SHOT: the Stellar path to the H0 Tension in the Gaia, TESS and JWST era

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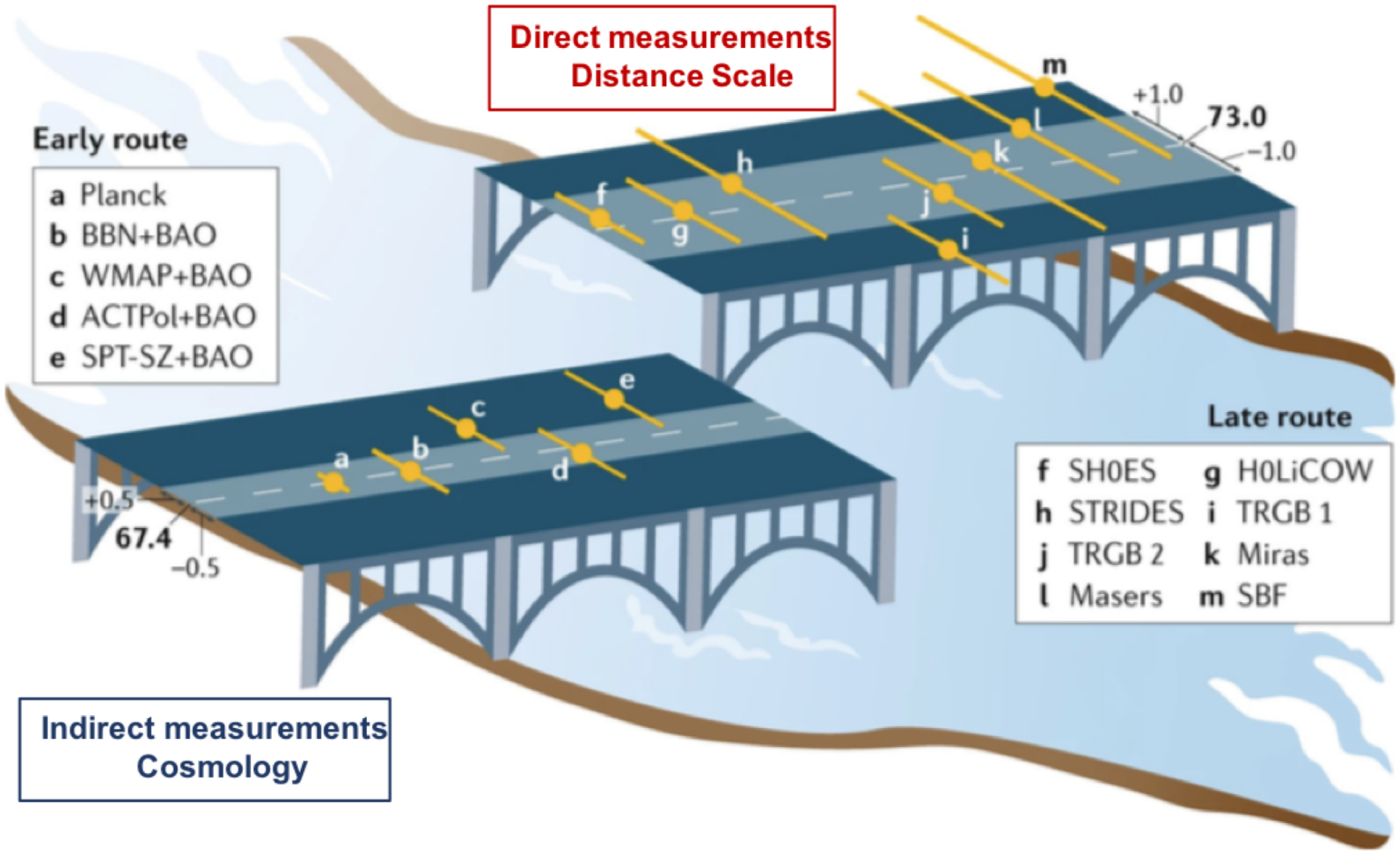
GAIA – DPAC (CU7)

