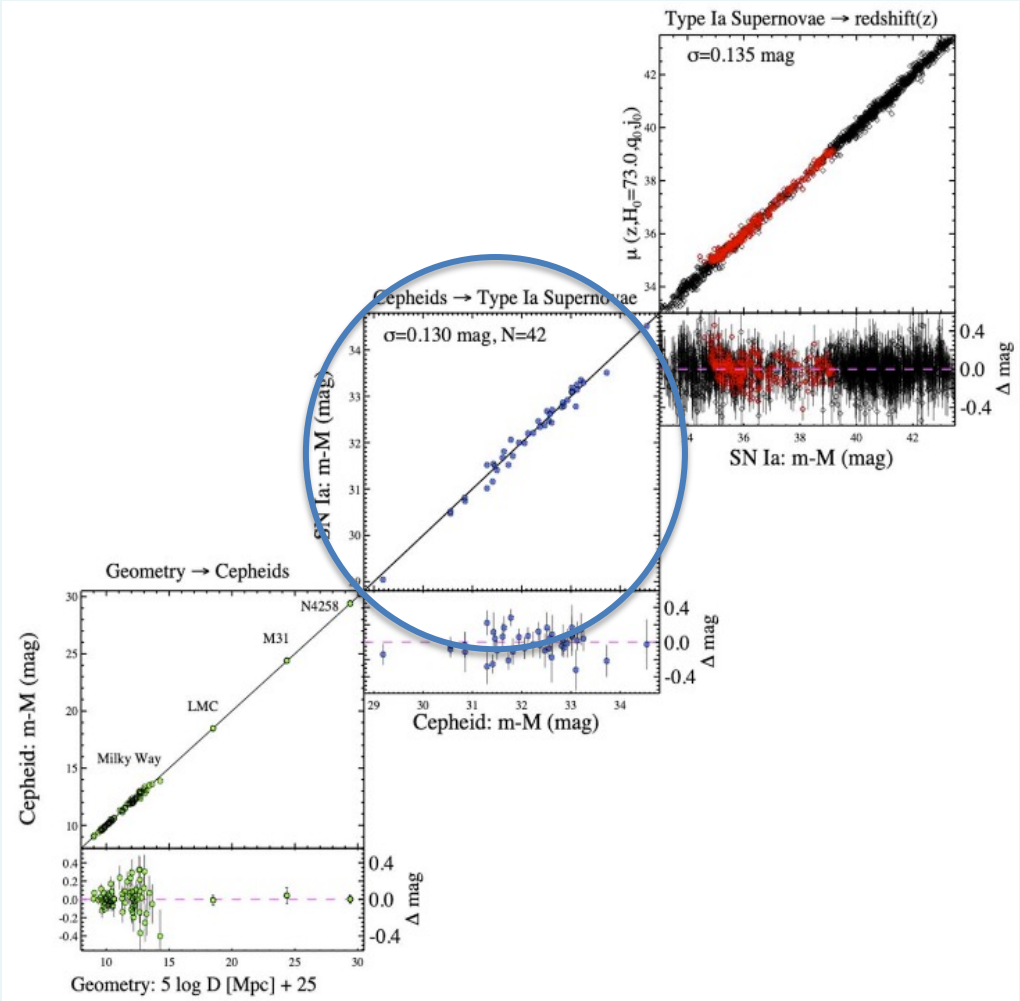
- This effect will be hopefully reduced in next Gaia releases



The second step: Classical Cepheids



~1060 Cepheids in Gaia DR3 with high-precision parallaxes (distances)

