Long-Period Variables as Distance & Age Indicators

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FNSNF

Gaia DPAC
Data Processing & Analysis Consortium
CU7: Variability

Outline

1. LPVs as distance indicators: the potential of SRVs
2. LPVs as age indicators: the period-age relation of Miras
3. Pulsation models of LPVs: recent results
4. LPVs & *Gaia*: the *Gaia* DR3 Catalog of LPV Candidates

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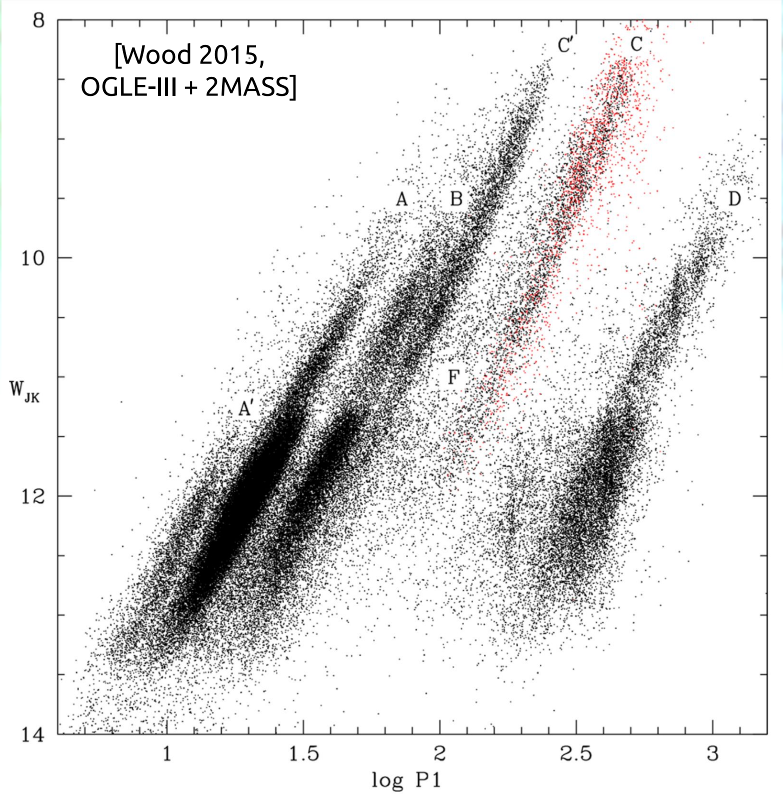
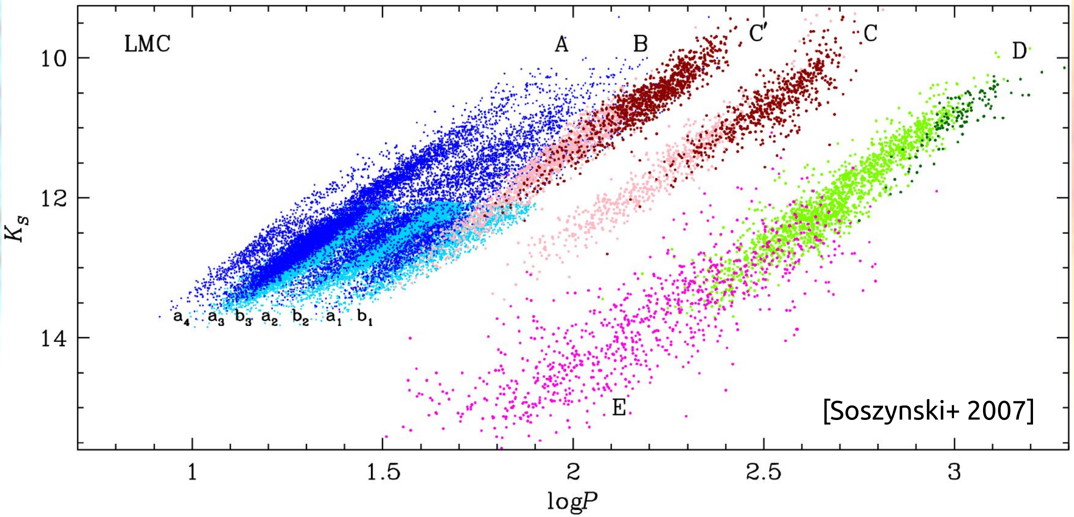
CU7: Variability

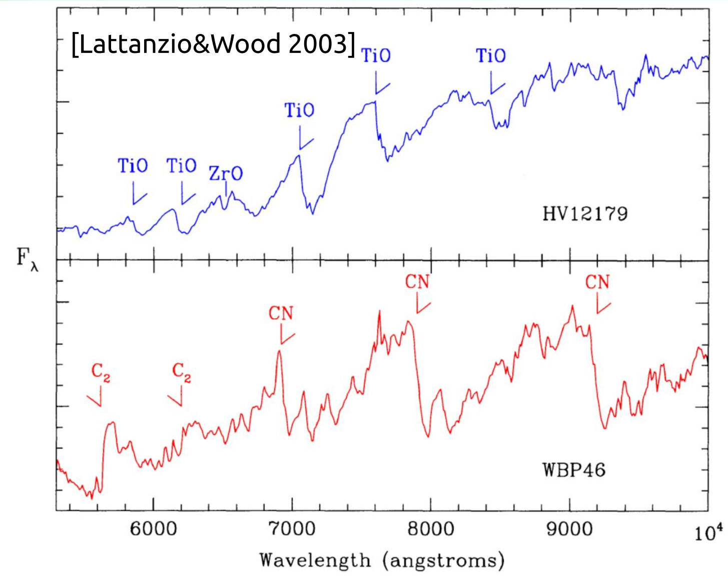
LPVs as Distance Indicators

OGLE-III Catalogs of LPVs in the Magellanic Clouds

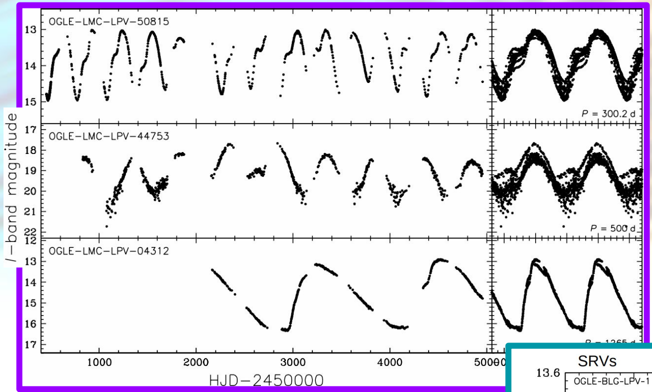




Chemical type: O-rich / C-rich



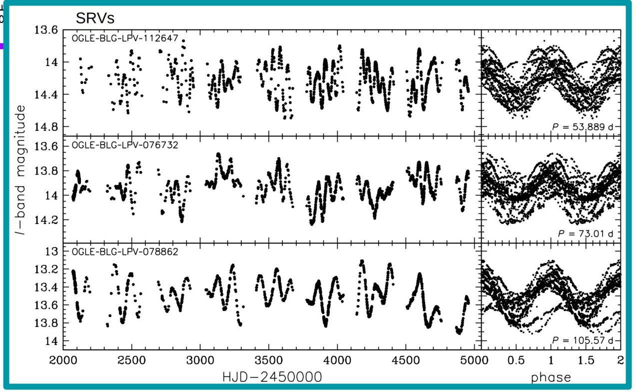
[Soszynski+ 2009]



