

# Long-Period Variables as Distance and Age Indicators in the Era of *Gaia* and LSST

Michele Trabucchi

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At the cross-roads of astrophysics and cosmology:  
Period-luminosity relations in the 2020s

IAU Symposium 376  
Budapest - 17-21/04/2023

# Outline

Assessing the potential of LPVs (not only Miras!) as distance and age indicators, in the era of very large-scale, time-domain astronomical surveys.

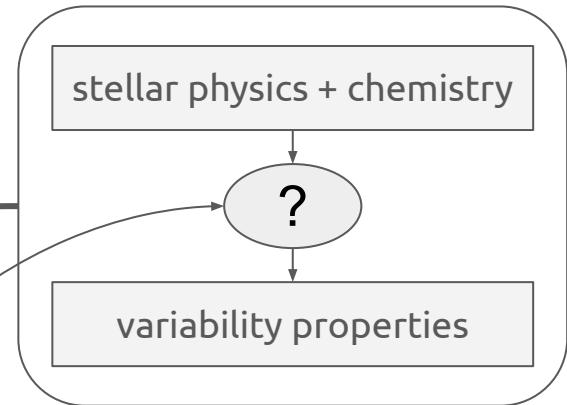
- Pulsation models of Long-Period Variables
- The period-age relation of Long-Period Variables
- Semi-regular variables as distance indicators

# LPV pulsation models



## Literature:

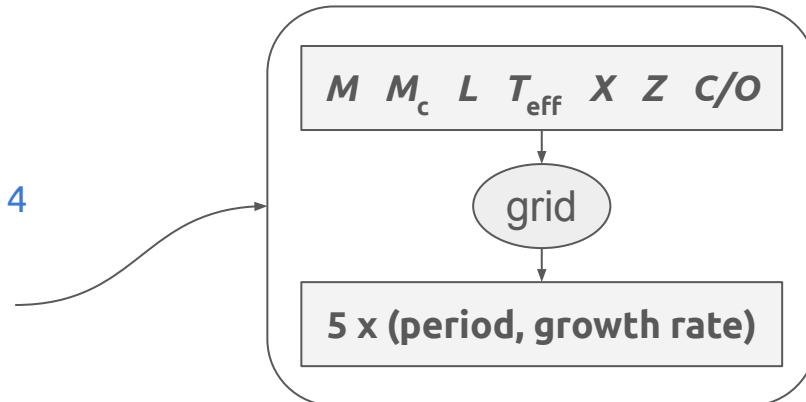
- fragmented/inhomogeneous
- incomplete/poor coverage of space of stellar parameters
- only 1 or 2 pulsation modes



# LPV pulsation models

Pulsation code [Fox & Wood 1982](#); [Wood & Olivier 2014](#)

- 1D (spherically symmetric star)
- radial (spherically symmetric oscillation)
- non-adiabatic
- *linear*



Grid: several million different combinations of parameters.

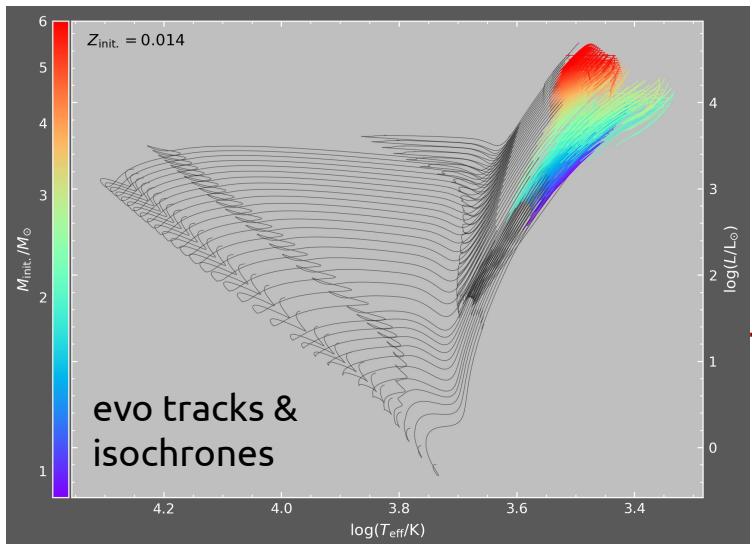
- Widest, most densely sampled grid of LPV models.
- First systematic investigation of:
  - chemistry-pulsation connection
  - pulsating C-rich giants

[Trabucchi+ 2019](#)

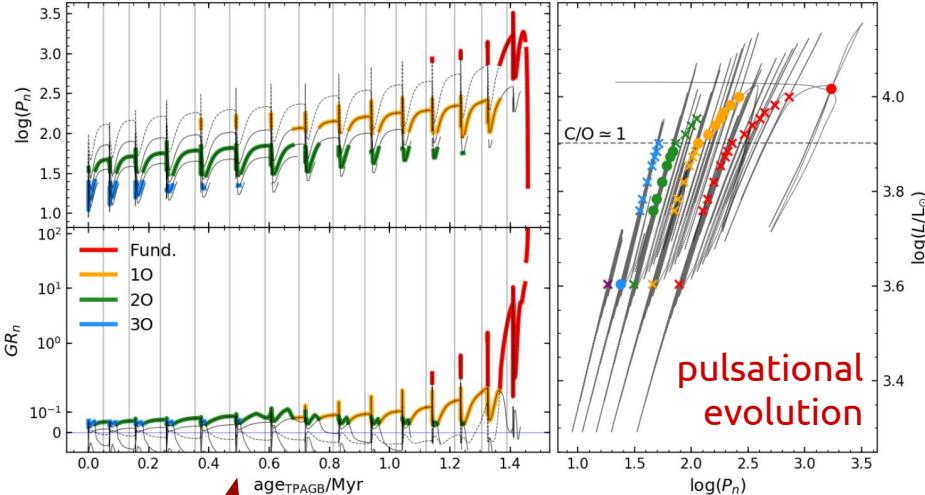
Periods independent of composition (mostly)  
Instability dependent on composition

# LPV pulsation models

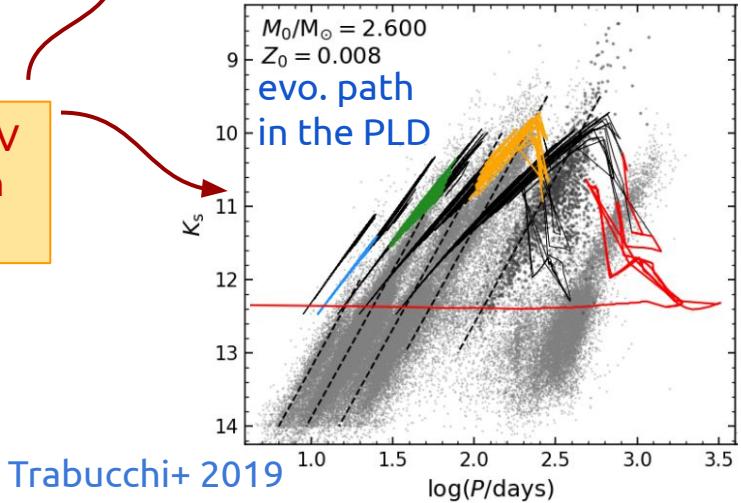
Grid fully compatible and easily interfaceable with evolutionary models



grid of LPV  
pulsation  
models



pulsational evolution



Trabucchi+ 2019

# LPV pulsation models

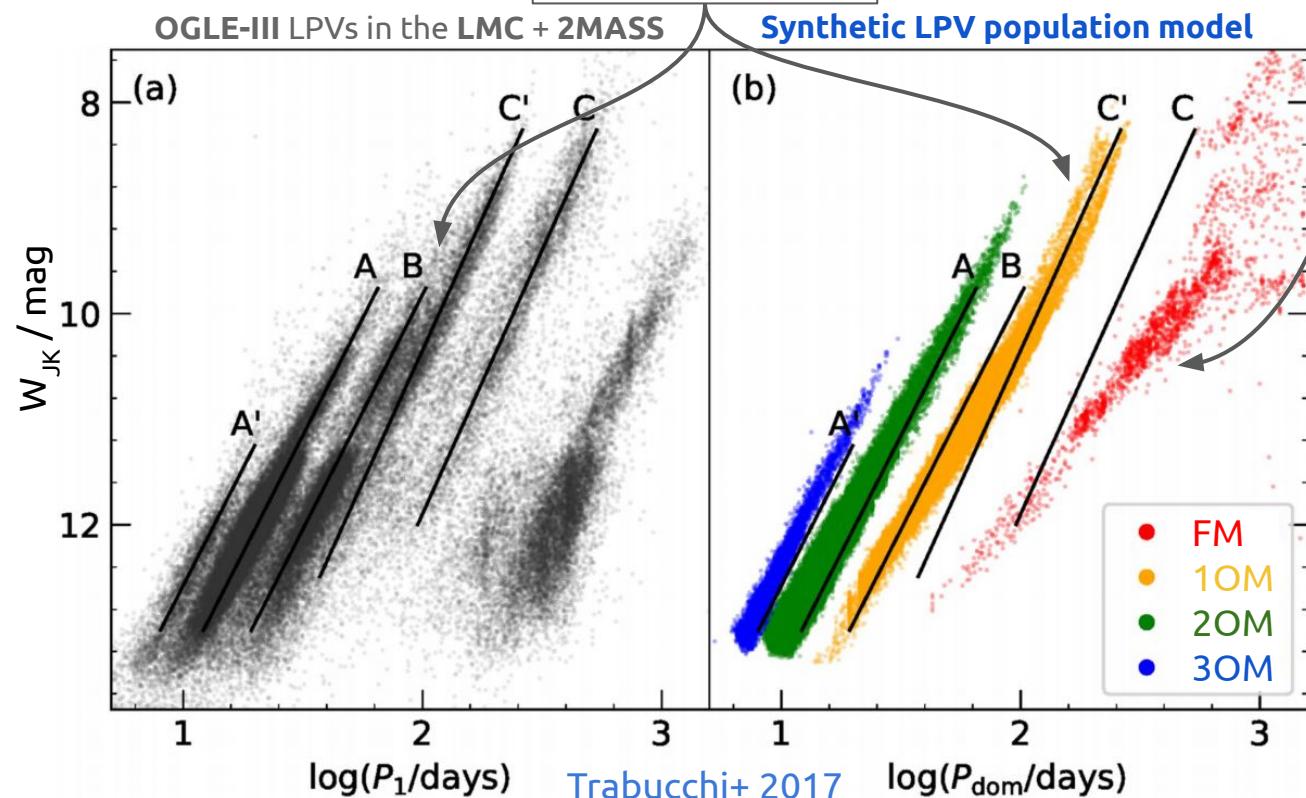
## Goal:

Capability of building a synthetic version of the period-luminosity diagram of LPVs in the LMC.