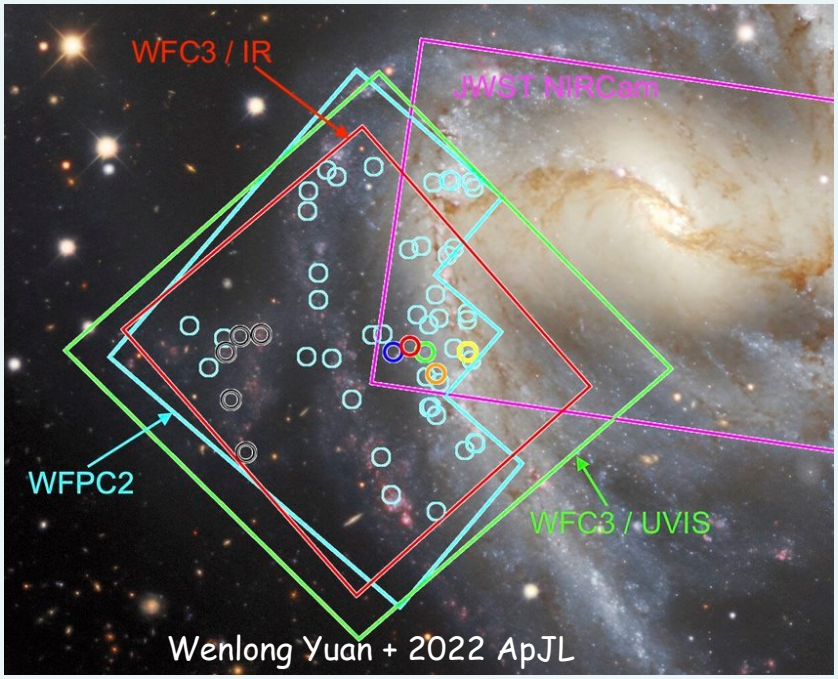


Possible approaches to reduce the PL systematics

Wenlong Yuan + 2022 ApJL

Possible approaches to reduce the PL systematics

To work in the NIR/MIR



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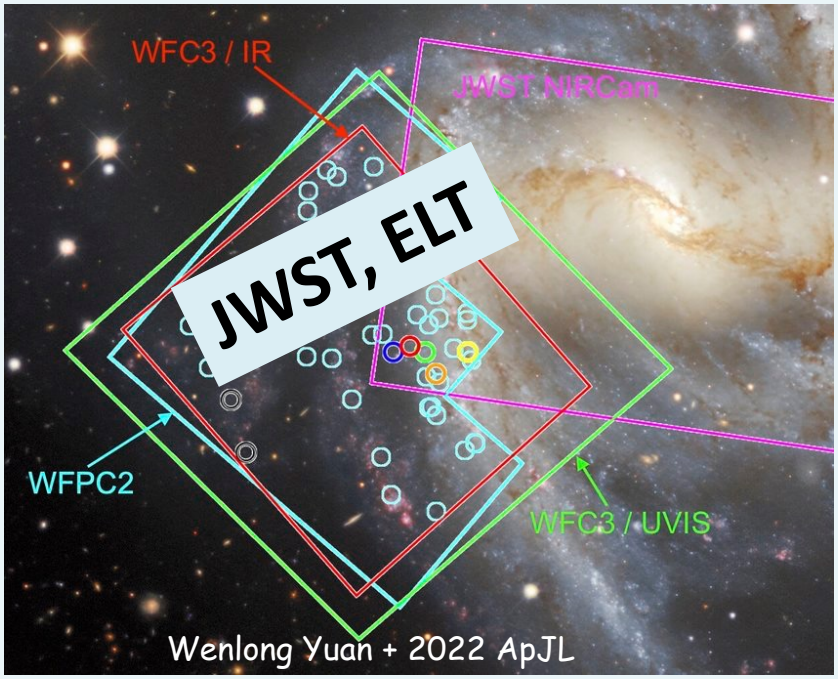

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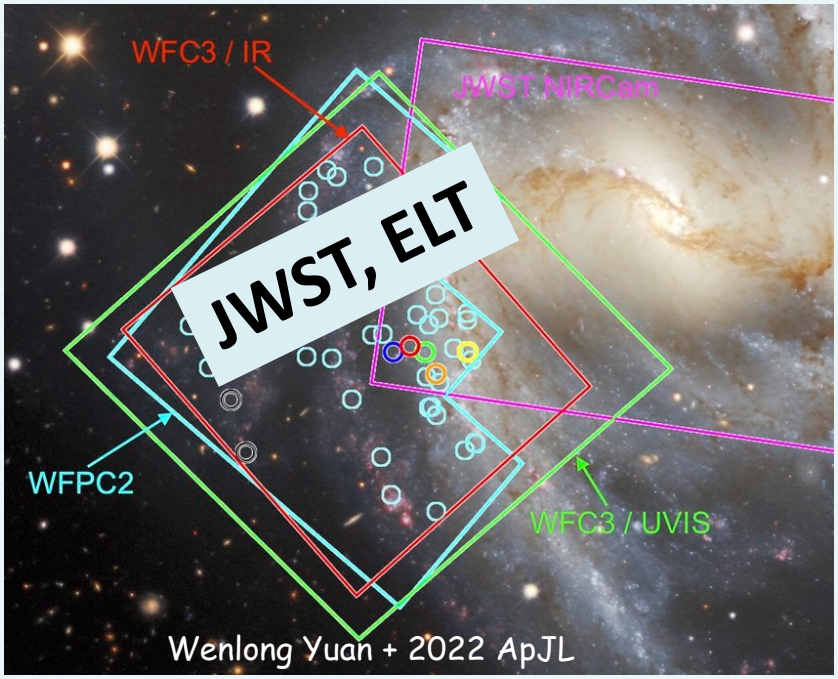