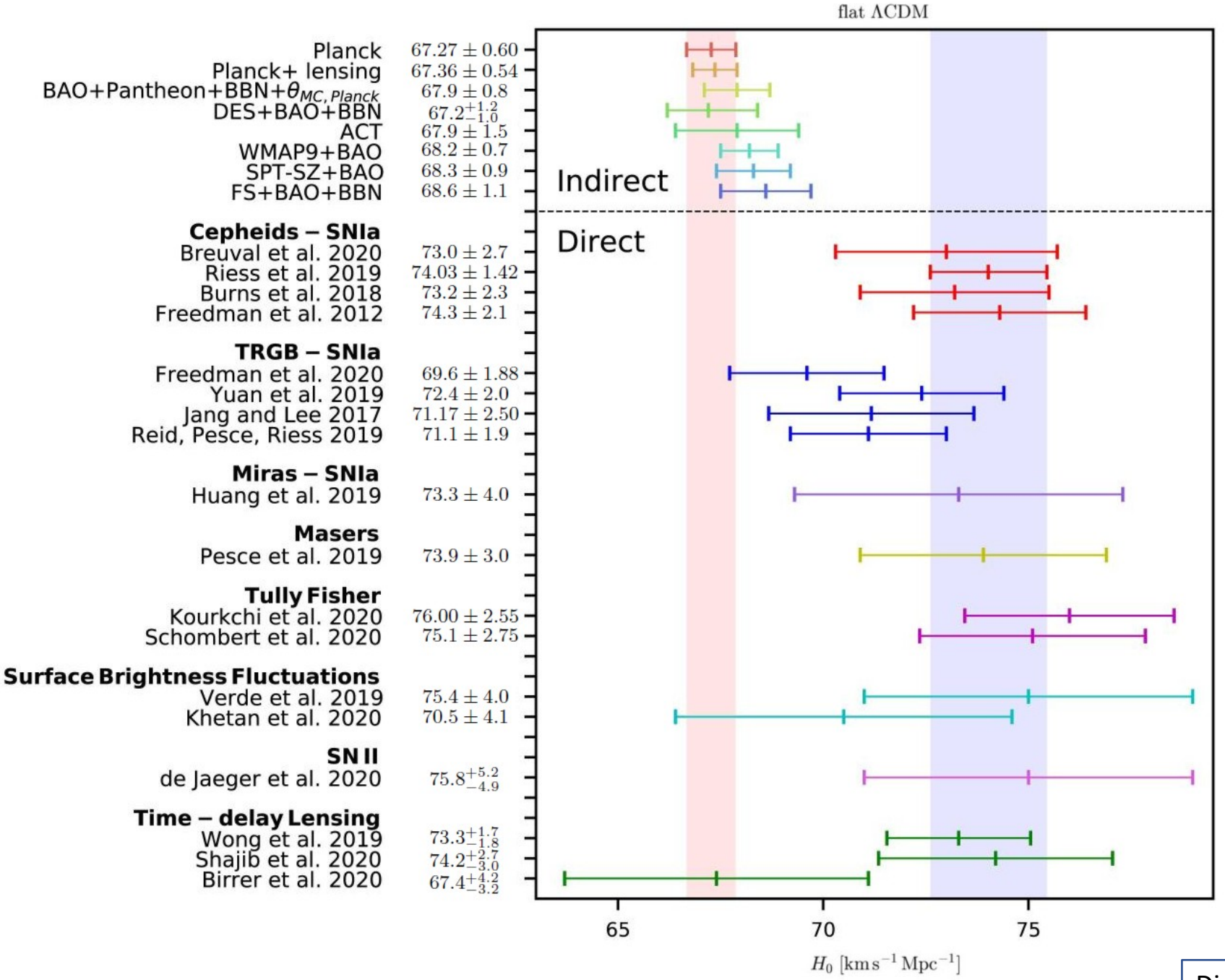
On Behalf of the SHOT Team

Audizione schede INAF – 20 Maggio 2021

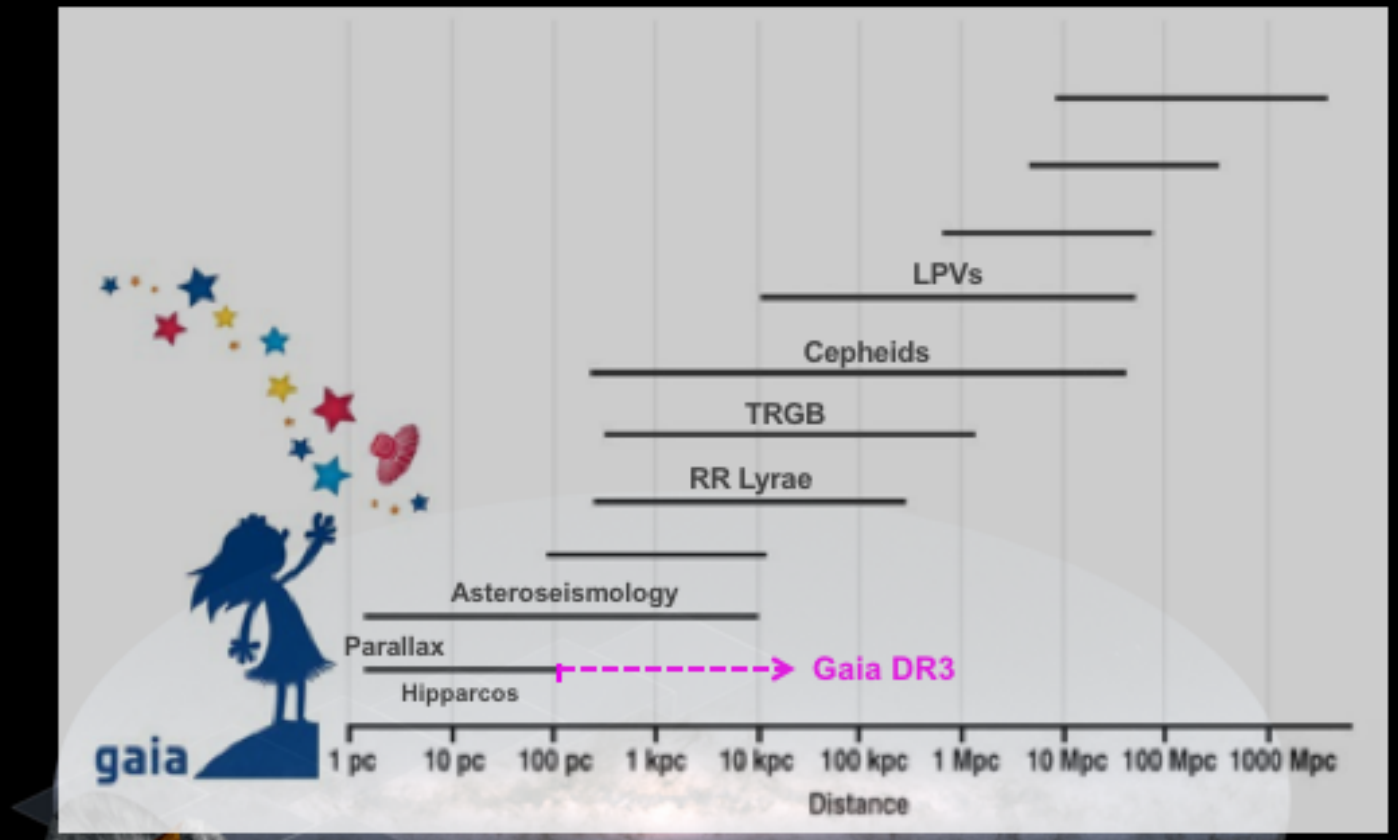
The H0 Tension



Riess 2019



Di Valentino 2020

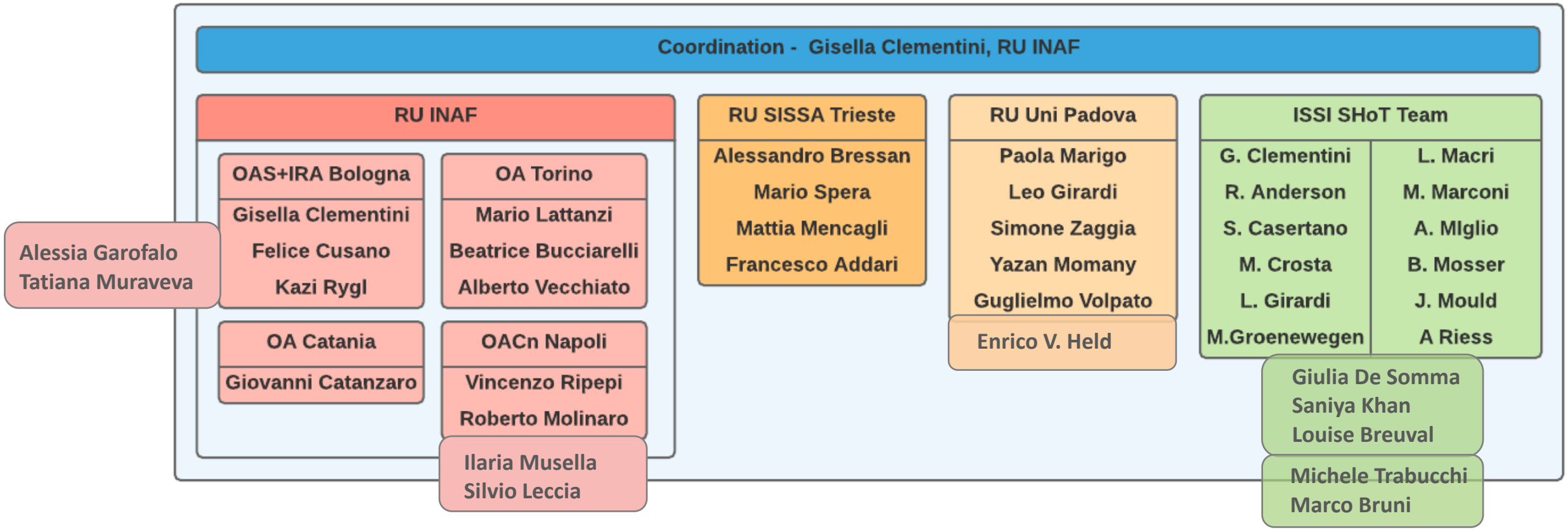


The purpose of the **SH0T project** is to **raise the accuracy of the astronomical distance ladder** and quantify the H0 tension and the associated systematics from the point of view of stellar distance indicators by specifically tackling uncertainties and systematics affecting stellar standard candles. Main assets are the diverse expertise of our team and our privileged access to data sets from space mission such as Gaia, TESS and JWST, and from ground-based photometric and spectroscopic surveys spanning different wavelength ranges.

The SHOT Team

- ISSI International Team
(https://www.issibern.ch/teams/shot/)

- PRIN MUR 2020 Team



The SH0T Project develops through complementary approaches (astrometry, asteroseismology, theory of stellar evolution, stellar pulsation, stellar populations, photometry and time series analysis, high resolution spectroscopy and abundance analysis), which are briefly summarised below:

1. exploitation of Gaia EDR3 new parallaxes and DR3 new catalogues of variable stars

2. study of Gaia's parallax offset and systematics in the framework of relativistic models

3. constrains/corrections to Gaia parallax zero-point with asteroseismology

4. derivation of new luminosity-metallicity (LZ), infrared period-luminosity (PL), PL-metallicity (PLZ) and period-Wesenheit (PW, PWZ) relations for RR Lyrae and Cepheids calibrated on Gaia parallaxes

5. measure of metal abundance from high resolution spectra of Cepheids and RR Lyrae to constrain the metallicity effect on the PLZ, PWZ relations

6. assessment of model uncertainties and biases of the Tip of the Red Giant Branch (TRGB) luminosity as distance indicator

