Advancements in the modelling and interpretation of Long-Period Variables

Michele Trabucchi
michele.trabucchi@unige.ch

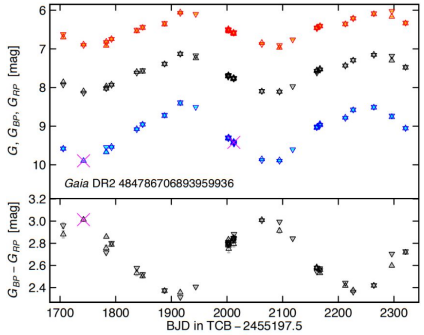
ASTRONOMICAL OBSERVATORY
UNIVERSITÉ DE GENÈVE

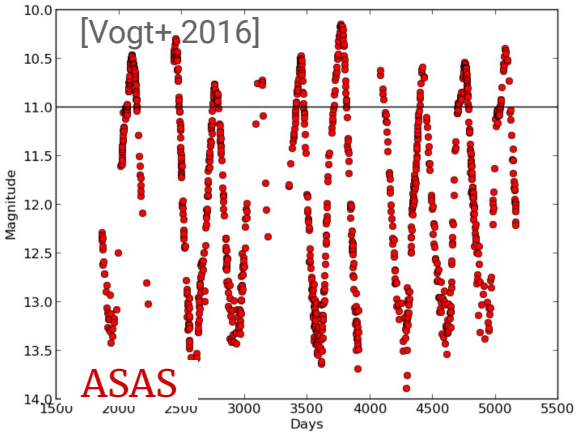
FNSNF Project 188697
Long-period variables as distance and age estimators in the *Gaia* era

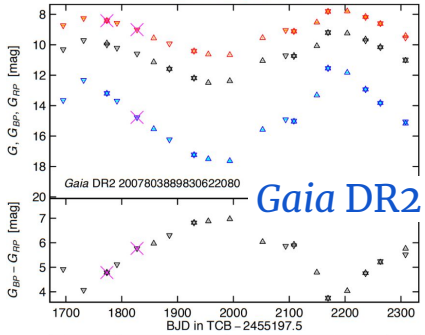
STERKE erc

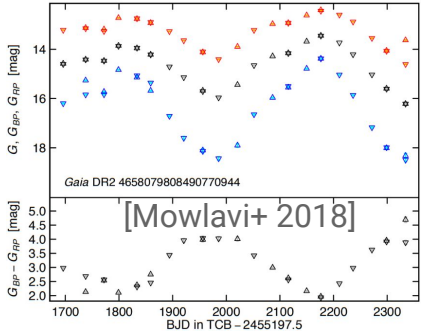
Dipartimento di Fisica e Astronomia Galileo Galilei
OSSERVATORIO ASTRONOMICO DI PADOVA
UNIVERSITÀ DEGLI STUDI DI PADOVA

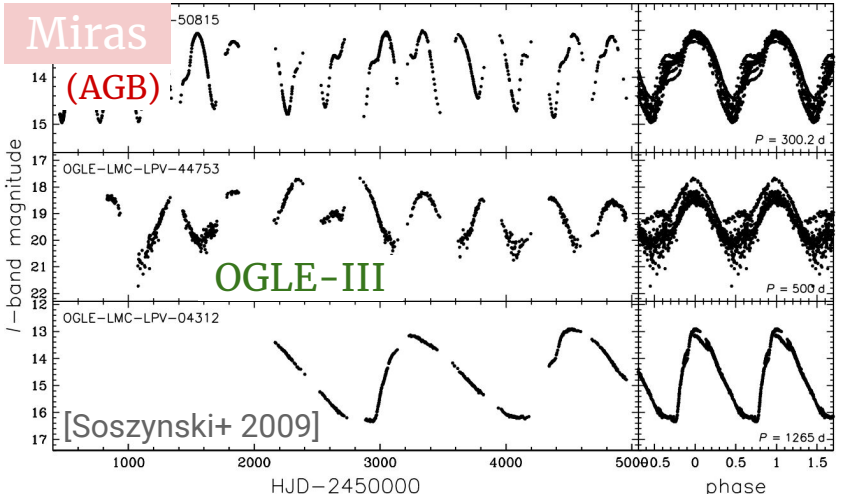
Long-Period Variables

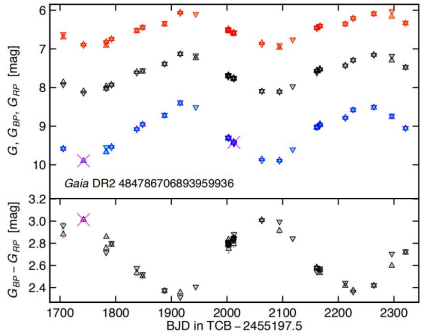

Gaia DR2 4847867068939599936
BJD in TCB − 2455197.5

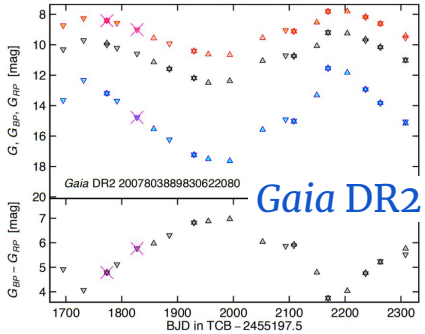

[Vogt+ 2016]
ASAS
Magnitude
Days


Gaia DR2 2007803889830622080
Gaia DR2
BJD in TCB − 2455197.5

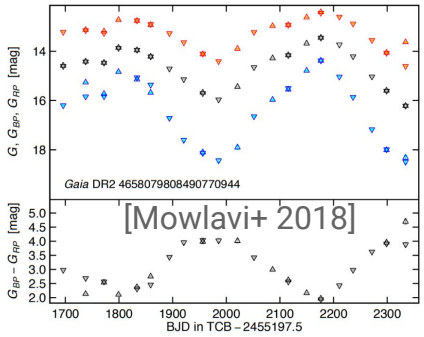

Gaia DR2 4658079808490770944
[Mowlavi+ 2018]
BJD in TCB − 2455197.5


Miras
(AGB)
-50815
P = 300.2 d
OGLE-LMC-LPV-44753
OGLE-III
P = 500 d
OGLE-LMC-LPV-04312
[Soszynski+ 2009]
P = 1265 d
I-band magnitude
HJD−2450000
phase

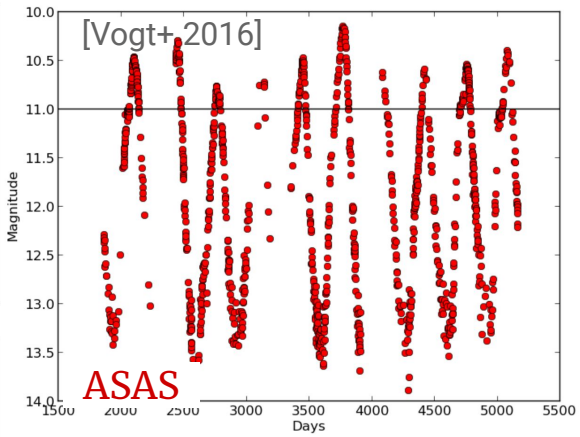




Gaia DR2



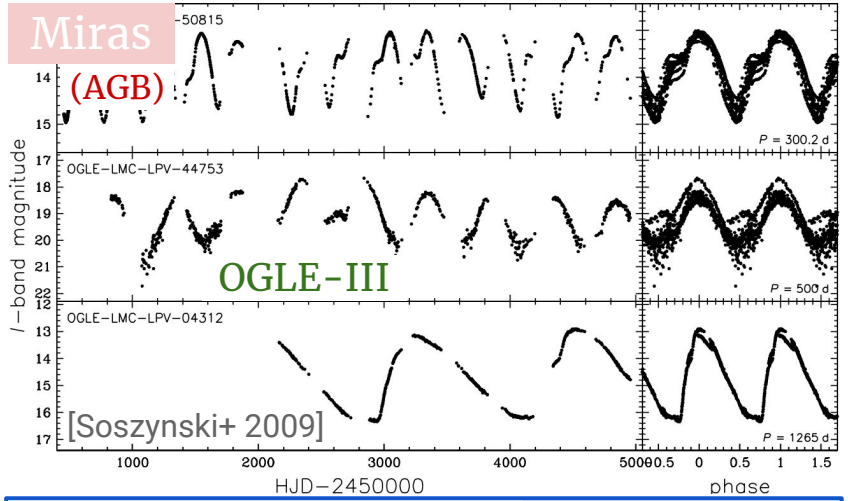
[Mowlavi+ 2018]



ASAS

Miras

(AGB)



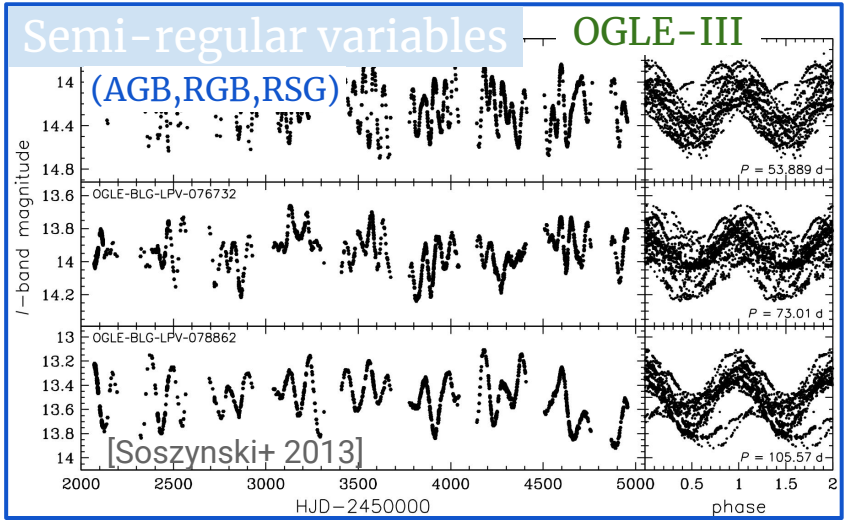
OGLE-III

[Soszynski+ 2009]