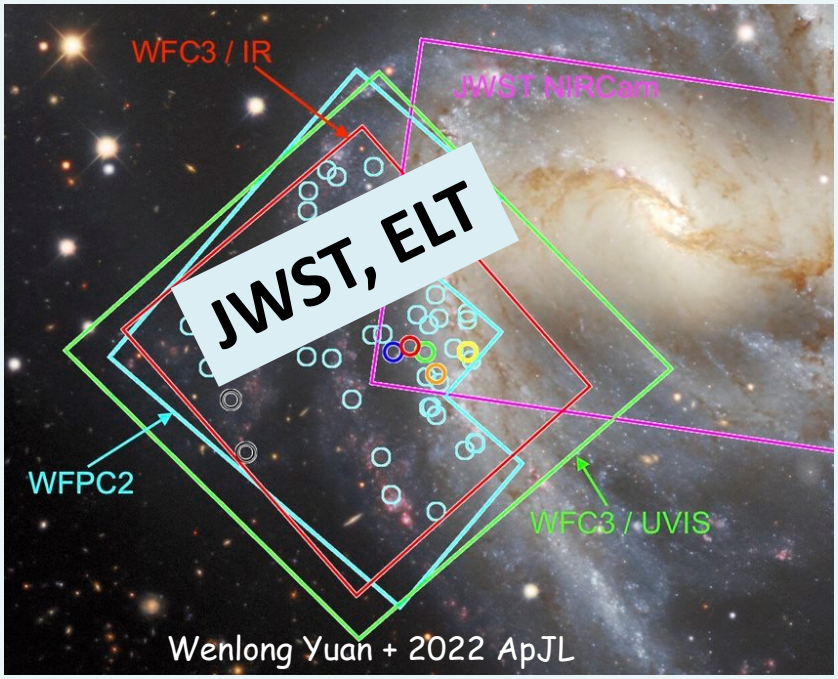
To adopt Wesenheit functions

e.g. $W(B,V)=V-\gamma(B-V)$

$\gamma=A_V/E(B-V)$

Possible approaches to reduce the PL systematics

To work in the NIR/MIR



To adopt Wesenheit functions

e.g. $W(B,V)=V-\gamma(B-V)$

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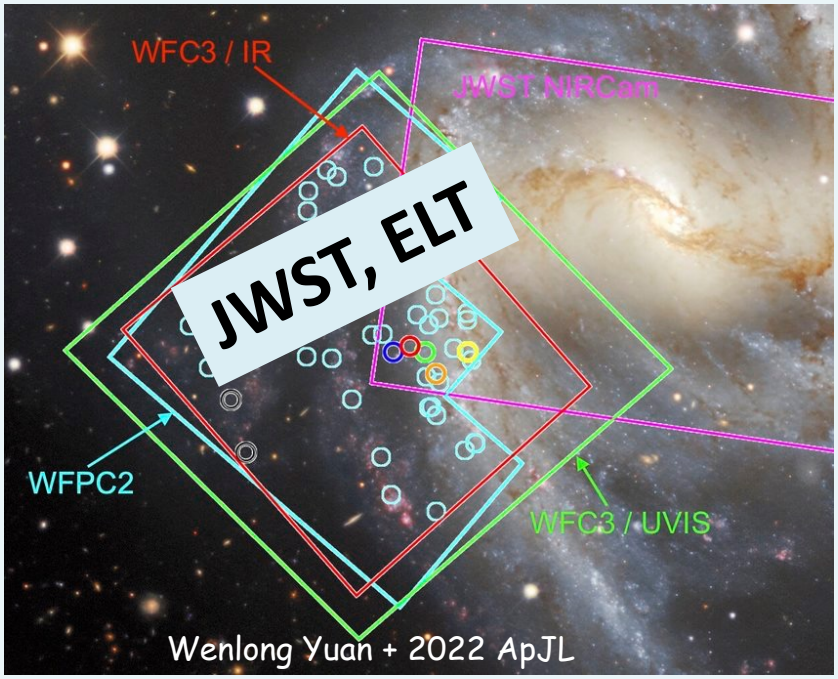
Advantages:
- It is reddening free by definition
- It partially corrects for the color extension of the strip

Disadvantages:
- It is not a true PLC relation
- It relies on the assumption of an extinction law (e.g. Cardelli+ 1989)

Possible approaches to reduce the PL systematics

To work in the NIR/MIR



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Rubin-LSST

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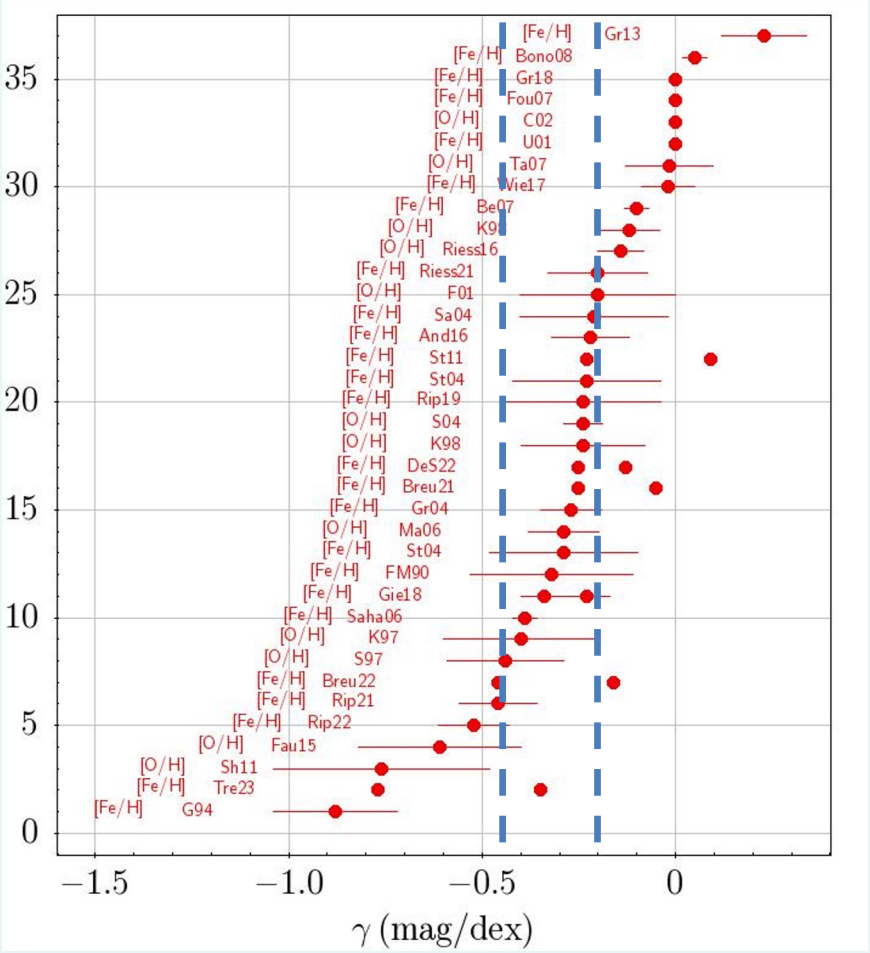
The debated metallicity effect on PL and PW relations