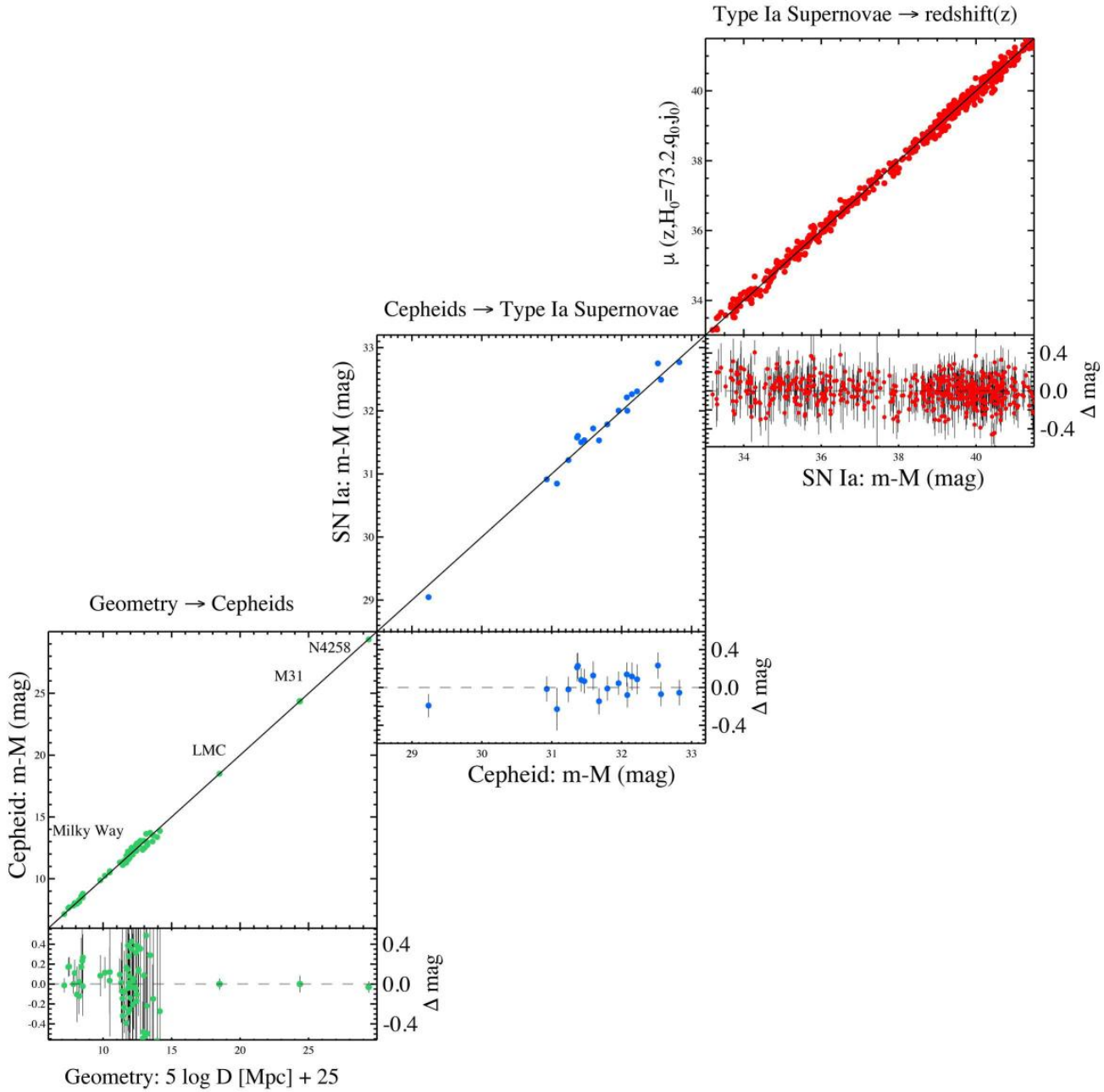
7. derivation of new pulsation models of Cepheids and RR Lyrae

8. study of the impact of single- and binary-star evolutionary processes on the demography of standard candles

9. LPVs and Carbon stars as distance indicators, using new opacities, new LPV models and probing population effects through LPV population synthesis

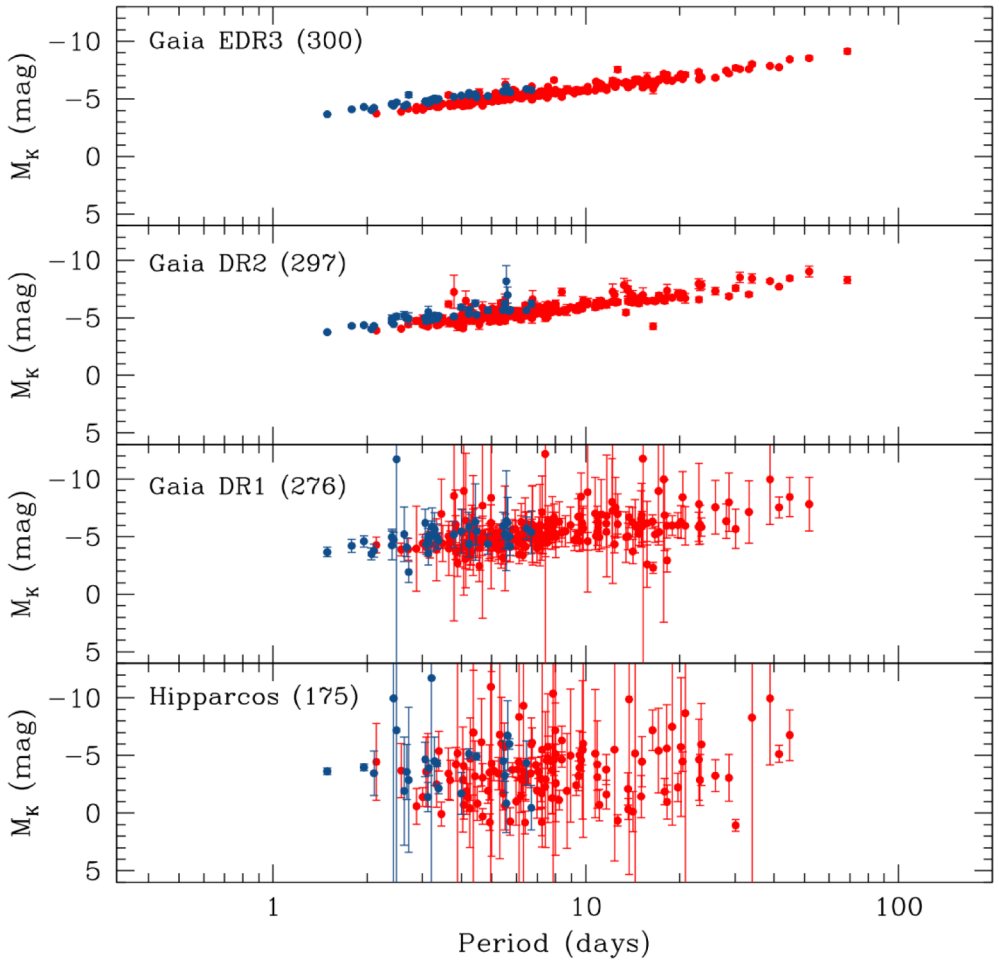
10. measure of geometric distances to nearby galaxies via masers

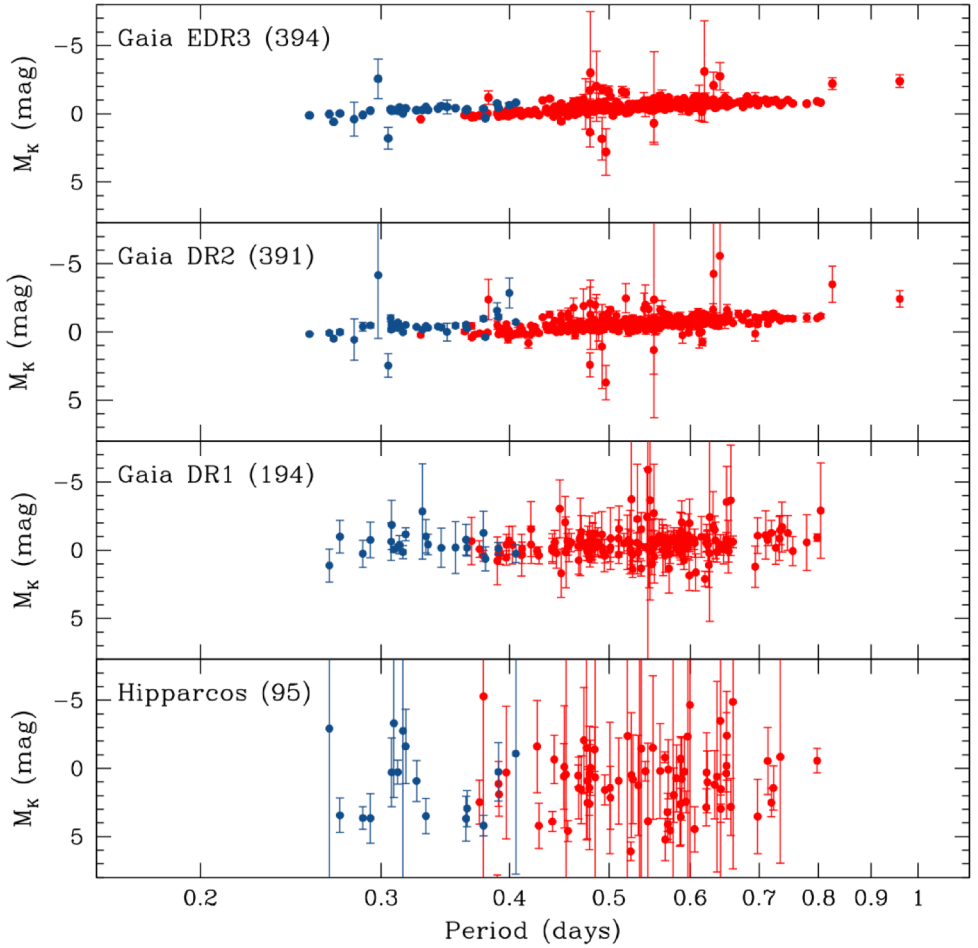
Standard candles calibrated with Gaia parallaxes within <10 kpc are then used to extend the distance ladder for galaxies up to a few Mpc, setting basic anchors in the path to measuring H0. Fundamental anchors specifically addressed in the SH0T project are the Large Magellanic Cloud (LMC; for which we exploit data from the VMC survey) and M31, as well as a few dwarf galaxies and Galactic Globular Clusters (GGCs) normally used as sanity checks in the calibration of the extragalactic distance scale.