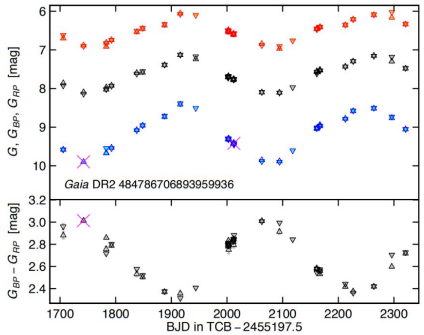
Semi-regular variables

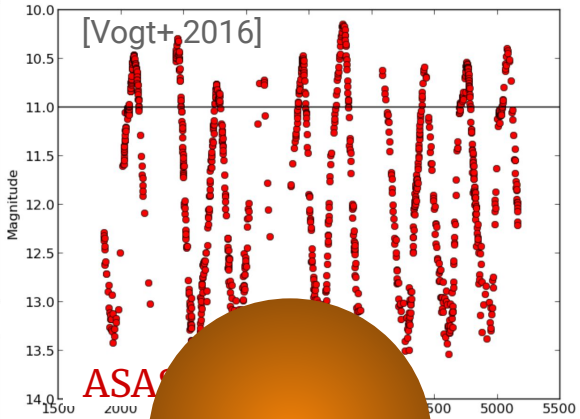
OGLE-III

(AGB,RGB,RSG)



[Soszynski+ 2013]





PULSATION

DUST FORMATION

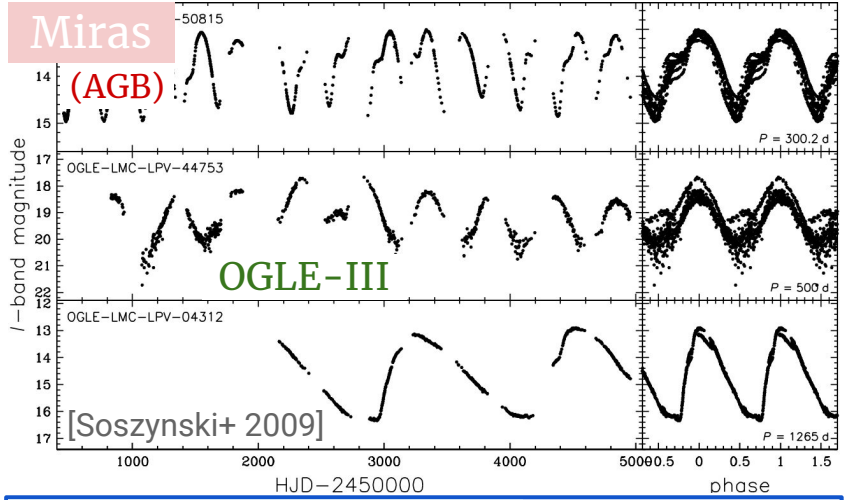
STELLAR WINDS

[Mowlavi+ 2018]

Gaia DR2

Miras

(AGB)



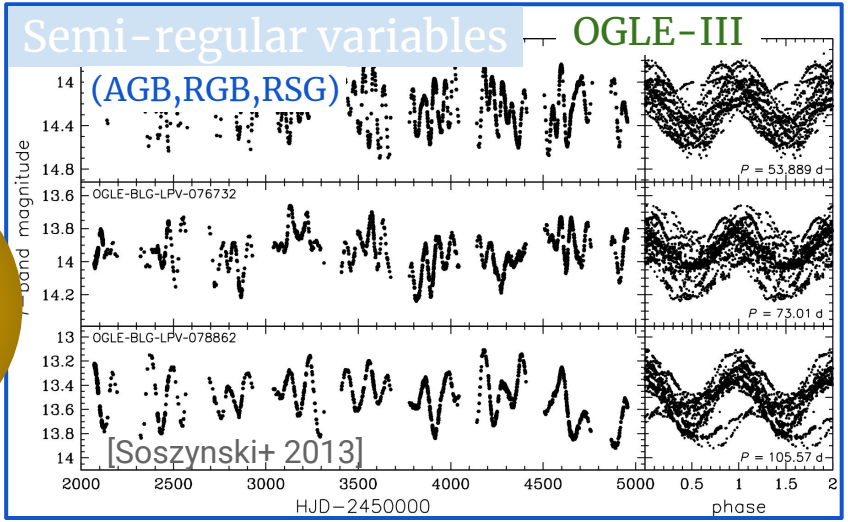
OGLE-III

[Soszynski+ 2009]

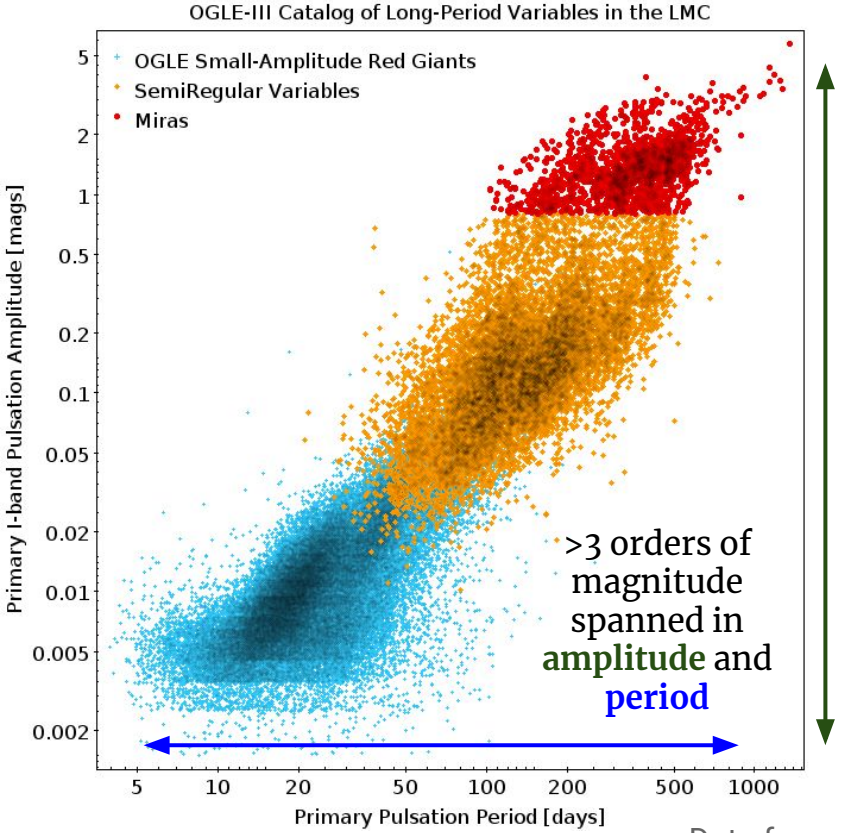
Semi-regular variables

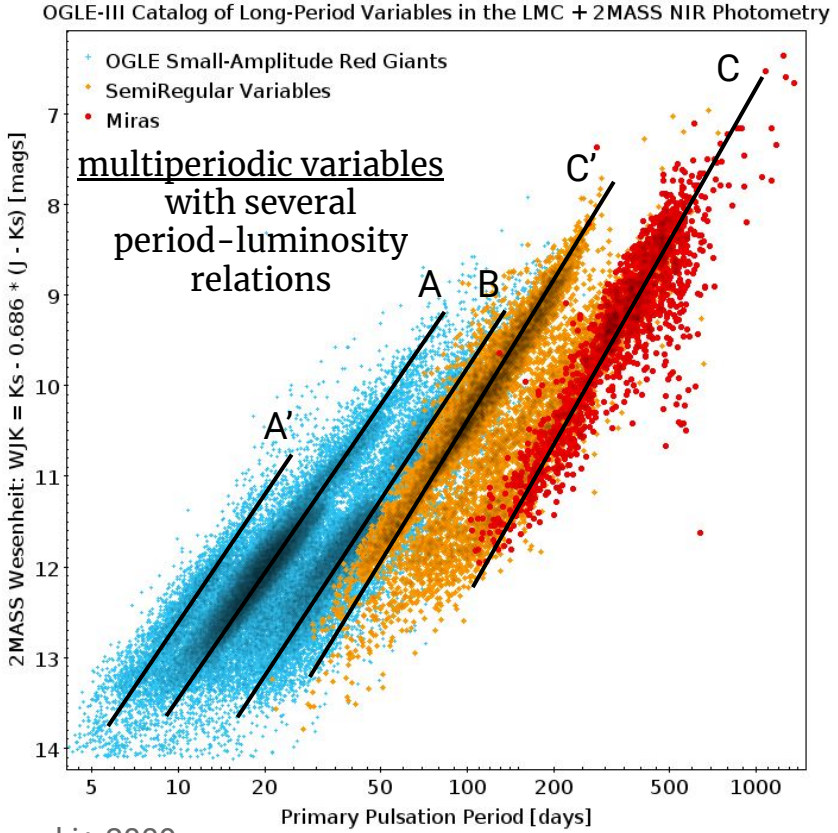
(AGB,RGB,RSG)

