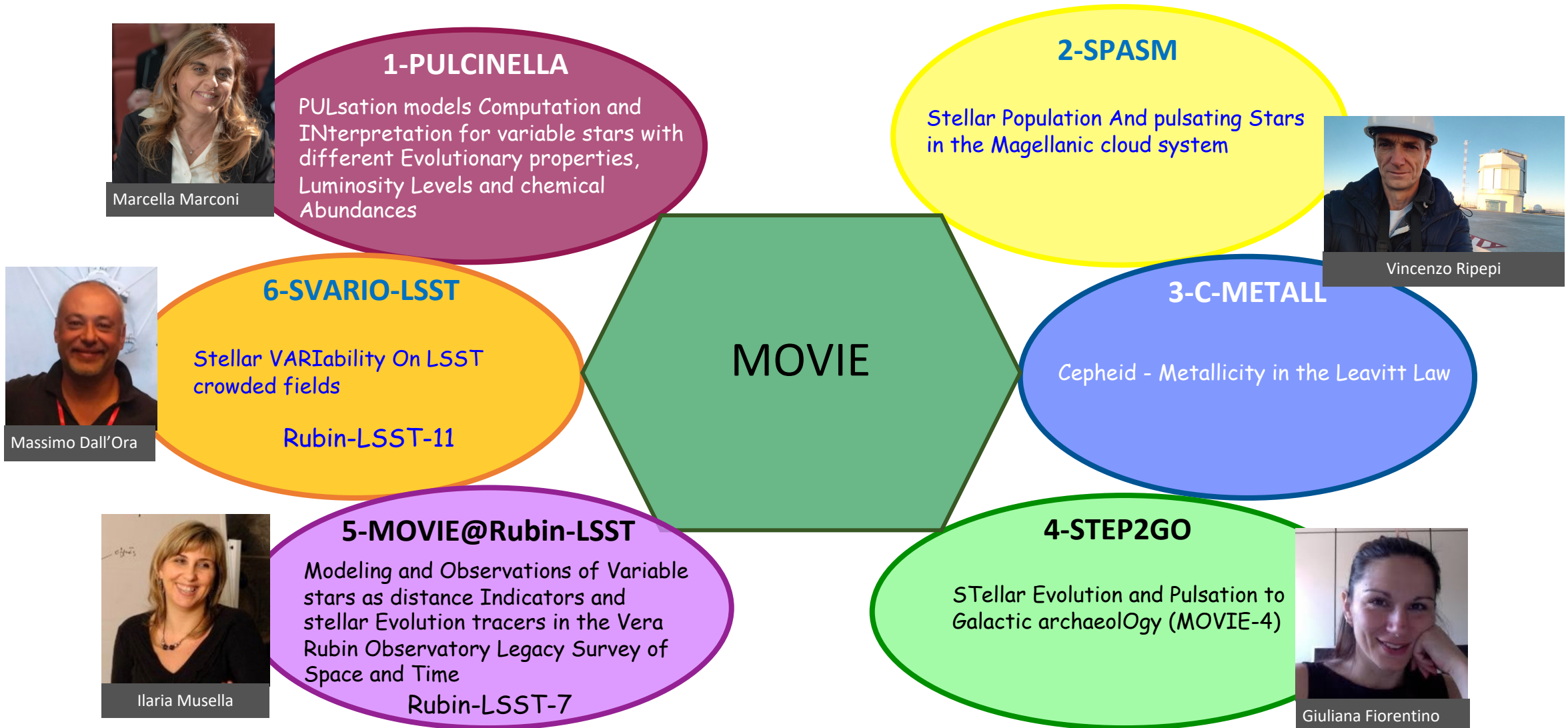# Modeling and Observations of Variable stars as distance Indicators and stellar Evolution tracers (MOVIE)
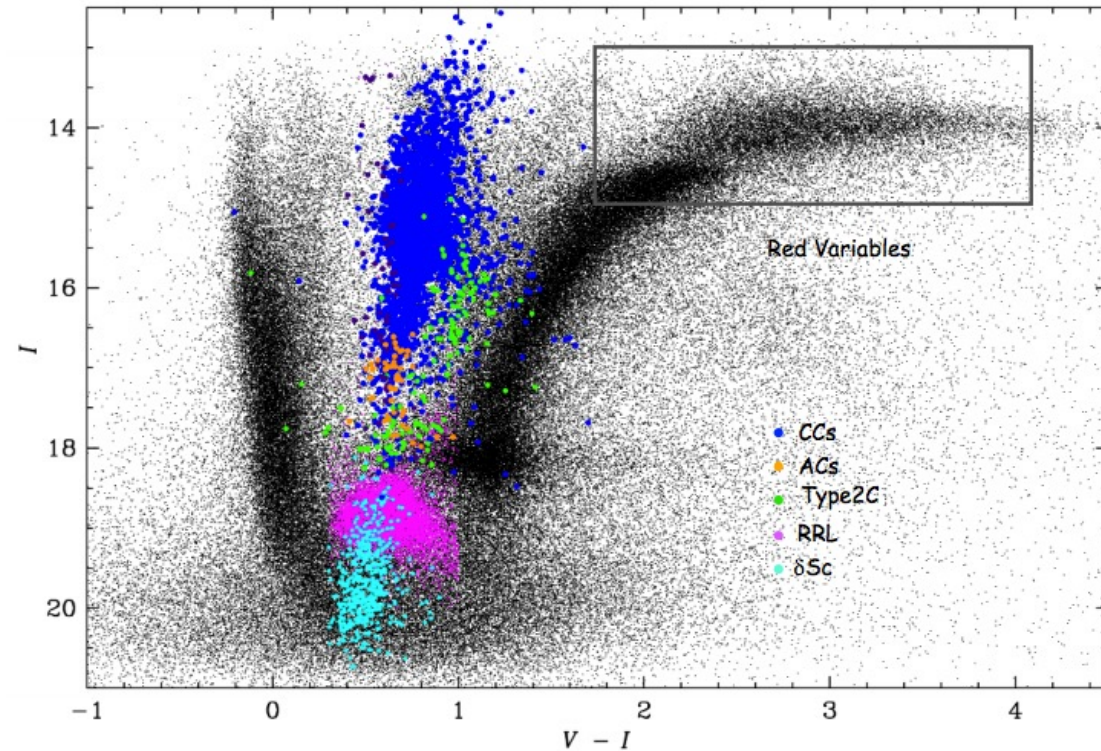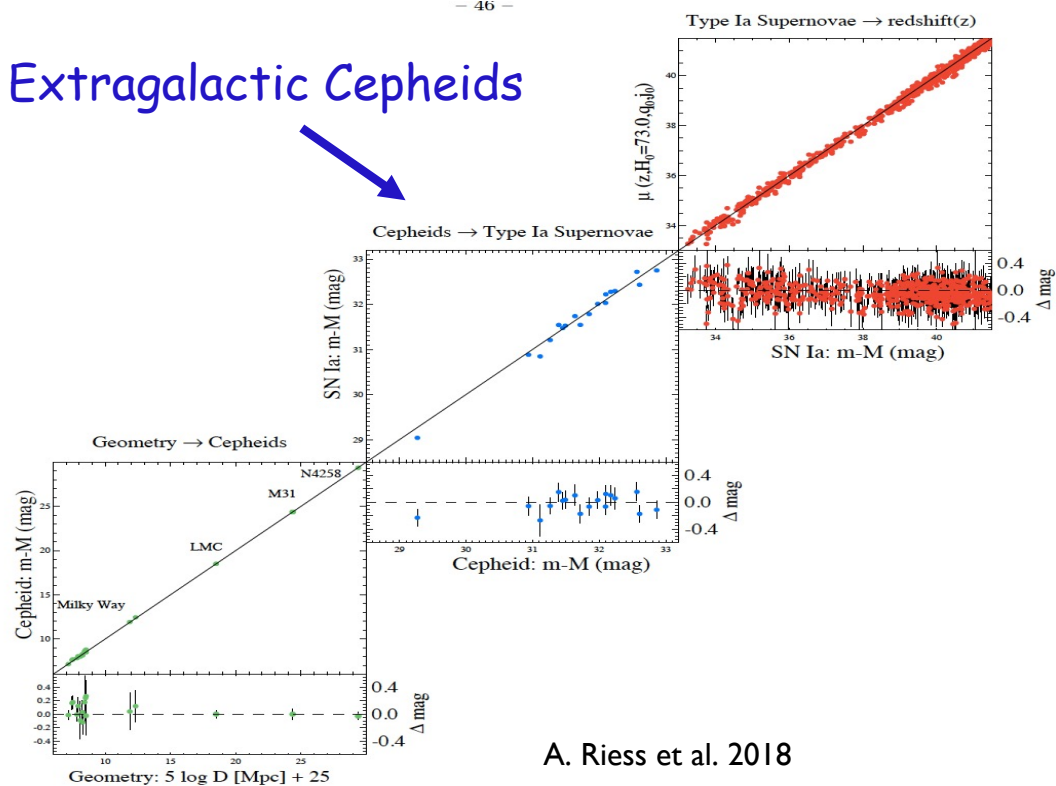
Pulsating stars

Pulsation properties are related to intrinsic stellar parameters

Distance indicators
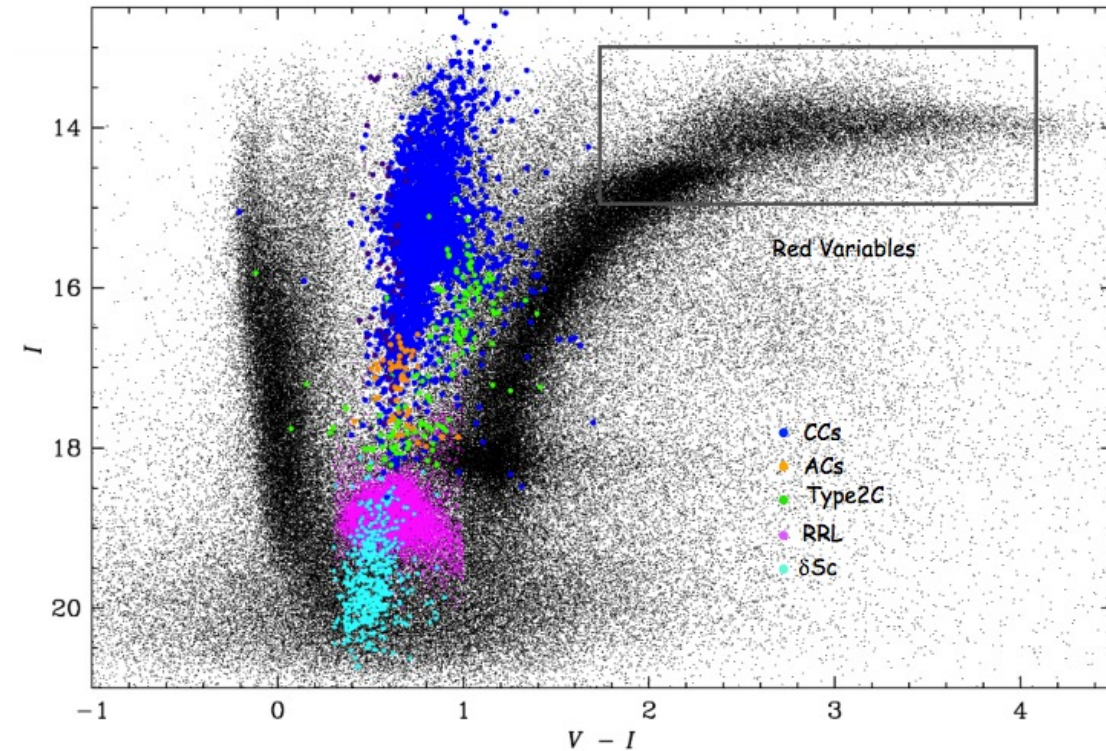
Stellar population tracers