Geometry – Cepheids – SN Ia distance ladder (Riess et al. 2019)

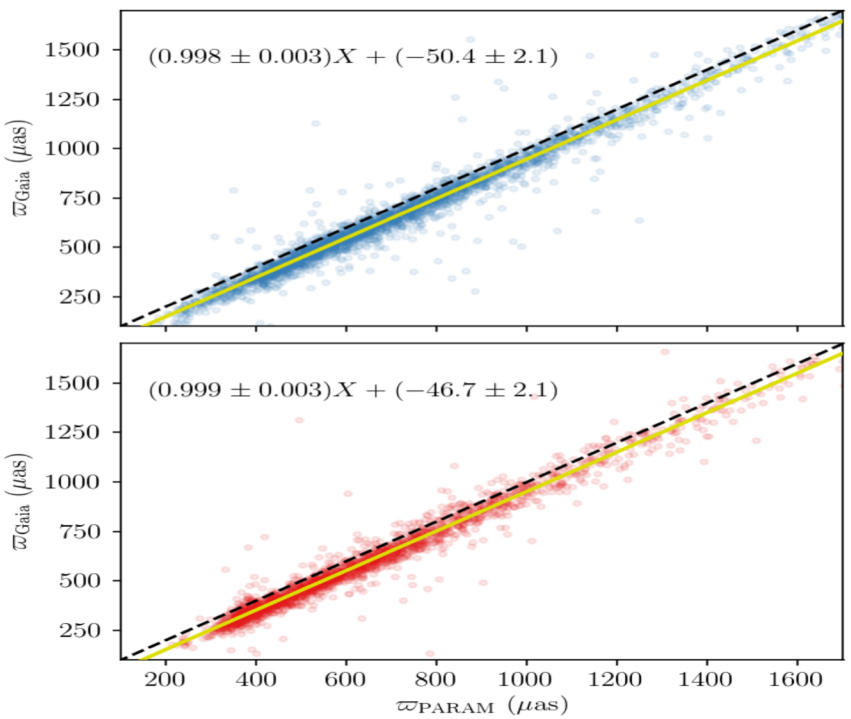
1. Gaia Parallaxes

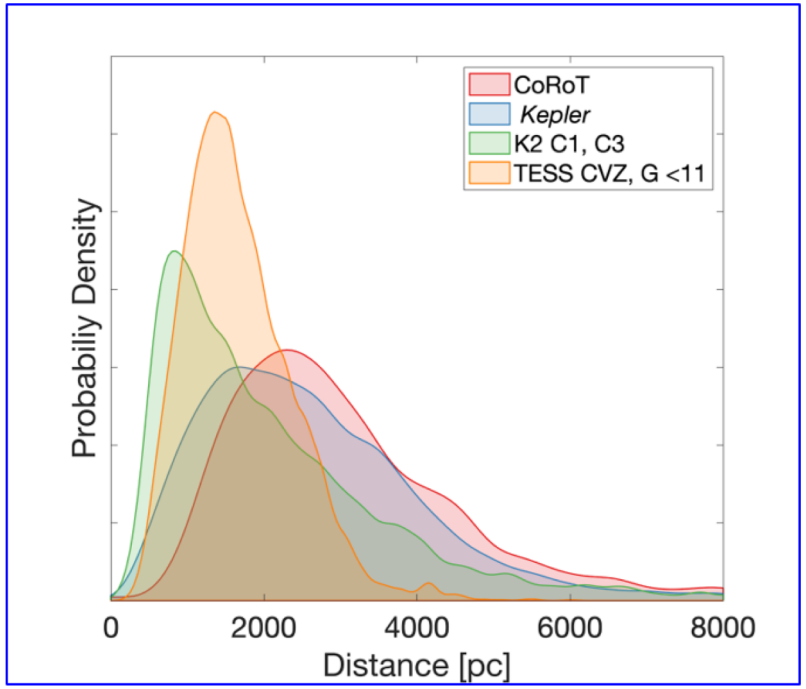




- more and better characterised Cepheids and RR Lyrae stars with Gaia DR3 (May 2022)

2. Gaia Parallax zero-point off-set





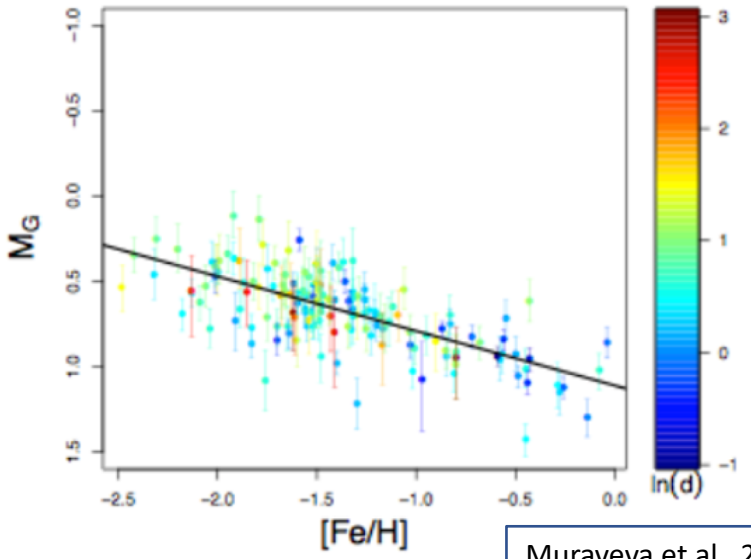
Khan et al. 2019

- from asteroseismology

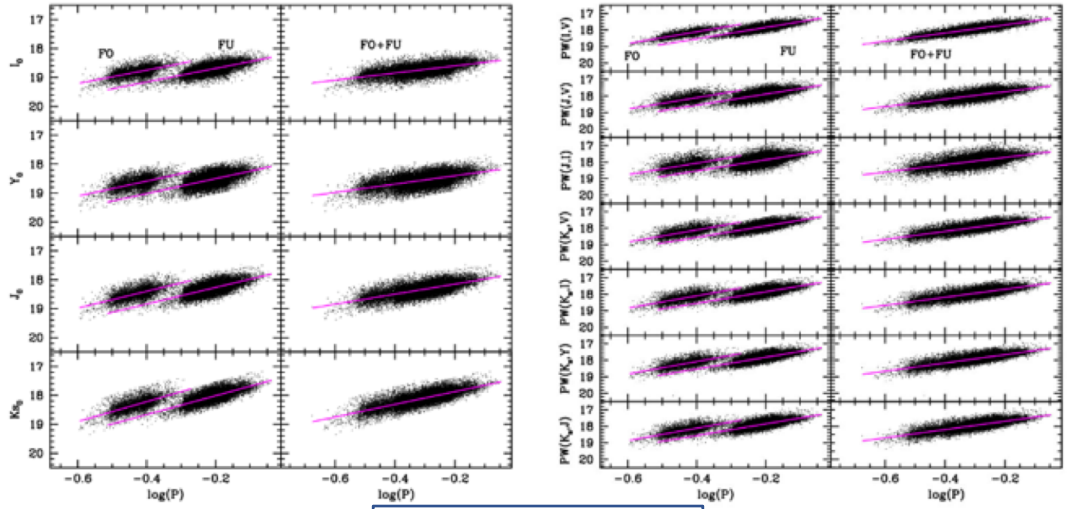
- in the framework of relativistic models (see also **GraviMetrA**)

- from RR Lyrae and Cepheid LZ, PL(Z), PW(Z) relations (see also **C-MetaLL**)