Variability sub-type

Miras: $\Delta V > 2.5^{mag}$

SRV(*): $\Delta V < 2.5^{mag}$



[Soszynski+ 2013]

Period-luminosity relation of O-rich Miras

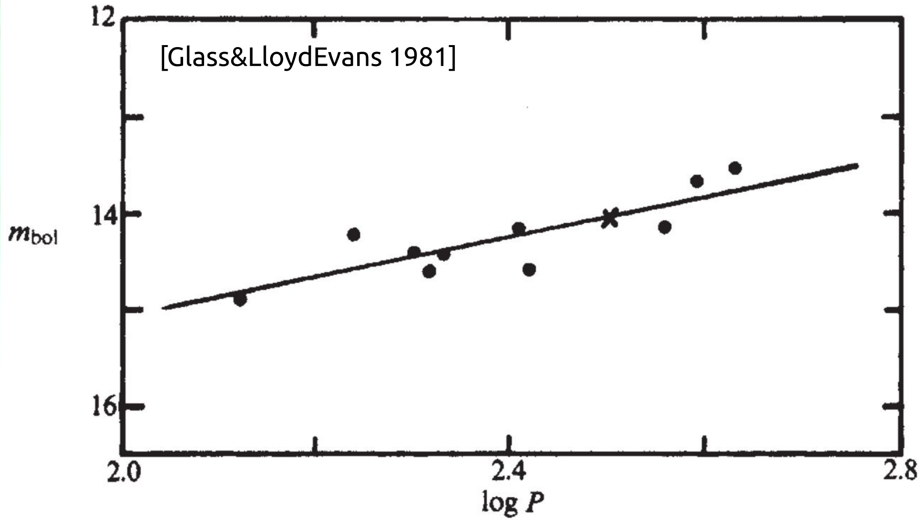
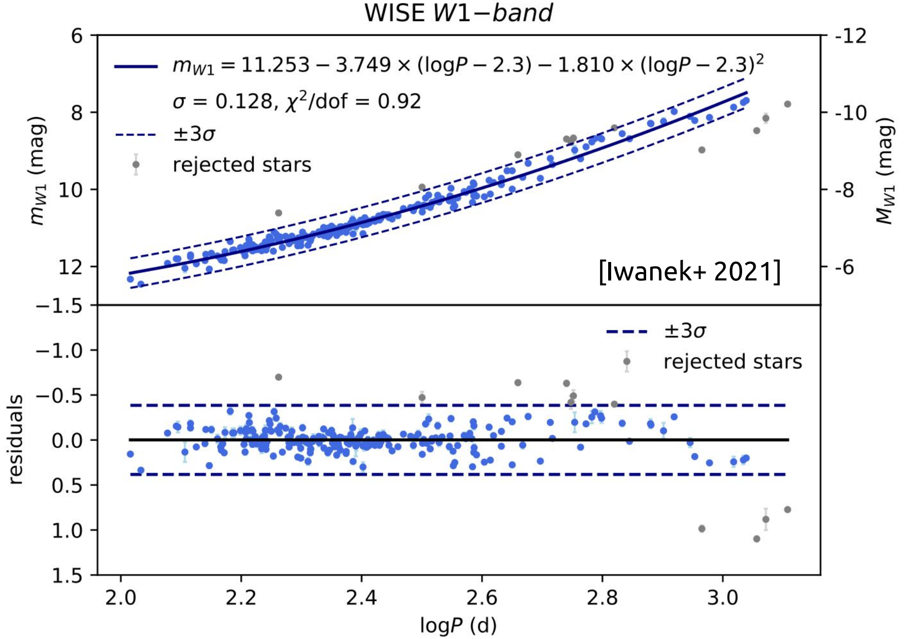


Fig. 1 m_{bol} for LMC Miras plotted against log P (days). ×, The carbon star. The best fitting linear regression line is shown.

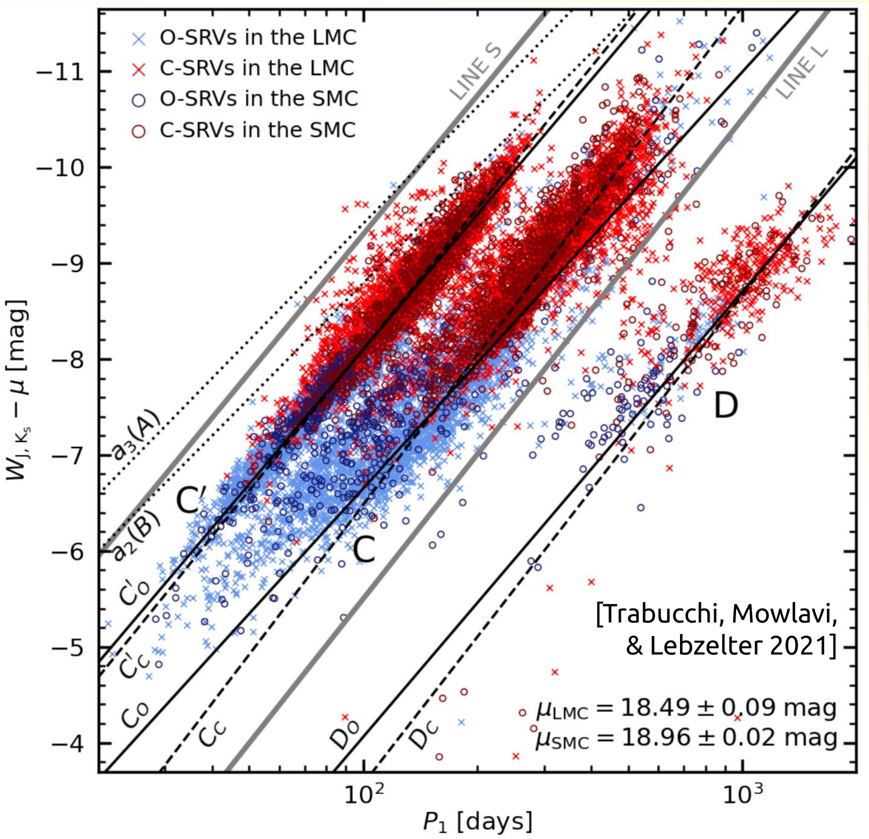


In the MCs, Miras are **<2%** of the LPVs!