Comparison with observations:  
OGLE-III + 2MASS

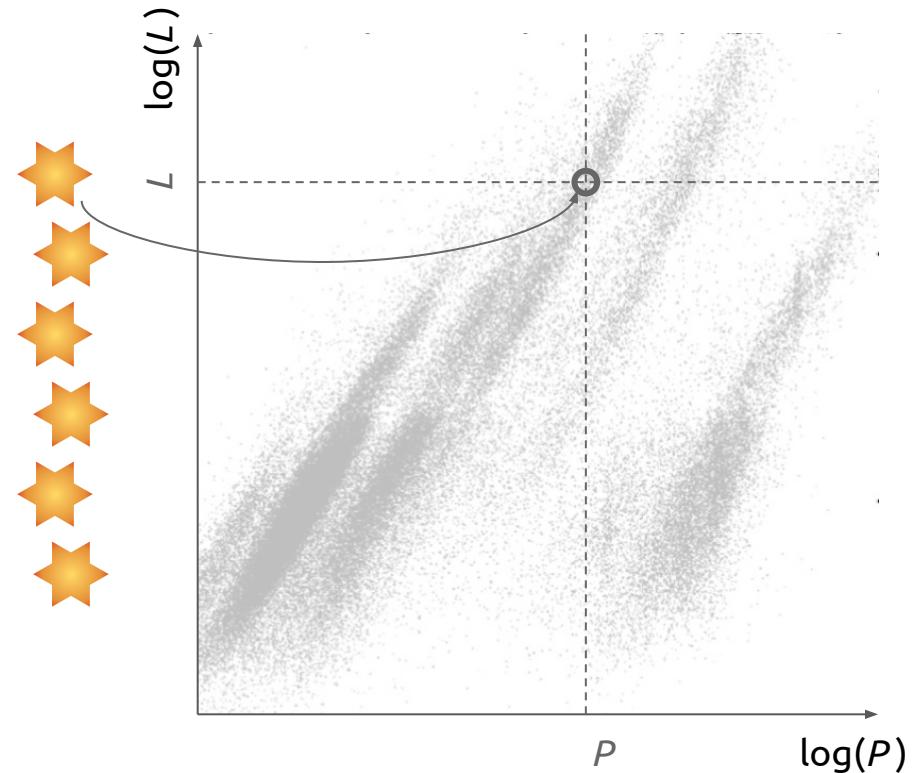
2 PL relations  
for 1 pulsation mode:  
observational  
selection bias

linear approx.  
breaks down



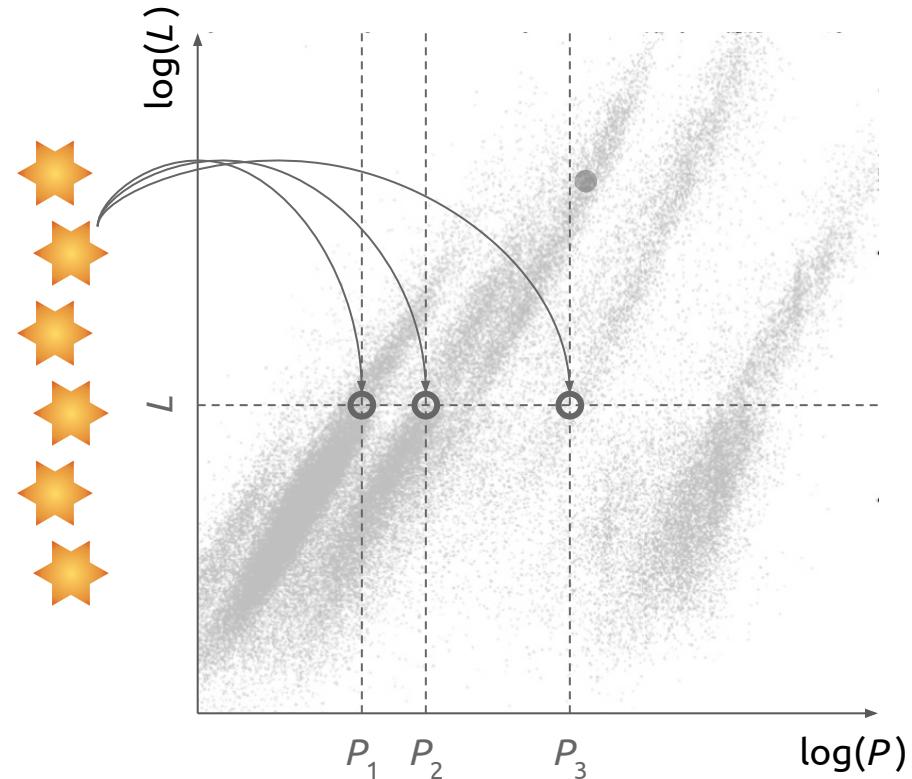
# PL diagram 101

- For each star, plot luminosity as a function of period



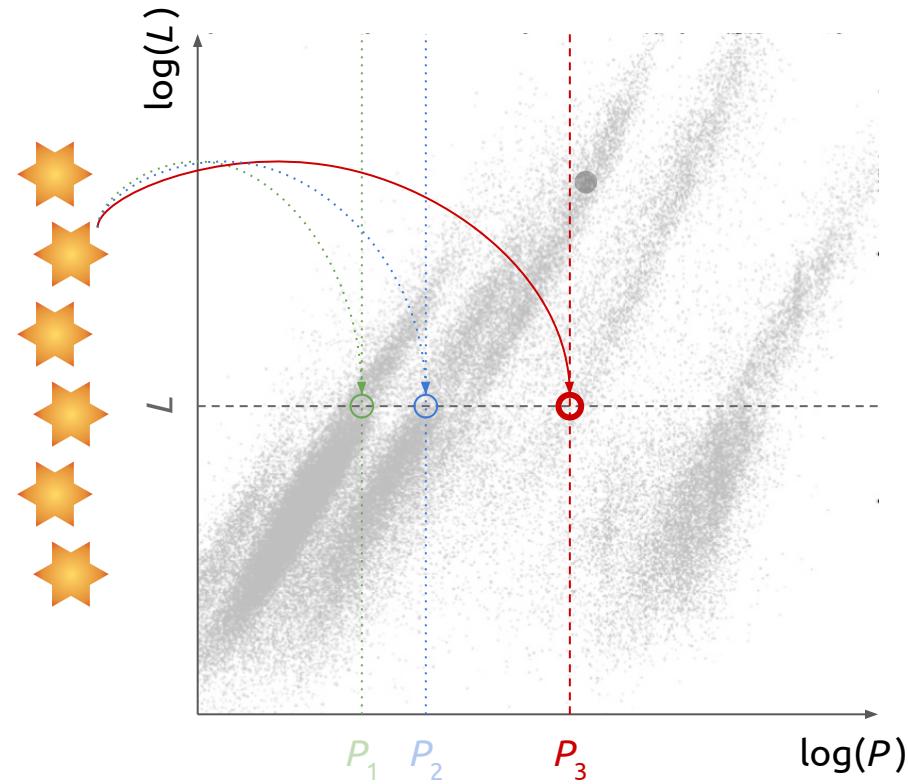
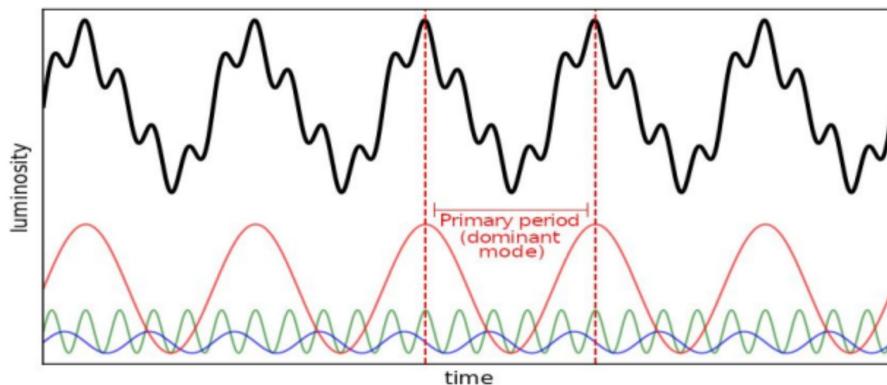
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- For each star, plot luminosity as a function of period
- What about multiperiodic stars?



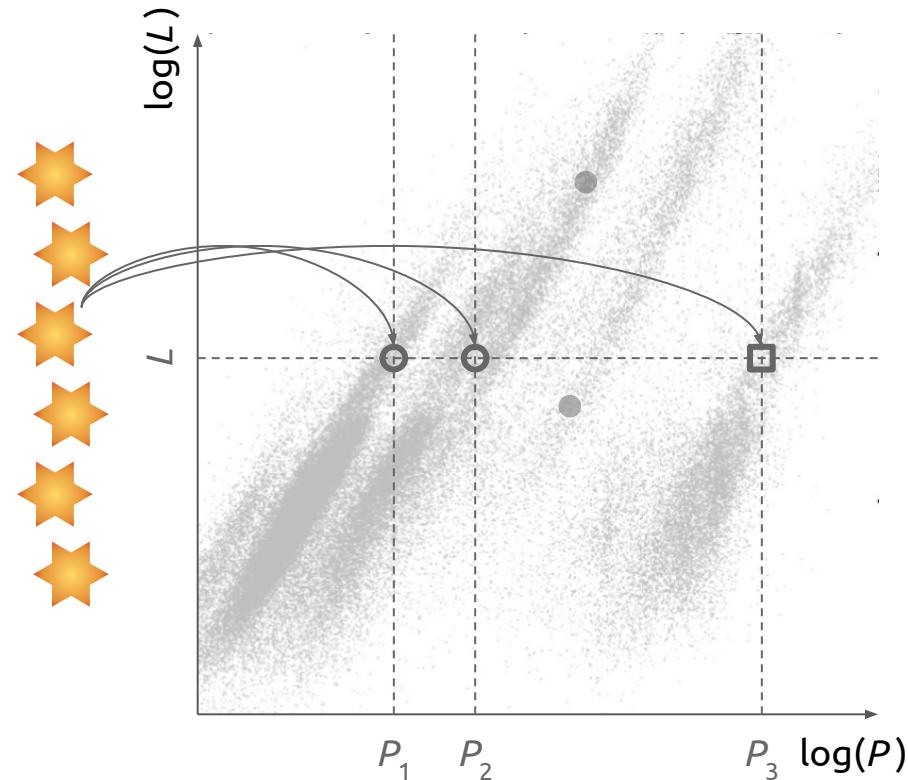
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- **"Dominant"** period taken as representative