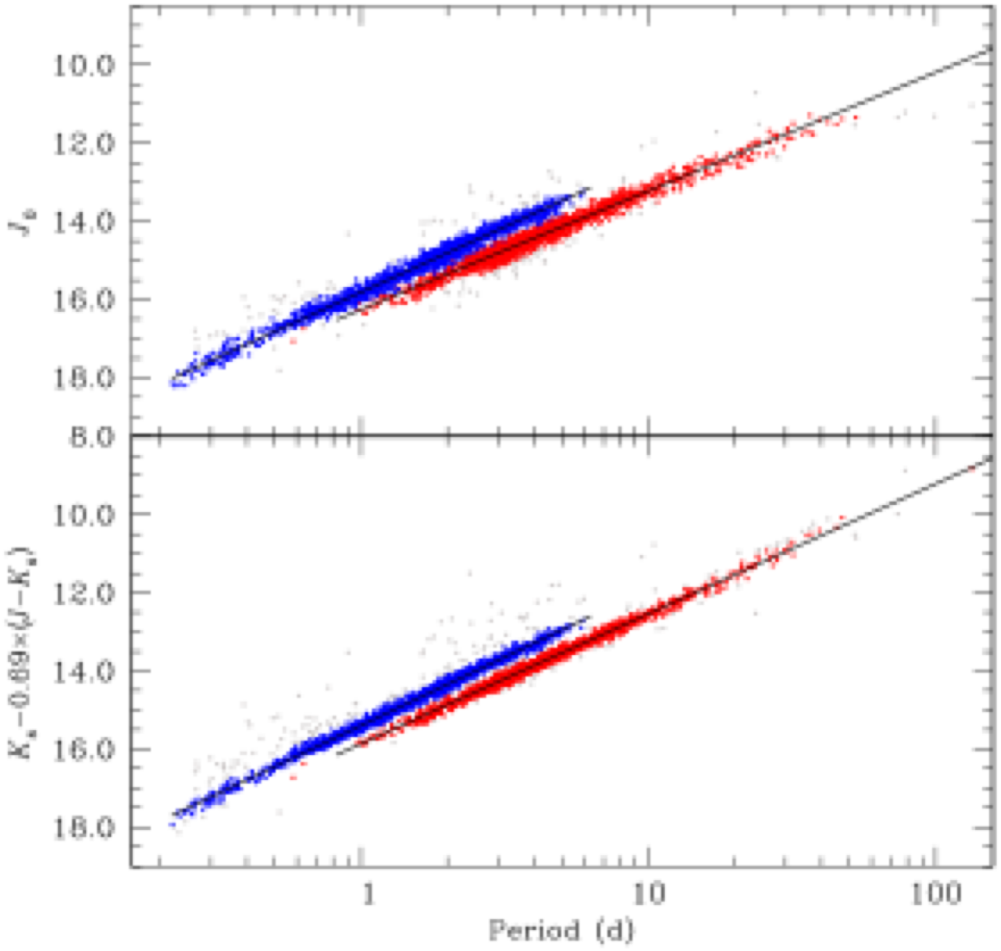
3. new LZ, PL(Z), PW(Z) relations for RR Lyrae and Cepheids



Muraveva et al. 2018

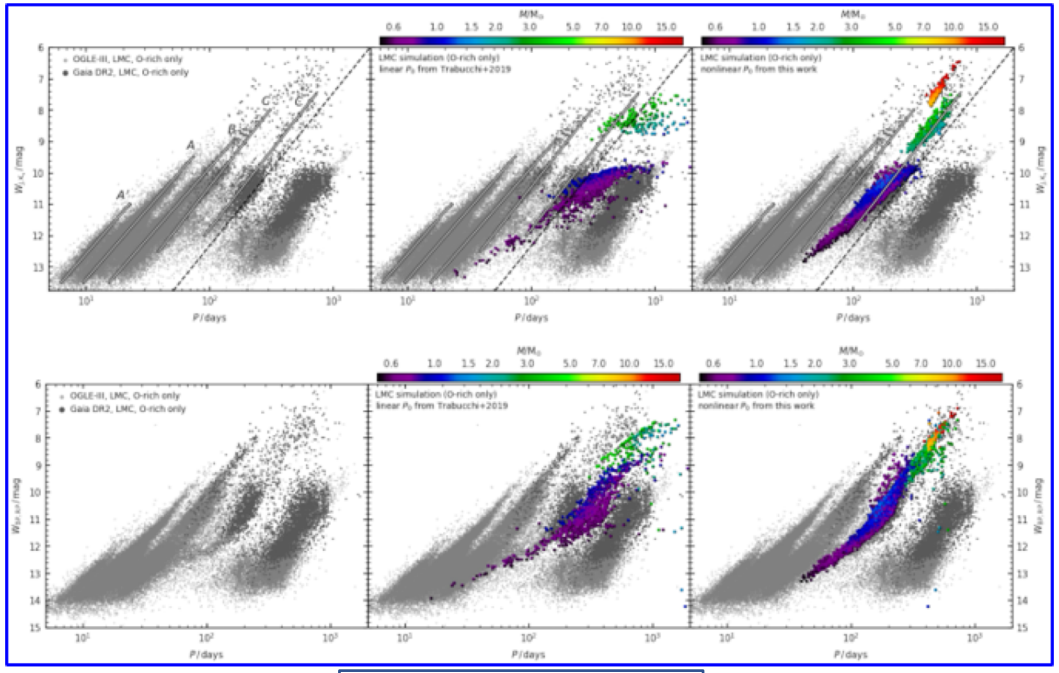


Cusano et al. 2021



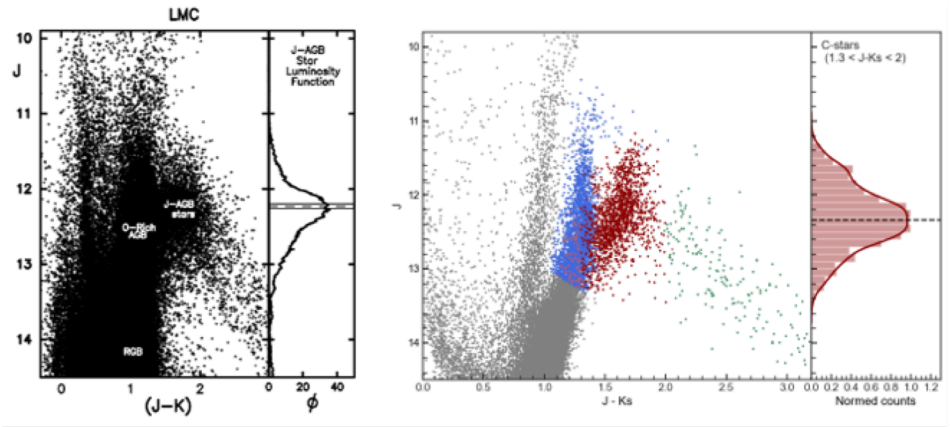
Ripepi et al. 2021, in prep.