Extragalactic Cepheids

A. Riess et al. 2018

Soszynski et al. 2009

Pulsating stars

Pulsation properties are related to intrinsic stellar parameters

Distance indicators

Stellar population tracers

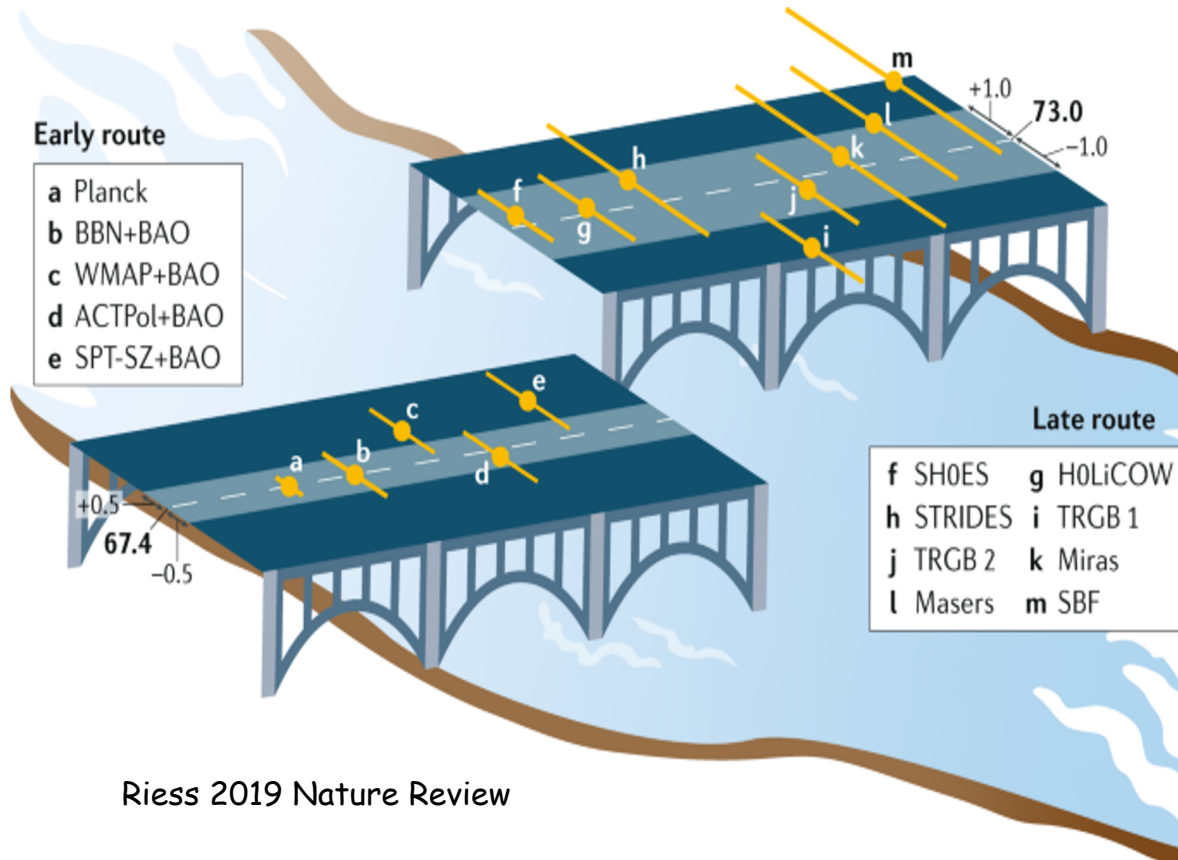Riess 2019 Nature Review

Soszynski et al. 2009

→ map 3D structure, radial trends, haloes, streams

A comprehensive theoretical and observational study of the pulsating stars properties is mandatory→ MOVIE

Scientific objectives

A comprehensive theoretical and observational study of the pulsating stars properties

- Constraints on individual and mean distances and calibration of the extragalactic distance scale (Hubble constant tension), thanks to Gaia results and proprietary photometric and spectroscopic data

- Empirical and theoretical tests on residual systematics, based both on models and photometric and spectroscopic surveys

- Constraints on stellar properties such as mass, age, luminosity and test of the consistency between evolutionary and pulsational predictions

- Constraints on individual metal abundances based both on spectroscopic and photometric analysis

- Galactic archaeology through the investigation of different classes of pulsating stars both in the Local Group

- Preparation of empirical and theoretical tools to optimize the scientific exploitation of future Rubin-LSST data

Team (staff/associate/postdocs/PhD)

1-PULCINELLA

M. Marconi, G. Bono, S. Cassisi, M. Di Criscienzo, G. De Somma, G. Fiorentino, S. Leccia, R. Molinaro, I. Musella, A. Pietrinferni, V. Ripepi, A. Bhardway

2-SPASM

V. Ripepi, M. Bellazzini, M. Cignoni, G. Clementini, F. Cusano, M. Dall'Ora, G. De Somma, M. Di Criscienzo, M. Gatto, A. Grado, S. Leccia, M. Marconi, R. Molinaro, I. Musella, P. Schipani, M. Spavone, C. Tortora, M. Tosi

6-SVARIO-LSST

M. Dall'Ora, S. Bonito, G. Bono, V. Braga, M. Di Criscienzo, G. Fiorentino, A. Garofalo, S. Leccia, M. Marconi, I. Musella, V. Ripepi, M. Tantalo, P. Trevisan

3-C-METALL

V. Ripepi, G. Catanzaro, G. Clementini, F. Cusano, G. De Somma, S. Leccia, M. Marconi, R. Molinaro, I. Musella, V. Testa, E. Trentin

5-MOVIE@Rubin-LSST

I. Musella, G. Bono, V. Braga, M. Di Criscienzo, M. Dall'Ora, G. De Somma, G. Fiorentino, S. Leccia, M. Marconi, R. Molinaro, V. Ripepi

4-STEP2GO

G. Fiorentino, V. Braga, S. Cassisi, M. Di Criscienzo, M. Dall'Ora, M. Fabrizio, M. Marconi, I. Musella, A. Pietrinferni, R. Ragusa, V. Ripepi, C. Tortora

Team (staff/associate/postdocs/PhD)

1-PULC...
M. Marcon...
S. Cassisi, M. Di C...
Somma, G. Fiore...
R. Molinaro,
Pietrinferni,
Bhar...

2-SPASM
M. Bellazzini, M. Cignoni, G.
..., F. Cusano, M. Dall'Ora, G.
..., M. Di Criscienzo, M. Gatto,
..., S. Leccia, M. Marconi, R.
..., I. Musella, P. Schipani, M.
...one, C. Tortora, M. Tosi

6-SVARIO-LSST
M. Dall'Ora, S. Bonito,
G. Bono, V. Braga, M. Di
Criscienzo, G. Fiorentino,
A. Garofalo, S. Leccia, M.
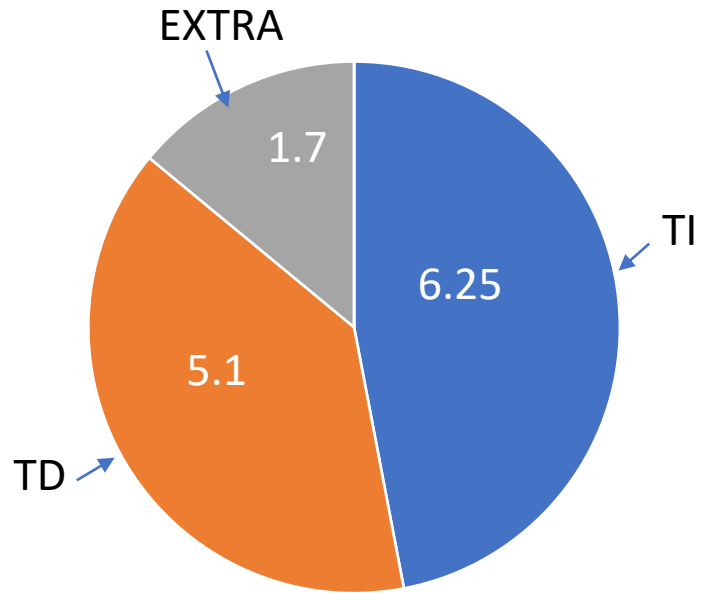Marconi, I. Musella, V. Ripepi,
M. Tantalo, P. Trevisan

3-C-METALL
V. Ripepi, G. Catanzaro, G. Clementini,
F. Cusano, G. De Somma, S. Leccia, M.
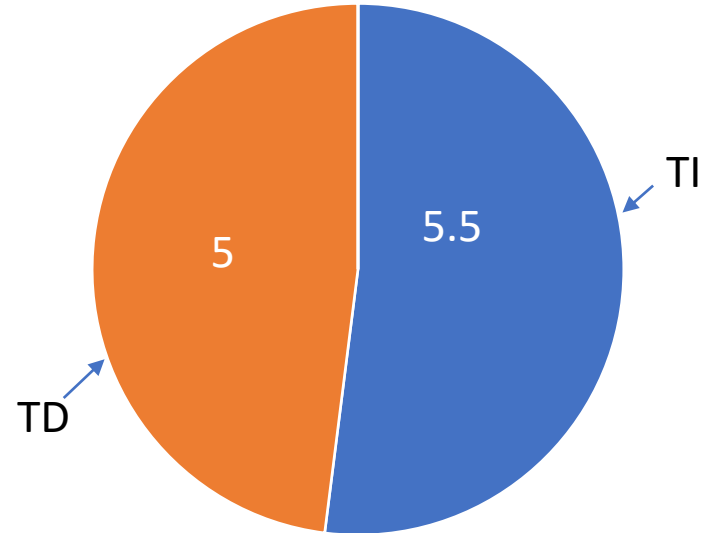Marconi, R. Molinaro, I. Musella, V.
Testa,
E. Trentin

5-MOVIE@Rubin...
I. Musella,
G. Bono, V. Braga, M. Di...
M. Dall'Ora, G. De So...
Fiorentino, S. Leccia, M.
Molinaro, V. Ripepi...