OGLE-III



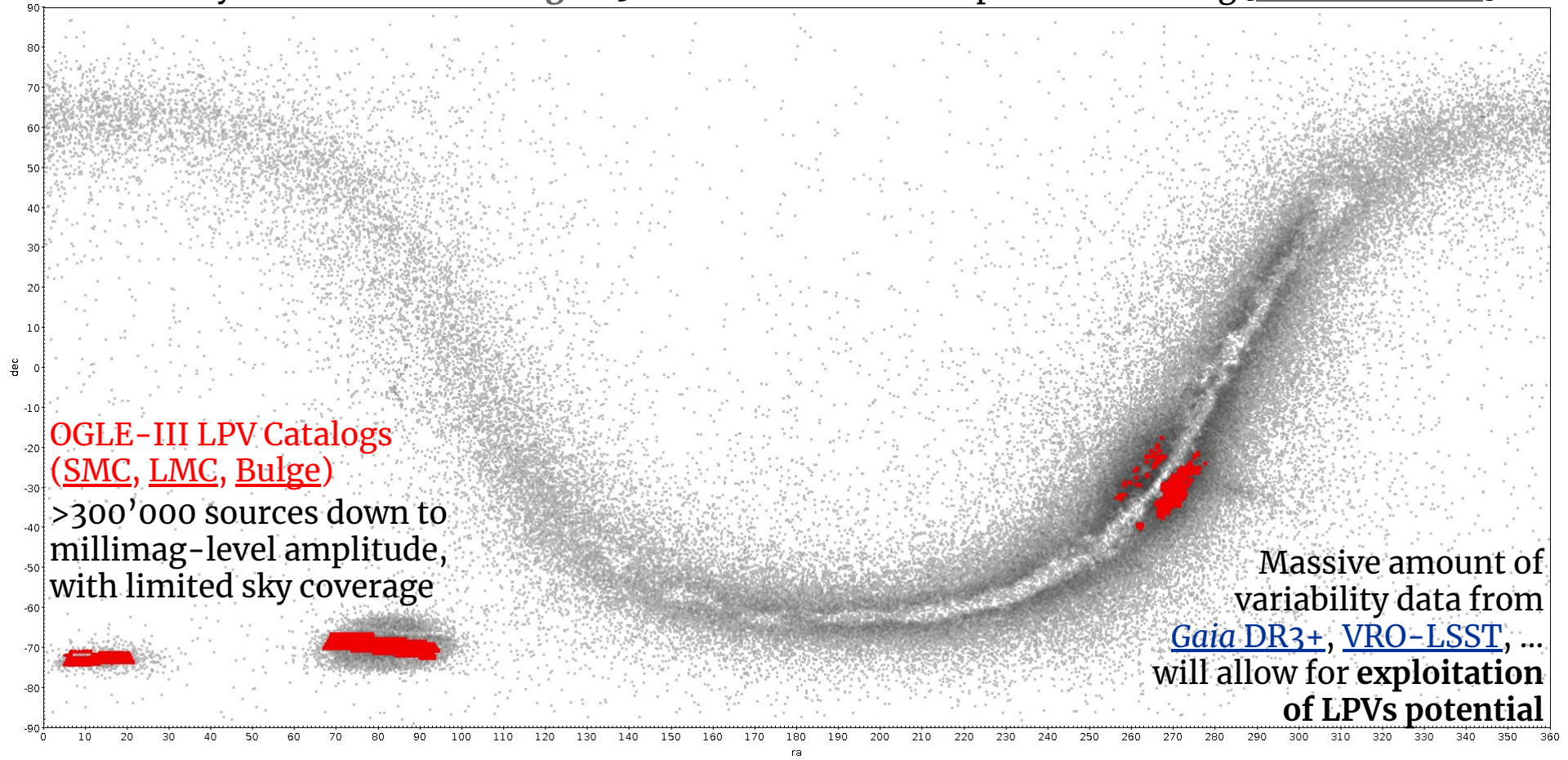
[Soszynski+ 2013]





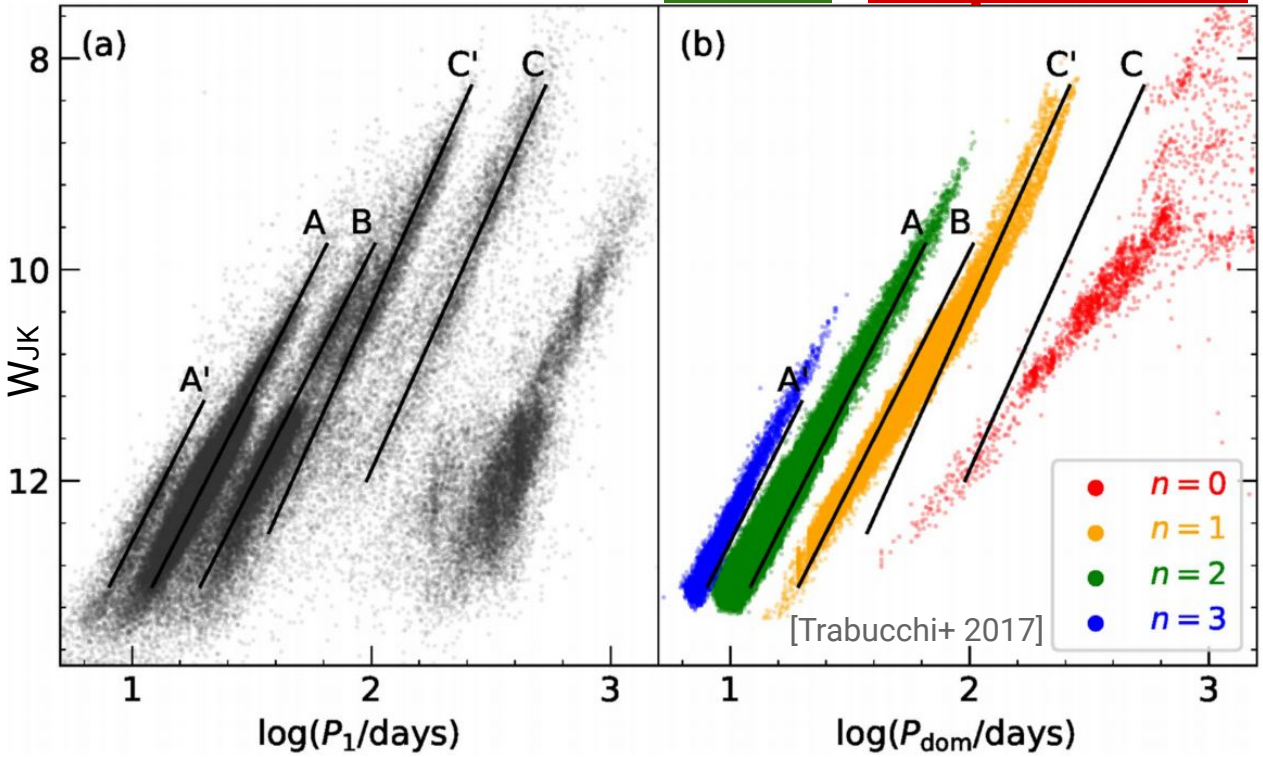
Data from: Soszynski+ 2009

Full-sky *Gaia* DR2 LPV catalog: >150'000 sources with amplitude > 0.2 mag [Mowlavi+ 2018]



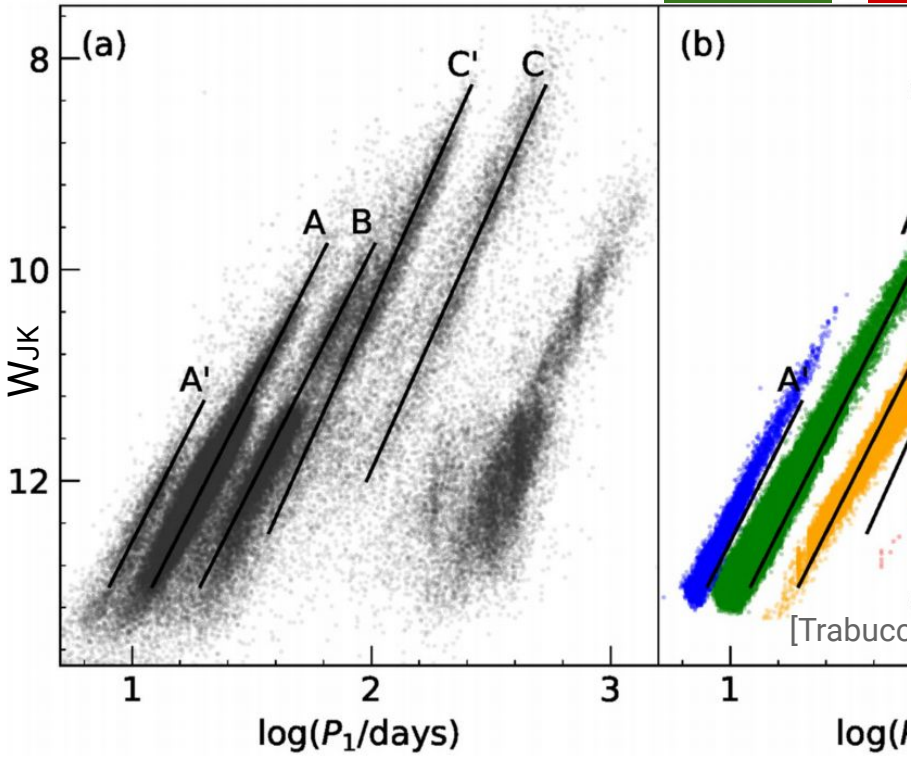
OGLE-III LPVs in the LMC + 2MASS

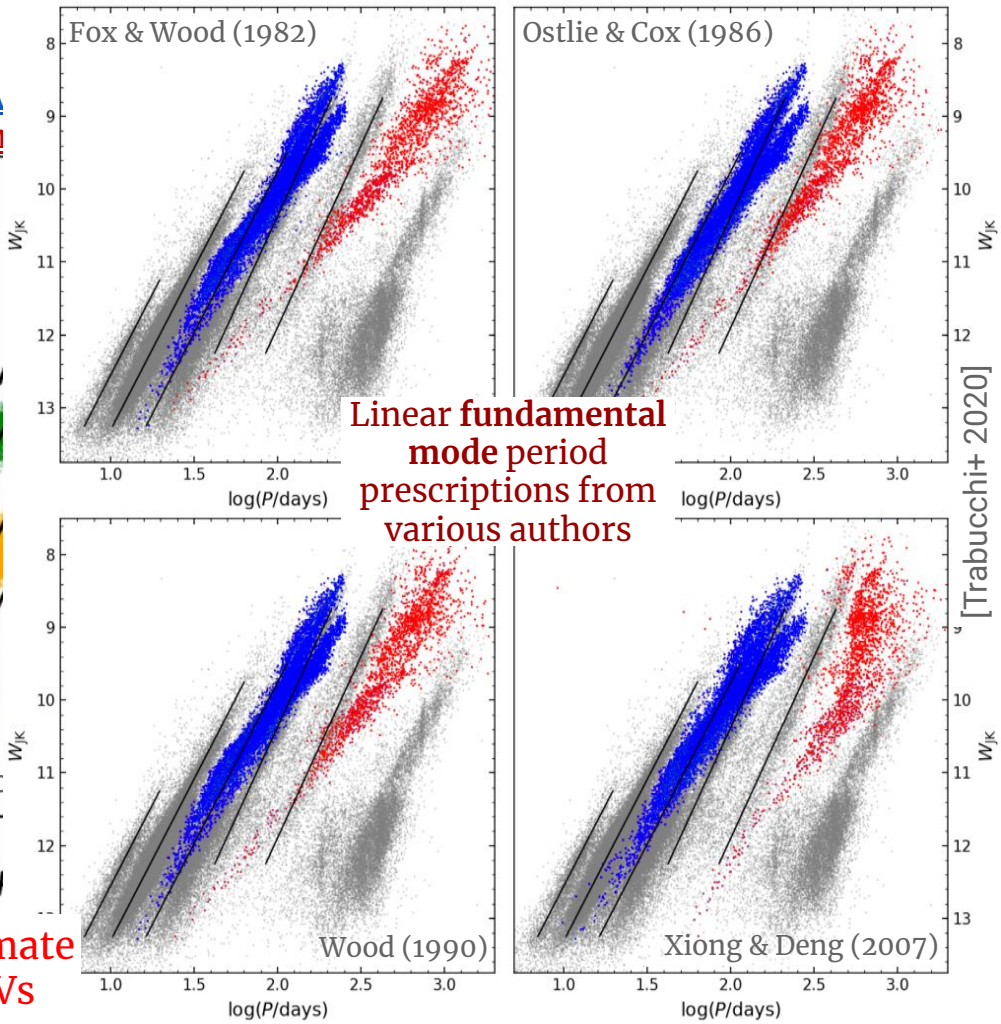
Synthetic LPV population model:
TRILEGAL + linear pulsation models