3. LPVs and Carbon stars as distance indicators



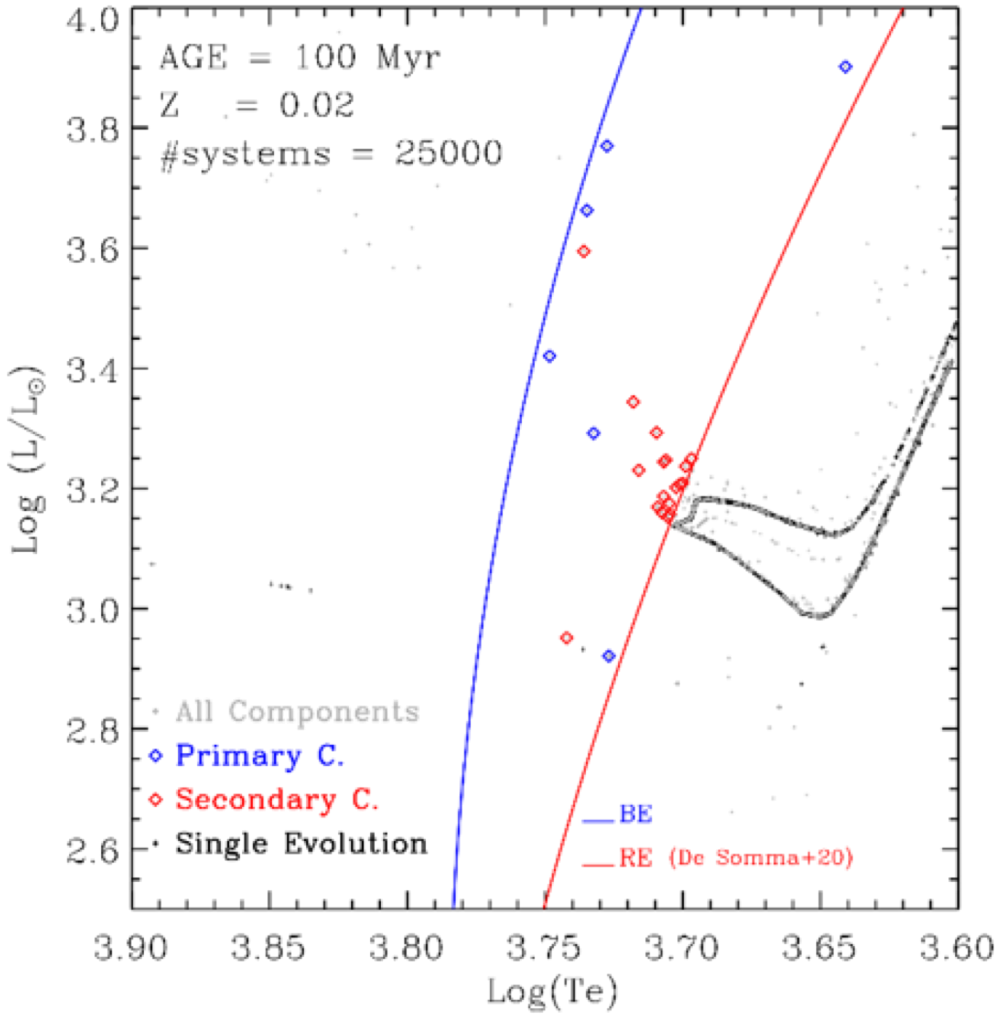
Trabucchi et al. 2021

- extend non linear models of LPVs to C stars and a variety of chemical mixtures

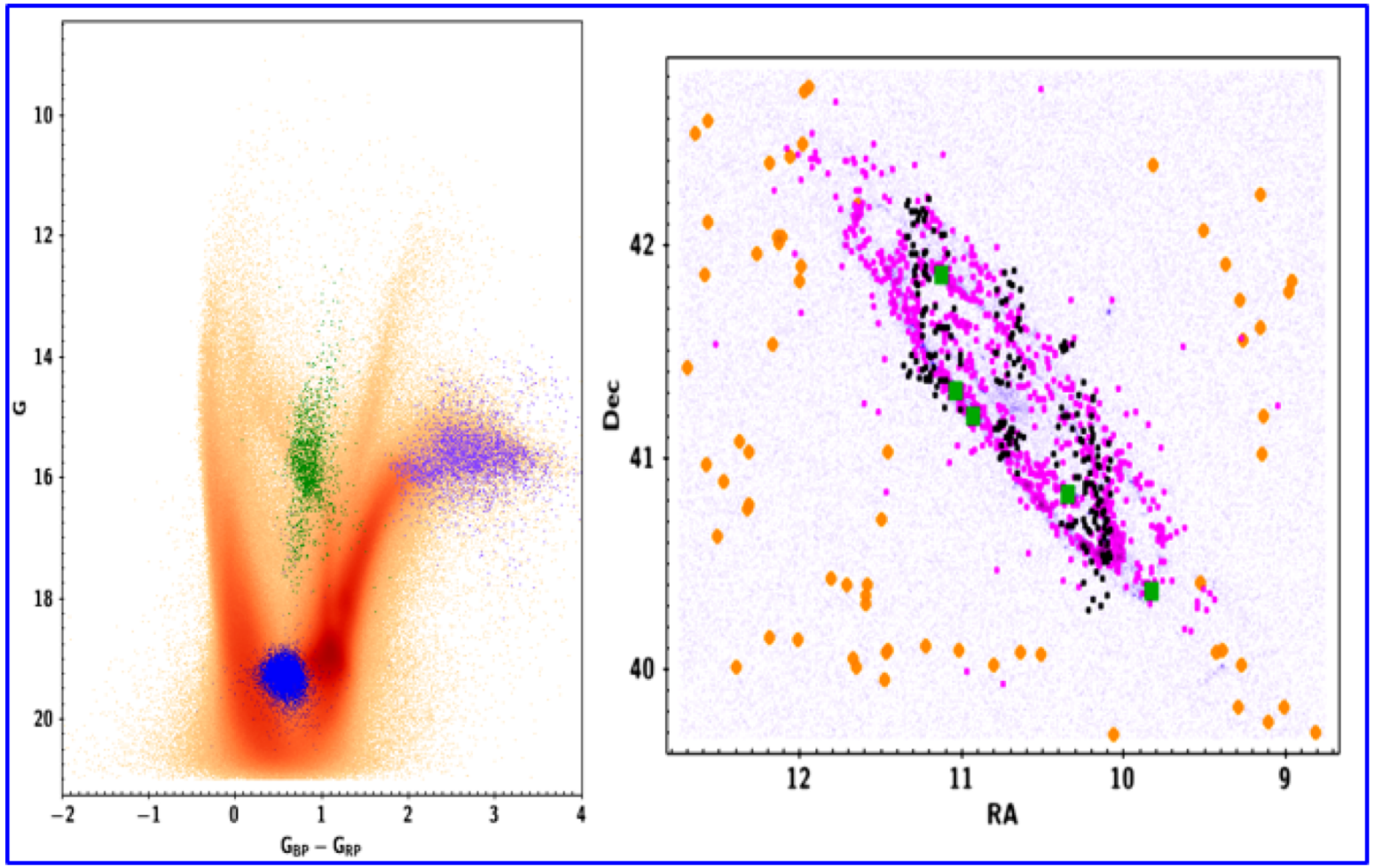


- investigate age metallicity effects on the AGB J-band distance indicator

4. IMPACT OF SINGLE/BINARY-STAR EVOLUTIONARY PROCESSES ON STANDARD CANDLES



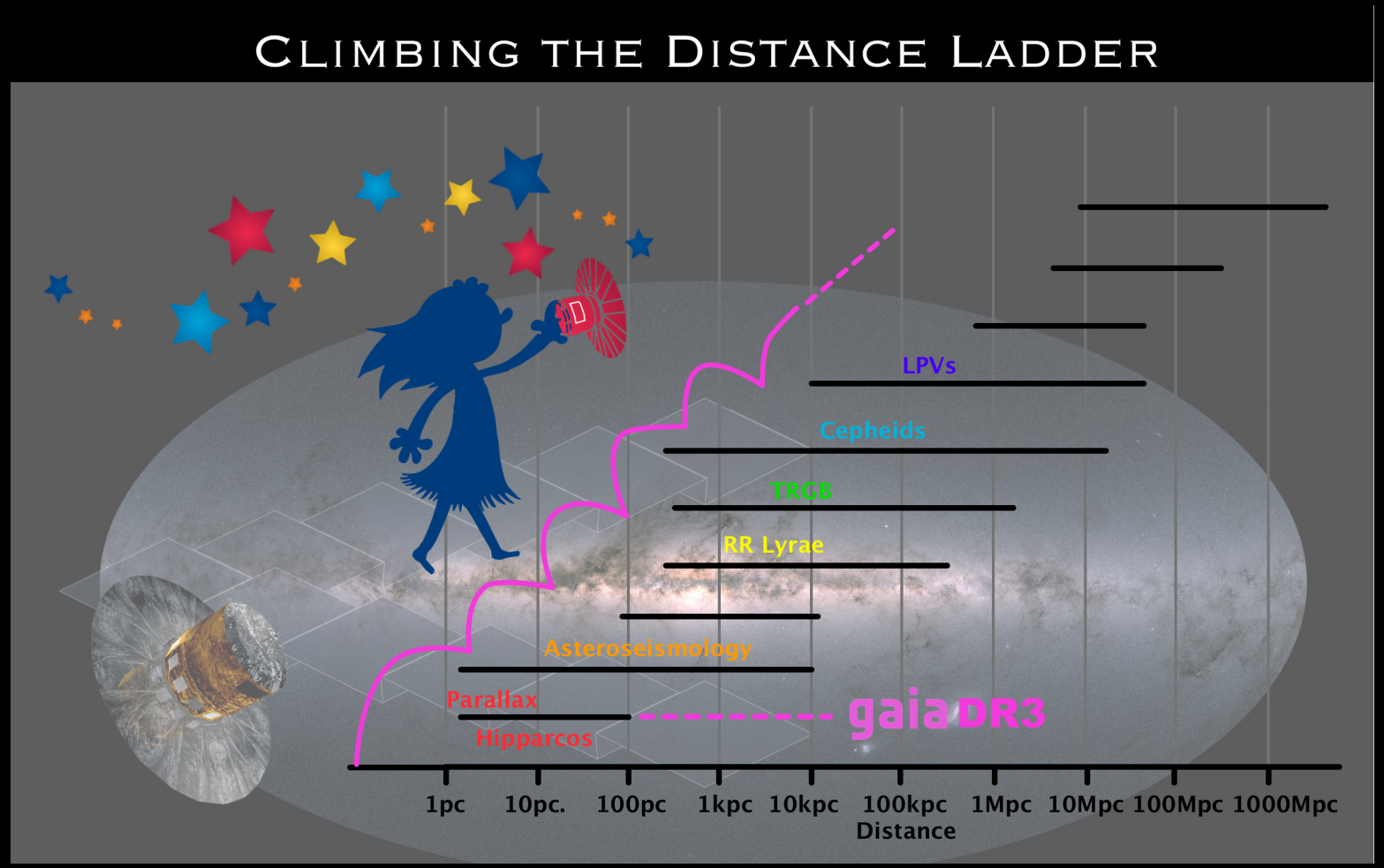
3. Sanity Checks and New Anchors



- sanity check among different indicators (RR Lyrae, Cepheids, LPVs, …)
- definition of new anchors of the distance ladder (M31 vs LMC)

Public Outreach

Climbing the Distance Ladder



Activities of the SH0T project are organized in 6 scientific WPs, plus WP0 for management and WP7 for Public Outreach (see Table 2).