...-STEP2GO
V. Braga, S. Cassisi, M. Di
Dall'Ora, M. Fabrizio, M.
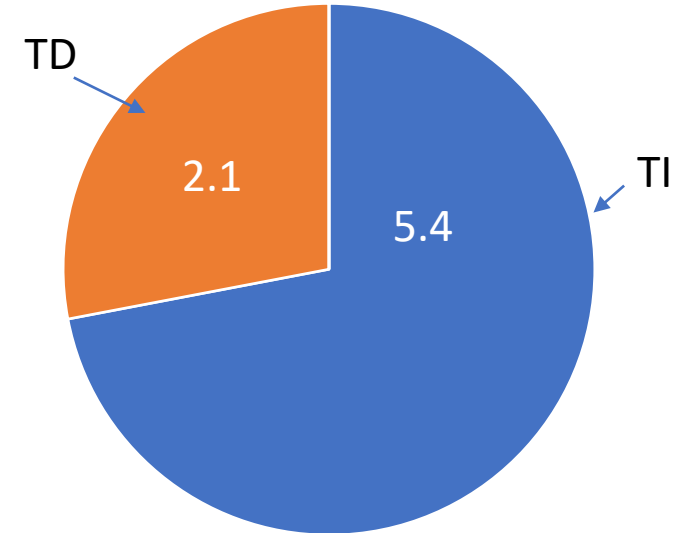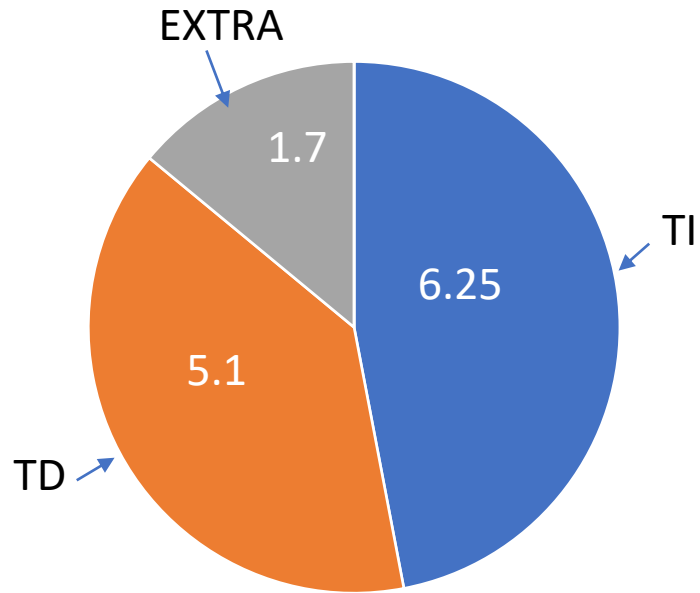...sella, A. Pietrinferni, R.
Ragusa,
...ipepi, C. Tortora

INAF IN ITALIA

MILANO   TRIESTE
PADOVA
TORINO
BOLOGNA
FIRENZE
TERAMO
ROMA
NAPOLI
CAGLIARI
PALERMO
CATANIA

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

w w w . i n a f . i t

Confirmed FTE

2021
- TI 6.25
- TD 5.1
- EXTRA 1.7

2022
- TI 5.5
- TD 5

2023
- TI 5.4
- TD 2.1

Confirmed + potential FTE
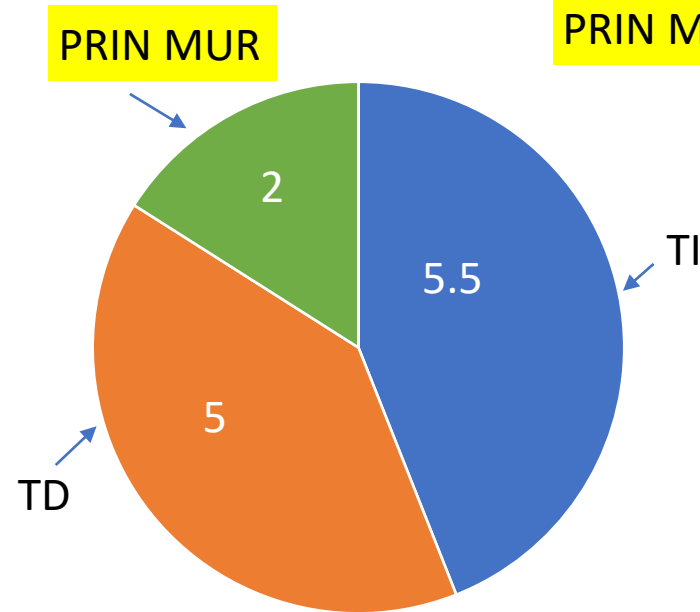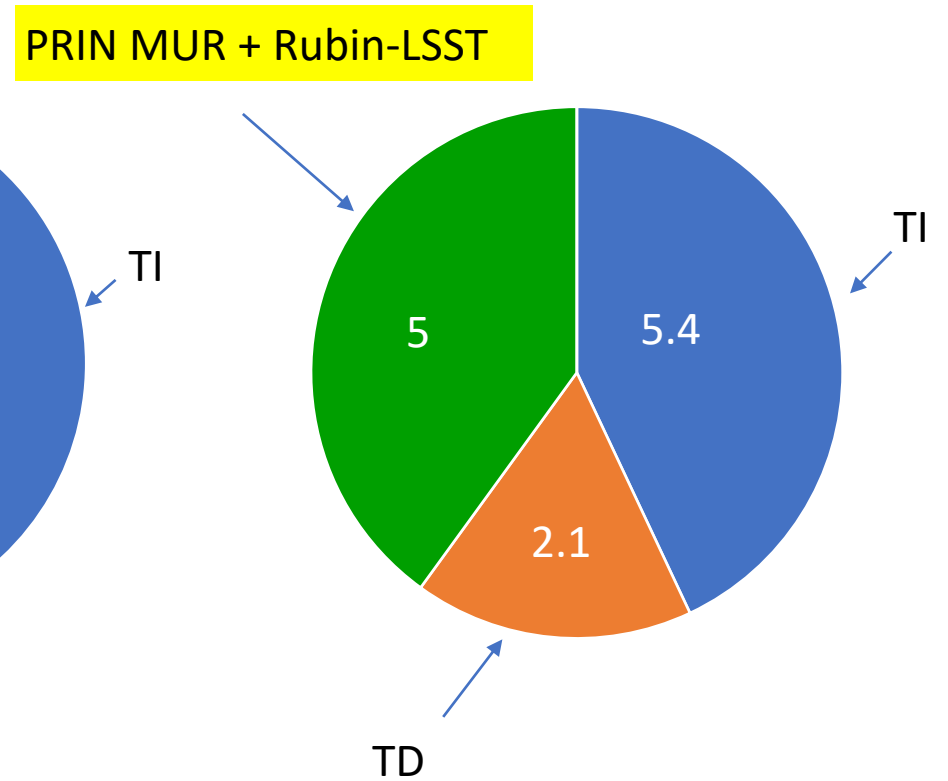
Fundings (2021-2023)

CONFIRMED (Keuro)
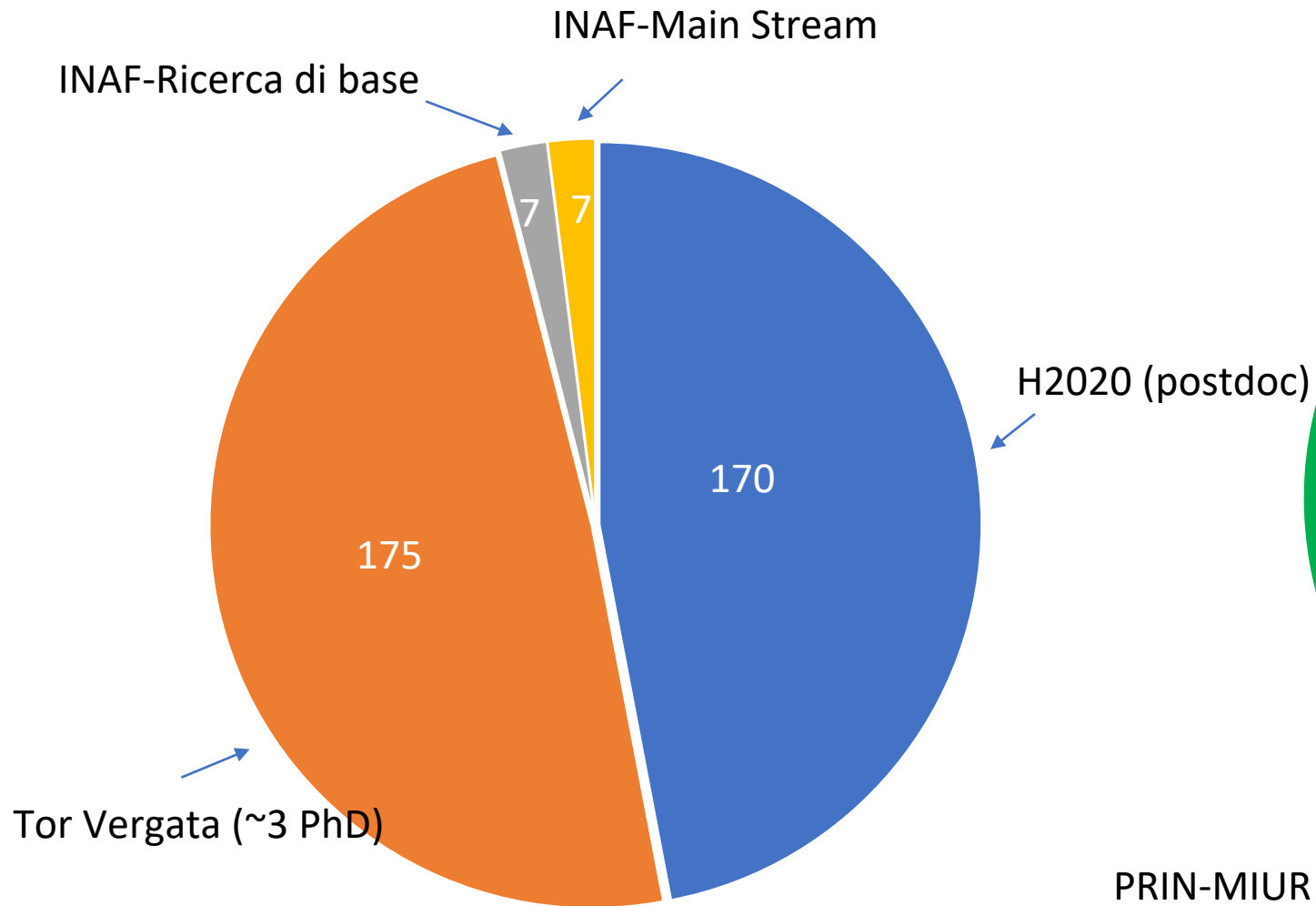
- INAF-Ricerca di base
- INAF-Main Stream
- H2020 (postdoc): 170
- Tor Vergata (~3 PhD): 175
- 7
- 7

POTENTIAL (Keuro)