OGLE-III LPVs in the LMC + 2MASS

Synthetic LPV TRILEGAL + lin



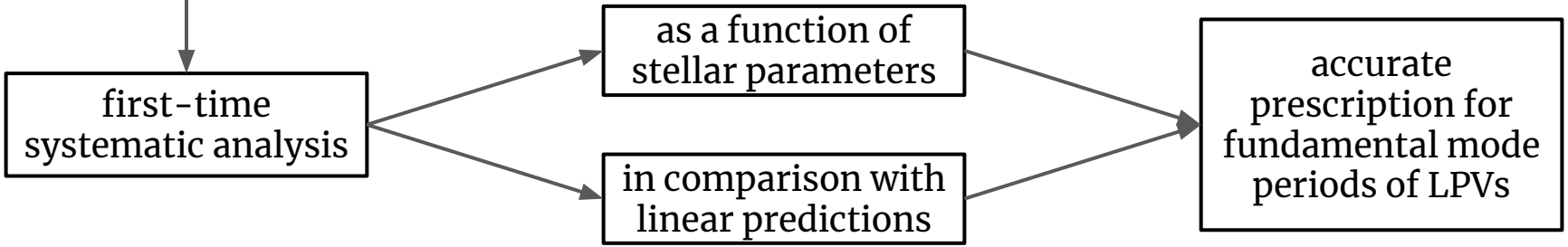


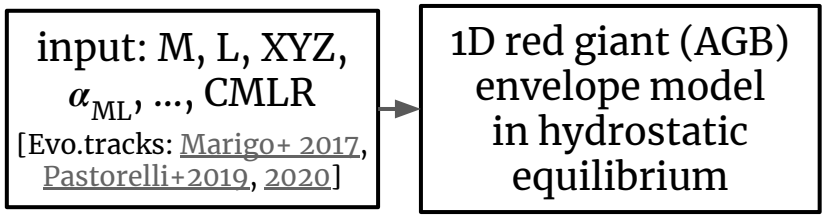
Linear **fundamental mode** period prescriptions from various authors

[Trabucchi+ 2020]

Linear pulsation models systematically overestimate the pulsation period of fundamental-mode LPVs

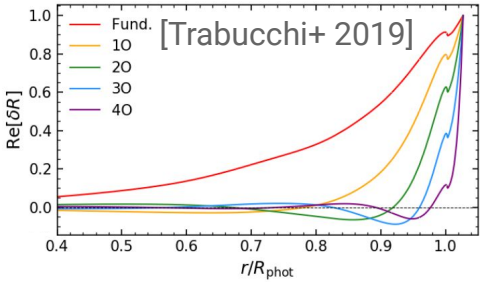

Monthly Notices
of the
ROYAL ASTRONOMICAL SOCIETY
MNRAS 500, 1575–1591 (2021)
Advance Access publication 2020 October 29
doi:10.1093/mnras/staa3356
Modelling long-period variables – II. Fundamental mode pulsation in the non-linear regime
Michele Trabucchi [1,2]★ Peter R. Wood,[3] Nami Mowlavi,[1] Giada Pastorelli [2,4] Paola Marigo,[2]
Léo Girardi[5] and Thomas Lebzelter[6]


first-time systematic analysis
as a function of stellar parameters
in comparison with linear predictions
accurate prescription for fundamental mode periods of LPVs


input: M, L, XYZ,
α_{ML}, ..., CMLR
[Evo.tracks: Marigo+ 2017, Pastorelli+2019, 2020]
1D red giant (AGB) envelope model in hydrostatic equilibrium

linear stability analysis
[Fox+Wood 1982, Wood+Olivier 2014]

linear pulsation properties: periods, growth rates, ...

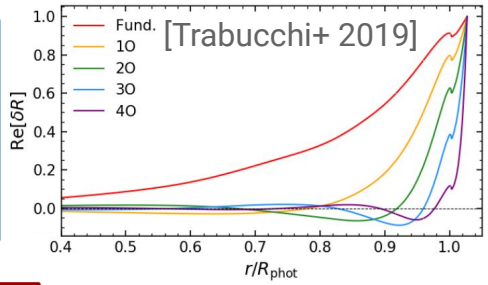


input: M, L, XYZ, α_{ML}, ..., CMLR
[Evo.tracks: Marigo+ 2017, Pastorelli+2019, 2020]

1D red giant (AGB) envelope model in hydrostatic equilibrium

linear stability analysis
[Fox+Wood 1982, Wood+Olivier 2014]

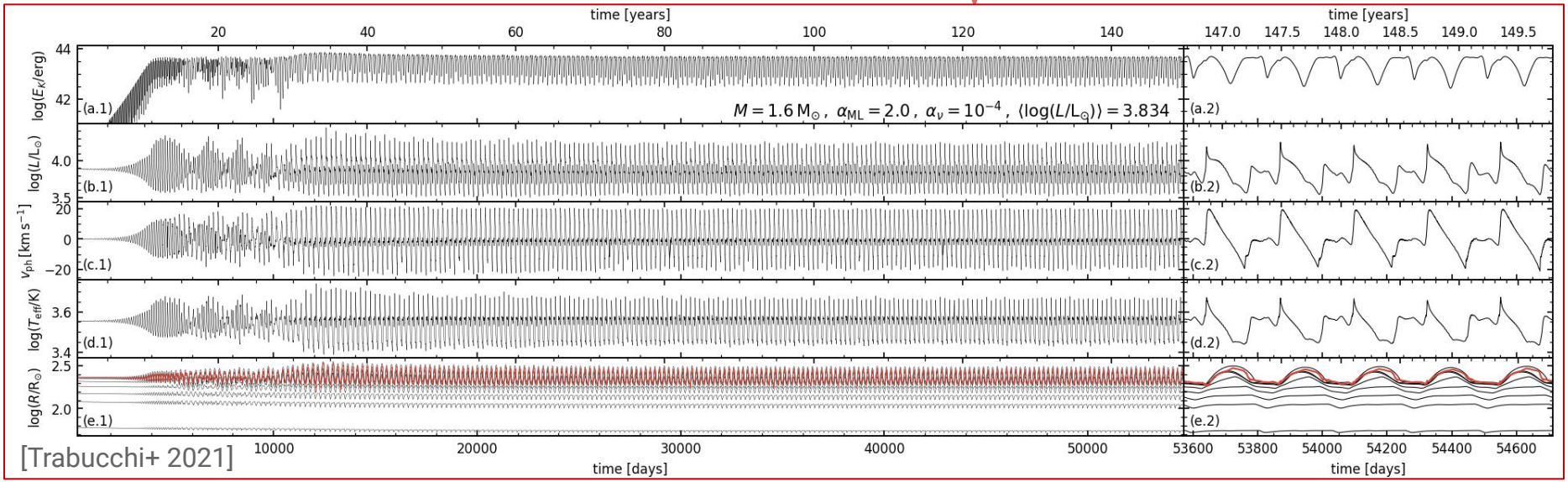
linear pulsation properties: periods, growth rates, ...



input: M, L, XYZ, α_{ML}, ..., CMLR
[Evo.tracks: Marigo+ 2017, Pastorelli+2019, 2020]

1D red giant (AGB) envelope model in hydrostatic equilibrium

non-linear time series
[Wood 1974, Keller+Wood 2006]



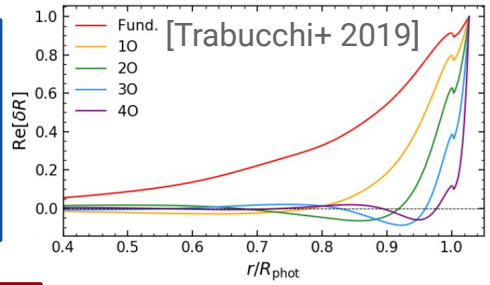
L + ΔL

input: M, L, XYZ, α_{ML}, ..., CMLR
[Evo.tracks: Marigo+ 2017, Pastorelli+2019, 2020]

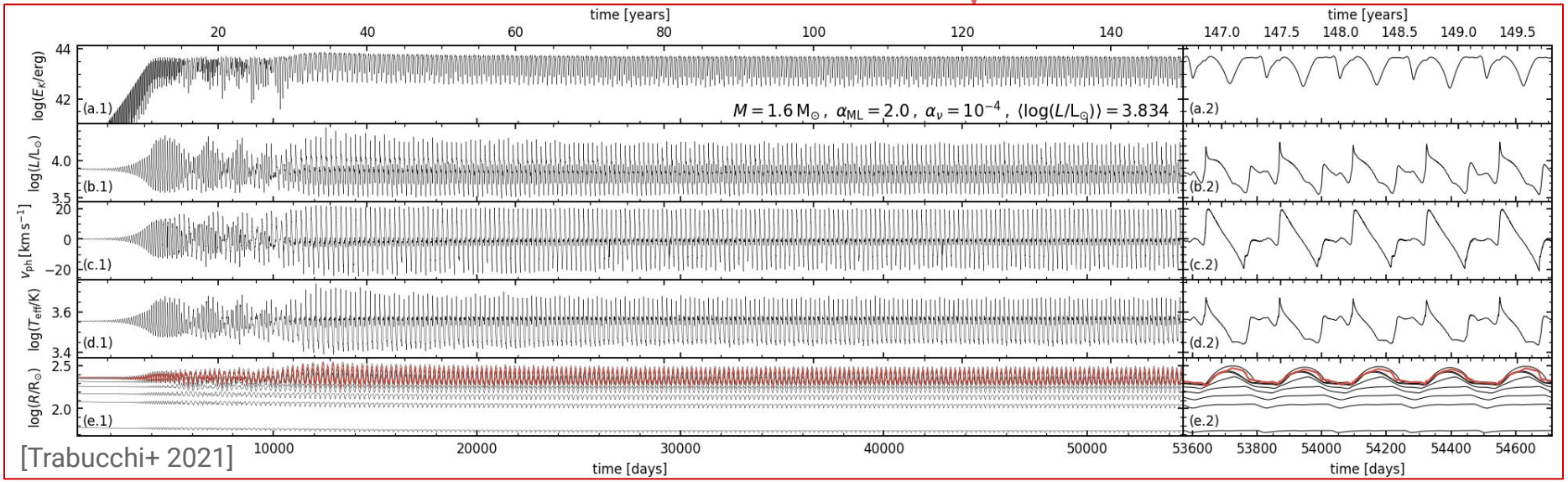
1D red giant (AGB) envelope model in hydrostatic equilibrium

linear stability analysis
[Fox+Wood 1982, Wood+Olivier 2014]

linear pulsation properties: periods, growth rates, ...