O-rich Miras are **<0.5%** in the LPVs in LMC, **<0.2%** in the SMC

Semi-regular variables
(by the OGLE classification)

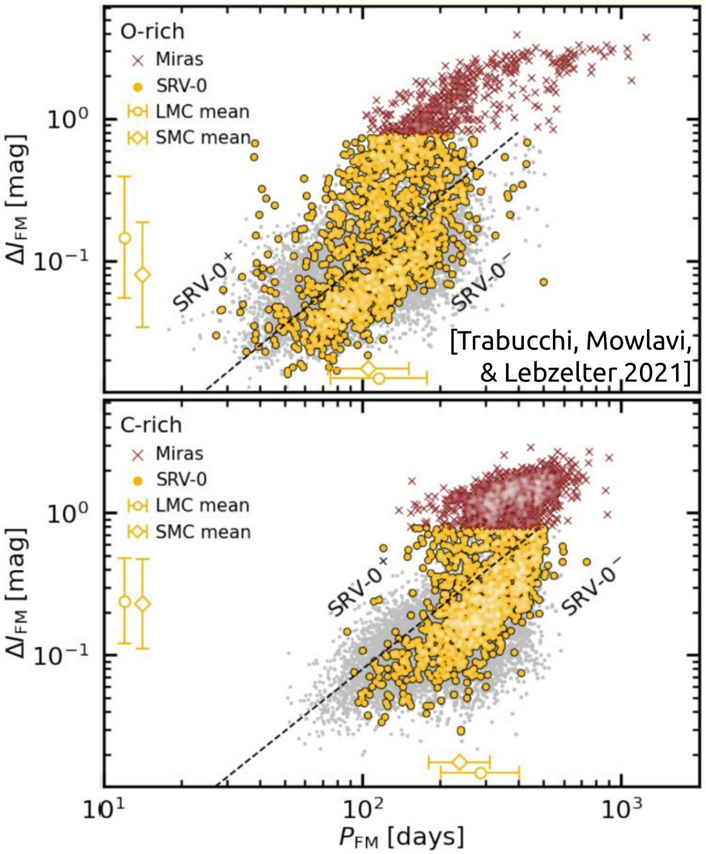
- As bright as some Miras
- Same PLR as Miras, + a 2^{nd} one
- Brighter than Cepheids in the IR
- Probe older populations



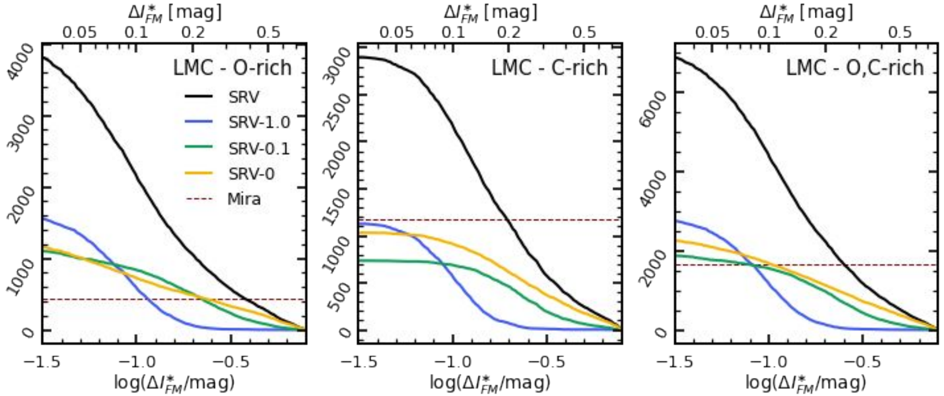
[Trabucchi, Mowlavi, & Lebzelter, in prep.]

Semi-regular variables
(by the OGLE classification)

- As bright as some Miras
- Same PLR as Miras, + a 2nd one
- Brighter than Cepheids in the IR
- Probe older populations
- Much more numerous than Miras
- Often more numerous than Cepheids

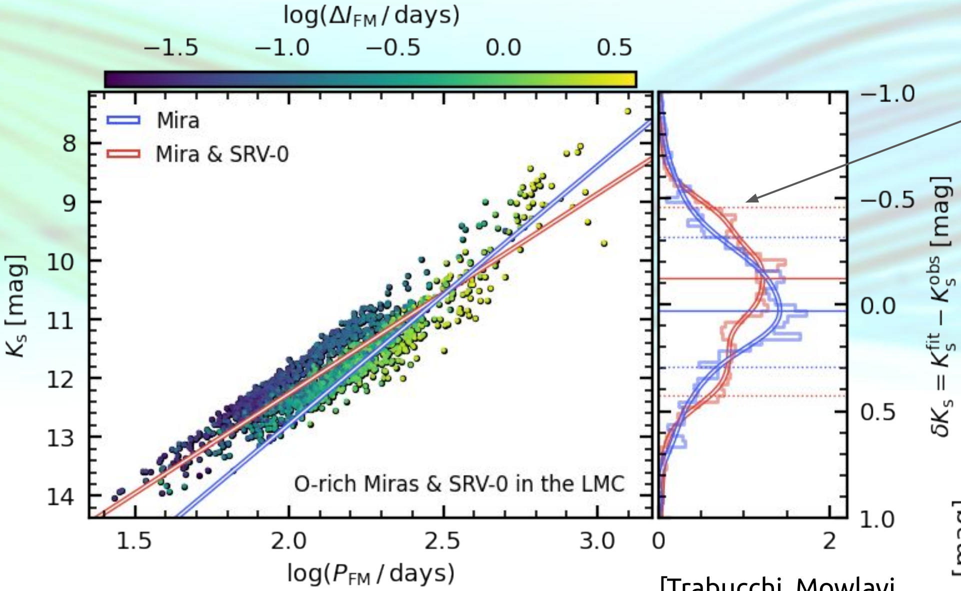


[Trabucchi, Mowlavi, & Lebzelter 2021]



[Trabucchi, Mowlavi, & Lebzelter, in prep.]

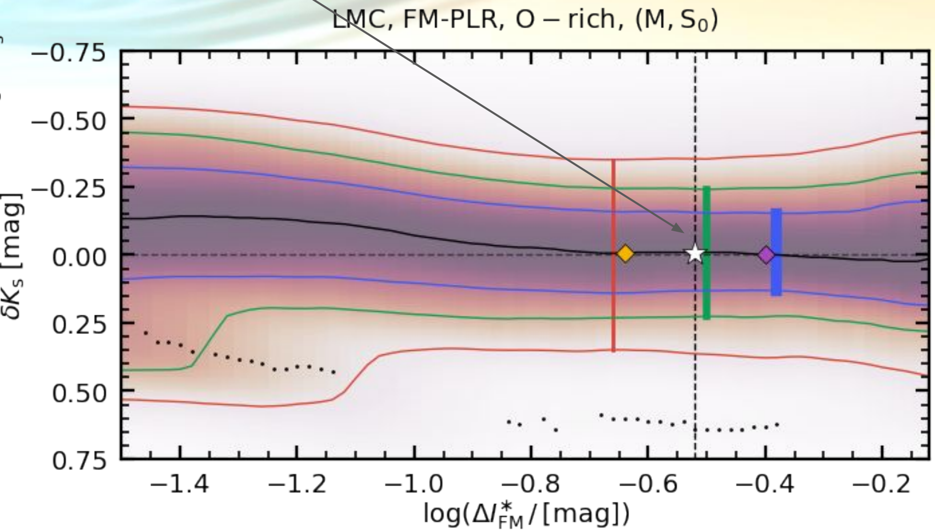
PL relations obtained from different "calibration sets" (Miras/SRVs, O-/C-rich, ...)