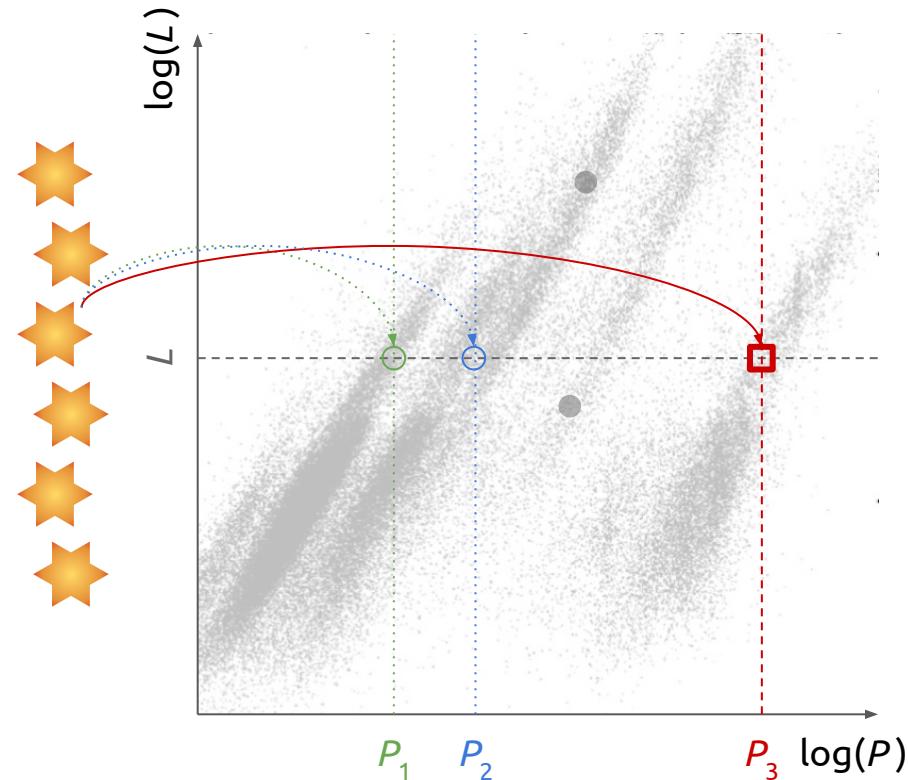
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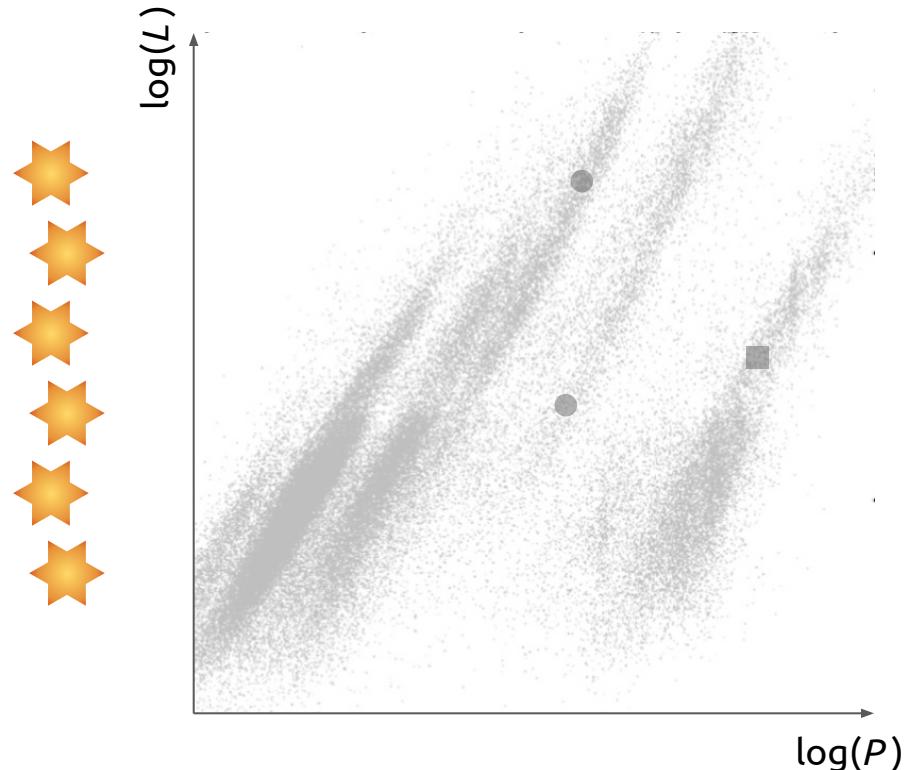
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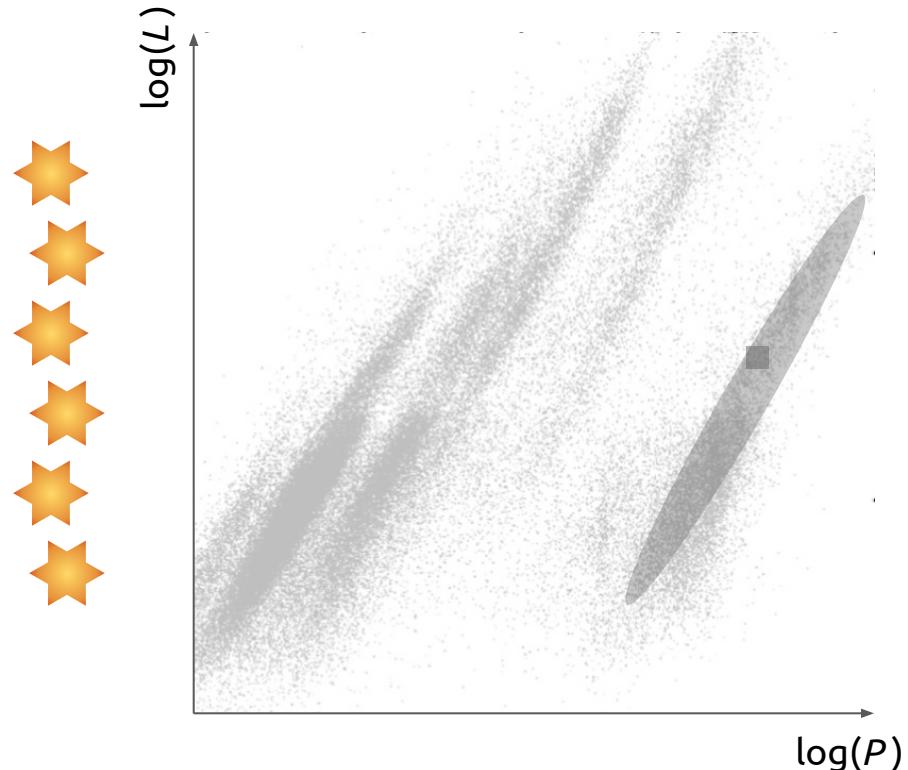
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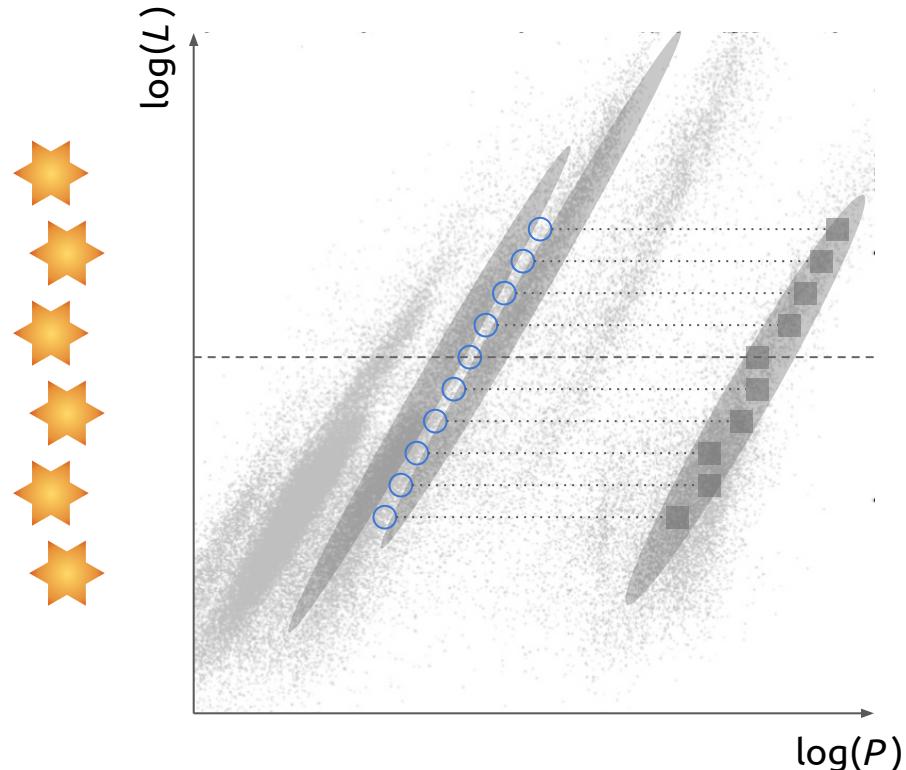
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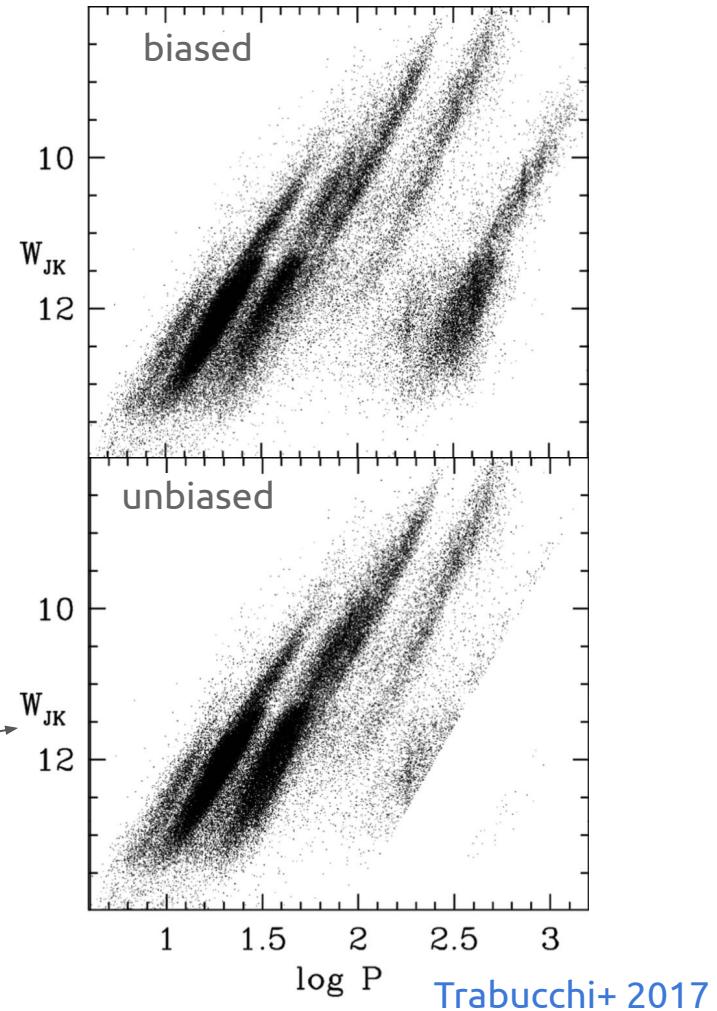
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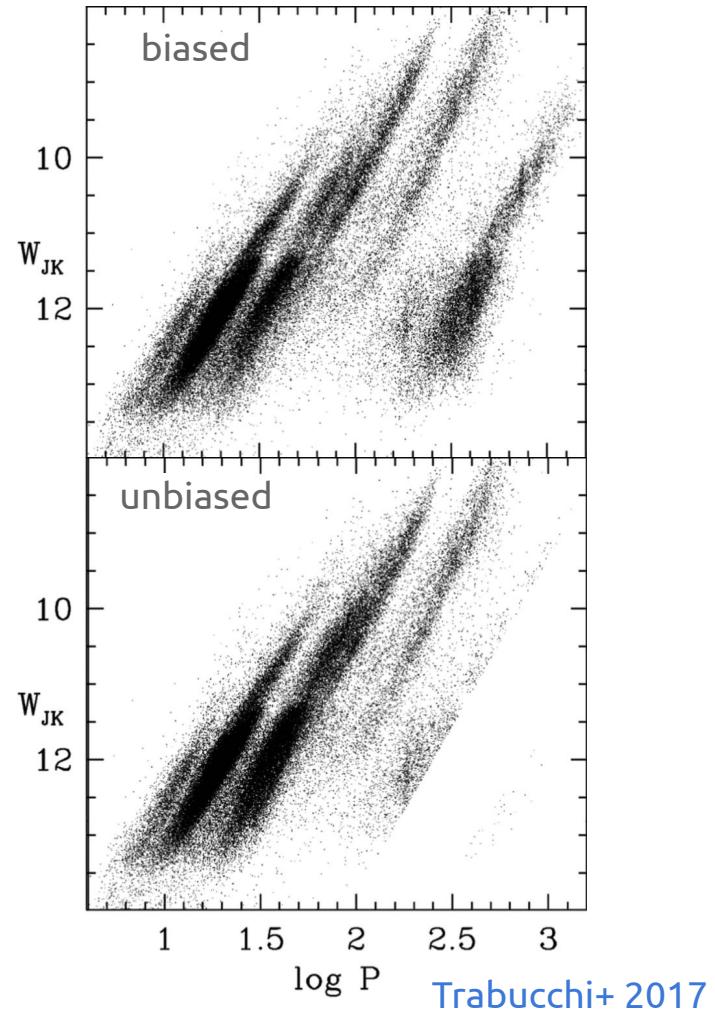
Trabucchi+ 2017

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- "Dominant" period taken as representative
- All periods must emerge from the same process - not

1. High complexity of the PLD of LPVs  
(multi-periodicity, non-pulsation periods, ...)
2. Pulsation models + synthetic pop. model =  
powerful approach for understanding LPVs

- canceled: gap between sequences B and C'
- When LSPs are properly accounted for, the gap between sequences B and C' effectively disappears