non-linear time series
[Wood 1974, Keller+Wood 2006]



Change M, α_{ML}

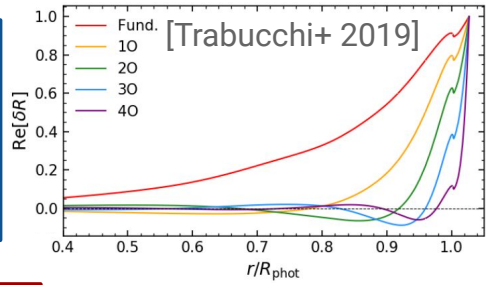
L + ΔL

input: M, L, XYZ, α_{ML}, …, CMLR
[Evo.tracks: Marigo+ 2017, Pastorelli+2019, 2020]

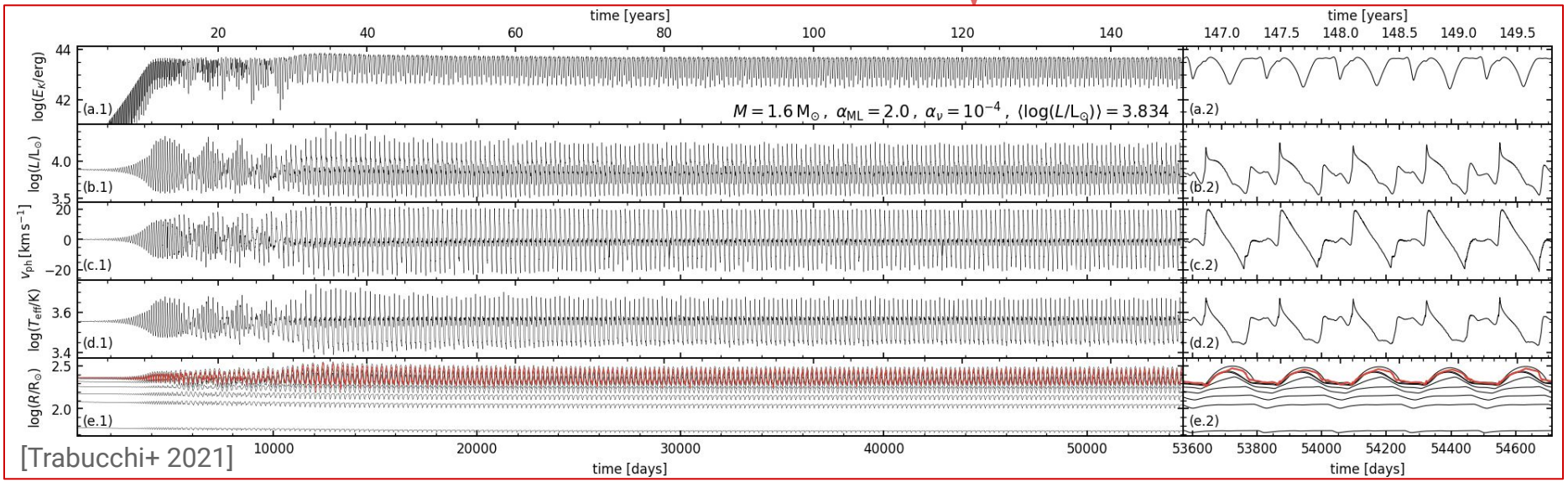
1D red giant (AGB) envelope model in hydrostatic equilibrium

linear stability analysis
[Fox+Wood 1982, Wood+Olivier 2014]

linear pulsation properties: periods, growth rates, …



non-linear time series
[Wood 1974, Keller+Wood 2006]



Change M, α_{ML}

L + ΔL

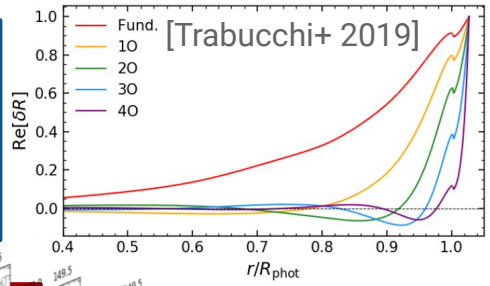
input: M, L, XYZ, α_{ML}, ..., CMLR
[Evo.tracks: Marigo+ 2017, Pastorelli+2019, 2020]

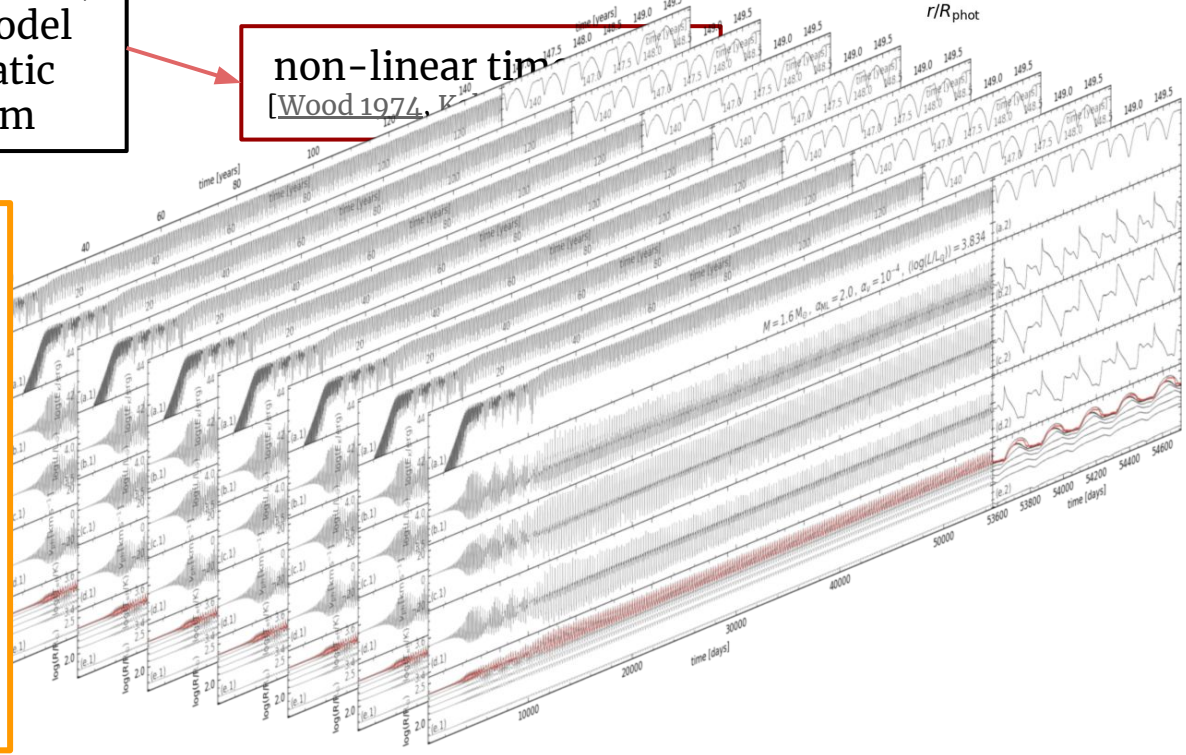
1D red giant (AGB) envelope model in hydrostatic equilibrium

linear stability analysis
[Fox+Wood 1982, Wood+Olivier 2014]

linear pulsation properties: periods, growth rates, ...

non-linear tim
[Wood 1974, K

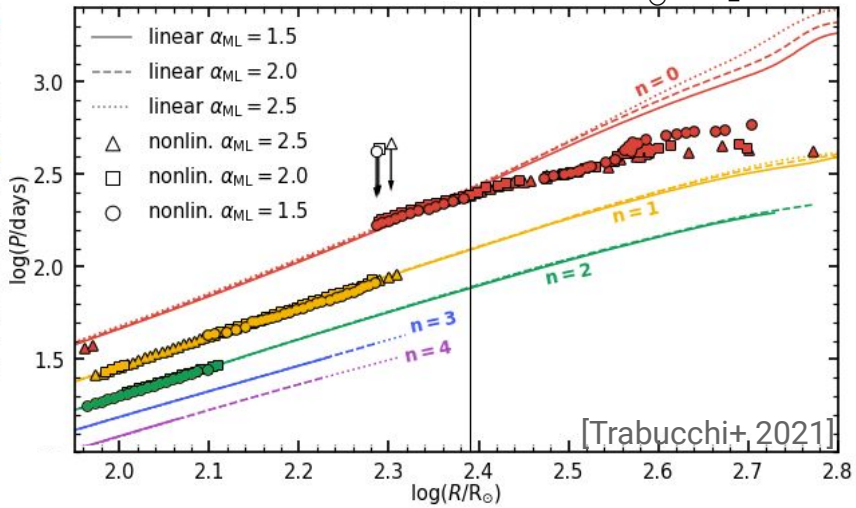




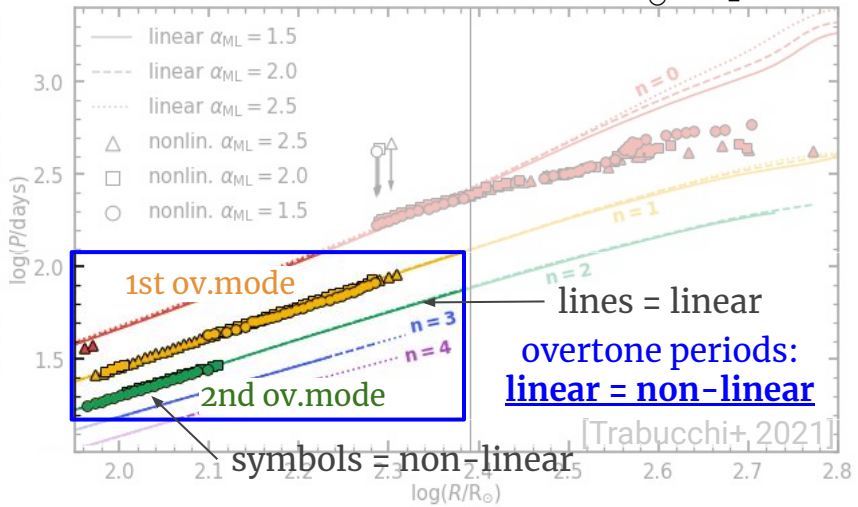
Grid of non-linear models

Parameter	Values
Z	0.006
X	0.7
C/O	0.55
α_{ML}	1.5, 2.0, 2.5
α_{ν}	10^{-4}, 0.05, 0.1, 0.2
$M/M_{\odot}$	0.6, 1.0, 1.6, 2.6, 4.4, 7.0
$\log(L/L_{\odot})$	[2.5, 5.0], step: 0.01