[Trabucchi, Mowlavi, & Lebzelter, in prep.]

Comparison of PLRs performances by distribution of residuals

"sweet spot": narrowest, best-centered distribution of residuals **includes SRVs**



Miras + SRVs = extra constraints on astrophysical distances from PL relation

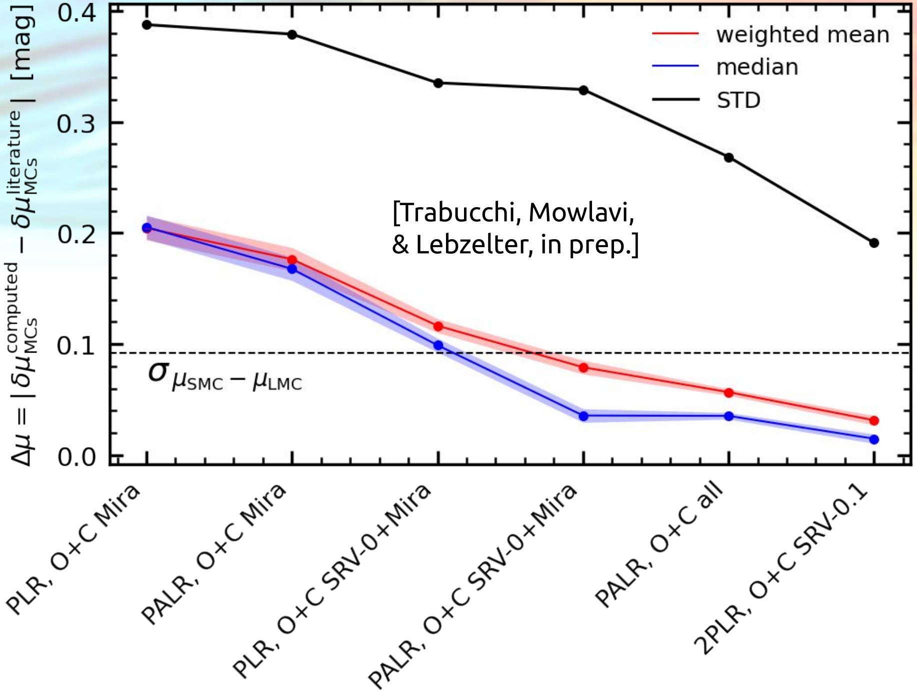
Further information from other variability parameters:

1. photometric amplitude
2. secondary period (in bi-periodic SRVs)

Overall benefits:

1. x2 (or more) distance-tracing sources
2. +25-50% precision, accuracy
3. combined O-/C-rich LPVs PLRs
4. can account for metallicity effects

preliminary results



LPVs as Age Indicators

LPVs as Age Indicators

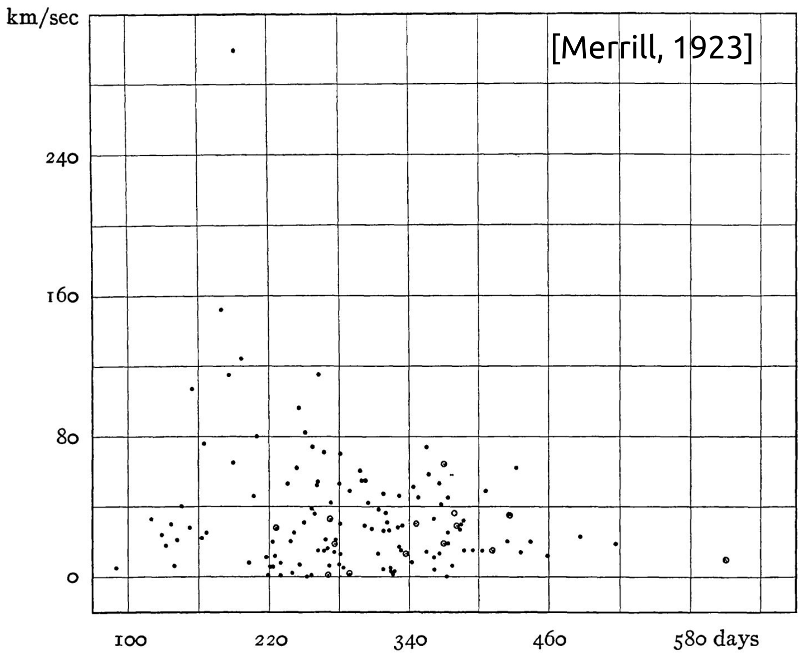


FIG. 5.—Residual radial velocity and period. Class Se stars are indicated by circles.