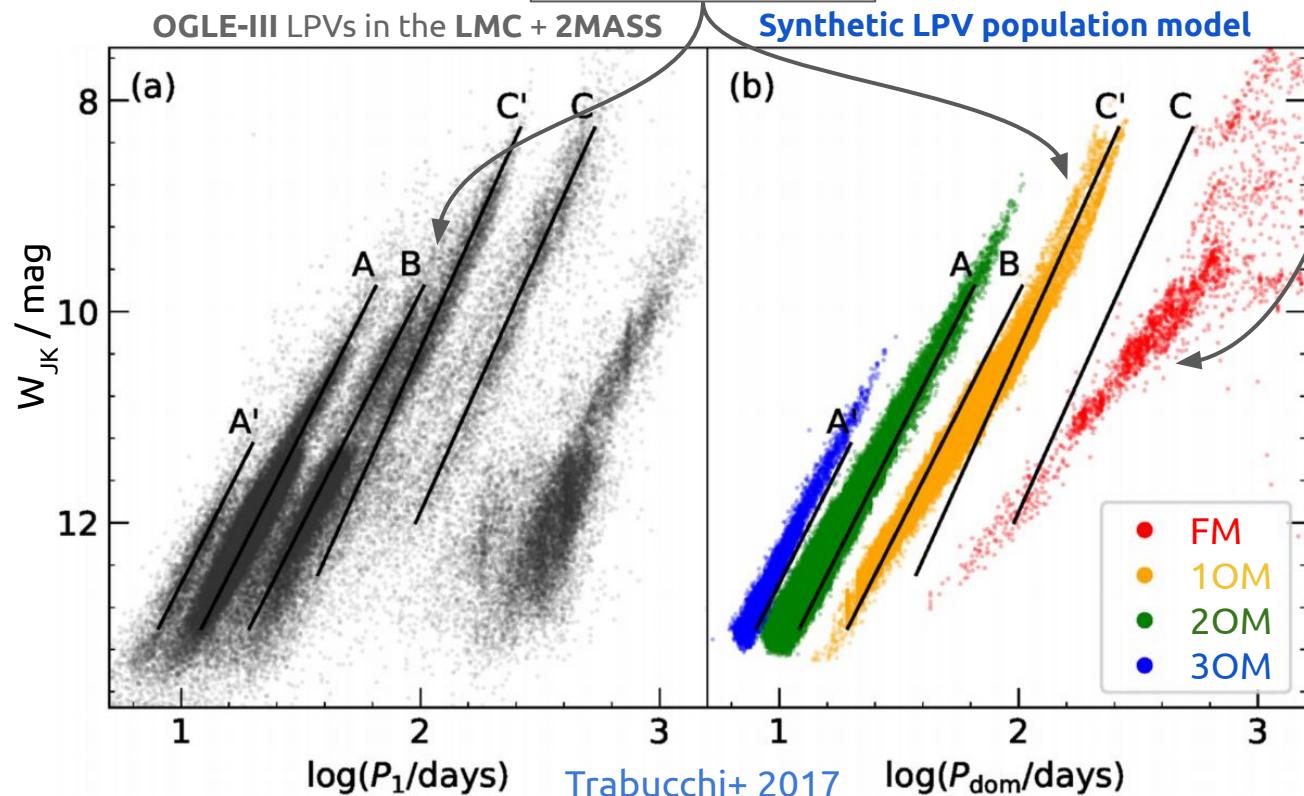
Trabucchi+ 2017

# LPV pulsation models

FM pulsators intrinsically non-linear: large amplitude

2 PL relations  
for 1 pulsation mode:  
observational selection bias

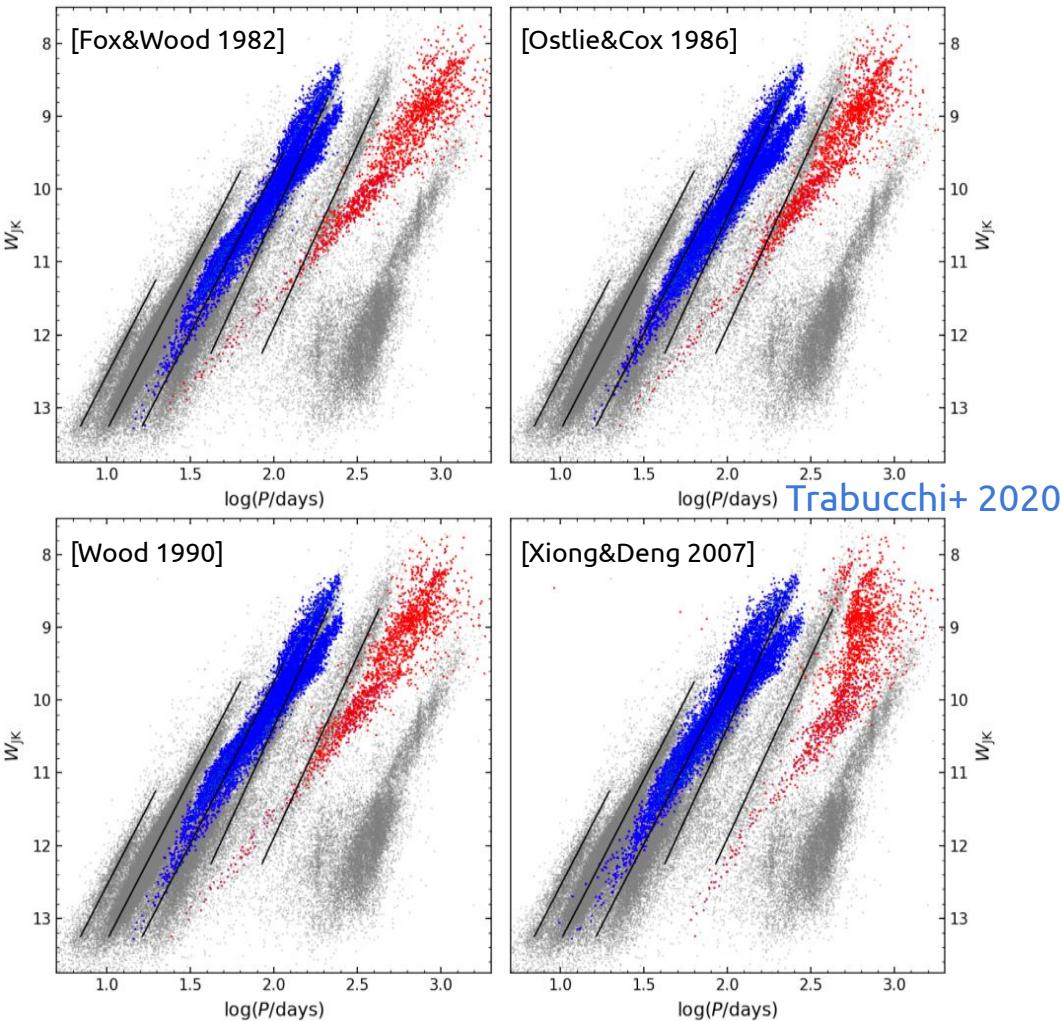
linear approx.  
breaks down



# LPV pulsation models

FM pulsators intrinsically non-linear: large amplitude

The vast majority of prescriptions from literature that are most commonly adopted to link pulsation and stellar structure/evolution are based on linear models, and overestimate the FM period.



# LPV pulsation models

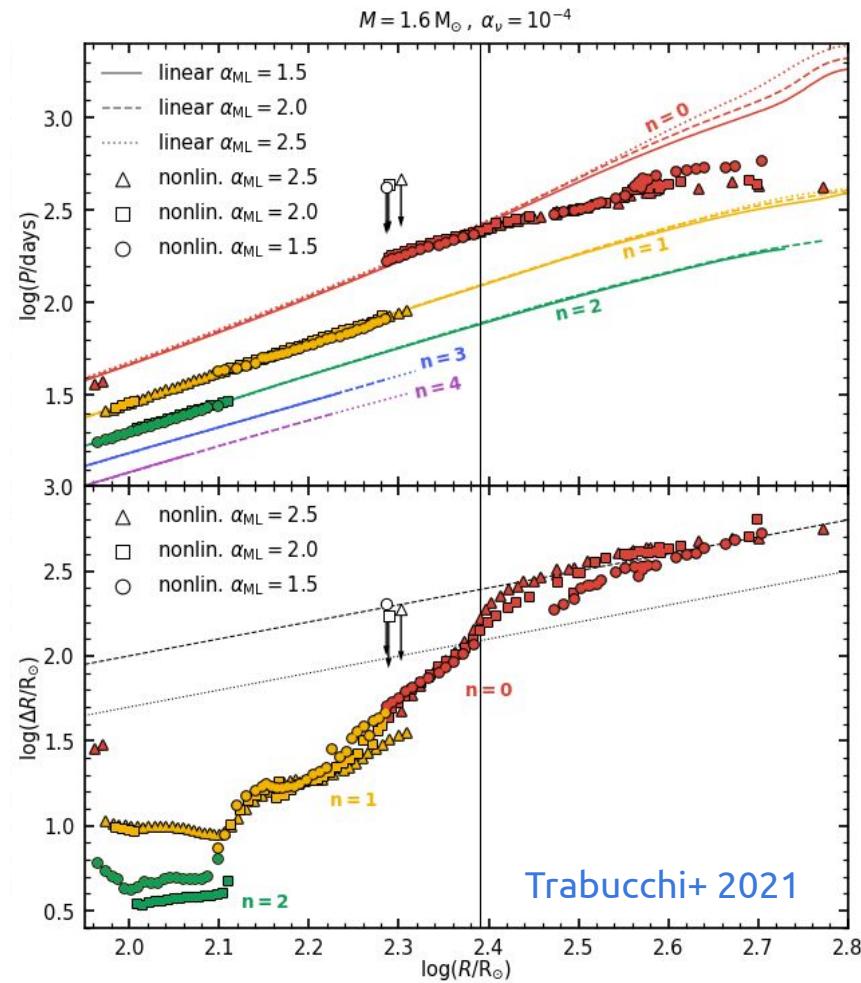
Pulsation code [Wood 1974, Keller & Wood 2006](#)

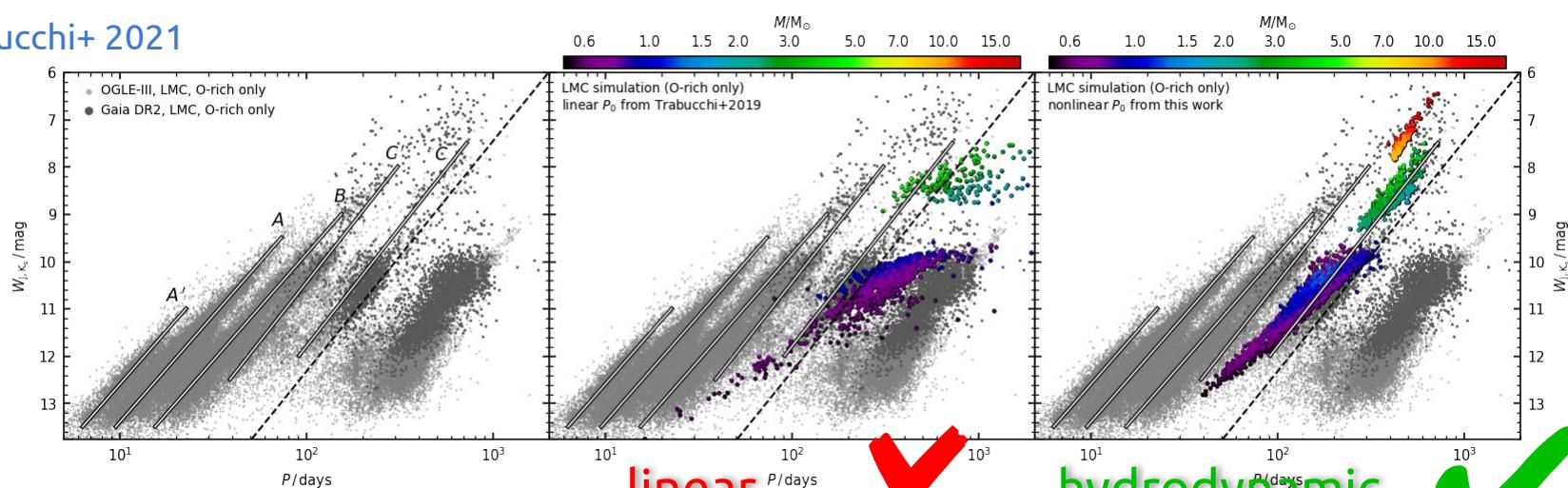
- 1D (spherically symmetric star)
- radial (spherically symmetric oscillation)
- non-adiabatic
- **hydrodynamic (non-linear)**

Limited portion of the grid (fixed chemistry).