- INAF-Ricerca di base: 20
- PRIN-MIUR: 160
- Rubin-LSST: 105
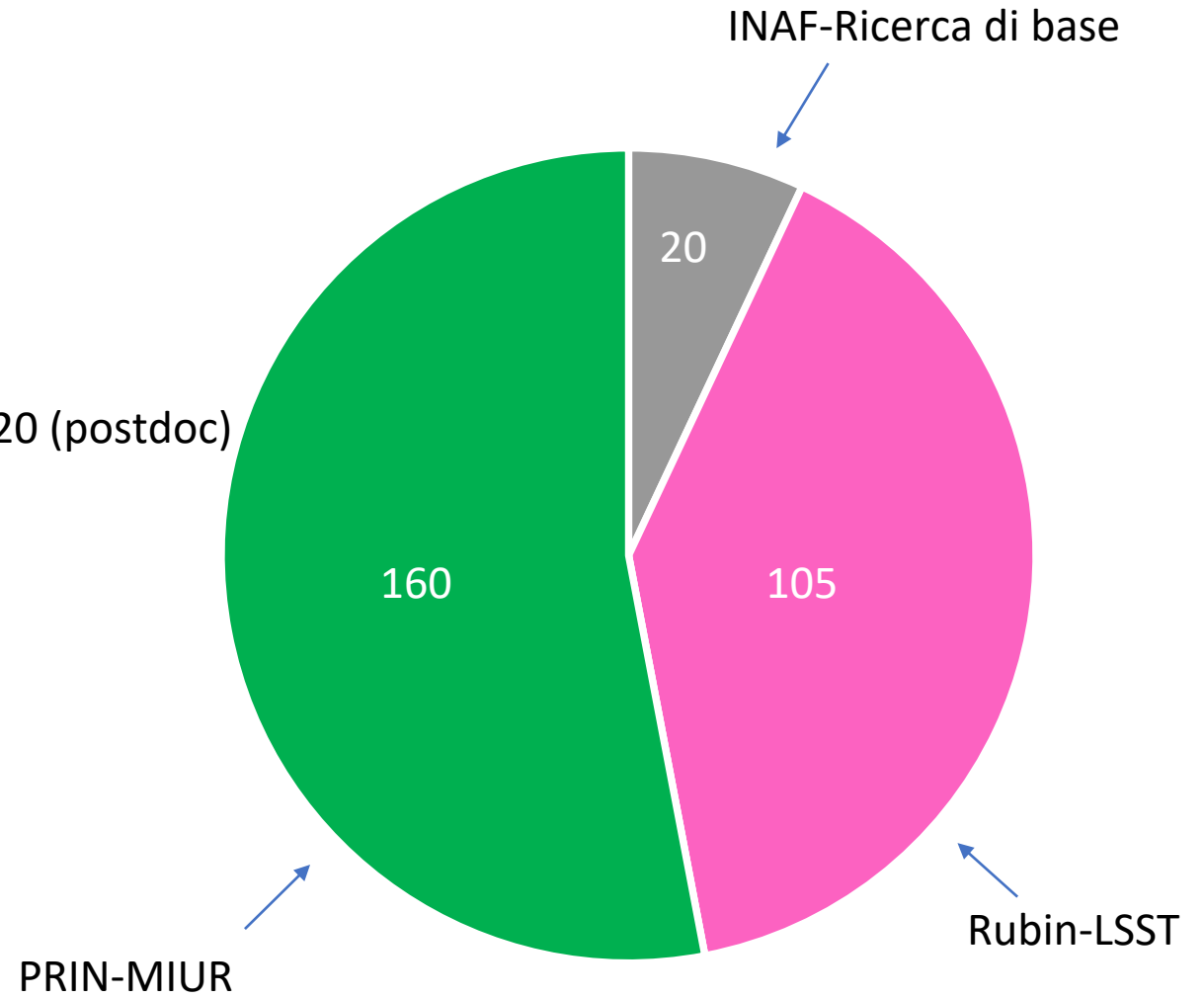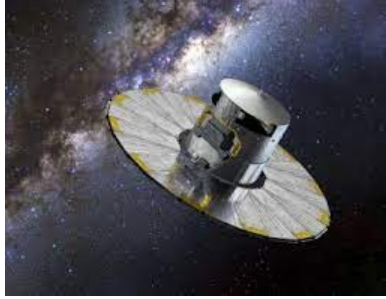
Sinergies with other programs/projects/infrastructues

Gaia

Huge contribution to the Gaia DPAC (Naples team in collaboration with OAS) since 2006 in the field of classification and characterization of pulsating stars RR Lyrae and Cepheids (see talk by M. Lattanzi.)

GaiaUniverse – Lattanzi et al.
VSNG – G. Clementini et al.
SHOT – G. Clementini et al.

Rubin-LSST

Rubin-LSST – M. Brescia et al.

VST

Significant involvement in VST (GTO) and VISTA public surveys since 2011.

VISTA

Great efforts both for the in-kind contribution and for the preparation to the scientific exploitation of Rubin-LSST data.
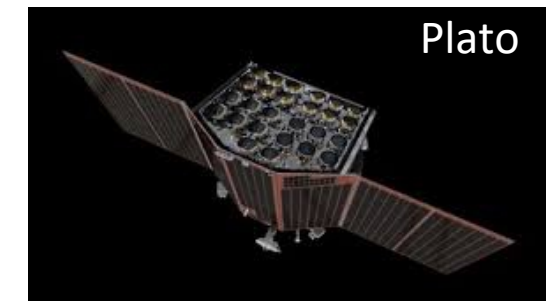
Sinergies with other programs/projects/infrastructues

VLT

TNG

MICADO/Maory

MAVIS
Deeper than HST, sharper than JWST

Cubes

LBT

REM

CTA
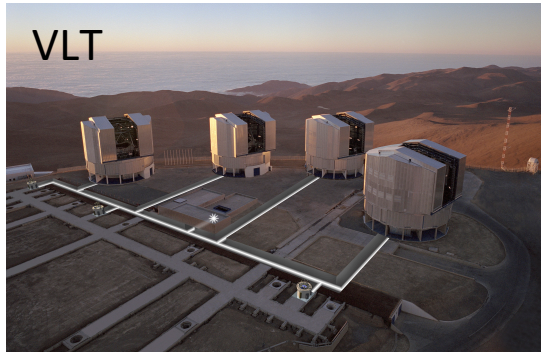
CUBES - S. Cristiani

PROGRESS

Plato

4MOST@VISTA

Main Stream PLATO - S. Cassisi et al.
Helas – M.P. Di Mauro et al.