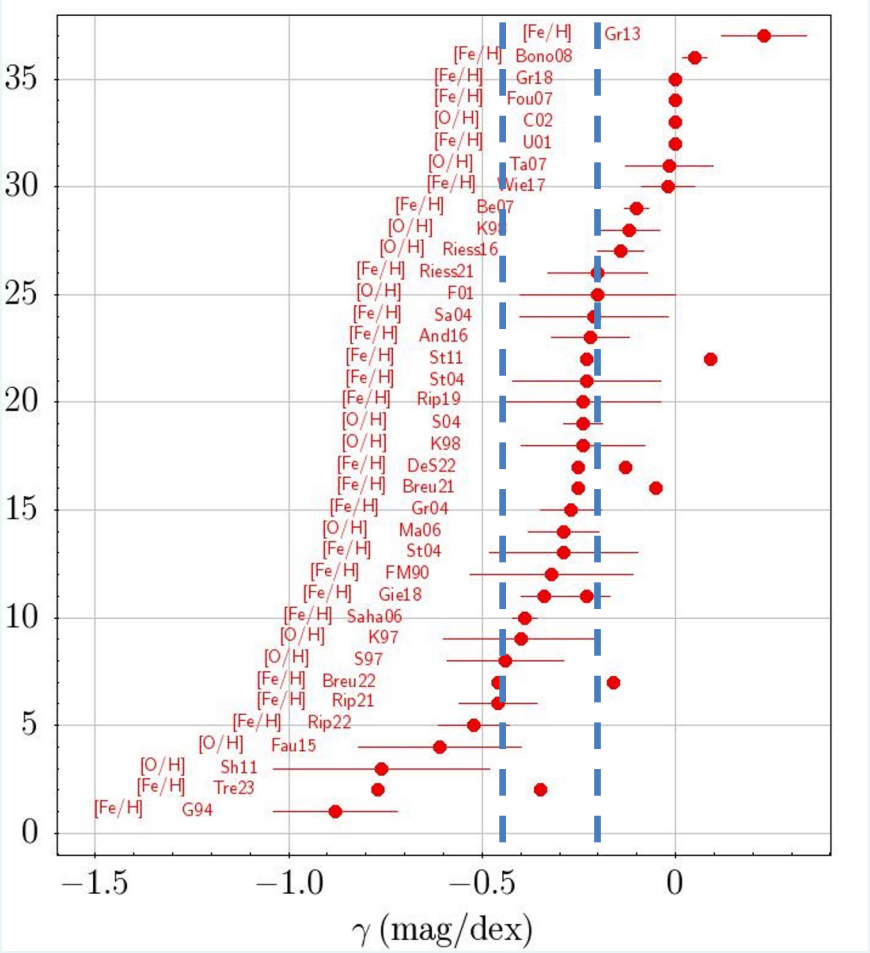


Trentin+2023 in prep

Apart from the dependence on the wavelength, which is uncertain, many recent estimates give discrepant results, in the interval from -0.20 to -0.45 mag/dex

- Still an open problem.

The debated metallicity effect on PL and PW relations



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- Still an open problem.

fiber multiobject (4MOST@VISTA, MOONS@VLT, WEAVE@WHT) and slit NIR spectrographs (e.g. CRIRES+@VLT), but also **ELT** spectroscopic instruments

The role of the Mass-Luminosity relation

Model predictions show that brighter/fainter ML relation by 0.2 dex implies a shorter/longer distance scale by ~ 5 % → increase/decrease of H_0 by ~ 5 %

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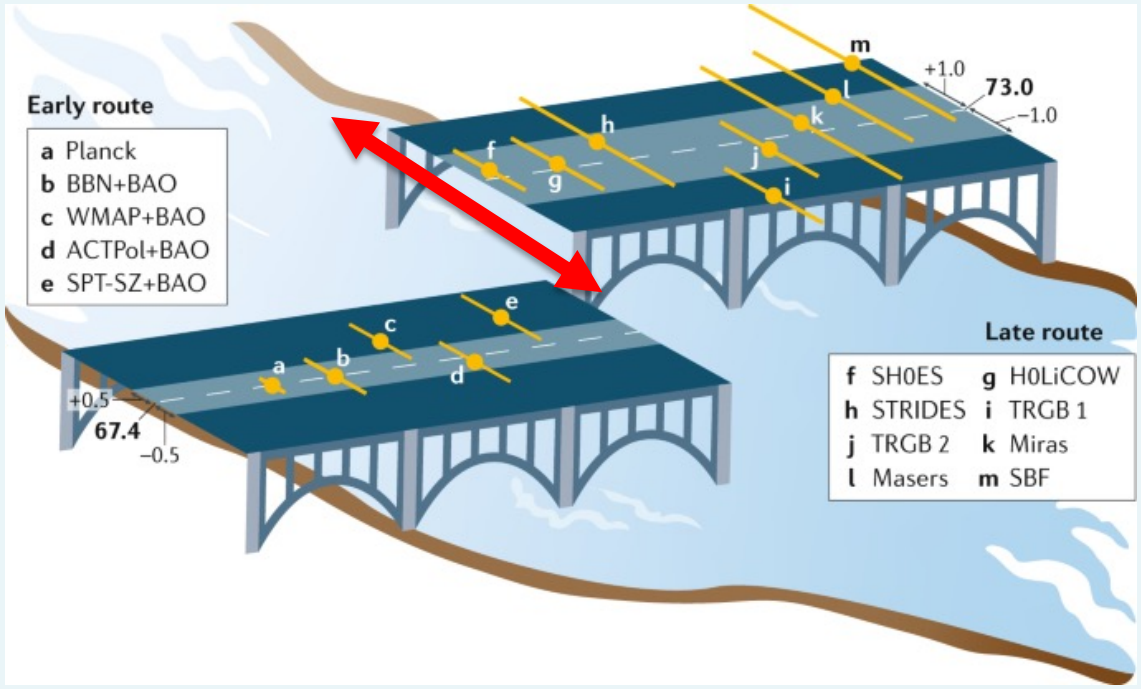
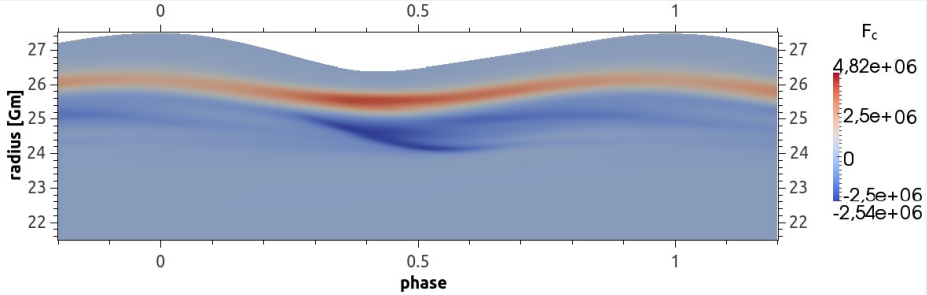
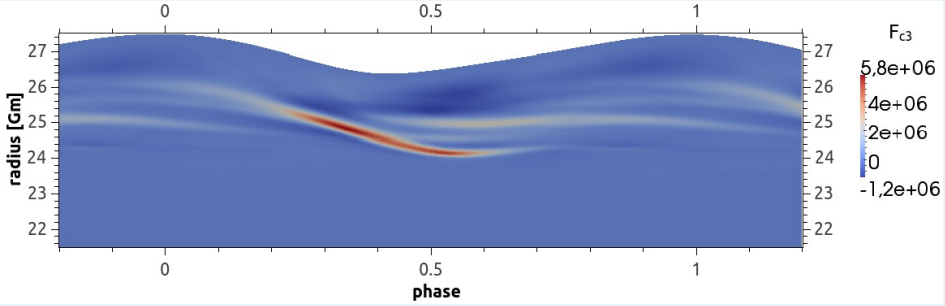