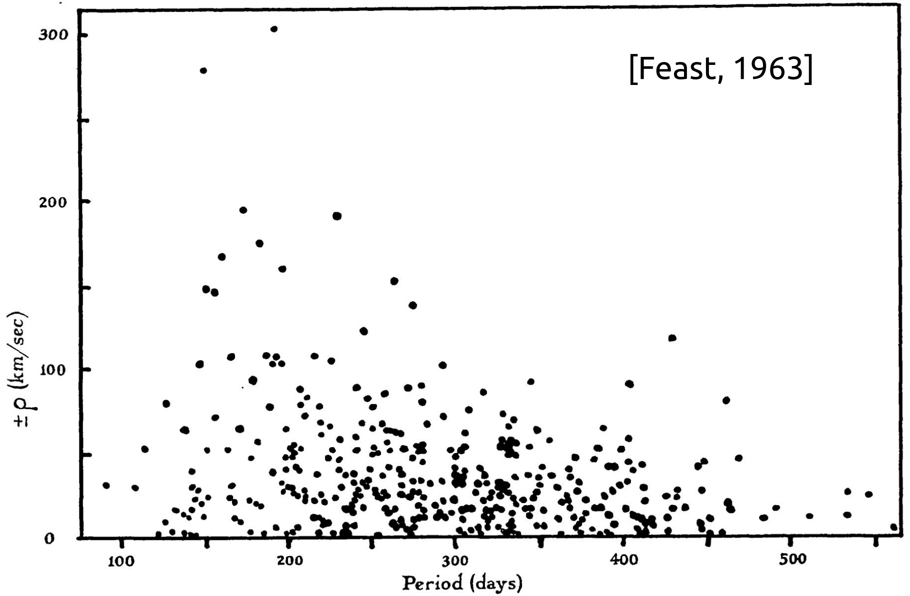


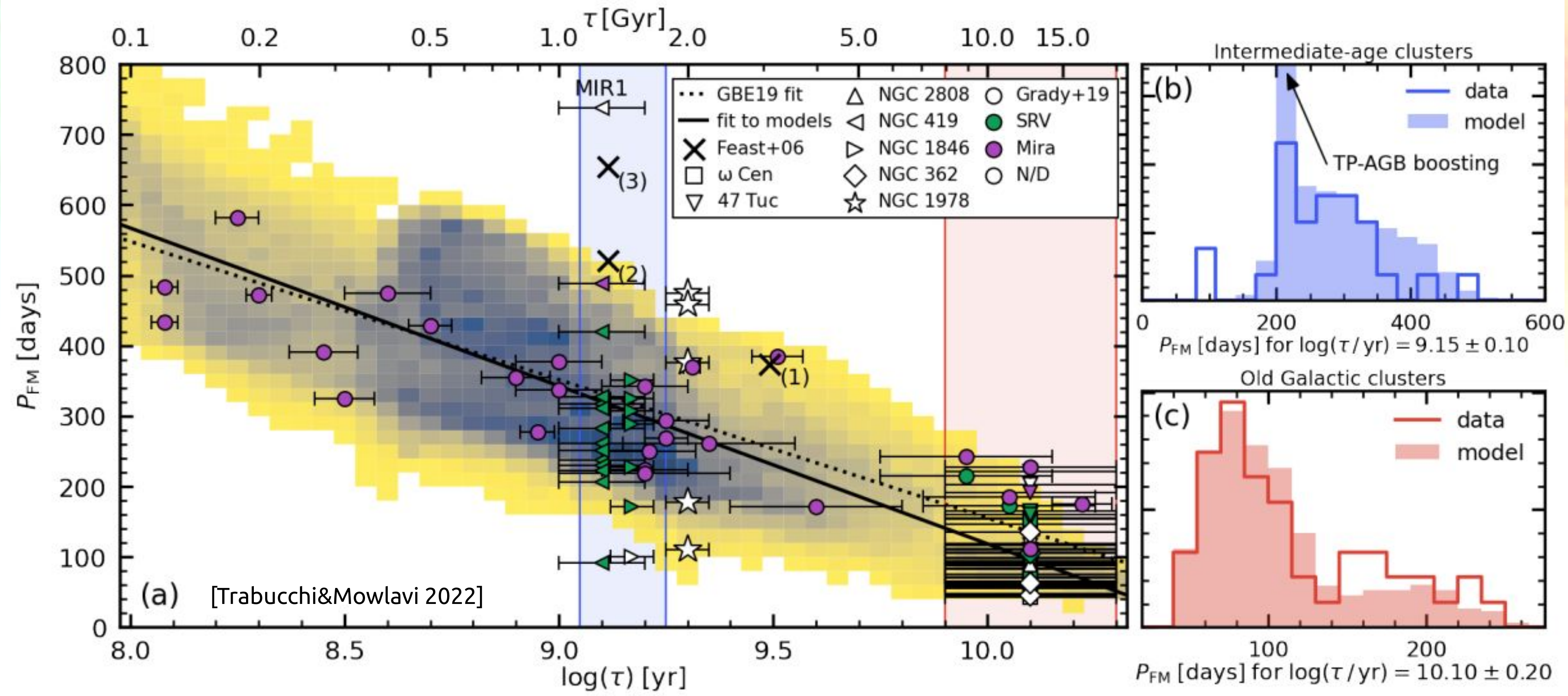
FIG. 4.—*Relation of residual velocity (ρ) to period for Me variables.*

Period-age relation of LPVs

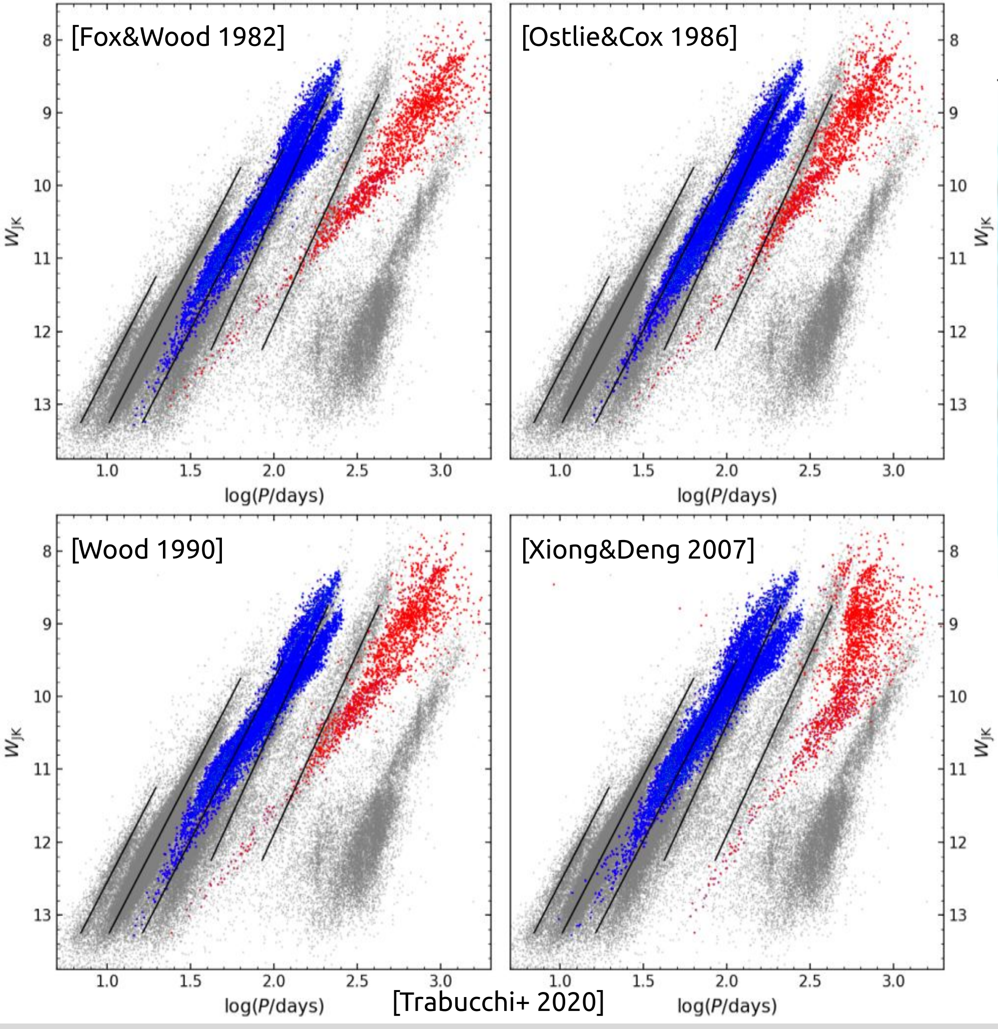
- Shorter-period LPVs have kinematics of older populations
- Massive (young) LPVs are brighter = longer period

Simulated period-age relation:

- FM period prescription from hydrodynamic pulsation models (Trabucchi+ 2021)
- Isochrones with detailed TP-AGB evolution (Marigo+ 2017, Pastorelli+ 2019,20)
- Comparison with observations of LPVs in star clusters (see Grady+ 2019)