- First systematic investigation of LPV pulsation in the non-linear regime
- Confirmed pulsation-induced readjustment of envelope structure, causing shorter FM period ([Ya'ari & Tuchman 1996, Lebzelter & Wood 2015](#))

Future developments: chemistry, multi-periodicity

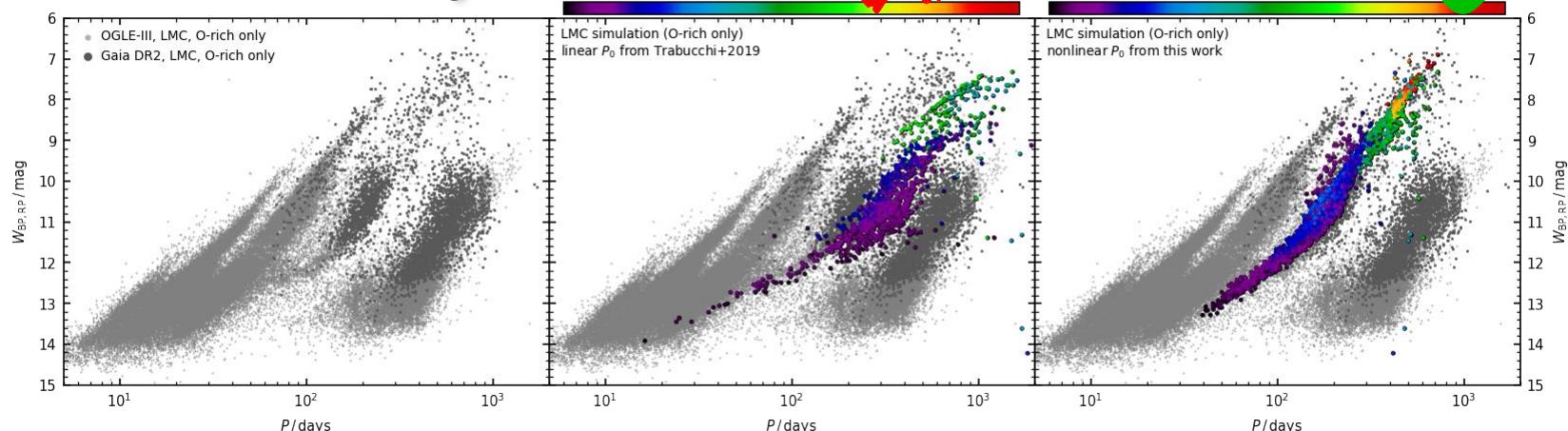




observations only

linear

hydrodynamic



# LPV pulsation models

Main difference between linear & hydrodynamic models:

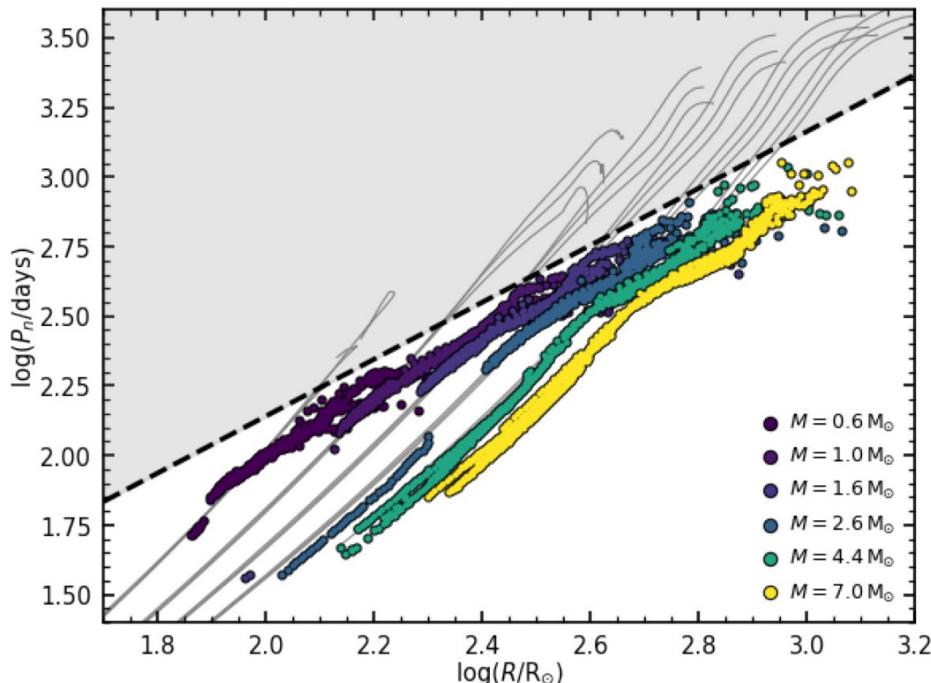
- linear: period increase indefinitely with radius
- hydrodynamic: period saturates

Non-linear behaviour determines right edge of FM PLR

Example: impact on mass estimate (roughly...)

- for long-period, relatively massive AGB stars, linear prescriptions cause to underestimate the mass by ~50% to ~100%
- for low-mass AGB stars, linear prescriptions cause to overestimate the mass by a factor ~2-4 at short periods, and twice as much for long periods

**Always use non-linear prescriptions for the FM period!**



Trabucchi+ 2021

# LPV pulsation models

New calculations ongoing, preparatory for VRO-LSST

- Grid upgrade: full hydrodynamic
- Extension to other chemical parameters
- Multi-periodicity properties
- Template folded curves of surface parameters ( $L$ ,  $T_{\text{eff}}$ ,  $R_{\text{phot}}$ )
- Envelope structure throughout pulsation cycle
- Preliminary light curve templates

## 2. The period-age relation of LPVs

# Period-age relation of LPVs

Historically known from kinematic studies

(Merrill 1923; Wilson & Merrill 1942; Feast 1963)

Shorter-period LPVs = hotter kinematics = older

Basic explanation:

- PLR: longer period = brighter
- more luminous = more massive
- massive stars evolve faster, the ones we see are young
- thus: the longer the period, the younger the star

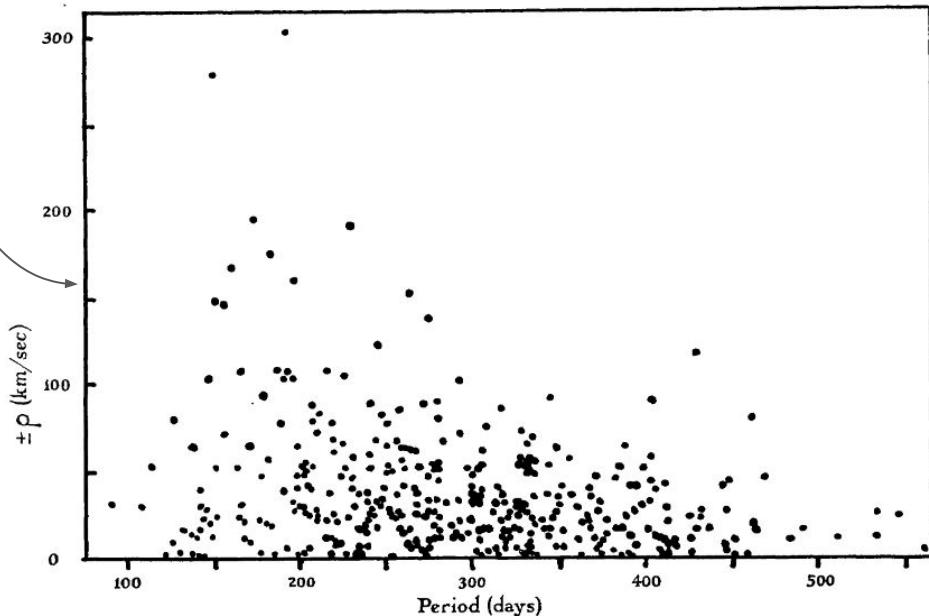


FIG. 4.—Relation of residual velocity ( $\rho$ ) to period for Me variables.

# Period-age relation of LPVs

Monthly Notices  
of the

ROYAL ASTRONOMICAL SOCIETY

MNRAS **483**, 3022–3035 (2019)

Advance Access publication 2018 December 4

JOURNAL ARTICLE

## Mira variables in the Milky Way's nuclear stellar disc: discovery and classification

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Jason L Sanders , Noriyuki Matsunaga, Daisuke Kawata, Leigh C Smith, Dante Minniti, Philip W Lucas

Monthly Notices of the Royal Astronomical Society, Volume 517, Issue 1, November 2022,  
Pages 257–280, <https://doi.org/10.1093/mnras/stac2274>

Published: 18 August 2022 Article history ▾

doi:10.1093/mnras/sty...

Astronomy  
& Astrophysics

## Age gradients throughout the Galaxy with long-period variables

J. Grady,<sup>1</sup> V. Belokurov ,<sup>1,2</sup> and N. W. Evans<sup>1</sup> 

<sup>1</sup>Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK

<sup>2</sup>Center for Computational Astrophysics, Flatiron Institute, 162 5th Avenue, New York, NY 10010, USA

A&A 660, A35 (2022)  
<https://doi.org/10.1051/0004-6361/202141805>  
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ROYAL ASTRONOMICAL SOCIETY

MNRAS **492**, 3128–3142 (2020)

Advance Access publication 2020 January 7

## Age demographics of the Milky Way disc and bulge

J. Grady, V. Belokurov , and N. W. Evans<sup>★</sup>

Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, U.K.

THE ASTROPHYSICAL JOURNAL, 836:218 (5pp), 2017 February 20  
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<https://doi.org/10.3847/1538-4357/836/2/218>



CrossMark

## The VVV survey: Long-period variable stars

### I. Photometric catalog of ten VVV/OGLE tiles<sup>★</sup>

F. Nikzat<sup>1,2</sup>, C. E. Ferreira Lopes<sup>3</sup>, M. Catelan<sup>1,2,4</sup>, R. Contreras Ramos<sup>1,2</sup>, M. Zoccali<sup>1,2</sup>, A. Rojas-Arriagada<sup>1,2</sup>, V. F. Braga<sup>5,6</sup>, D. Minniti<sup>7,8</sup>, J. Borissova<sup>2,9</sup>, and I. Becker<sup>1,10</sup>

## Absence of an X-shaped Structure in the Milky Way Bulge Using Mira Variable Stars

Martín López-Corredoira<sup>1,2</sup>

<sup>1</sup> Instituto de Astrofísica de Canarias, E-38205 La Laguna, Tenerife, Spain; [martinlc@iac.es](mailto:martinlc@iac.es)

<sup>2</sup> Departamento de Astrofísica, Universidad de La Laguna, E-38206 La Laguna, Tenerife, Spain

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# Period-age relation of LPVs

Few theoretical studies ([Wyatt & Cahn 1983](#); [Feast & Whitelock 1987](#); [Eggen 1998](#))

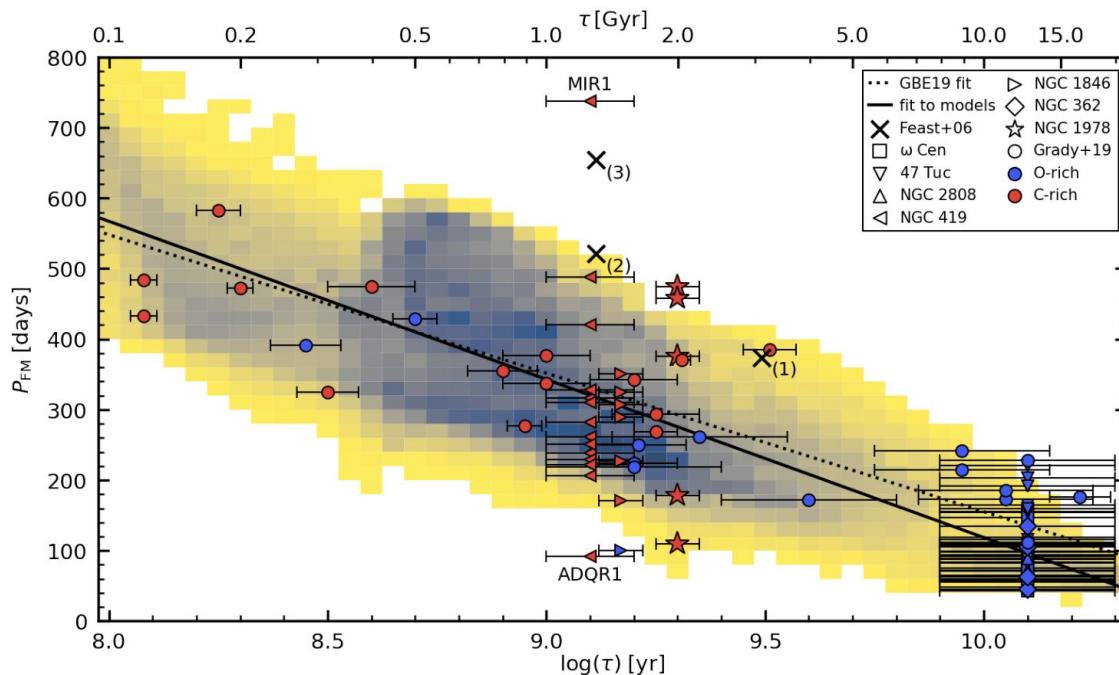
New non-linear FM prescription  
enables first accurate and systematic  
model-based investigation:

**state-of-the-art isochrone models**

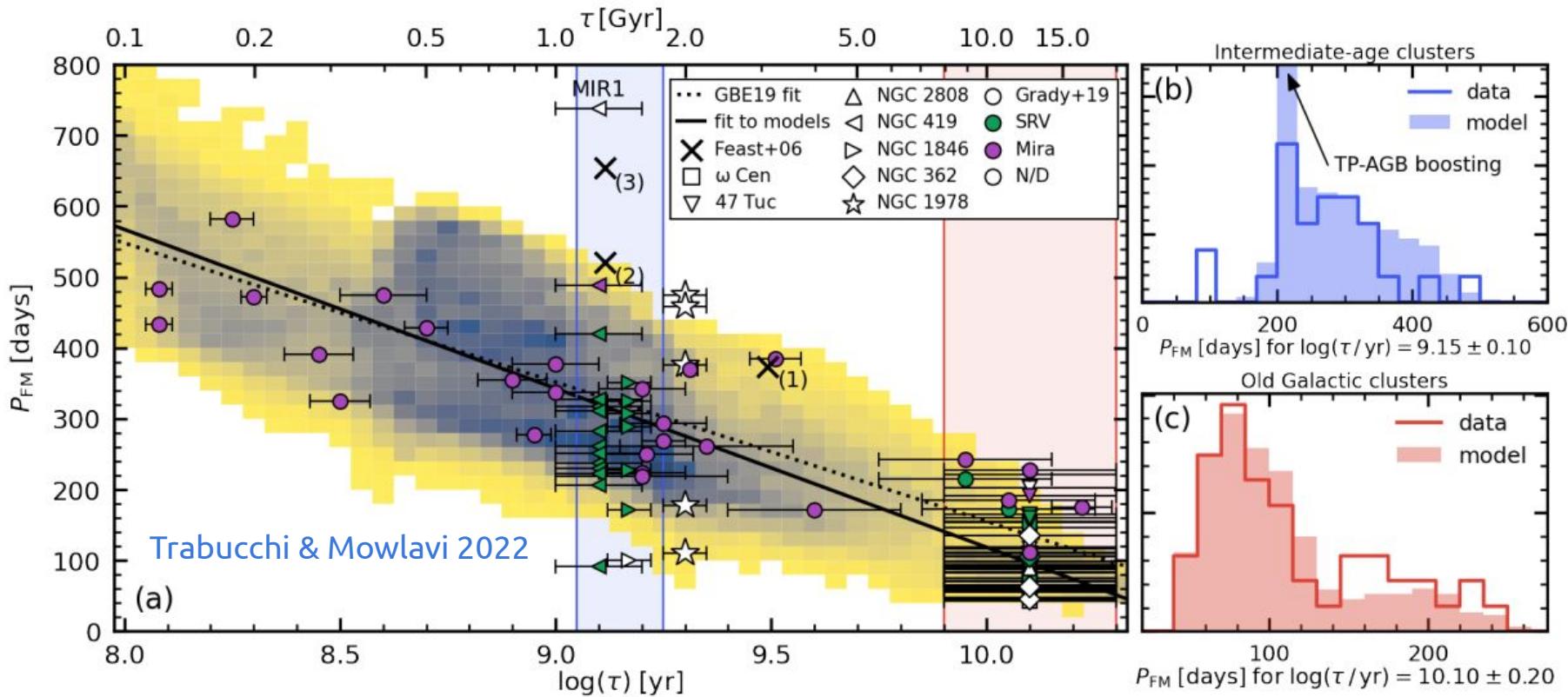
+

**non-linear pulsation models**

Compared with Miras/SRVs in clusters



# Period-age relation of LPVs



# Period-age relation of LPVs

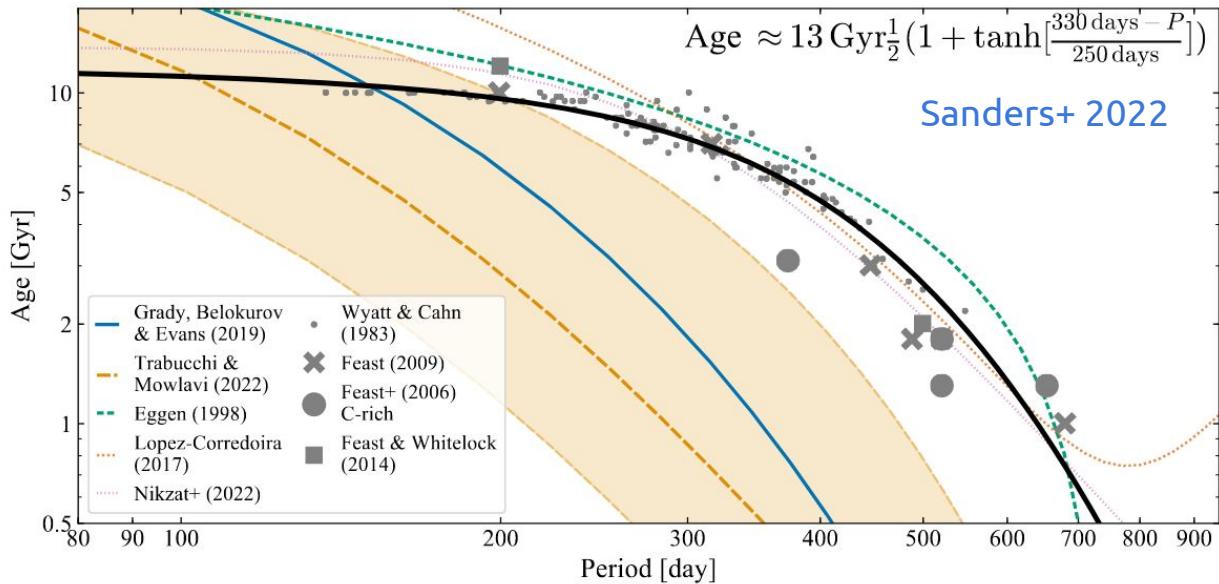
Several unknowns:

Sensitivity of period-age distribution on metal content

Selection effects:  
inclusion/exclusion of SRVs and completeness of Mira sample

Sensitivity of photometric amplitude on metal content and impact on source selection

Sensitivity of pulsation instability on metal content

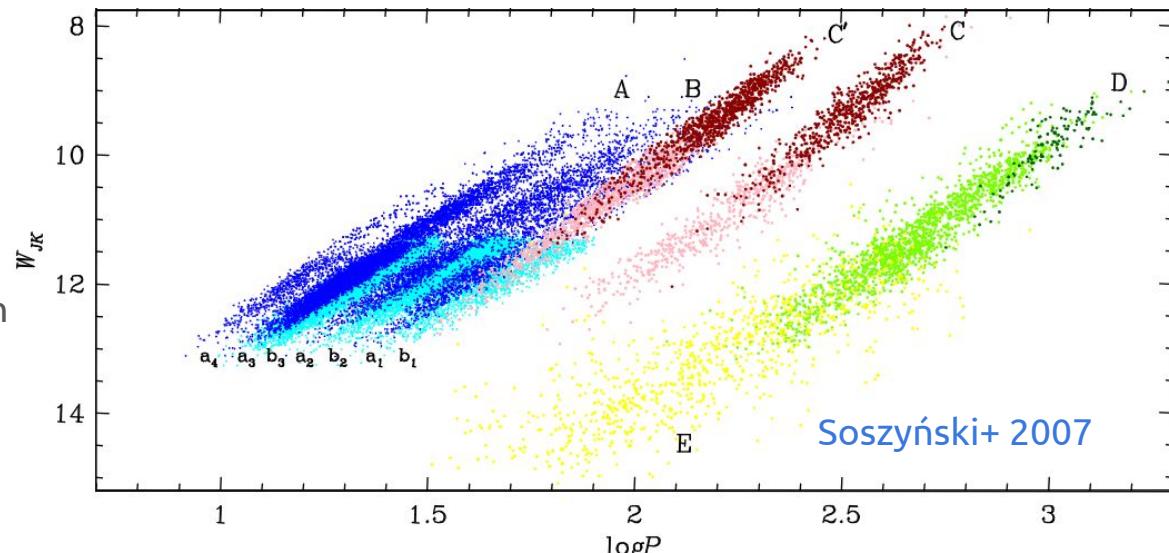


# 3. SRVs as *distance* indicators

# SRVs as distance indicators

Motivation:

- Same PLR of Miras, plus another one
- Longer-lived than Miras:
  - SRVs more numerous in any given stellar population ( $\times 10$  in the MCs)
  - Probe older populations (and much brighter than RR Lyr)
- Less dusty than Miras
- Smaller amplitude = less scatter
- Similar to or brighter than Cepheids
- Often more numerous than Cepheids
- Multiperiodicity is annoying but is also physically informative