The role of convection

Current stellar evolution and pulsation models are 1D but there are first attempt to model pulsation through 2D or 3D hydrodynamical simulations

e.g. *Mundprecht et al. 2013, 2015 MNRAS* → 2D approach to pulsation)





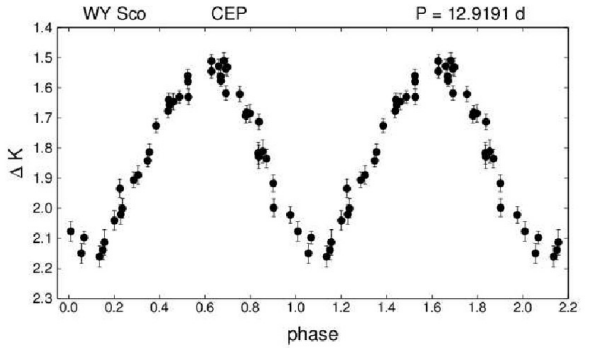
→ More realistic simulations of the convection–pulsation interaction in Cepheids

→ guidelines for developing descriptions of convection to be applied in 1D modelling.

See also Geroux & Deupree (2015), Deupree (2021)

Perspectives to improve the Cepheid distance scale

On the observational side



- Calibrate accurate PL and PW relations in the NIR/MIR filters (← JWST)
- Better quantify the metallicity effect (← 4MOST, MOONS, WEAVE, CRIRES+, ELT)
- Use extensive multi-filter sets of PW relations to constrain distances and the extinction law (← Rubin LSST)

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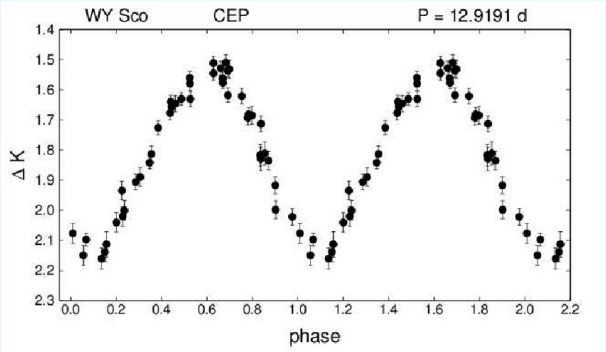

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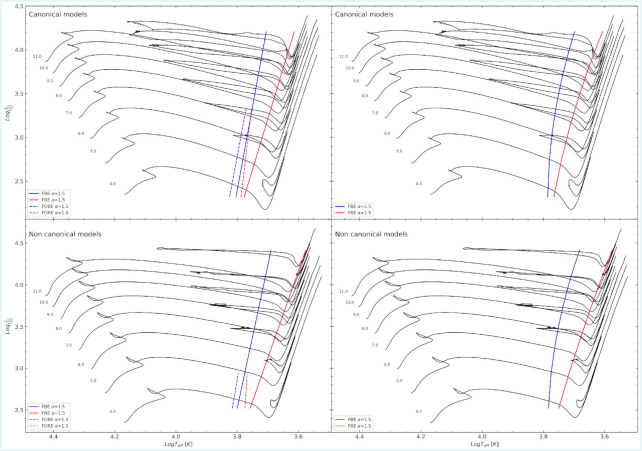
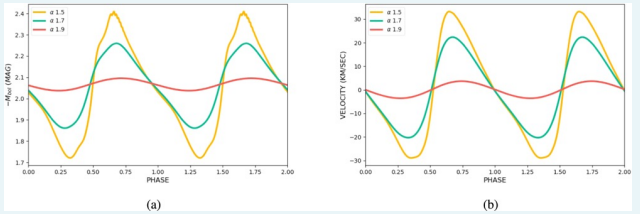
On the theoretical side

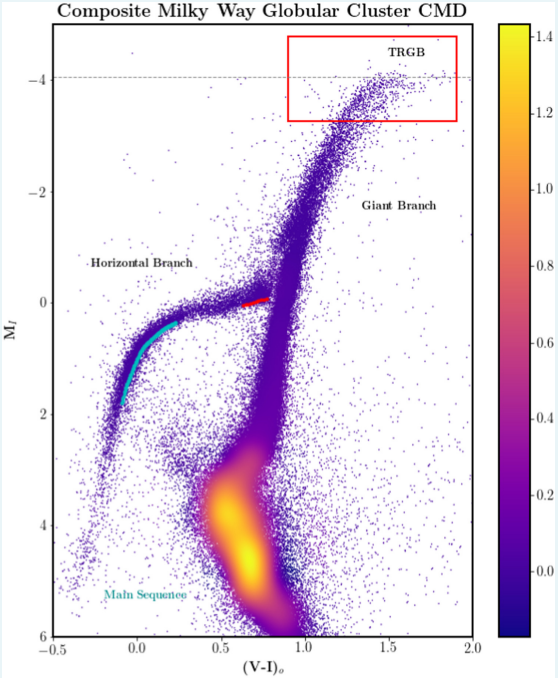
- Improve the physical inputs in stellar evolution and pulsation models (→ML relation)