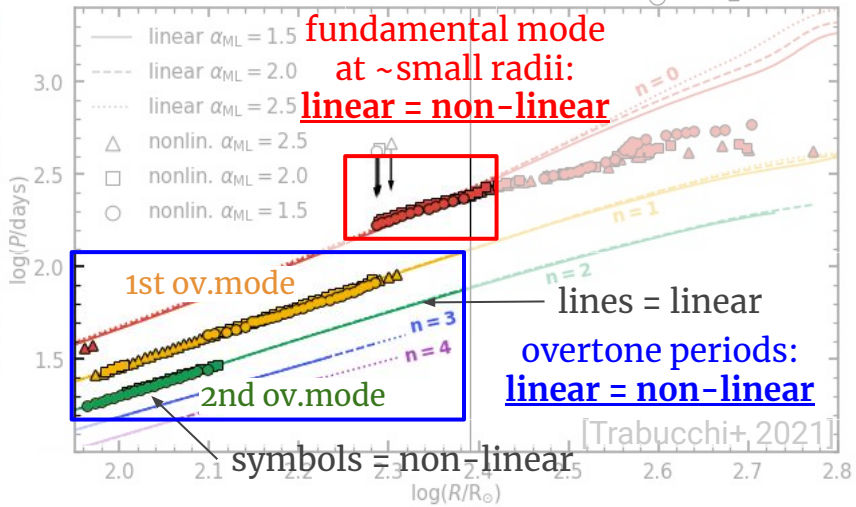
Period-Radius relation for $1.6M_{\odot}$ sequence



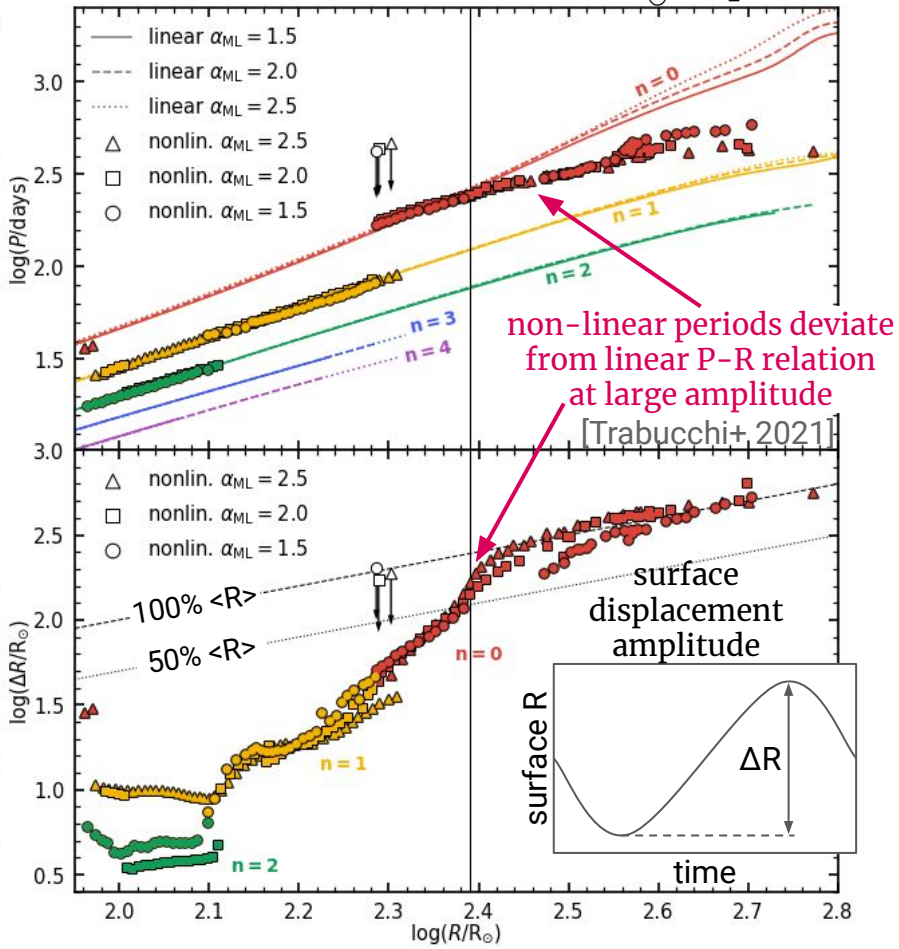
Period-Radius relation for $1.6M_\odot$ sequence



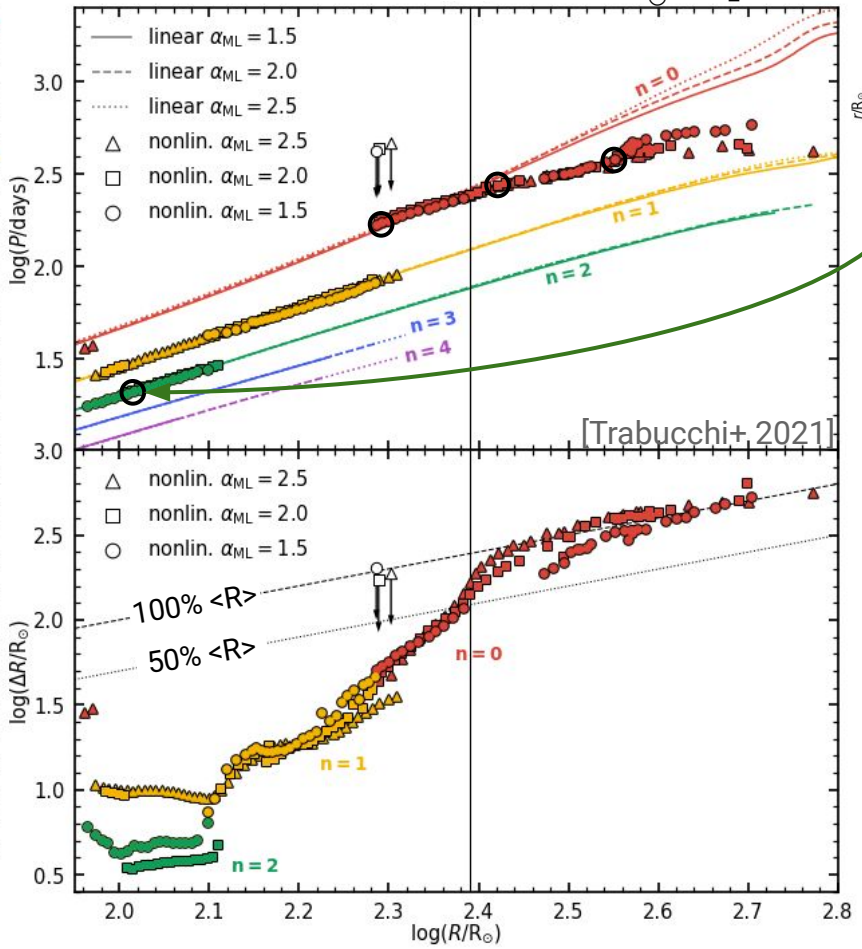
Period-Radius relation for $1.6M_\odot$ sequence



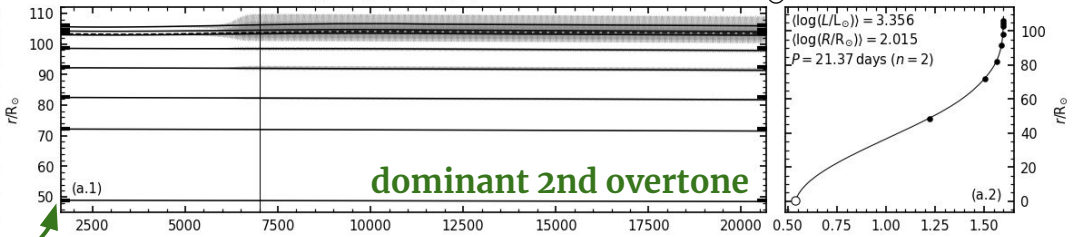
Period-Radius relation for $1.6M_\odot$ sequence



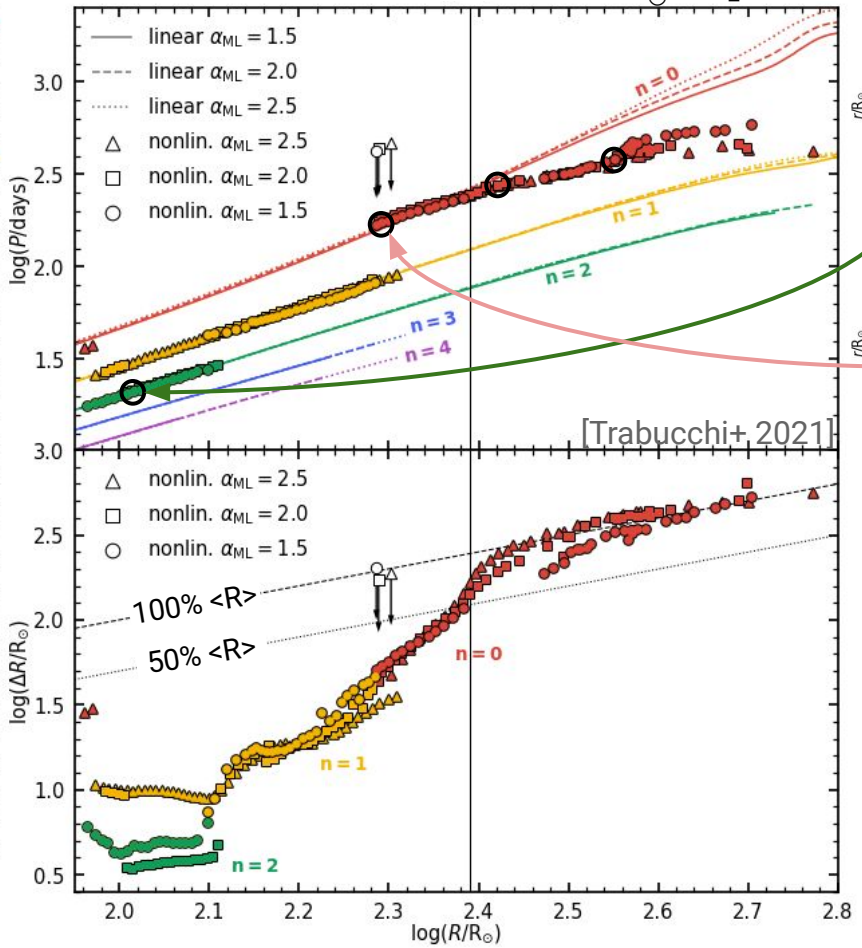
Period-Radius relation for $1.6M_\odot$ sequence