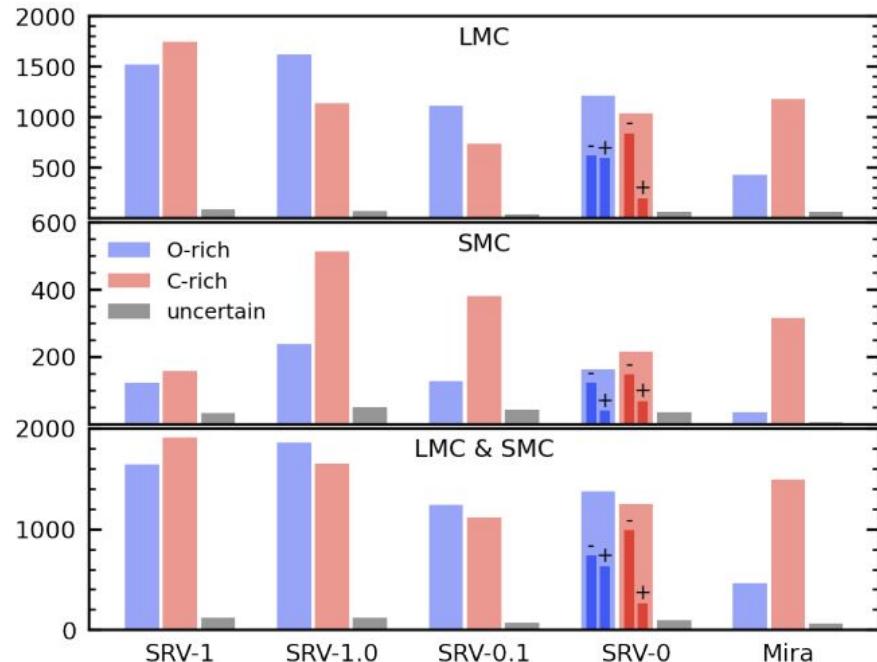


# SRVs as distance indicators

Trabucchi+ 2021

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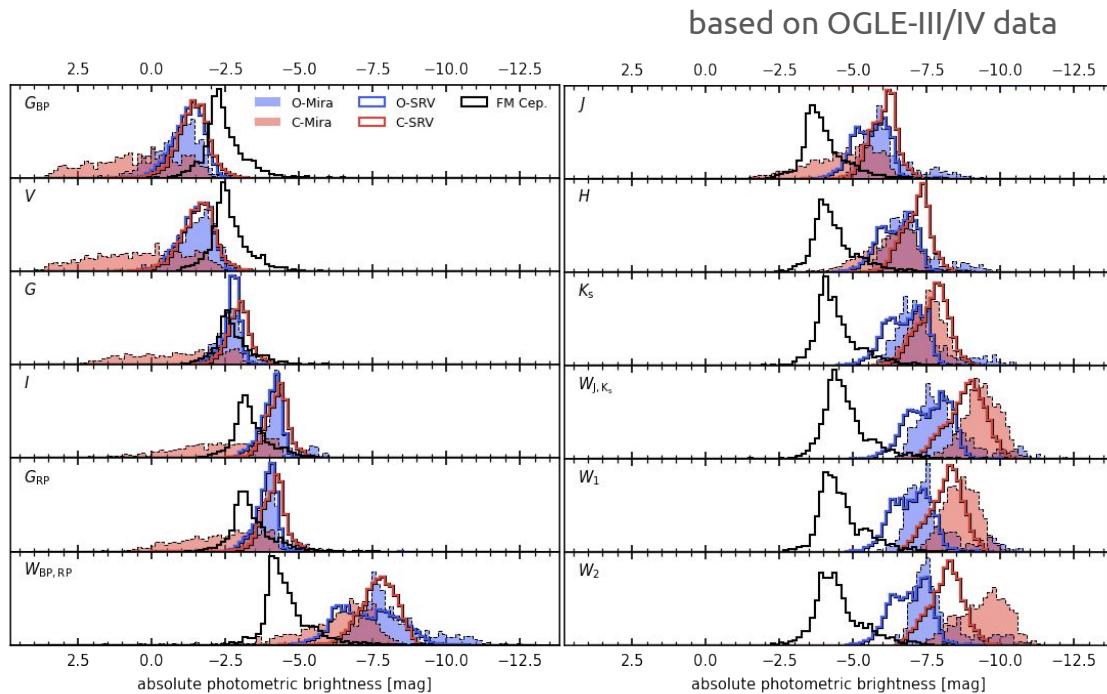
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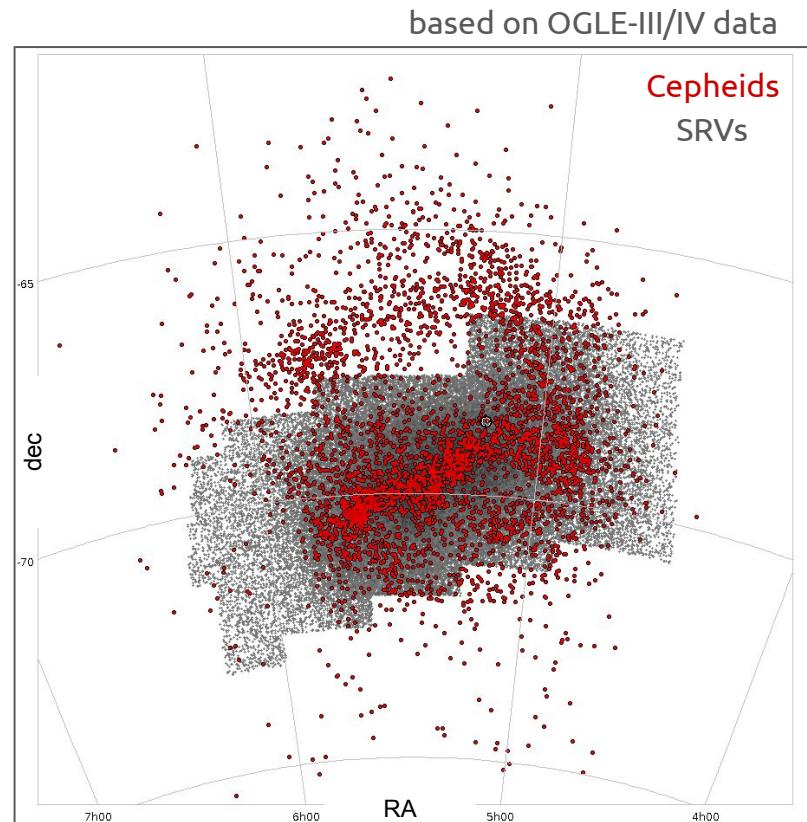
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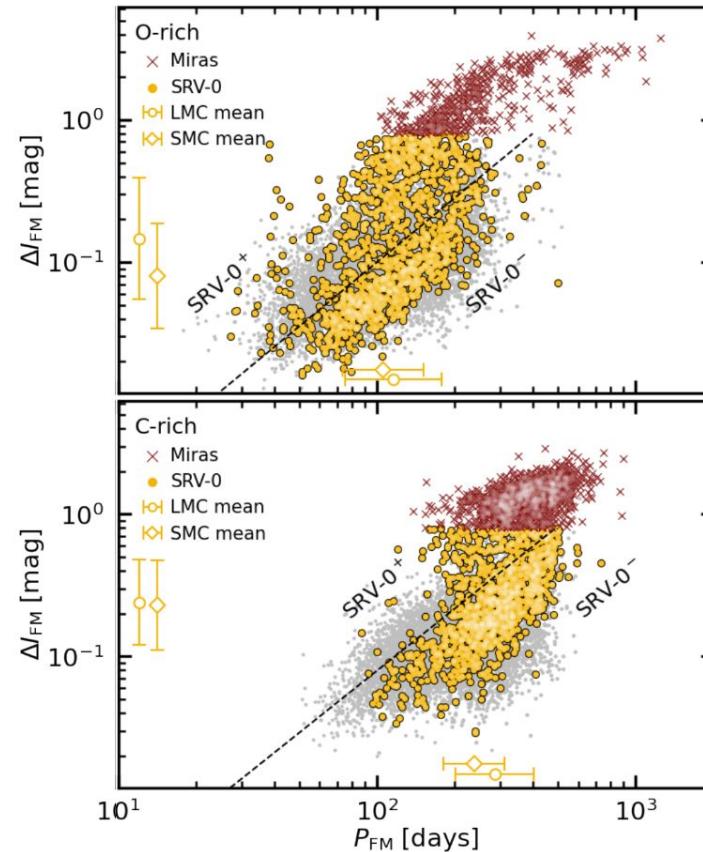
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# SRVs as distance indicators

Characterization:

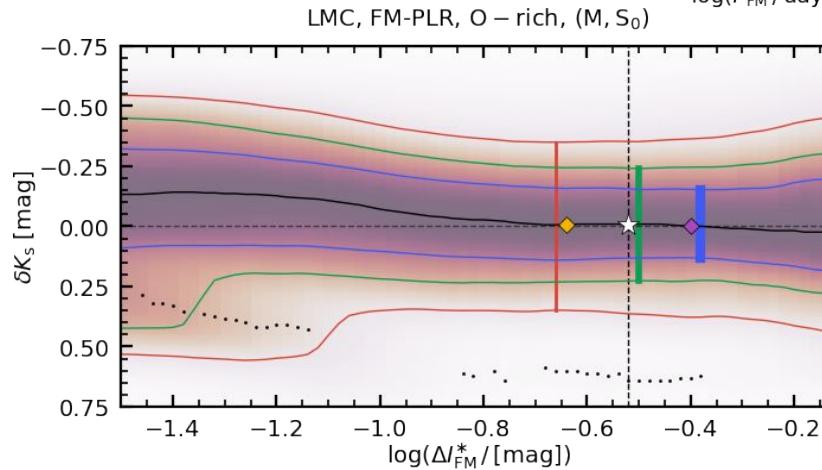
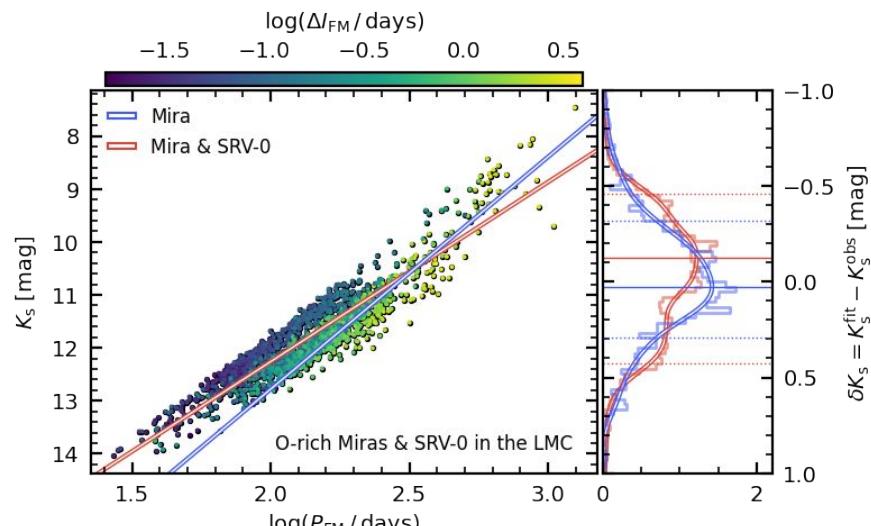
- 4 subtypes of SRVs: mono-/bi-periodic, dominated by FM-/1OM-pulsation
- mono-FM SRVs are very similar to Miras, except they have smaller amplitudes, calling for revised classification
- there is no reason for not using them as distance indicators (as numerous as Miras!)
- smaller-amplitude SRVs (bi-periodic and 1OM-dominated) are more challenging to deal with but much more numerous



# SRVs as distance indicators

Benefit assessment:

- Blindly combining SRVs and Miras does not improve distance determination
- PLR scatter increased and residual distribution more asymmetric
- Amplitude threshold tuned to find best tradeoff for optimizing:
  - accuracy
  - precision
  - large number of sources

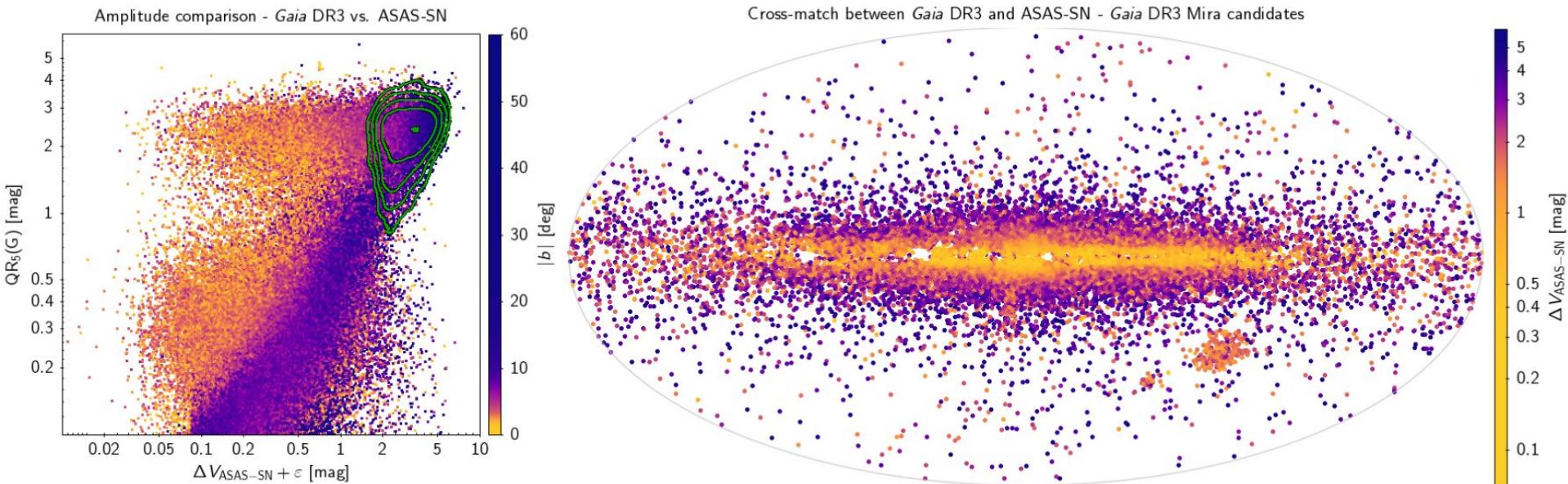


Trabucchi+ in prep.