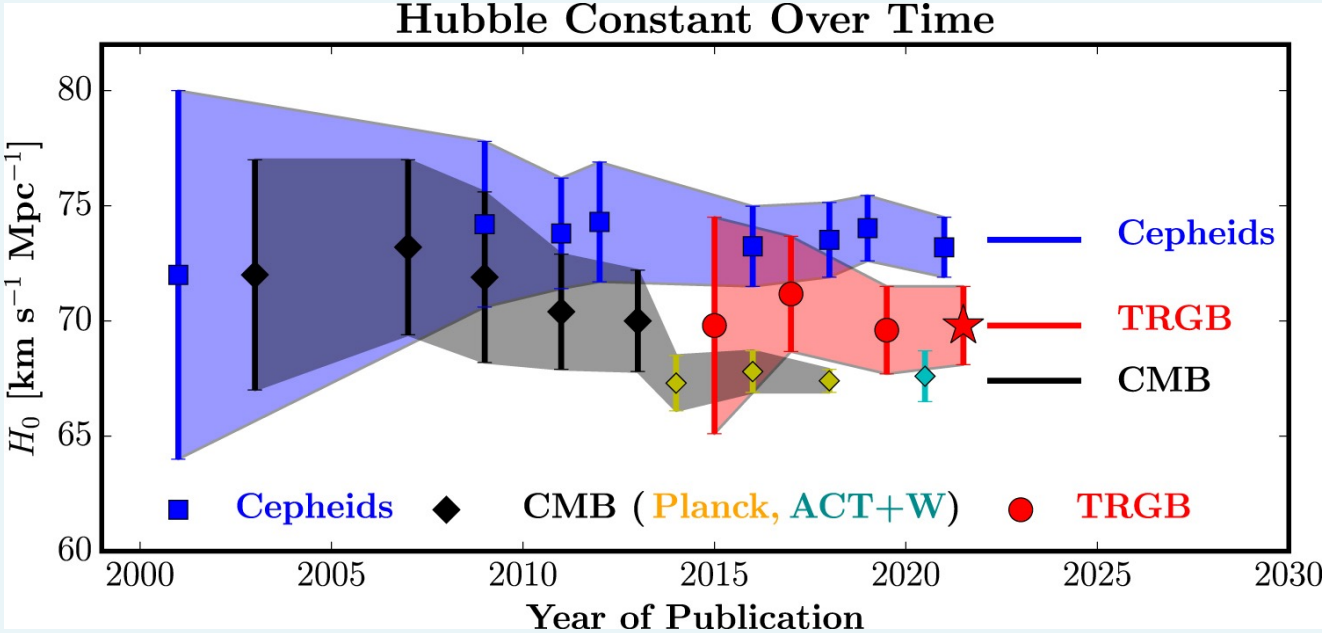


- Improve the treatment of super-adiabatic convection



Using the Tip of the RGB as second step





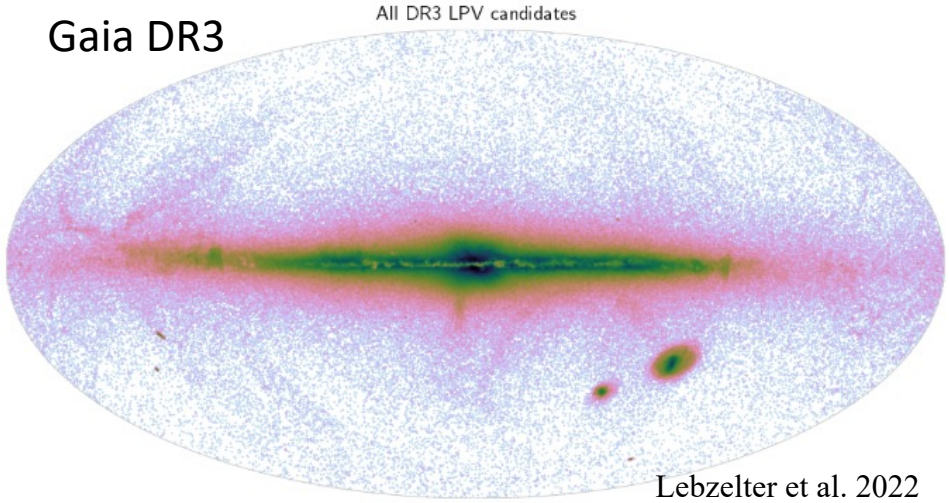
Freedman 2021 ApJ

- The sample of galaxies with TRGB distances and SN Ia will increase ← **mostly with JWST**
- The distance limit of ~20 Mpc will at least double ← **JWST, ELT**

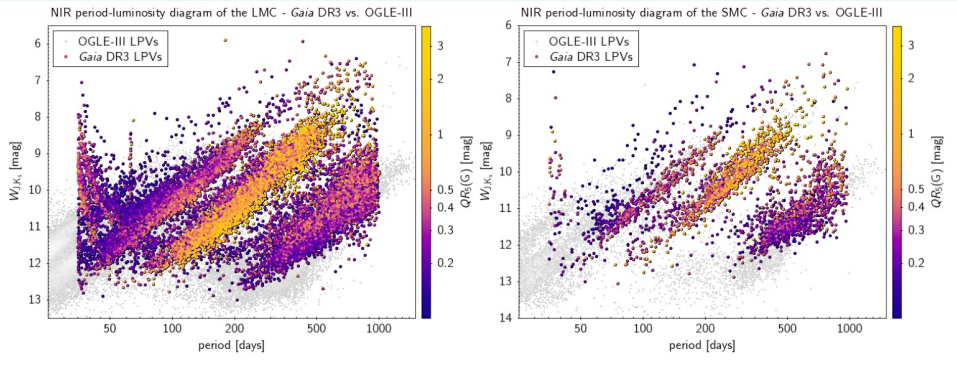
Other promising standard candles: Long Period Variables