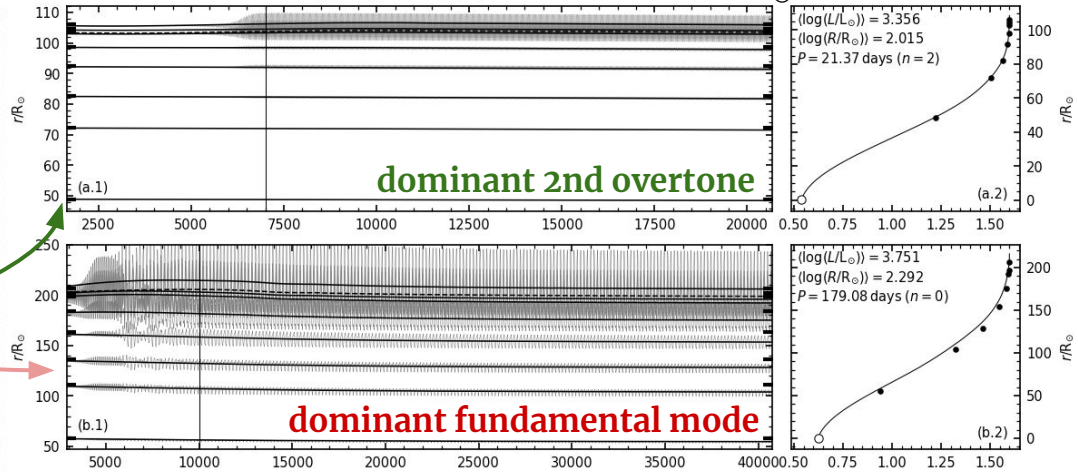
Interior pulsation for selected $1.6M_\odot$ models



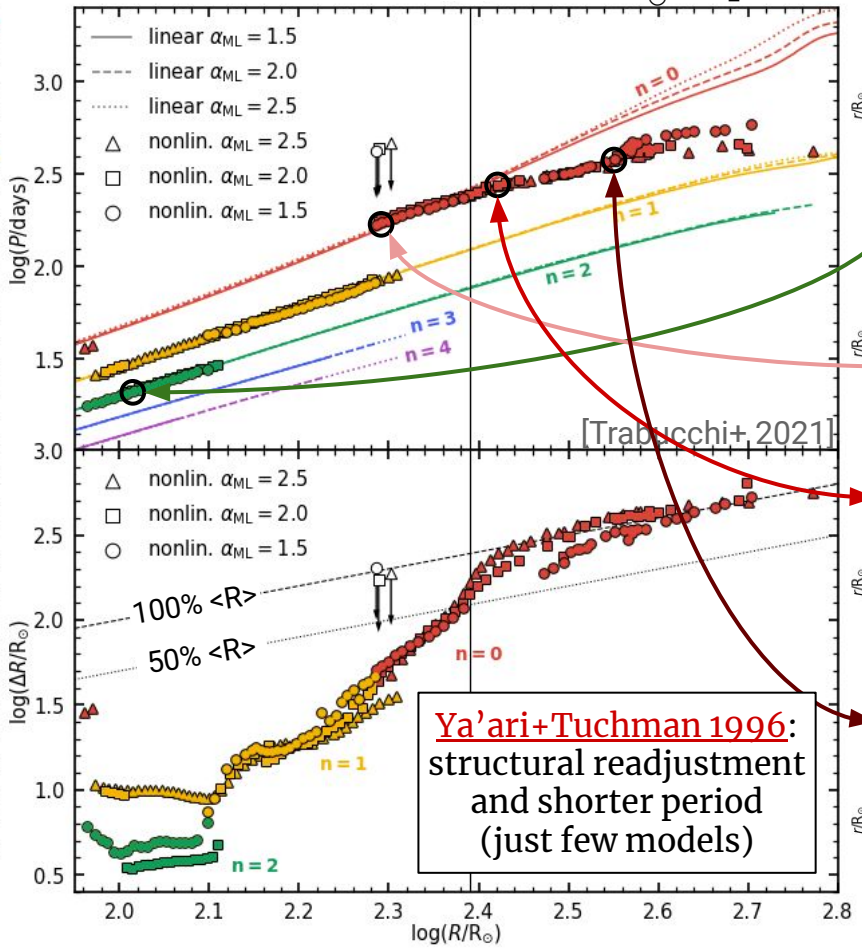
Period-Radius relation for $1.6M_\odot$ sequence



Interior pulsation for selected $1.6M_\odot$ models

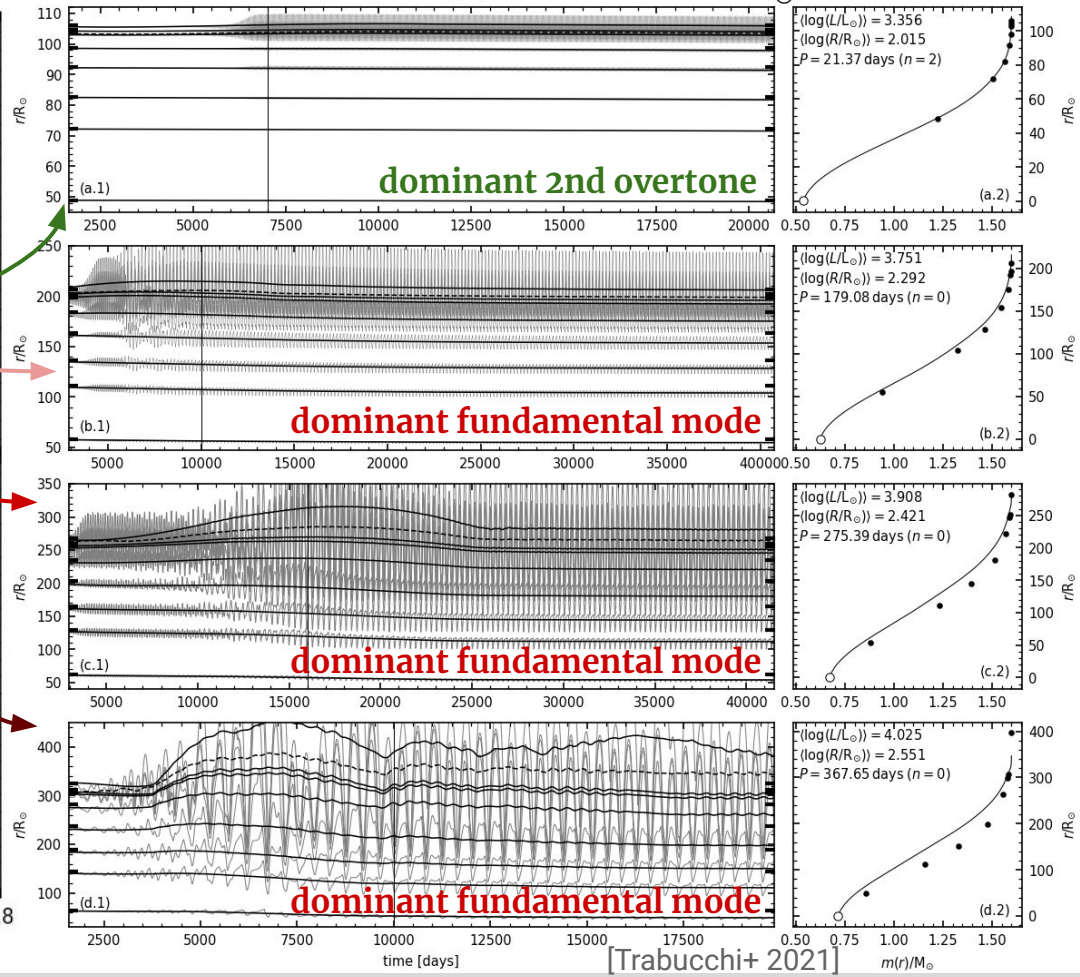


Period-Radius relation for $1.6M_\odot$ sequence



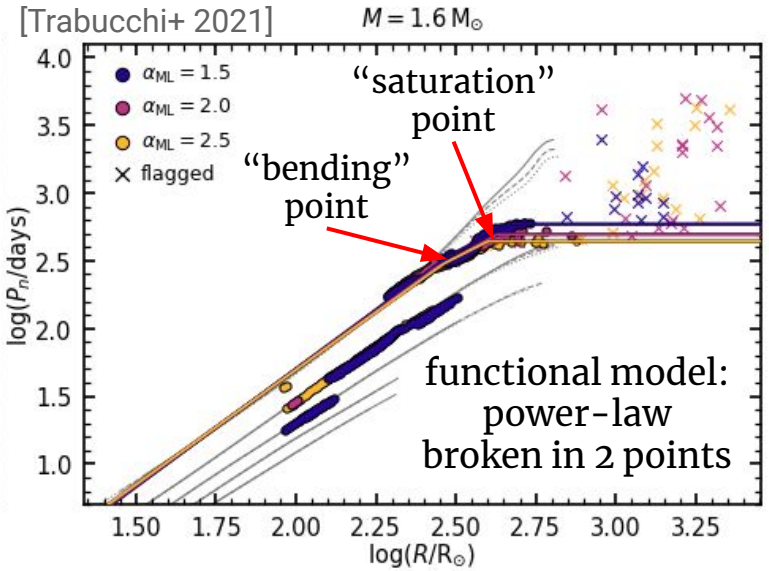
Ya'ari+Tuchman 1996: structural readjustment and shorter period (just few models)