Scientific results from PULCINELLA

- From the theoretical point of view, the computation of extended and detailed sets of evolutionary and pulsational models has allowed us to predict all the relevant properties of pulsating stars in different evolutionary phases and at various chemical abundances.
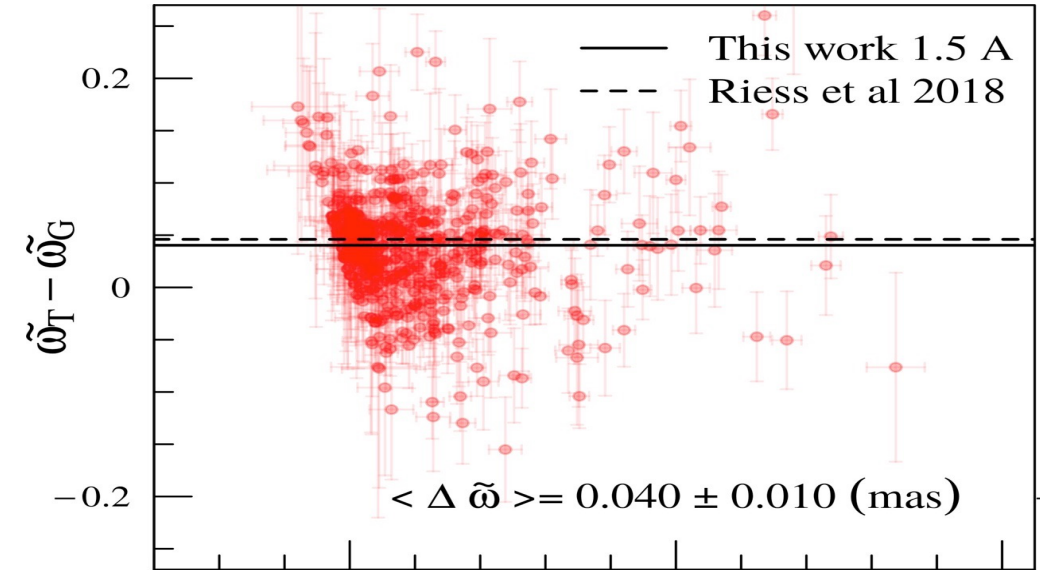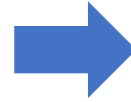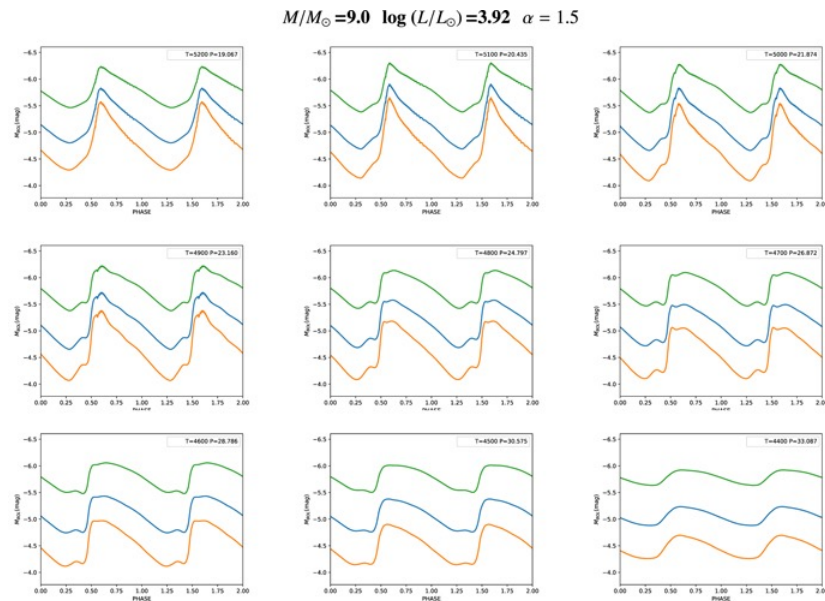
Marconi et al. 2018 ApJL
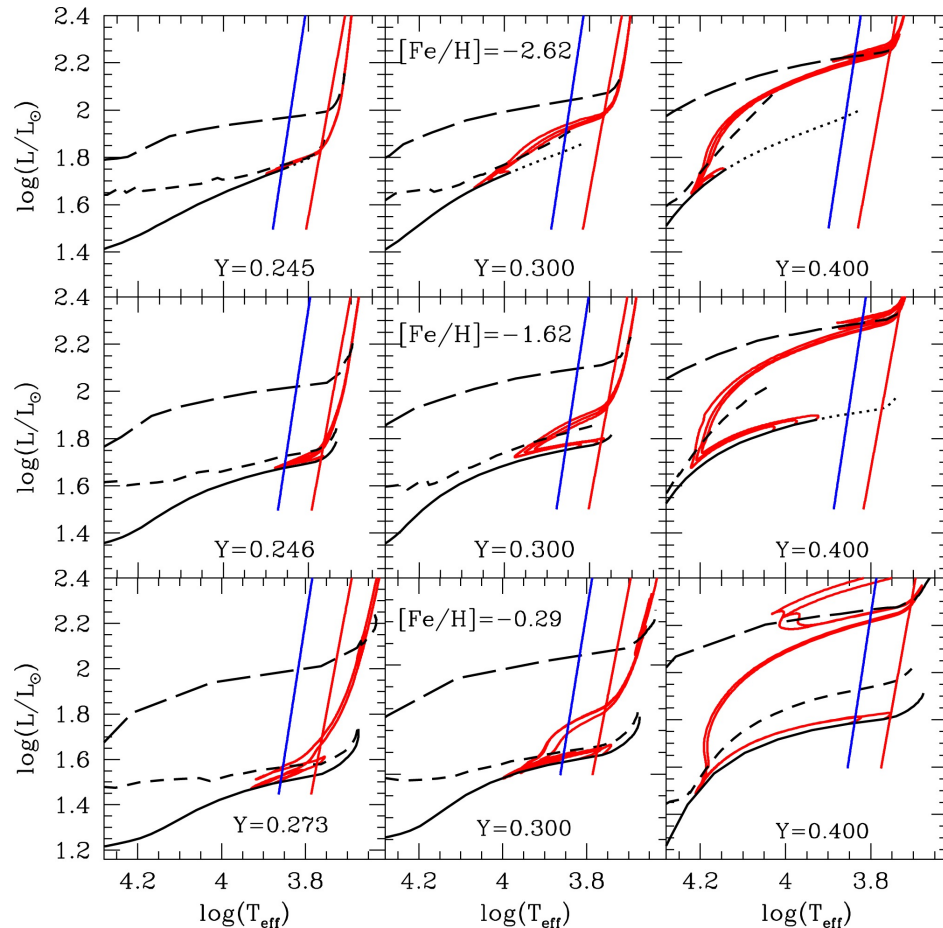
Marconi et al. 2017 MNRAS
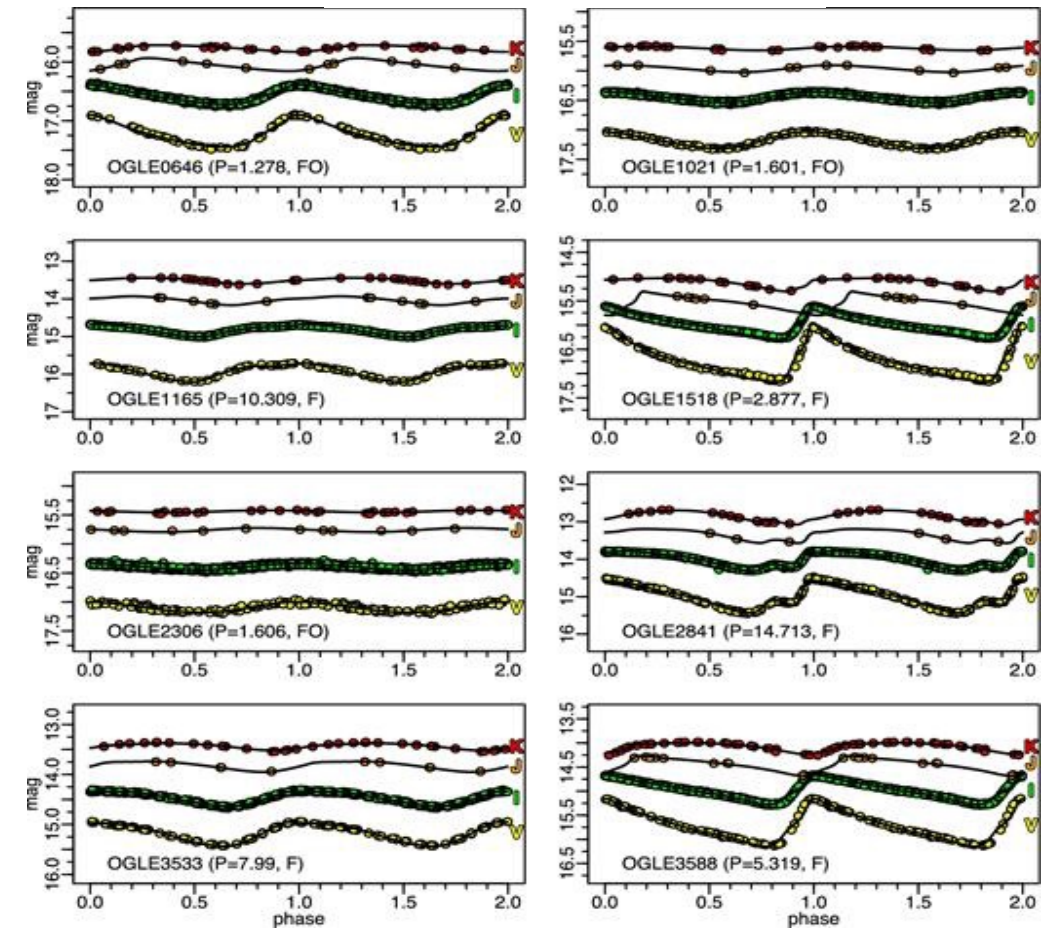
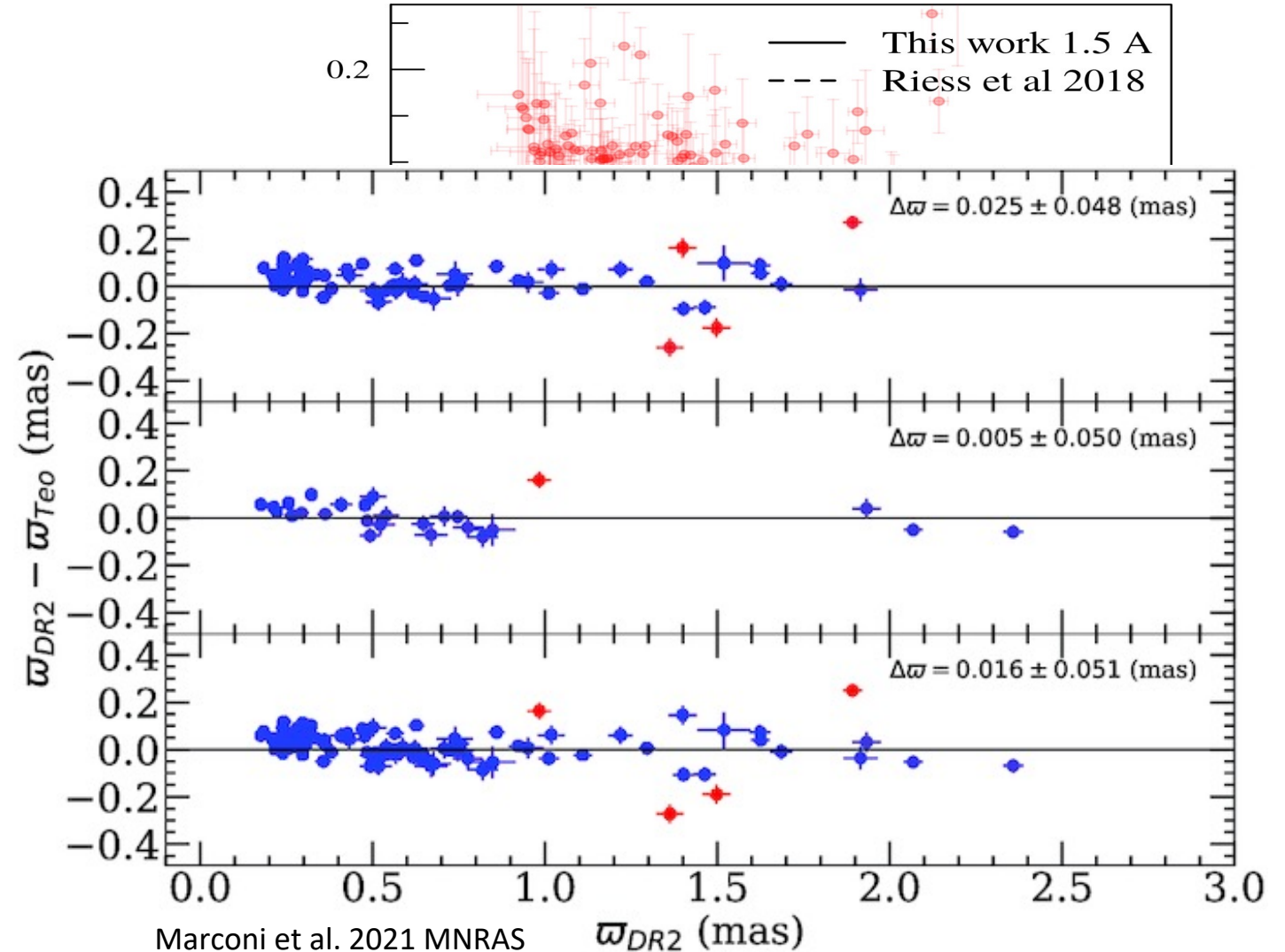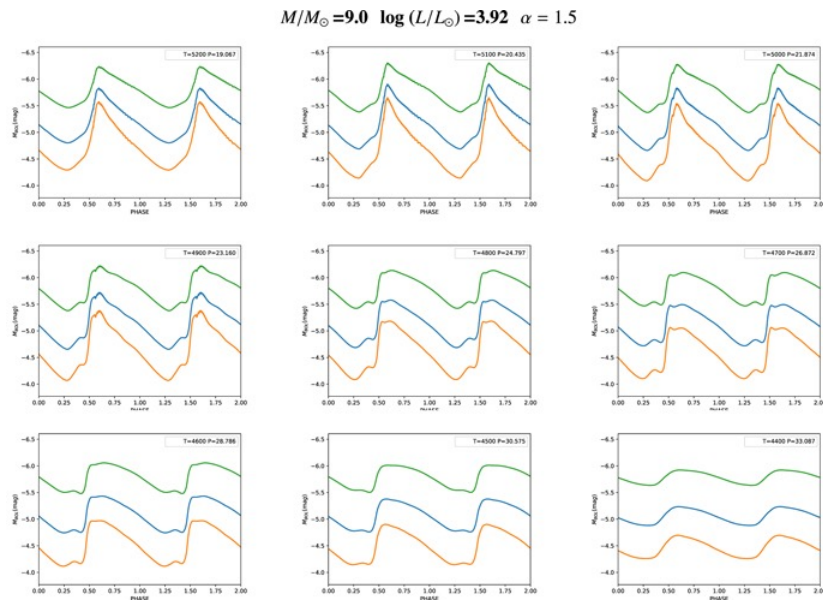# Scientific results from PULCINELLA

- Current theoretical scenario was successfully applied to Gaia results for both Cepheids and RR Lyrae
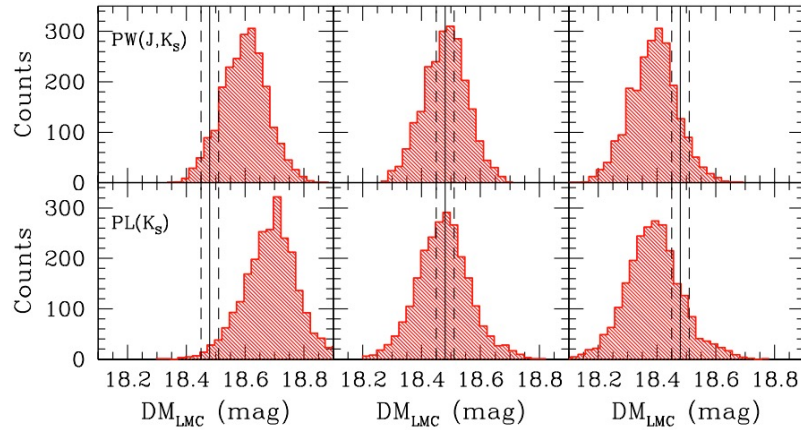

De Somma, Marconi, Molinaro etal. 2020 ApJS

Scientific results from PULCINELLA

- Current theoretical scenario was successfully applied to Gaia results for both Cepheids and RR Lyrae


Marconi et al. 2021 MNRAS

Scientific results from C-METALL

First 20 stars with HARPS-N spectra + Literature and DR2 parallaxes → hints of metallicity dependence of both intercept and slope of PL/PW relations → distance of the LMC → constraint on the Gaia parallaxes ZP offset.