On the observational side

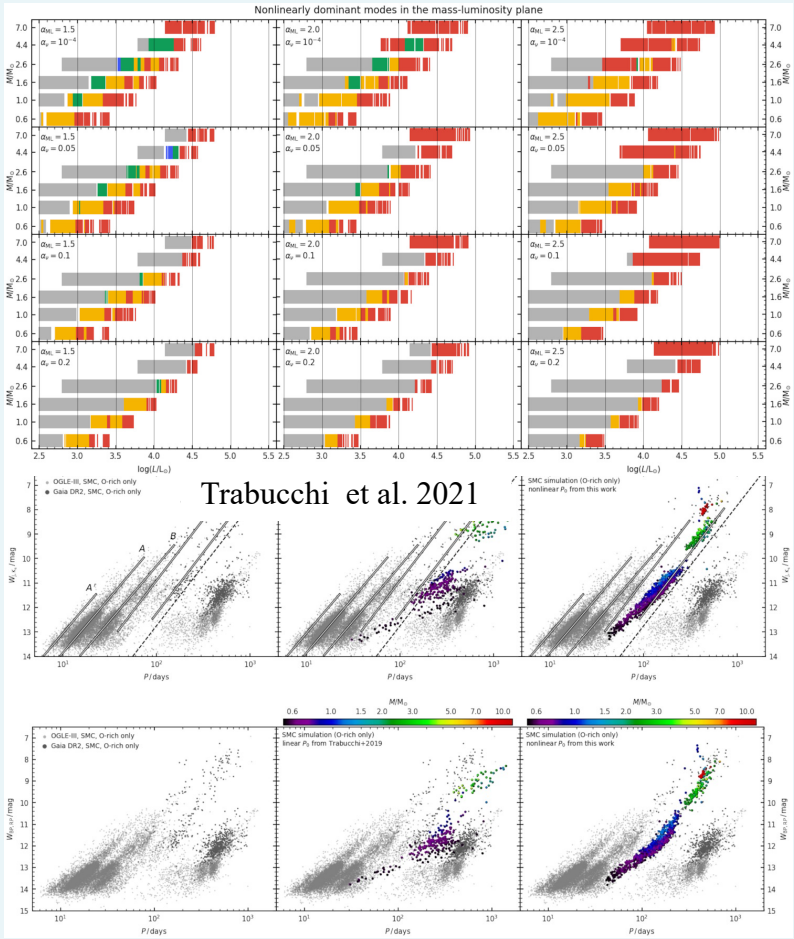
Gaia DR3



Lebzelter et al. 2022



On the theoretical side



Trabucchi et al. 2021

Other promising standard candles: Long Period Variables

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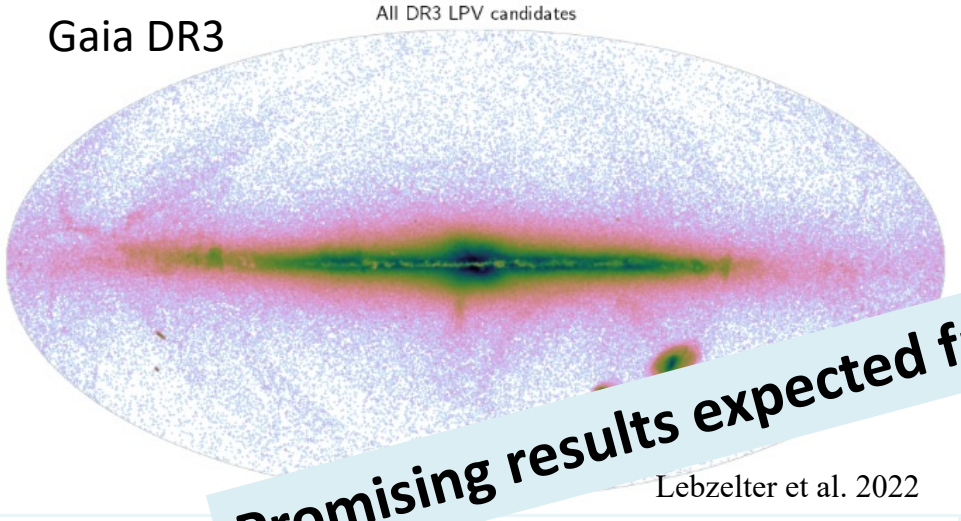

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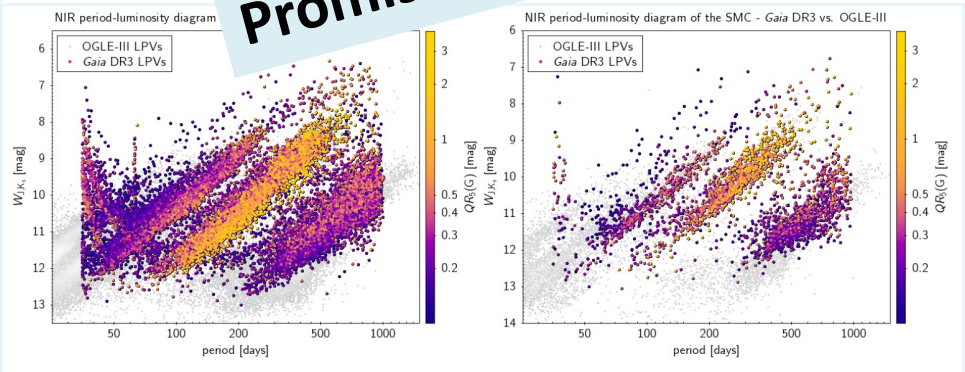