Table 2: Work Packages

WP	Topic	sub-WP	Subtopic	Main contributors
WP0	Management			Gisella Clementini
WP1	Gaia parallax offset	WP1.1	Relativistic corrections; internal and external comparisons	RU INAF (OA Torino)
		WP1.2	From Asteroseismology	RU INAF (OAS Bologna), RU UniPD, RU SISSA
		WP1.3	From LZ, PL(Z), PW(Z) relations	RU INAF (OACn Napoli, OAS Bologna)
WP2	Gaia PL relations of Cepheids and RR Lyrae	WP2.1	Metallicities	RU INAF (OA Catania)
		WP2.2	Variables in GGCs	RU UniPD
		WP2.3	Gaia LZ, PL(Z),PW(Z) relations	RU INAF (OAS Bologna, OACn Napoli)
		WP2.4	Pulsation models	RU INAF (OACn Napoli)
		WP2.5	Single and binary stellar evolution and population models	RU SISSA, RU UniPD
WP3	TRGB	WP3.1	Gaia calibration	RU INAF (OAS Bologna)
		WP3.2	Evolution and population models	RU SISSA, RU UniPD
WP4	Miras and other AGB	WP4.1	LPV pulsation models	RU UniPD
		WP4.2	Population models (including Miras, J-AGB)	RU UniPD, RU SISSA
WP5	Masers with VLBI		Maser-emitting regions in the M31 disk	RU INAF (OAS and IRA Bologna)
WP6	Consistency checks	WP6.1	Consistency between distance indicators	RU INAF (all), RU SISSA, RU UniPD, ISSI Team
		WP6.2	Alternative cosmic distance anchors	RU INAF (all), RU SISSA, RU UniPD, ISSI Team
WP7	Public outreach			RU INAF (all), RU SISSA, RU UniPD

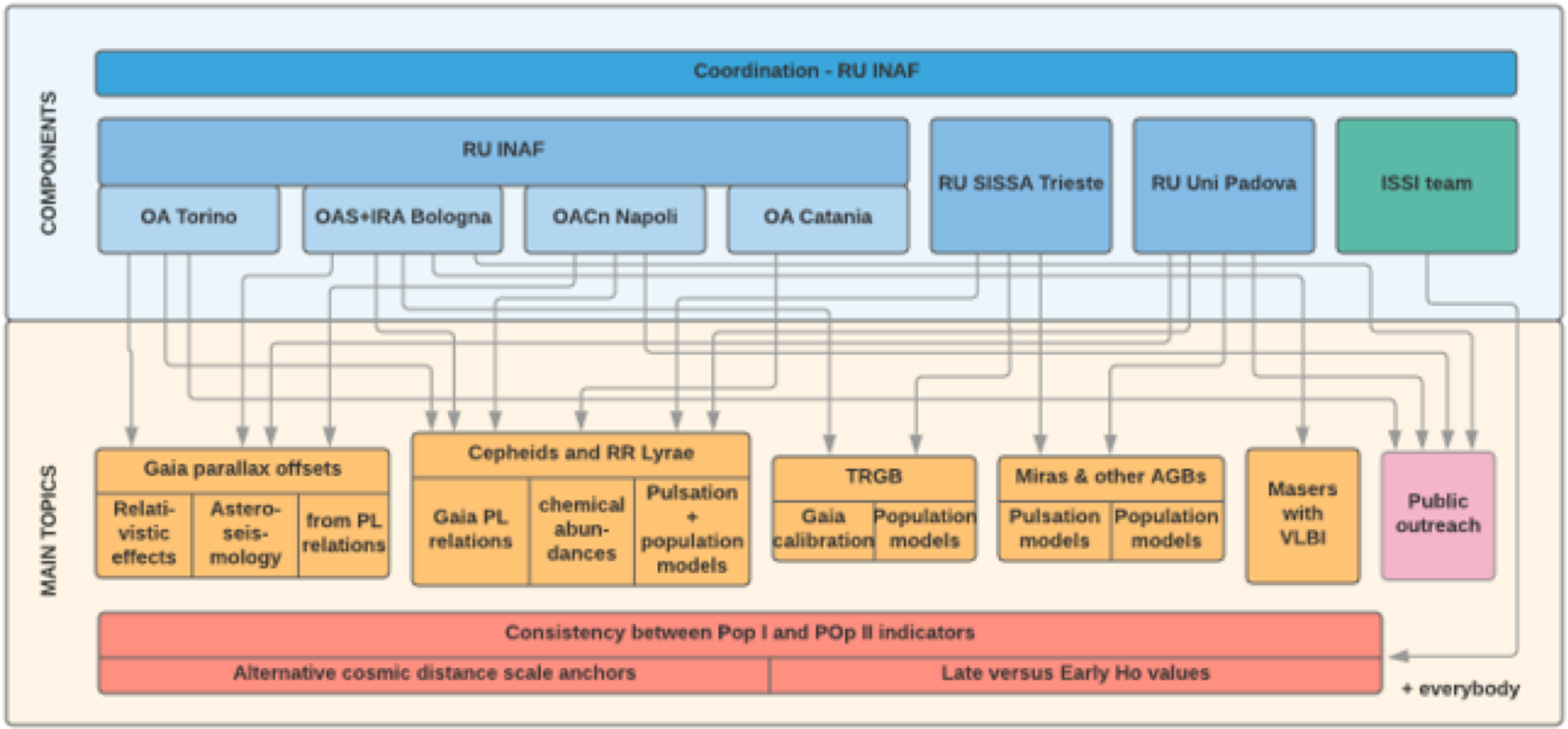

COMPONENTS
Coordination - RU INAF
RU INAF
OA Torino
OAS+IRA Bologna
OACn Napoli
OA Catania
RU SISSA Trieste
RU Uni Padova
ISSI team
MAIN TOPICS
Gaia parallax offsets
Relati-vistic effects
Astero-seis-mology
from PL relations
Cepheids and RR Lyrae
Gaia PL relations
chemical abun-dances
Pulsation + population models
TRGB
Gaia calibration
Population models
Miras & other AGBs
Pulsation models
Population models
Masers with VLBI
Public outreach
Consistency between Pop I and POp II indicators
Alternative cosmic distance scale anchors
Late versus Early Ho values
+ everybody