Ripepi, Catanzaro, Molinaro et al. 2020

Iron and other 28 chemical species in 50 CCs observed with HARPS-N + Literature +EDR3 parallaxes → improvement on the estimate of metallicity dependence of PL/PW relations

Ripepi, Catanzaro et al. in preparation
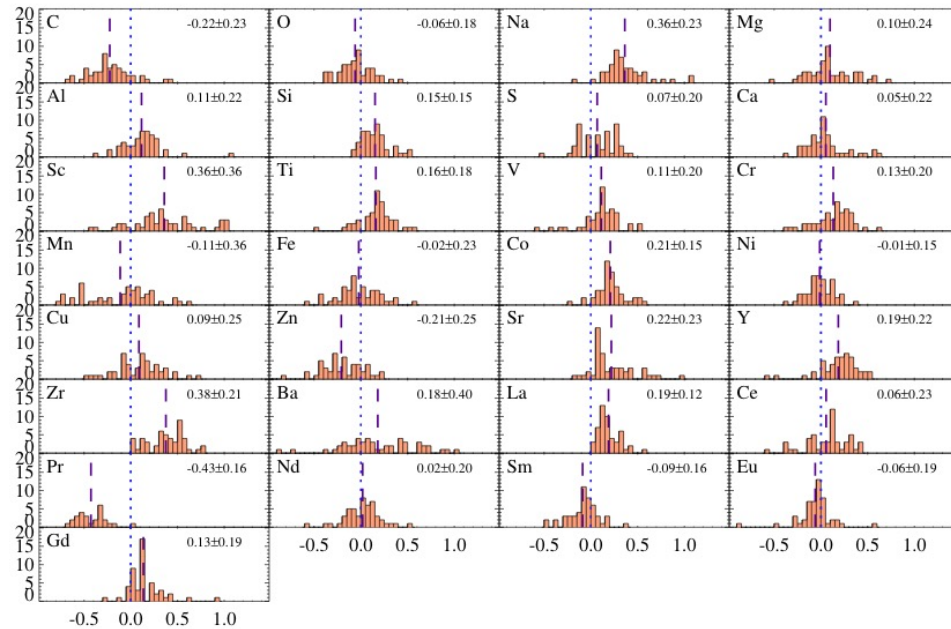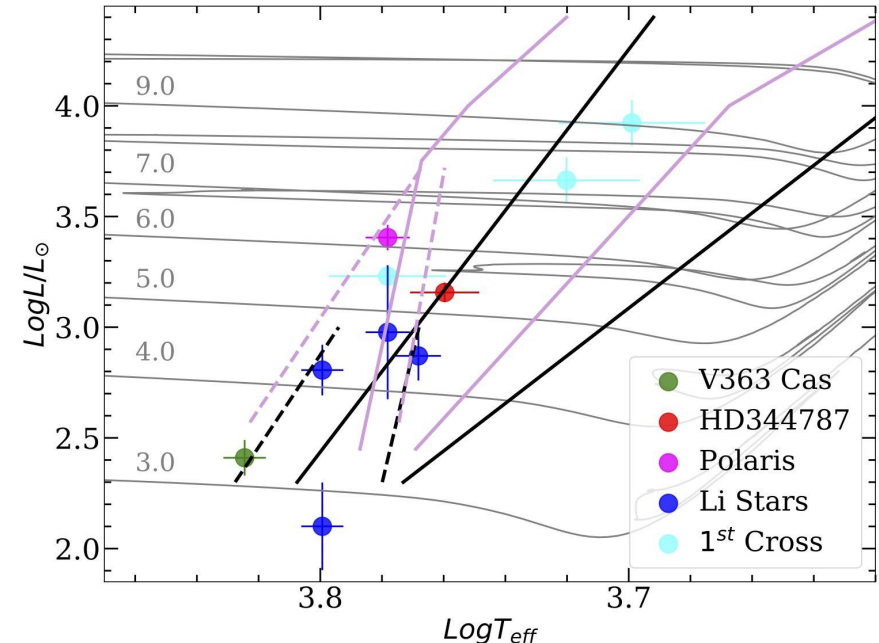
Peculiar CC with lithium (V363 Cas) and a Polaris analogue (HD344787) → constraints on stellar evolution and pulsation

Catanzaro, Ripepi, Clementini et al. 2020
Ripepi, Catanzato, Molnár et al. 2021
TNG News 2021

Scientific results from SPASM
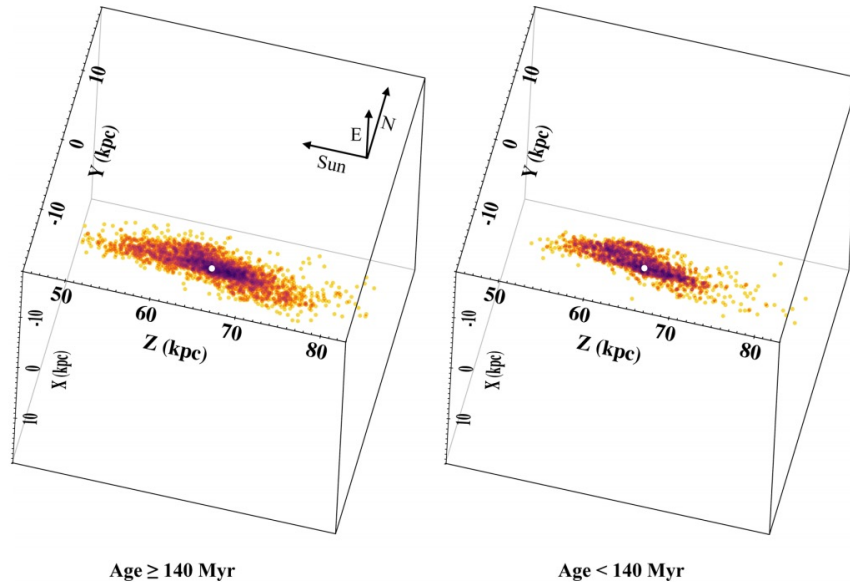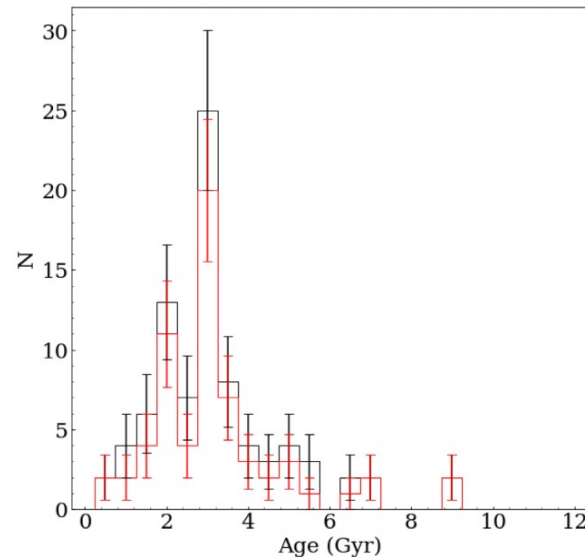

3D geometry of SMC based on CCs observed with VMC@VISTA → elongation along line of sight > 20kpc →   strong interaction with LMC;

Ripepi, Marconi, Moretti et al. 2016
Ripepi, Cioni, Moretti et al. 2017

Age ≥ 140 Myr   Age < 140 Myr
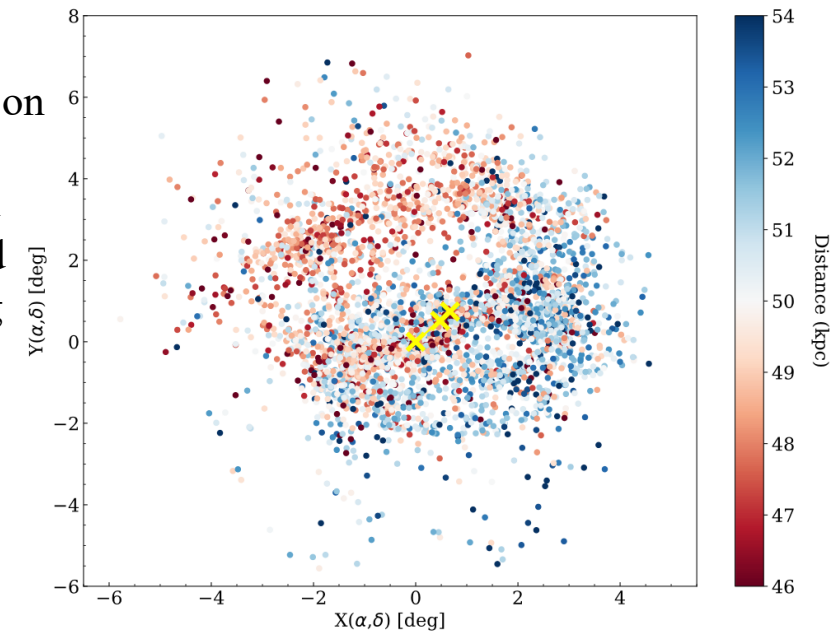
Star cluster search in LMC outskirts based on STEP and YMCA@VST →   high star formation 3 Gyr ago; → found 20 candidate SCs in the age gap.

Gatto, Ripepi, Bellazzini et al. 2020

3D geometry of LMC based on CCs observed with VMC@VISTA →   Bar and disk different inclination and highly structured →   strong interaction with SMC and MW.

Ripepi et al. 2021, in preparation

Scientific results from STEP2GO

Born in situ vs accreted using RRLs.

Photometric metallicity with RRLs.
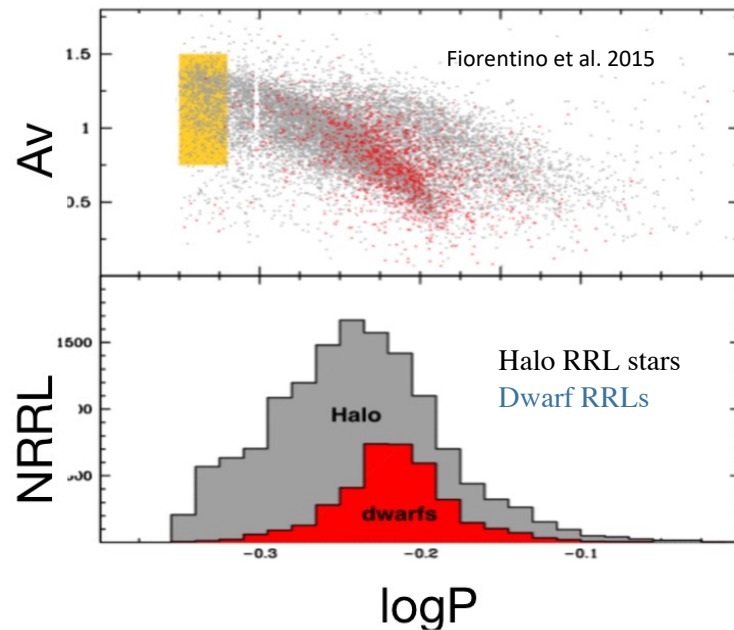
In a hierarchical scenario:
Major mergers are favoured
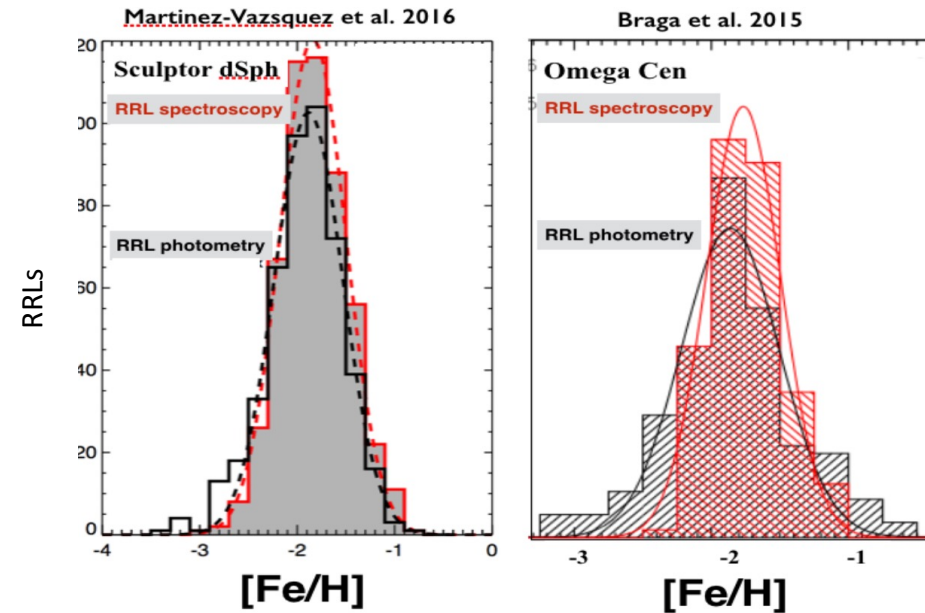
The early chemical evolution of dwarf
galaxies up to few Mpc can be drawn.