τ [Gyr]
0.1
0.2
0.5
1.0
2.0
5.0
10.0
15.0
MIR1
GBE19 fit
fit to models
Feast+06
ω Cen
47 Tuc
NGC 2808
NGC 419
NGC 1846
NGC 362
NGC 1978
Grady+19
SRV
Mira
N/D
(3)
(2)
(1)
(a)
[Trabucchi&Mowlavi 2022]
P_FM [days]
log(τ) [yr]
Intermediate-age clusters
(b)
data
model
TP-AGB boosting
P_FM [days] for log(τ / yr) = 9.15 ± 0.10
Old Galactic clusters
(c)
data
model
P_FM [days] for log(τ / yr) = 10.10 ± 0.20

LPV Pulsation Models



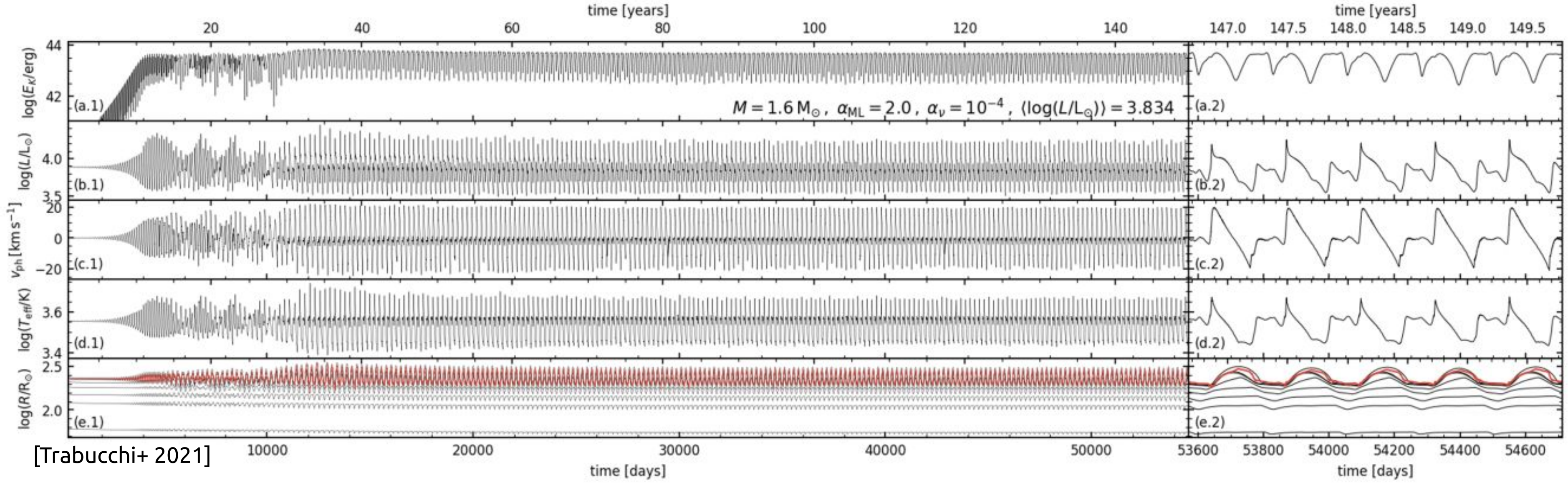
[Trabucchi+ 2020]

LPV Pulsation Models: Present

Linear pulsation models are *unable* to accurately predict the pulsation period of LPVs pulsating in the Fundamental Mode.

Non-linear hydrodynamic models predict:

1. structural readjustment to large-amplitude pulsation
2. higher mean density = shorter period
3. full agreement with observed PL relations



[Trabucchi+ 2021]

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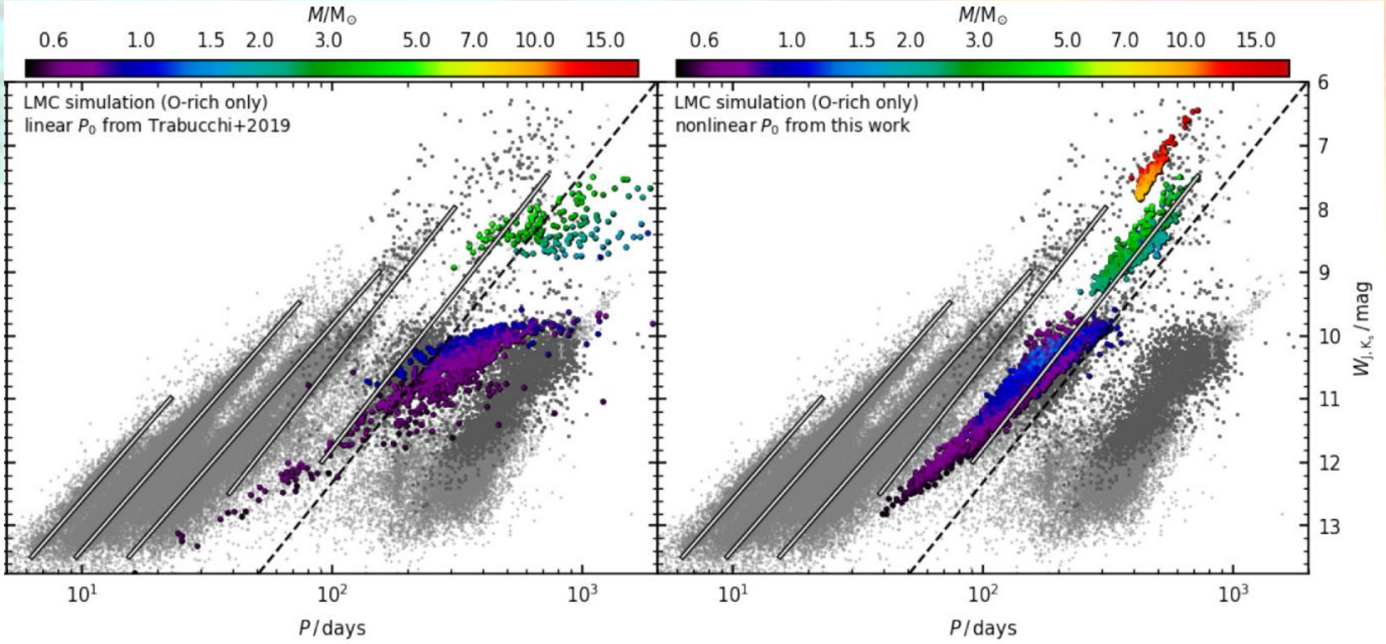


[Trabucchi+ 2021]

Updates / upgrades

1. Extension of models grid: metallicity, C/O, He content, …
2. Calibration of turbulent viscosity from OGLE, *Gaia* observations
3. Surface displacement / radial velocity curve templates from models