# SRVs as distance indicators

Adopting an amplitude-based separation between SRVs and Miras exposes us to biases

Lebzelter+ 2022

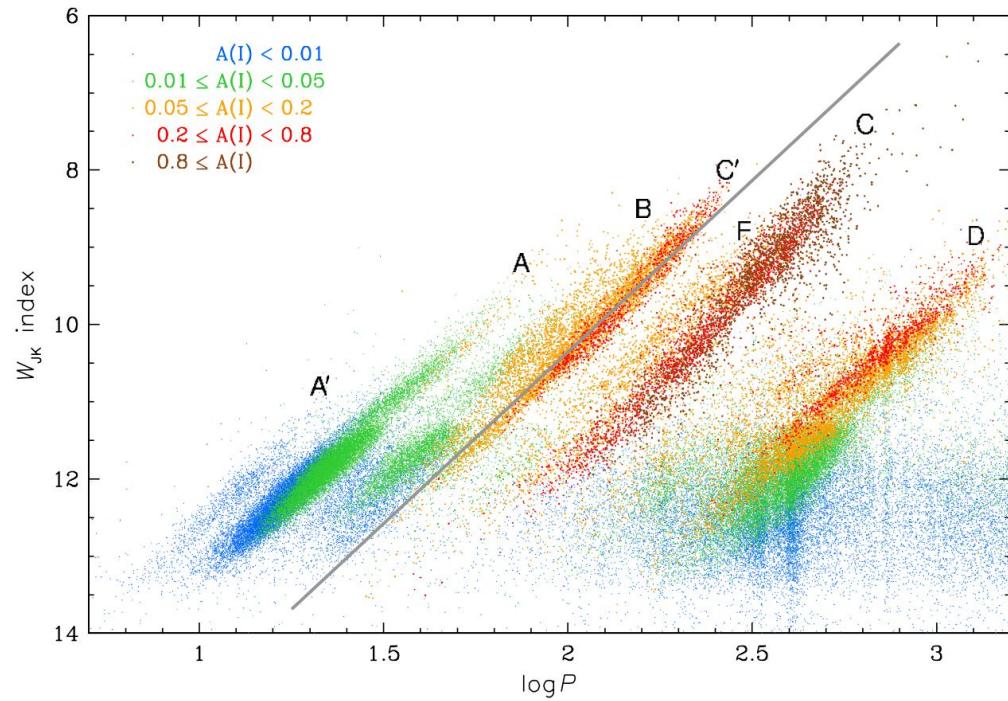


# SRVs as distance indicators

Improvement:

- Amplitude is an valuable second parameter
- LPVs in different amplitude ranges follow distinct PLRs

Soszyński+ 2013

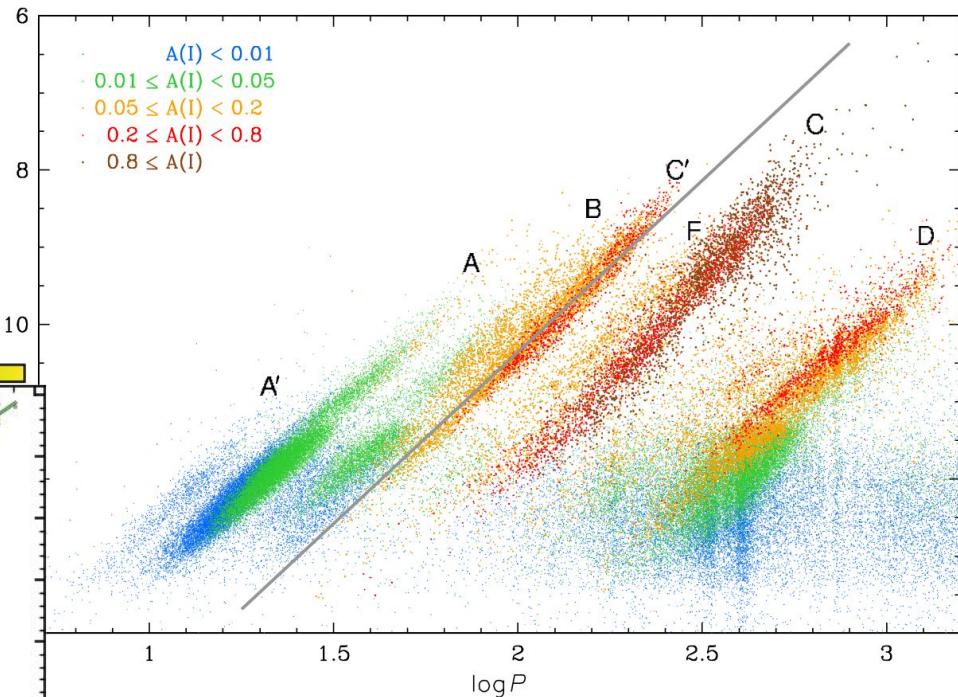
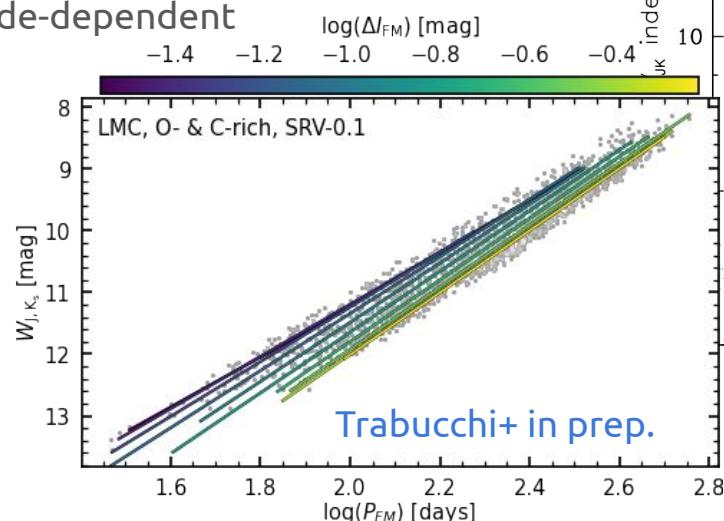


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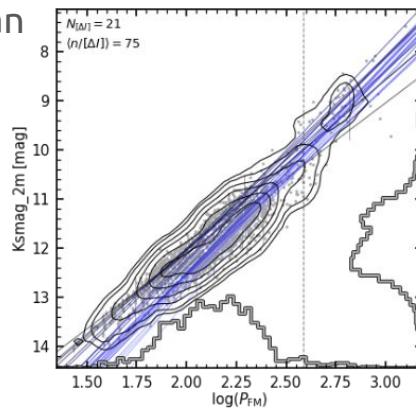
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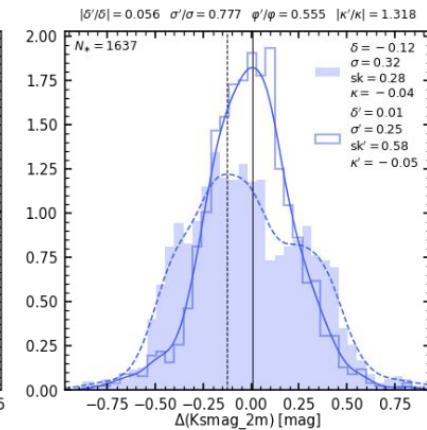
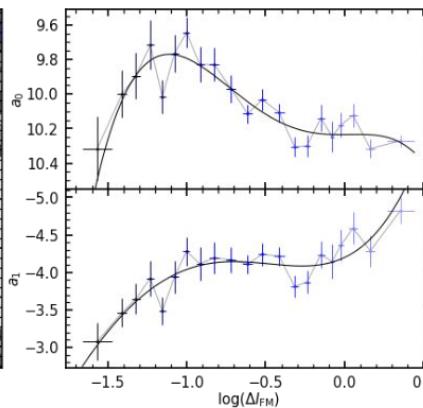
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- The period-amplitude-luminosity relation has effectively less scatter than the traditional PLR
- More accurate and precise



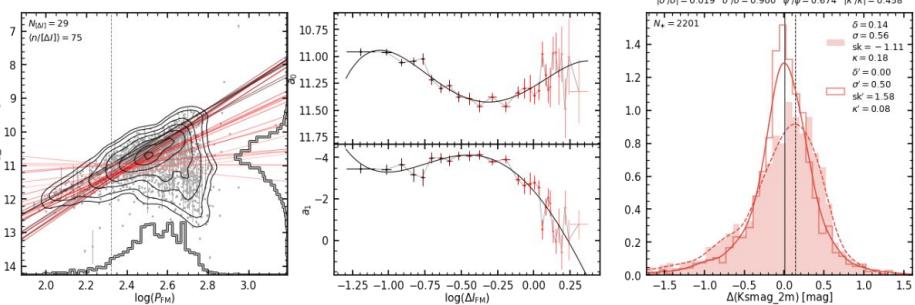
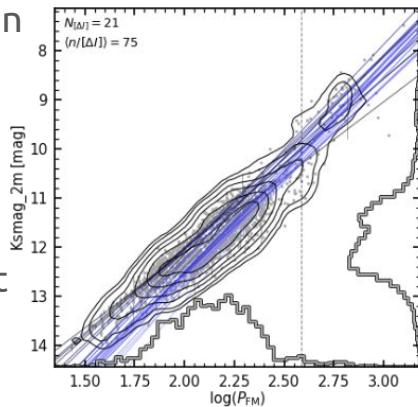
Trabucchi+ in prep.



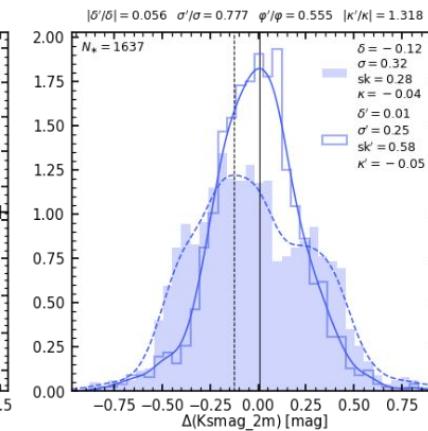
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- Works also for C-rich stars or combined O-/C-rich
- Possibly accounts for different metallicity effects



Trabucchi+ in prep.



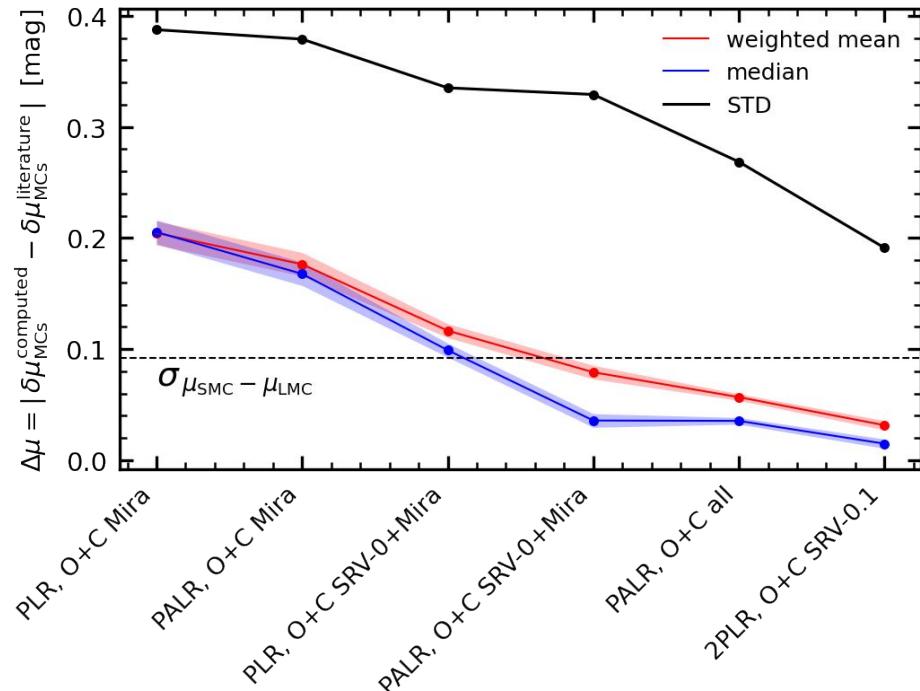
# SRVs as distance indicators

Improvement:

- Amplitude is an valuable second parameter
- LPVs in different amplitude ranges follow distinct PLRs
- The PLR coefficients (slope, zero-point) are amplitude-dependent
- The period-amplitude-luminosity relation has effectively less scatter than the traditional PLR
- More accurate and precise
- Works also for C-rich stars or combined O-/C-rich
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Trabucchi+ in prep.

preliminary results



# Take-home messages

- For FM period use only prescriptions based on nonlinear models
- The PL diagram of LPVs is more complex than you think!
- The PL relations depend on many selections (variability detection threshold, primary period classification, ...)
- SRVs are not as *wonderful* as Miras, but they can be useful! Let's not disregard them...
- ... but in any case be careful with the SRV-Mira transition!
- Do we even need such a distinction? Is the amplitude threshold a good criterion? Can we optimize it?
- Do not think only in terms of period, always consider also the amplitude! It's implicitly used for selection, and carries useful physical information!