Preliminary results from MOVIE@Rubin-LSST
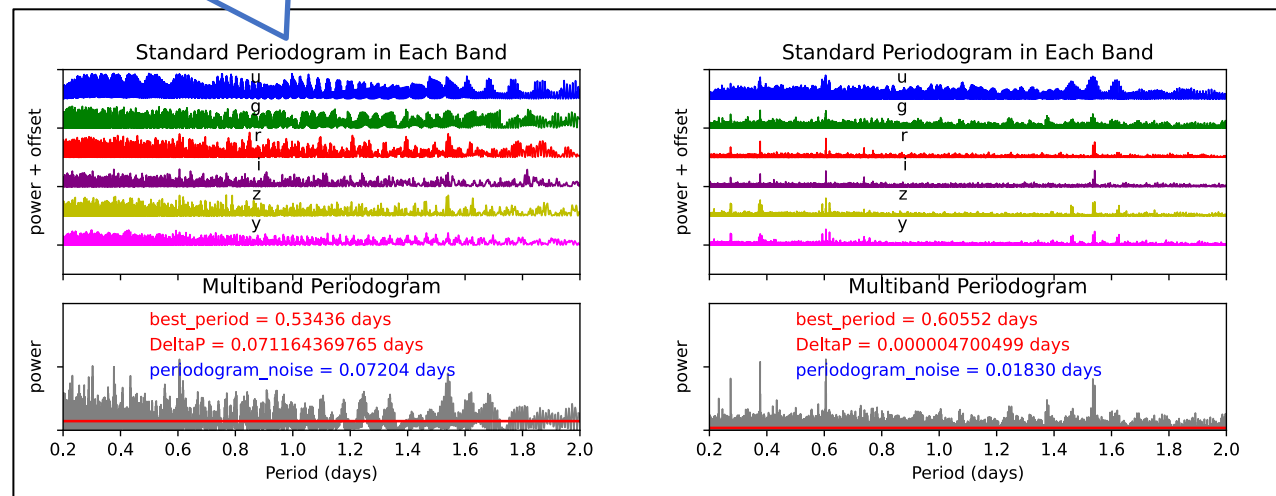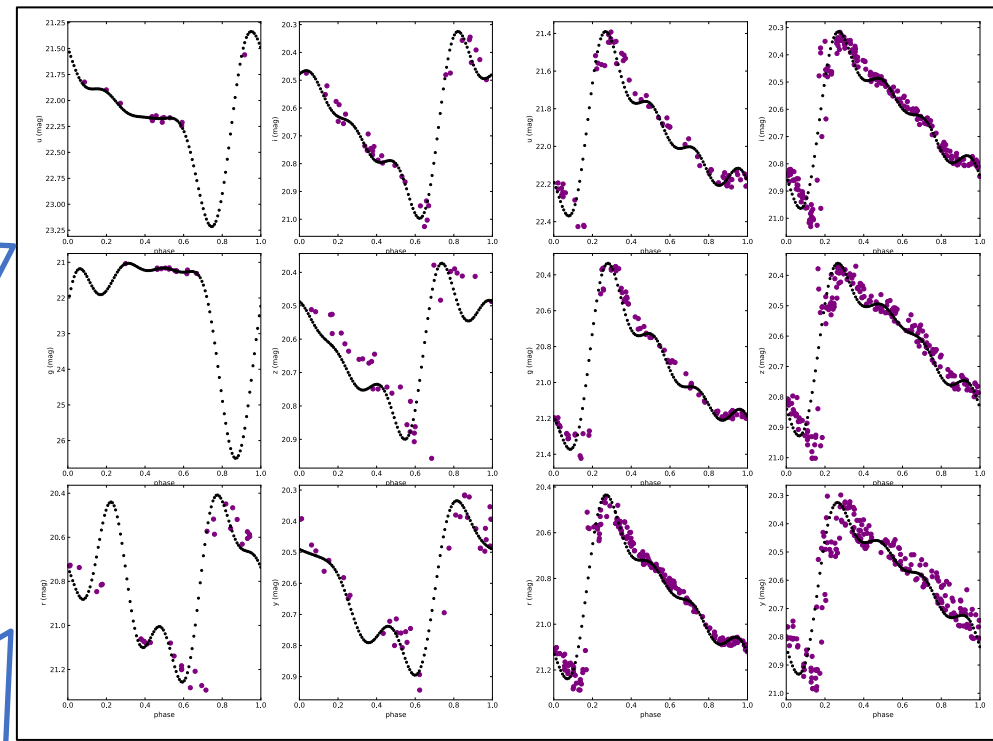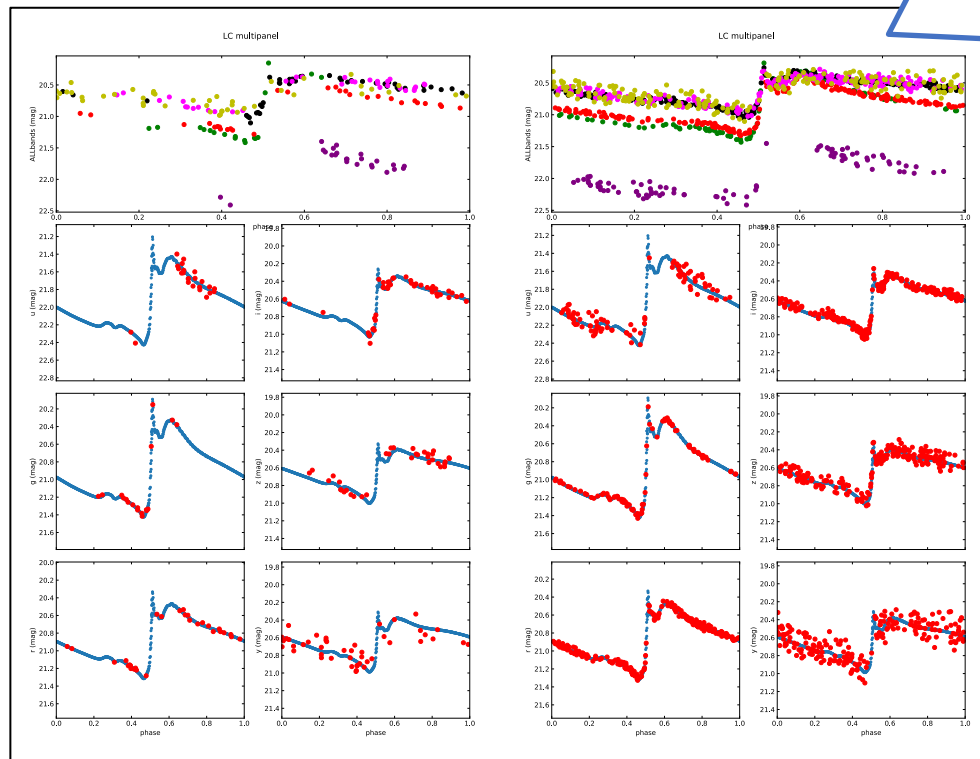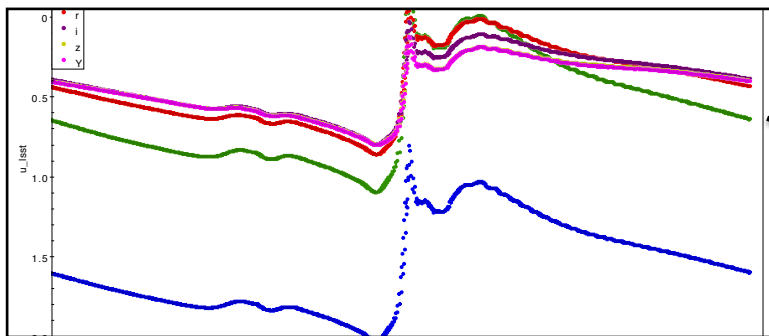
Preliminary results from SVARIO-LSST

An in-kind contribution to LSST-TVS-

Crowded Photometry Task force - PI M.
Dall'Ora.

Test-experiment on DECam data of a Bulge field
where NGC6569 is located.
Automatisation of PSF photometry and search
for variable stars and their characterisation.