Output / deliverables

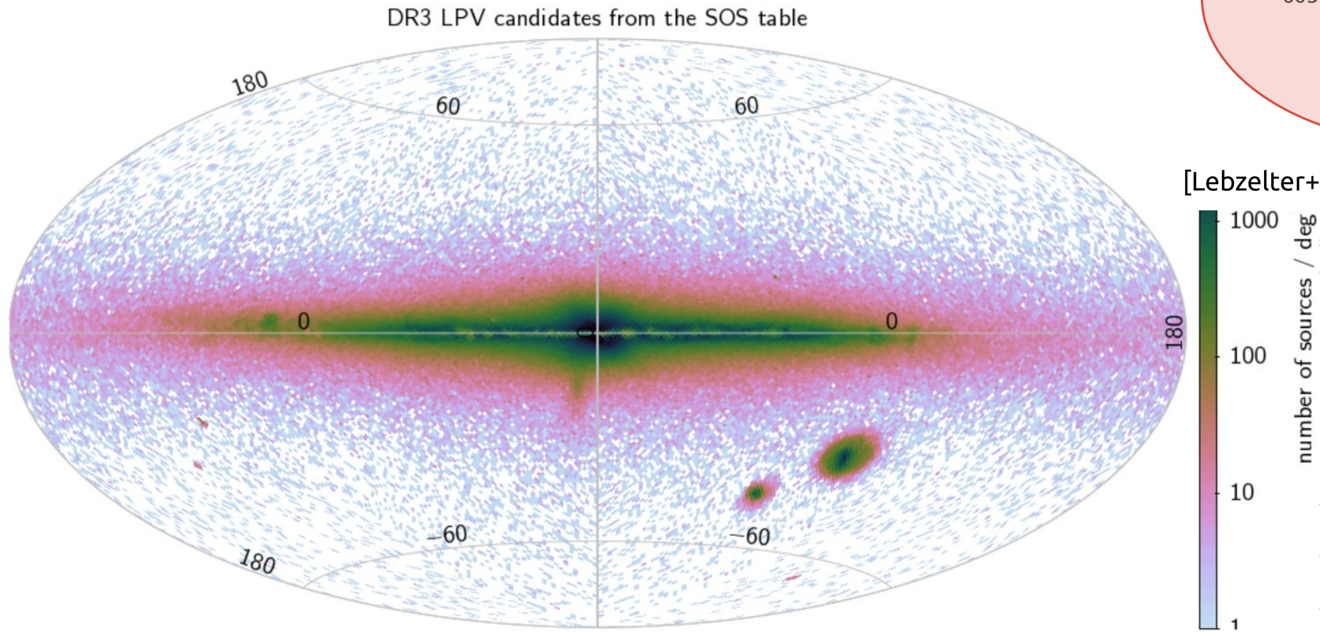
1. Light curve templates (*Gaia*, LSST, JWST, ...), at least for low-amplitude LPVs
2. Synthetic PL relations = effects of metallicity, star-formation history, …
3. Improved theoretical period-age & period-initial mass relation
4. Binary evolution in TRILEGAL = Long Secondary Periods

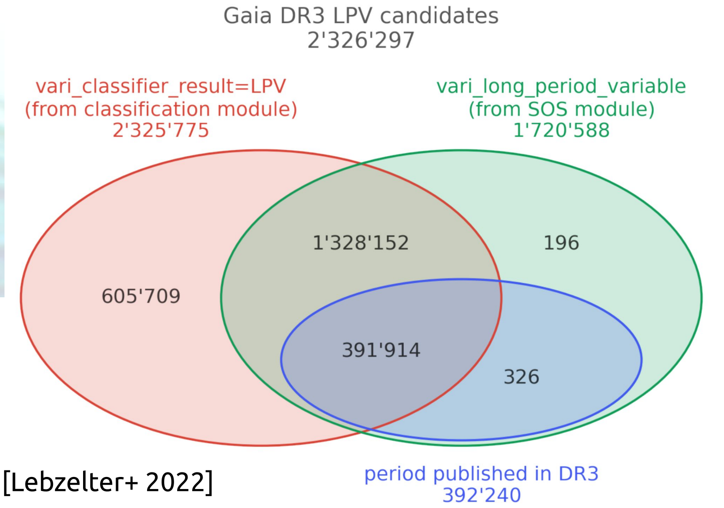
LPVs & *Gaia*

Gaia Data Release 3: The second *Gaia* catalogue of long-period variable candidates

T. Lebzelter[1]★, N. Mowlavi[2,3]★★, I. Lecoeur-Taibi[3], M. Trabucchi[4,2]★★★, M. Audard[2,3], P. García-Lario[6], P. Gavras[7], B. Holl[2,3], G. Jevardat de Fombelle[3], K. Nienartowicz[5], L. Rimoldini[3], and L. Eyer[2,3]

- Full sky, sources with amplitude $\Delta G > 0.1^{mag}$
- 2.3M LPVs with published phot. time series
- 1.7M with highly reliable classification
- 400K with period, amplitude, chemical type