Table 4: Project timeline

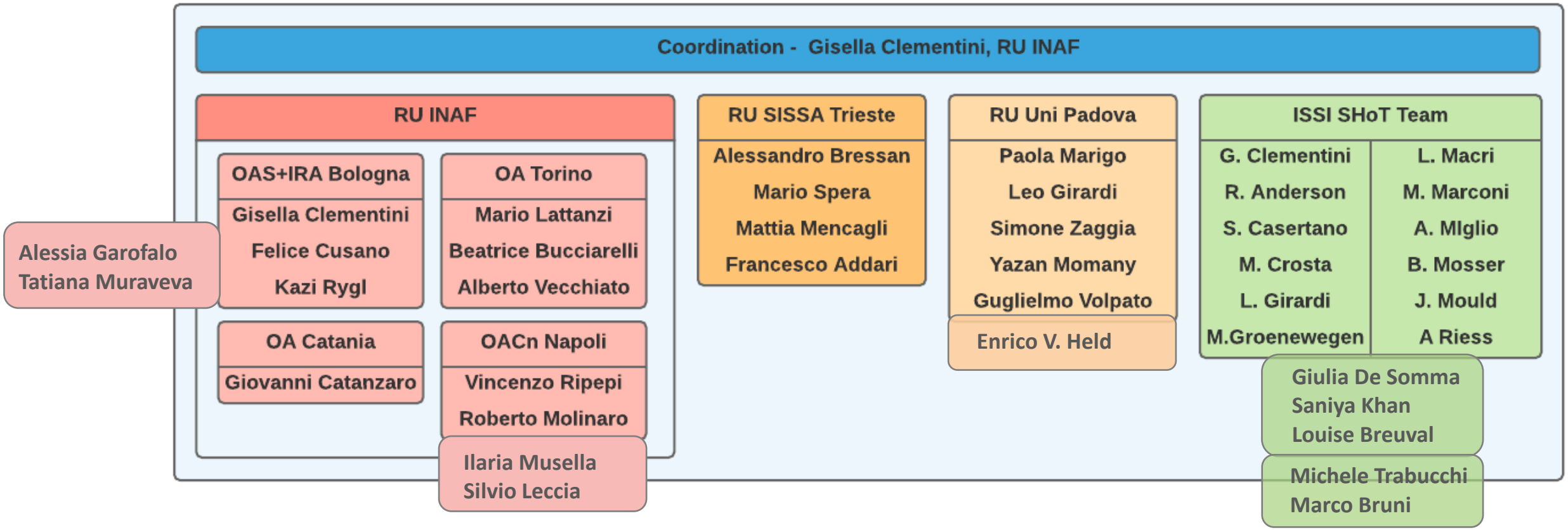
		Note: the project starting date is assumed to be the first quarter of 2022. **Coloured boxes coincide with active periods. Events/activities with a clear location in time are briefly written inside the table.**											
		YEAR 1				**YEAR 2**				**YEAR 3**			
WP	**sub-WP**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
WP0													
WP1	1.1	Internal comparison of EDR3,DR3 astrometries; cross-match to high accuracy external multiwavelegth catalogs (of Galactic sources and QSO's)				Comparisons of parallaxes from independent relativistic models and covariance with PPN-gamma and Basic Angle; systematics vs critical parameters (e.g., source color)				Quantification of possible mitigation strategies and their impact on the accuracy of distances for MW calibrators. Comparison to DR4 parallaxes if available			
	1.2	Data collection (Gaia DR3, TESS asteroseismology, match with multi-band photometry)				analysis of parallax offsets with PARAM+AIMS							
	1.3	Determination of the Gaia parallax zero-point offset from NIR data				Estimate of parallax offset from Gaia bands							
WP2	2.1	Proposal preparation, spectra acquisition, data reduction - Collection/omogenization of spectroscopic data available in literature				Chemical abundances determination for both RRL and DCEPs							
	2.2	Collecting data for all variables		Analysis of PL relations									
	2.3	PL/PW relations in the LMC based on NIR VMC data;		NIR time series observations of Galactic DCEPs with REM.		NIR data reduction and analysis; PLZ/PWZ determination for Galactic DCEPs				Impact of metallicity on the extragalactic distance scale			
	2.4	Pulsation models for DCEPs varying the chemical composition and input parameters				Pulsation models popII pulsating stars with different input physics				Multifilter PLZ/PWZ relations based on pulsation models for DCEPs and popII pulsators, calibration of extragalactic distance scale			
	2.5	PARSEC updates New single star tracks PARSEC-SEVN interface				SEVN: critical binary mass transfer processes			Test PL relations	Binary Population synthesis and impact on PL relations			
WP3	3.1	Gaia TRGB recalibration											
	3.2	PARSEC updates regarding RGB, as in WP2.5			RGB calibration in 47Tuc			Reevaluation of TRGB from models + Gaia + nearby galaxies					
WP4	4.1	New opacities + grids of non-linear LPV models											
	4.2	New opacities + extended grids of AGB tracks		Modeling of J-AGB branch			Models of LPV PL sequences, including Miras			Comparison with data (including JWST), discussion of systematics in distances			
WP5		Compile M31 maser candidates, submit JVLA proposal				Analyse JVLA data and propose follow-up with VLBI				Analyse VLBI data sets			
WP6	6.1					Year 2 comparison: mainly RRL, DCEPs, TRGB				Year 3 comparison: adding Miras, J-AGB, M31 masers			
	6.2					Data collection, JWST proposals				Discussion of alternative anchors			
WP7		Gaia DR3 events, VIVI-PADOVA1	SPERISTATE1	ERN1	KIDS-UNIVERSITY1	VIVI-PADOVA2	SPERISTATE2	ERN2	KIDS-UNIVERSITY2	VIVI-PADOVA3	SPERISTATE3	ERN3	KIDS-UNIVERSITY3
		year-round activities: CONFERENZE alla SPECOLA (Bologna), "Meaning of Light..." cartoons (Naples and Turin), SISSA for Schools (Trieste)											
Other important dates and events to consider:		Gaia DR3	JWST Early Release Science	end of TESS Year 4+ observations	JWST GO period starts								

The SHOT Team

- ISSI International Team
(https://www.issibern.ch/teams/shot/)

- PRIN MUR 2020 Team

FTE					
2021		2022		2023	
C	P	C	P	C	P
2.1	1.95	**1.65**	2.35	**1.55**	2.35



Fondi assegnati:

No financial support for the SH0T project has been obtained from INAF so far.

The project was presented in response to Call for Proposals 2020 for International Teams in Space and Earth Sciences of the **International Space Science Institute (ISSI) in Bern** and granted **25.4 Keuro** to support the living expenses, through a per diem and accommodation, of the 12 International Team core members plus 2 early-career scientists, while residing in Bern to attend two meetings of the team and to refund the travel expenses of the team leader.

Fondi richiesti:

In January 2021, SH0T has been submitted in response to the **2020 call for PRIN MUR projects**, with outcome from section expected in 2022. MUR requested contribution at submission of the project amounts to about **797 Keuro**.

Sinergy/close links with other ``schede'':

GaiaUniverse = L'Universo di Gaia: partecipazione Italiana alla missione Gaia (GaiaUniverse-0) – Coord. **M. Lattanzi** (OaTo)
GraviMetrA = Gravitational Metrology and Astronomy – Coord. **M. Crosta** (OATo)
C-MetaLL = Cepheid Metallicity in the Leavit Law (MOVIE - 3) – Coord. **V. Ripepi** (OACn)
VSNG = Variable Stars in Nearby Galaxies - Coodinatrice **G. Clementini** (OAS-Bo)
MOVIE = Modeling and Observations of Variable stars as distance Indicators and stellar Evolution tracers – Coord. **M. Marconi** (OACn)
PARSEC-COLIBRI-TRILEGAL = Coordinatore **L. Girardi** (OAPd)

GaLS (Rubin-LSST-5) = Gaia LSST Sinergy – Coord. **G. Clementini** (OAS-Bo)
4GRoundS = 4MOST Gaia RRLyrae Survey – Coord. **M. Bellazzini** (OAS-Bo)

Leaderships:

The members of our team include internationally recognized experts with more than 20 years activity and expertise in the fields interested by SH0T: astrometry, relativity, theory of stellar evolution, stellar pulsation, stellar populations, photometry and time series analysis of variable stars.

Cepheids and RR Lyrae stars with Gaia (leadership in Gaia DPAC)
Asteroseismology
Astrometry
Relativity
Stellar evolution models
Stellar pulsation models
Stellar populations

+ ISSI Team

Criticita’

Manpower needs to be hired to carry out the huge amount of work required by the SH0T project.
Specific funding has been requested with PRIN MUR 2020 “SH0T" - G. Clementini PI, to hire five Postdocs (PDs) and 1 Research Fellow (RF) to be dedicated to the project. The new hires will support the project activities summarised below.

Table 3: Personnel to be hired and research tasks

RU	Type	Duration	host institution	Main activities and relative WPs
INAF	RF	2 yr	OAS Bologna	Gaia calibration of LZ, PL(Z), PW(Z) relations (WP2.3) and TRGB (WP3.1)
	PD1	1 yr	OA Torino	Gaia parallaxes: systematics, correlations, and relativistic corrections (WP1.1)
	PD2	1.5 yr	OACn Napoli	Cepheids and RRL: revised LZ, PL(Z), PW(Z) relations from Gaia and VMC data (WP2.3) and derived Gaia parallax offsets (WP1.3); extension of pulsation models (WP2.4)
UniPD	PD3	2 yr	UniPD	Extended LPV pulsation models (WP4.1), galaxy simulations for Miras, J-band C-star (WP4.2) and TRGB methods (WP3.2)
	PD4	2 yr	UniPD	Data for variables and RGB stars in GGCs (WP2.2, WP3.2)
SISSA	PD5	1.5 yr	SISSA	New PARSEC stellar models (WP2.5, WP3.2); binary SEVN models (WP2.5)
Note: PD = postdoc (*assegno di ricerca*), RF = research fellow (*ricercatore a tempo determinato di tipo a)*				