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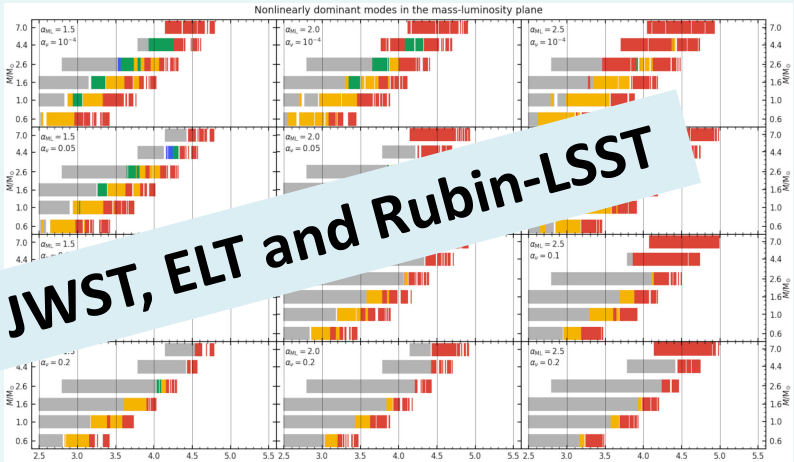
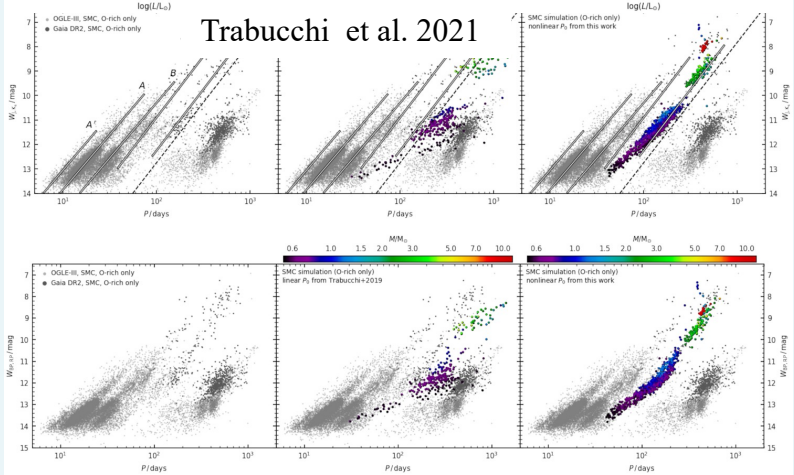
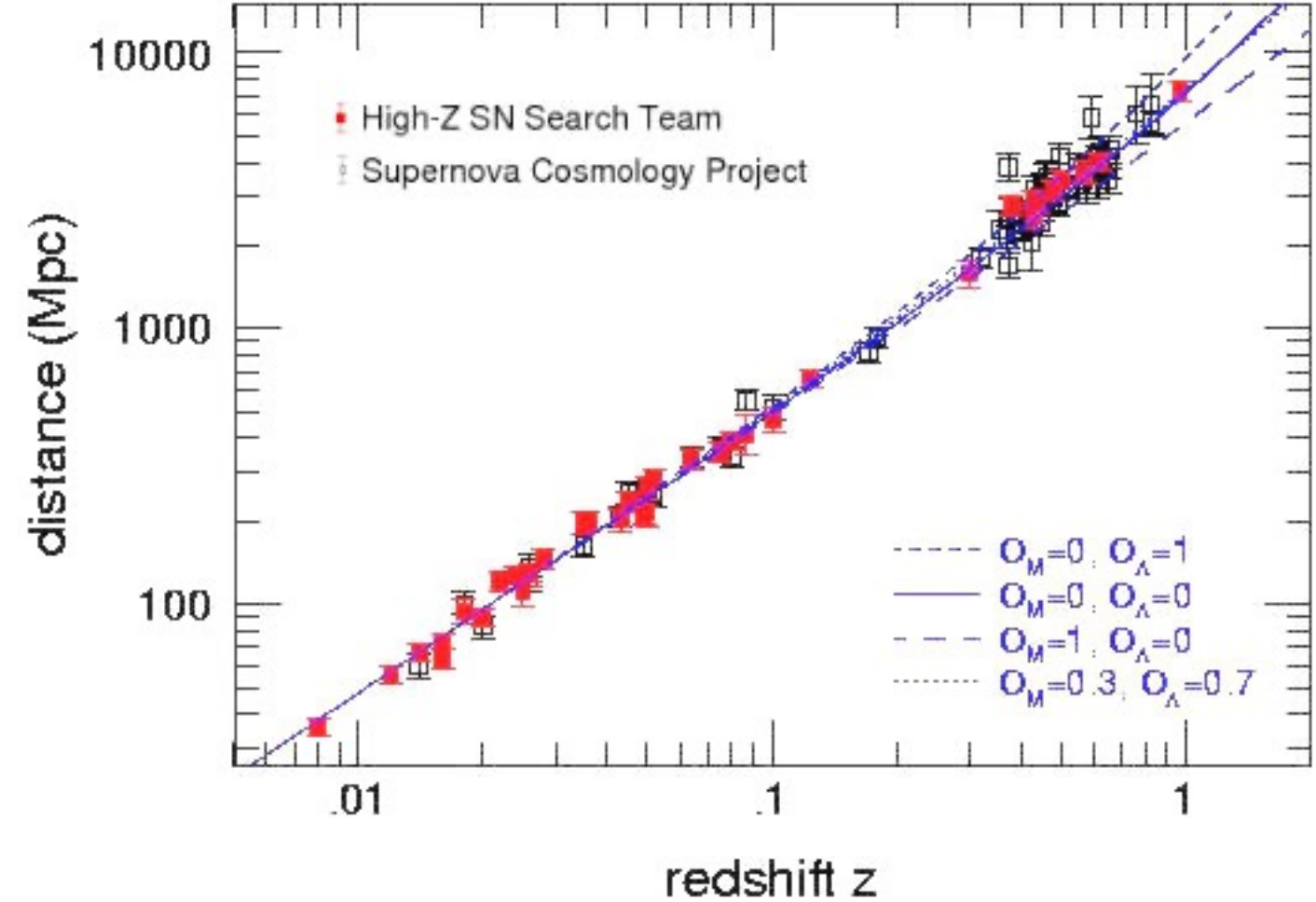


Trabucchi et al. 2021



Promising results expected from JWST, ELT and Rubin-LSST

The third step: SNIa Hubble diagram



Possible systematics of SNIa

Explosion scenario → environmental effects? More explosion mechanisms?

Anomalous reddening law ?

SNe in different types of galaxies could originate from different local environments and/or progenitor properties of SNe Ia (e.g. Khetan+2021)

Rubin-LSST and JWST will increase the number of SNe Ia hosted in galaxies where also SBF distances can be measured→ improving the calibration of SNe Ia, as well as in the estimation of H0.

Better characterization expected ← **JWST, SOXS, Rubin-LSST**

INAF present and future contribution

Improving the parallax measurements (e.g. Lattanzi+ 2018, Abbas+ 2022, Vallenari+2022, Butkevich+2023) and the pulsatig star distance scale calibration (e.g. Garofalo+2022, Clementini+2022, Ripepi+2022a, Molinaro+2023)
→ Gaia final release between 2025-2030

Quantifying systematic effects both on the observational (e.g. Bhardwaj+2022, Ripepi+2022b, Trentin+2023) and the theoretical (e.g. De Somma+2020,2022, Marconi+2021,2022, Musella+2022, Trabucchi+2021) side for pulsating stars
→ Rubin-LSST, 4MOST, ELT data

New self consistetent stellar evolution and pulsation codes → 3D treatment of convection

Oservational and theoretical characterization of SNIa (e.g. Tomasella+2023, Piersanti+2022) → SOXS, Rubin LSST data