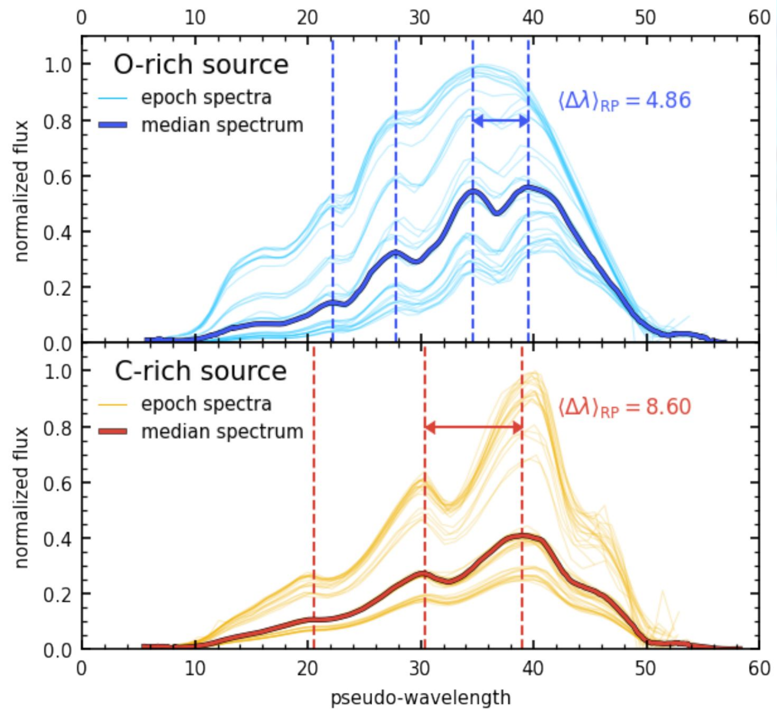


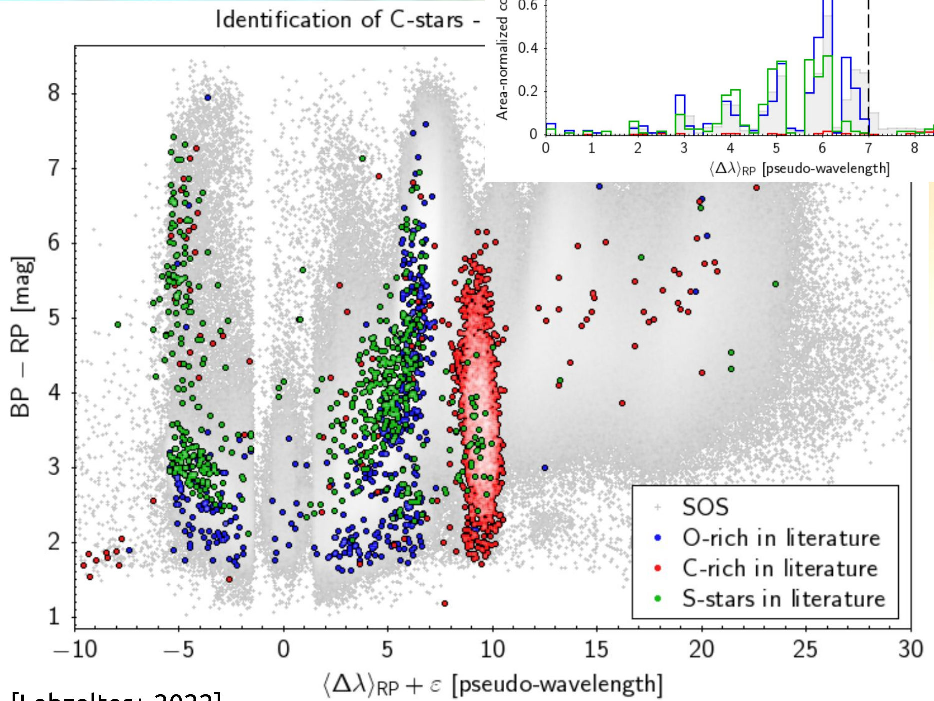


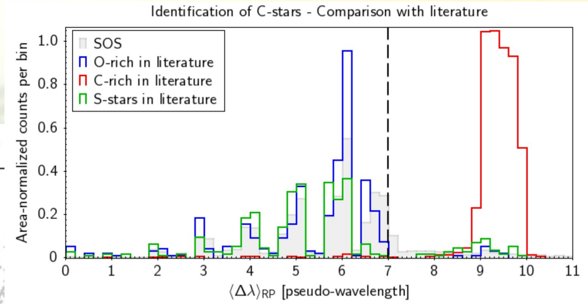
[Lebzelter+ 2022]

Selector	number of objects
LPV candidates in *Gaia* DR3	2 326 297
in classification table	2 325 775
in SOS table (2nd *Gaia* LPV catalogue)	1 720 588
including	
LPVs with $0 < \sigma_\pi/\pi < 0.15$	91 912
LPVs with periods	392 240
LPVs with QR5 > 0.2 mag	1 219 270
LPVs with QR5 > 1.0 mag	157 029
LPVs classified as C-stars	546 468
Sources in the 1st *Gaia* LPV catalogue	151 761
with periods	89 617
Sources in both *Gaia* LPV catalogues	145 635
with periods in both	73 362

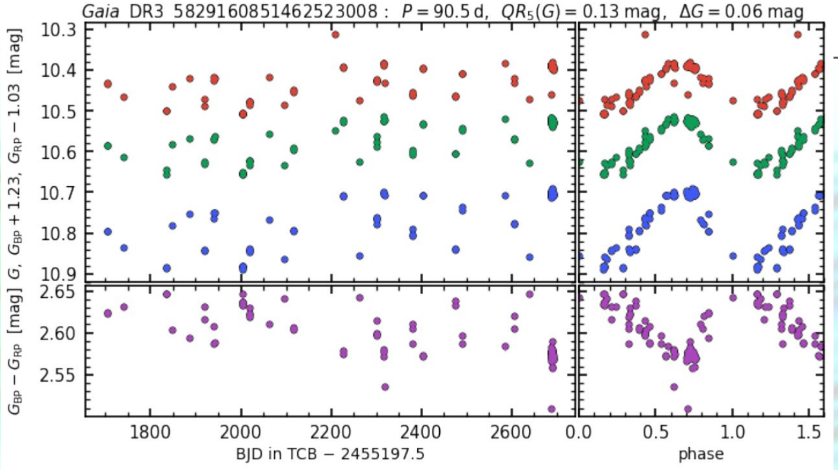
Distance between 2 highest peaks in low-res. G_{RP} spectrum traces chemistry of molecular bands = O-/C-rich







[Lebzelter+ 2022]



Photometric time series in G, G_{BP}, G_{RP}

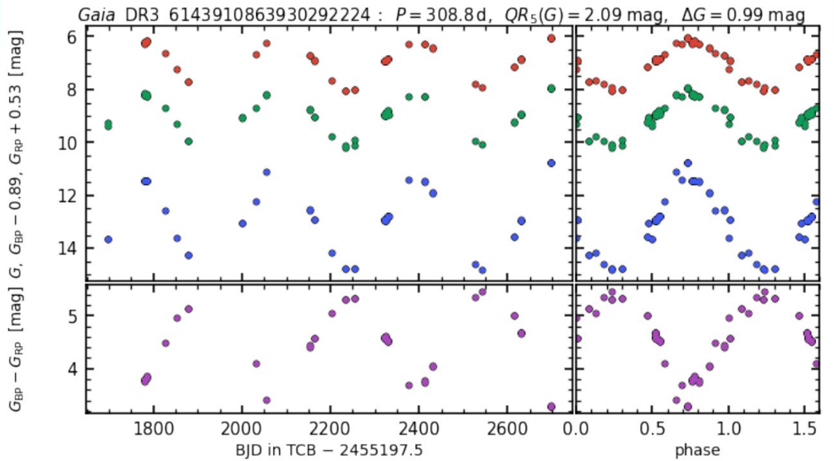
34 months obs. = periods 35-1000 days

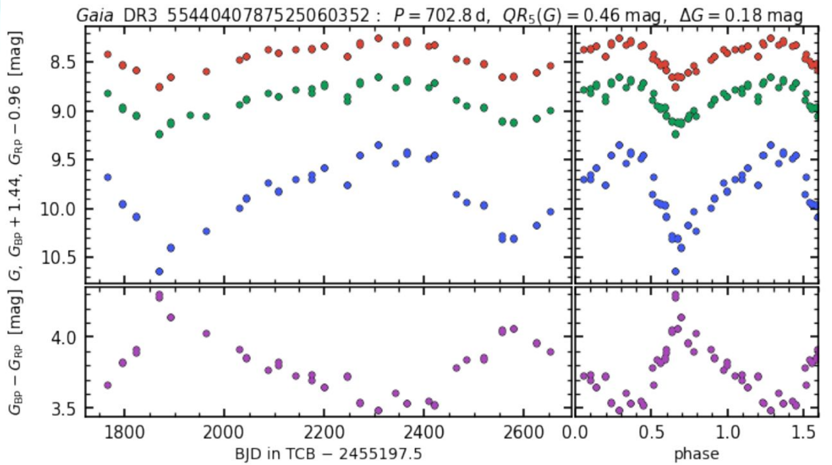
Recovery rate: >80%

Contamination rate: <2%

New discoveries: up to 6 times

>95% Mira periods = known values within 10%





Period-luminosity relations in the Magellanic Clouds and other LG galaxies