high quality photometry

high quality light curves
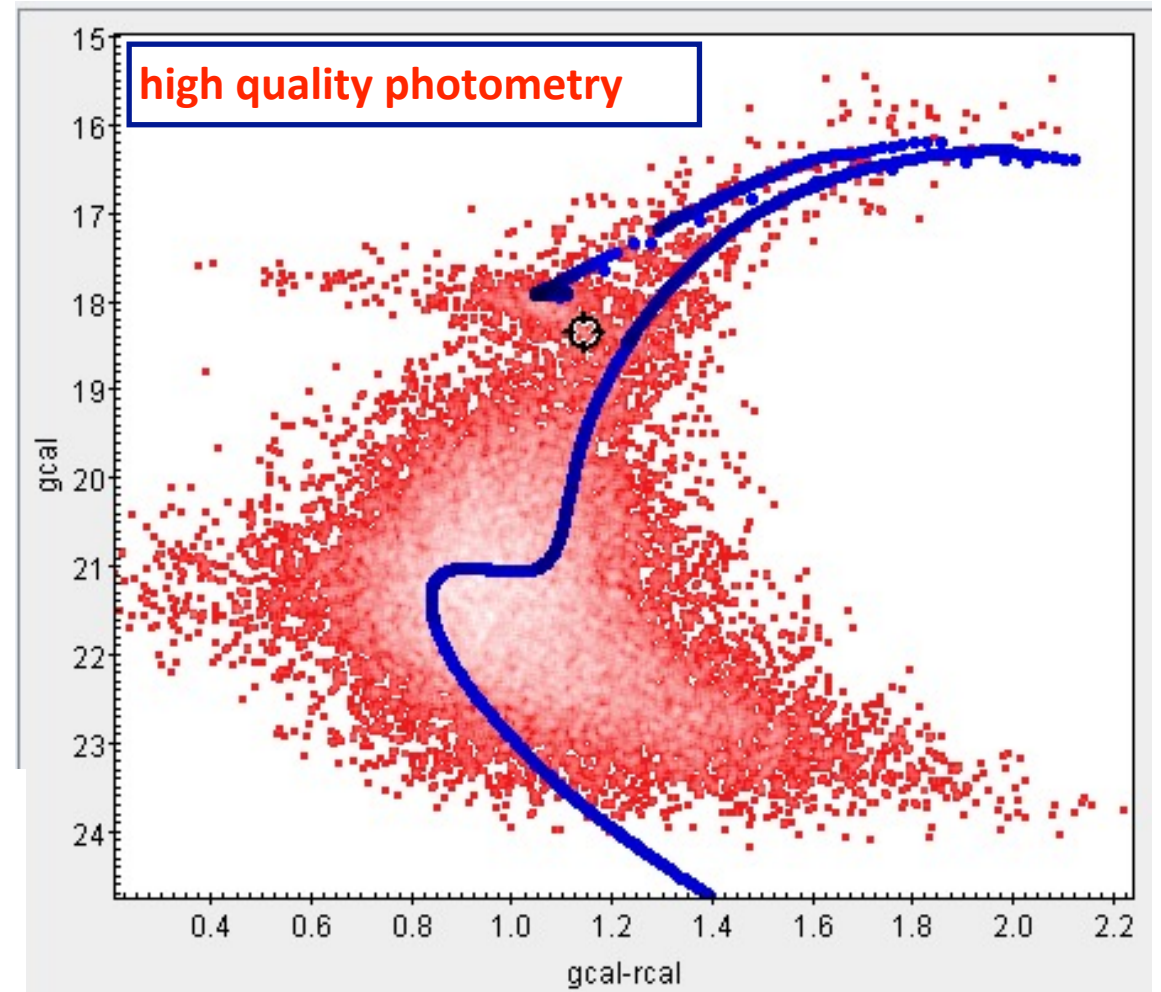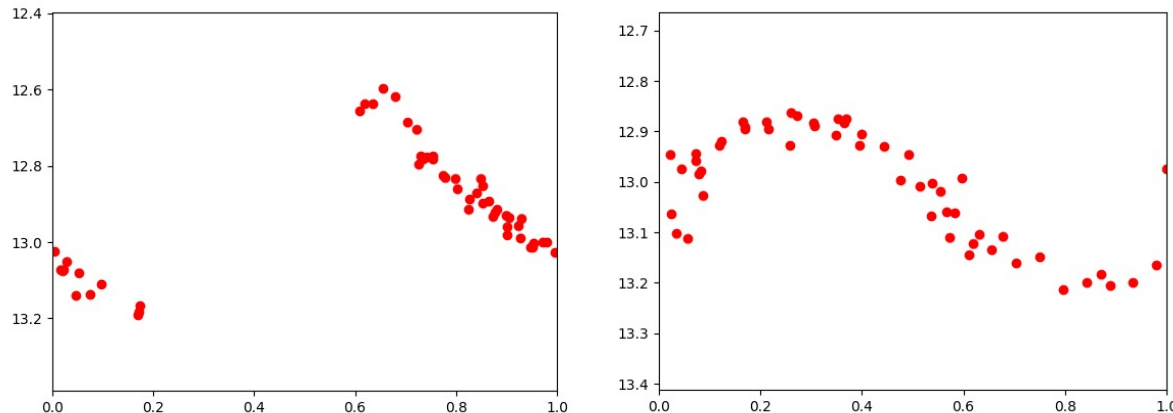
MOVIE LEADERSHIP

The team has a recognised leadership in the field ← large number of publications on high impact international journals (see the following slide)

More than 30 invited talks at international meetings in the last 10 years

PI-ship of 3 ESO VST GTO surveys (STEP, YMCA V. Ripepi; STREGA M.Marconi/I.Musella). Responsibility for Cepheid studies in the VMC@VISTA consortium (V. Ripepi).

Science team of MAVIS, ERIS and Chair Project Science Team for ELT (G. Bono), science team of CUBES (M. Marconi).

PI-ship of an in-kind project (TVS and SMWLV) "Tools for the simulation of Pulsating Stars" (I. Musella). Coordination of the TVS Distance Scale subgroup (M.Marconi).
Pi-ship of the project: "Cepheids and RR Lyrae as distance indicators and stellar population tracers: theory and observations" (Marconi/Musella)

Coordination of the TVS TF "Stellar variability in crowded fields" (M. Dall'Ora). PI-ship of the in-kind "Staff effort in support of Rubin commissioning: Image quality analysis" (G. Fiorentino). PI-ship of the in-kind contribution "Software Tools for Stellar Populations in Crowded Fields" (M. Dall'Ora)

M. Marconi is the coordinator of a H2020 project (Prestige) starting next December on the use of pulsating stars as distance indicators.

M. Marconi and V. Ripepi are editors of a Universe Special Issue on "Recent Advances in Pulsating Stars". G. Bono is member of the programme committee of MIAPP (TUM, Max Planck Garching)

Publications including PIs from the MOVIE kick off

Press releases

20

480

Non refereed ⟶ 450

⟵ With referee

> 28000 citations
H_{index}=70
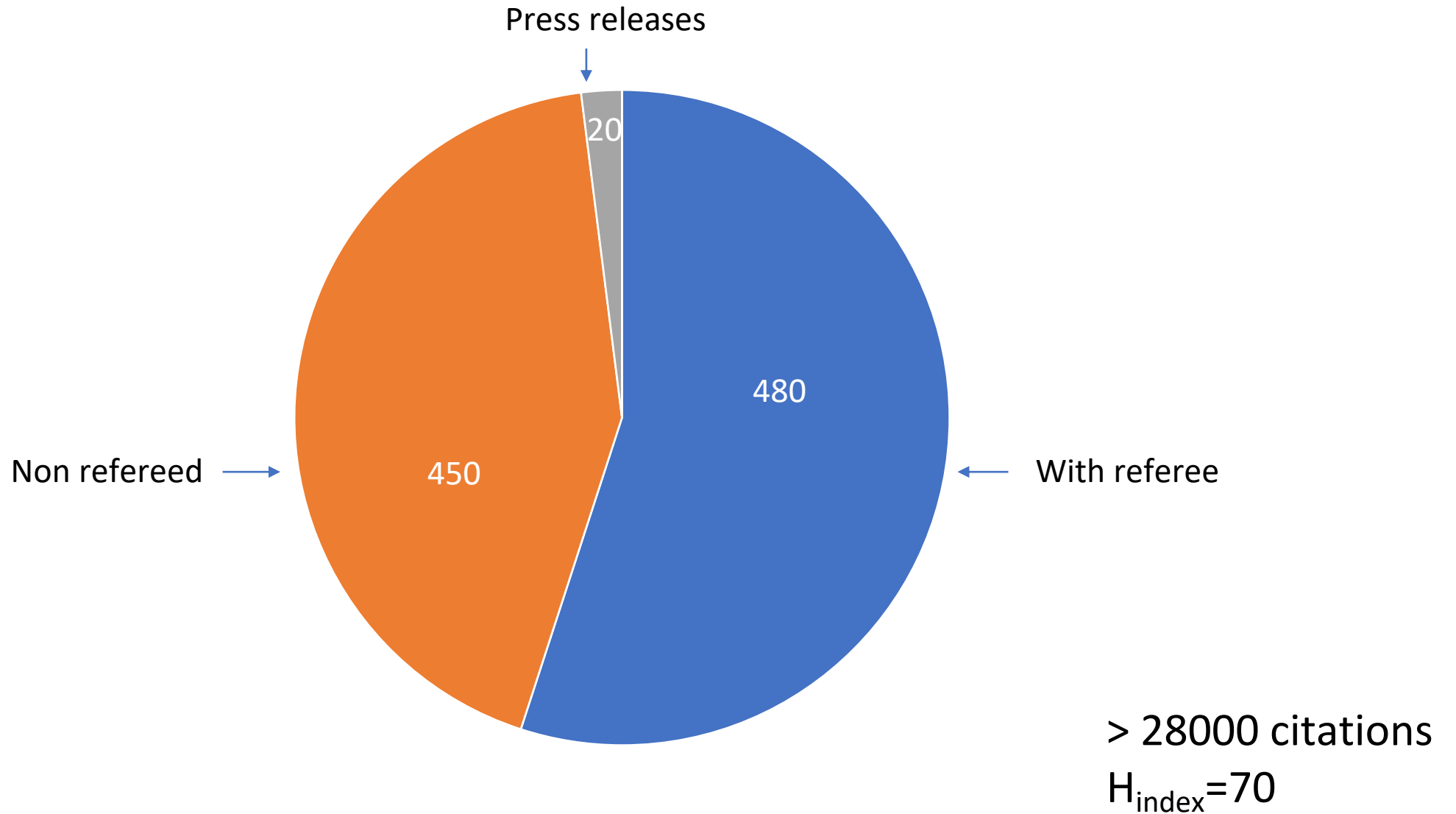
Critical points

- Funds (active PRIN MUR and Rubin-LSST applications) for meetings, travels, publications, hardware and PhD/postdocs

- At least 2 new positions of young researchers are needed to guarantee the success of the planned activities (only 3 assumed TI researchers in the last 3 years, all over 40)

- Career developments would be very important (also considering the many PI-ships and coordination duties)

Future developments

In the next few years we plan to:

-complete the development of an exhaustive theoretical scenario for different classes of pulsating stars and build an extensive theoretical database of light and radial velocity curves, as well as pulsation relations useful to constrain mean and individual distances and stellar properties, through the comparison with observations;

- study of the stellar populations of the MCs, especially the Small Magellanic Cloud (SMC) and its pulsating star content (Cepheids and RR Lyrae) by relying upon photometric proprietary data from surveys carried out in the optical and in the near-infrared with the OMEGACAM@VST (STEP and YMCA surveys) and VIRCAM@VISTA (VMC survey) instruments; High-mid-resolution spectroscopy of Cepheids and RRL with 4MOST@VISTA

-establish the metallicity dependence of Cepheid period-luminosity (PL) relations to investigate its impact on the estimate of H_0 through the cosmic ladder method, through high-resolution spectroscopy and multi-band photometry for a sample of 200 Galactic DCEPs, greatly enlarging the parameter space for the PLs determination with respect to the literature;

- Deeply investigate RRLs as the ideal old population tracers to shed light on Galactic Archaeology;

-develop the theoretical framework needed to simulate light curves for pulsating stars from Rubin-LSST and validate specific tools to characterise variable and static stellar population tracers in the crowded fields observed by Rubin-LSST, in particular in the Bulge region

Future developments

In the long-term we also plan to:

-update the physical and numerical inputs of the adopted hydrodynamical code in order to optimise its running and allow application to extended observational databases;

- improve the distance scale calibration in the Local Group and beyond thanks to Rubin-LSST and JWST future data;

- understand how the Galactic halo formed and evolved, which roles have had GCs, UFD and classical dwarfs in its formation

- investigate the 3D structure of the Bulge and the associated age and metallicity profiles thanks to Rubin-LSST capabilities

-provide extended sets of theoretical templates for the Rubin-LSST TVS Scientific Collaboration;

-prepare to scientifically exploit ELT MICADO@Maory and MAVIS in the study of stellar populations and in the identification of luminous pulsating stars at cosmologically interesting distances