Interior pulsation for selected $1.6M_\odot$ models



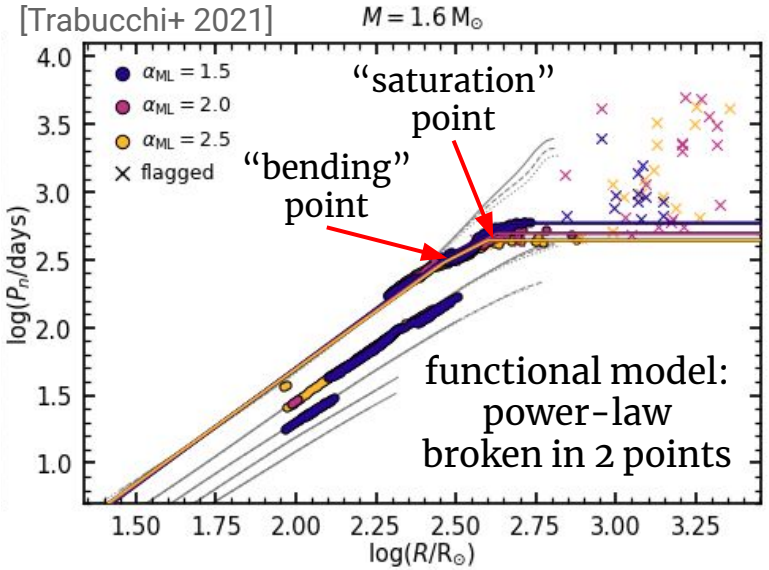
[Trabucchi+ 2021]

[Trabucchi+ 2021]



[Trabucchi+ 2021]

[Trabucchi+ 2021]

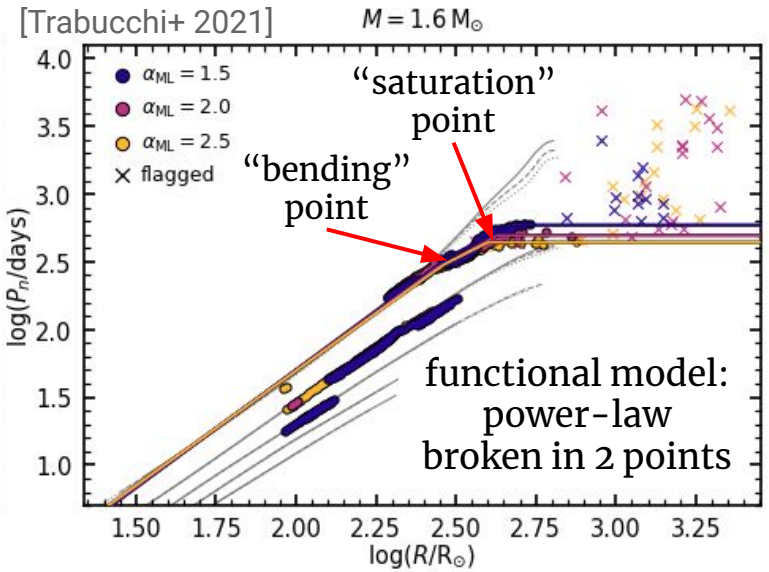


non-linear fundamental mode P-R relation

$$\log(P_0) = \begin{cases} \log(P_b) + \alpha \log(R/R_b) & \text{if } R < R_b \\ \log(P_b) + \beta \log(R/R_b) & \text{if } R_b \le R < R_s \\ \log(P_s) & \text{if } R_s \le R, \end{cases}$$

[Trabucchi+ 2021]

[Trabucchi+ 2021]



non-linear fundamental mode P-R relation

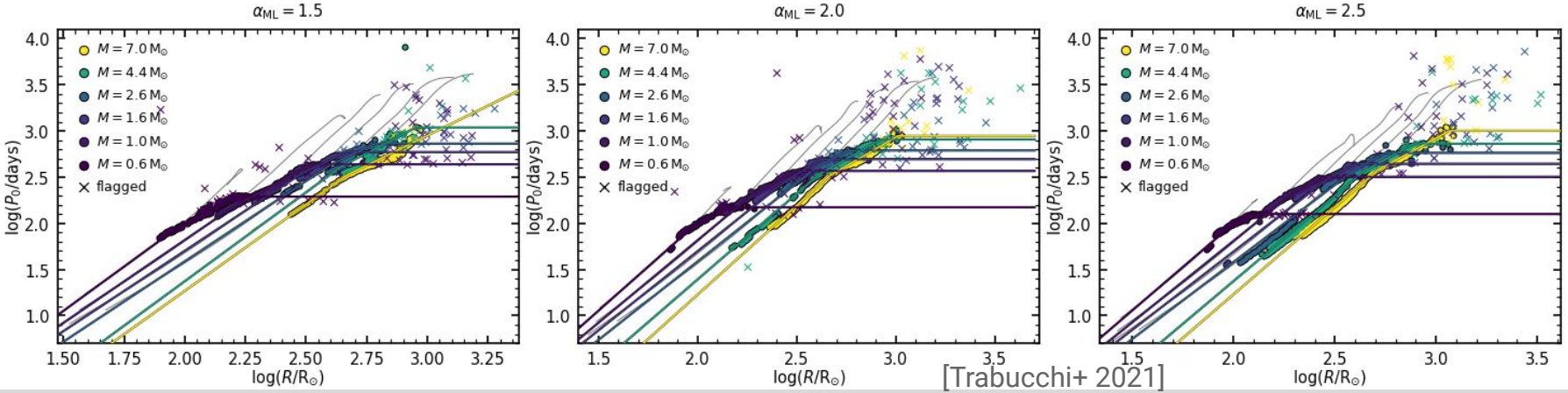
$$\log(P_0) = \begin{cases} \log(P_\mathrm{b}) + \alpha \log(R/R_\mathrm{b}) & \text{if } R < R_\mathrm{b} \\ \log(P_\mathrm{b}) + \beta \log(R/R_\mathrm{b}) & \text{if } R_\mathrm{b} \le R < R_\mathrm{s} \\ \log(P_\mathrm{s}) & \text{if } R_\mathrm{s} \le R, \end{cases}$$

Mass-dependence of best-fit parameters

$$K = \begin{cases} \log(k_\mathrm{b}) + \gamma_1^k \log(M/M_\mathrm{b}^k) & \text{if } M < M_\mathrm{b}^k \\ \log(k_\mathrm{b}) + \gamma_2^k \log(M/M_\mathrm{b}^k) & \text{if } M_\mathrm{b}^k \le M \end{cases}$$

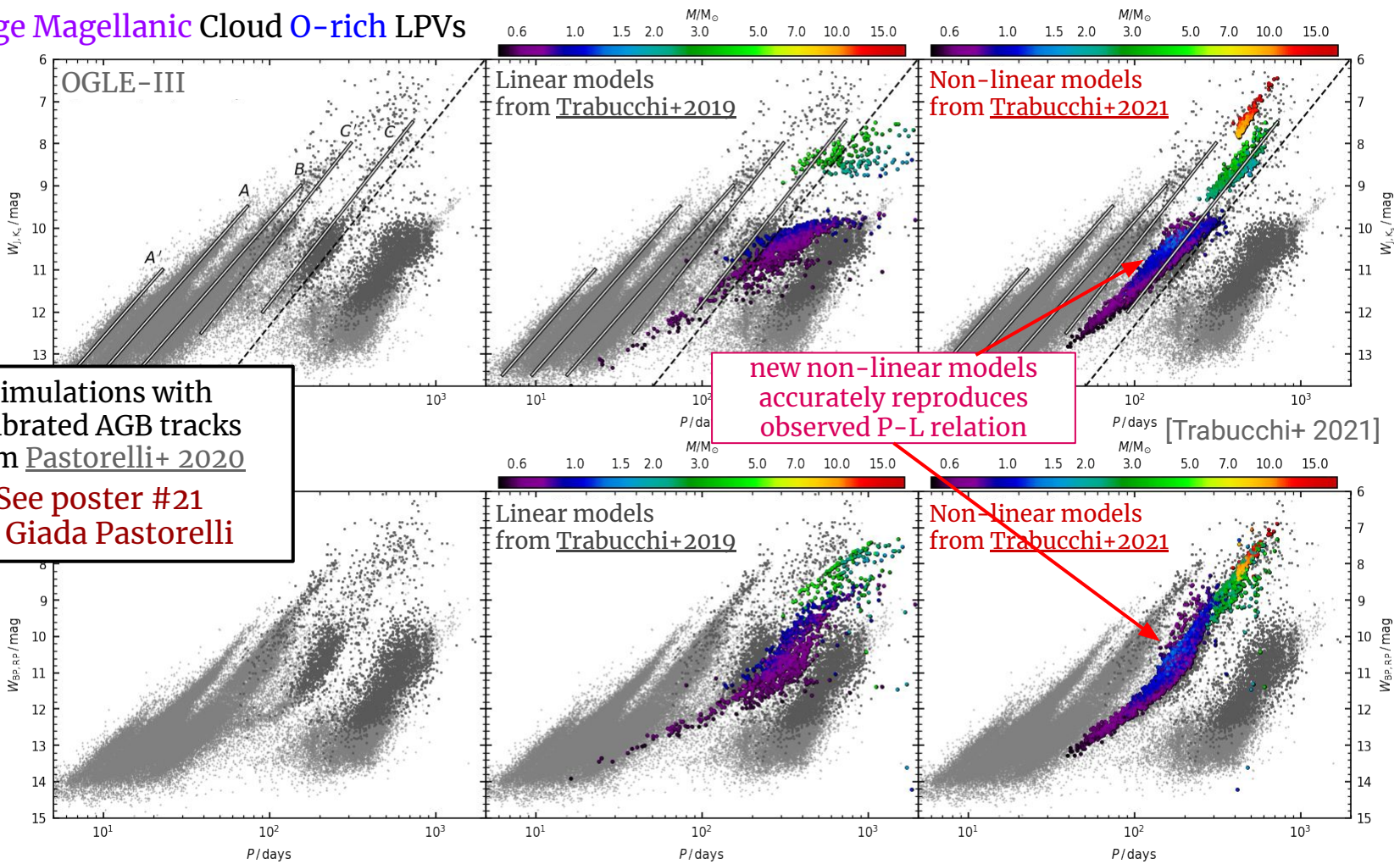
Parameter	k_b	M_b^k	γ_1^k	γ_2^k
$\log(R_\mathrm{b})$	$421\,R_\odot$	$2.6\,M_\odot$	0.952	0.114
$\log(P_\mathrm{b})$	440 d	$2.6\,M_\odot$	0.976	−0.264
$\log(R_\mathrm{s})$	$311\,R_\odot$	$1.0\,M_\odot$	1.590	0.654
$\log(P_\mathrm{s})$	388 d	$1.0\,M_\odot$	1.808	0.502
α	49.7	$2.6\,M_\odot$	−0.279	0.544

non-linear P-M-R relation



[Trabucchi+ 2021]

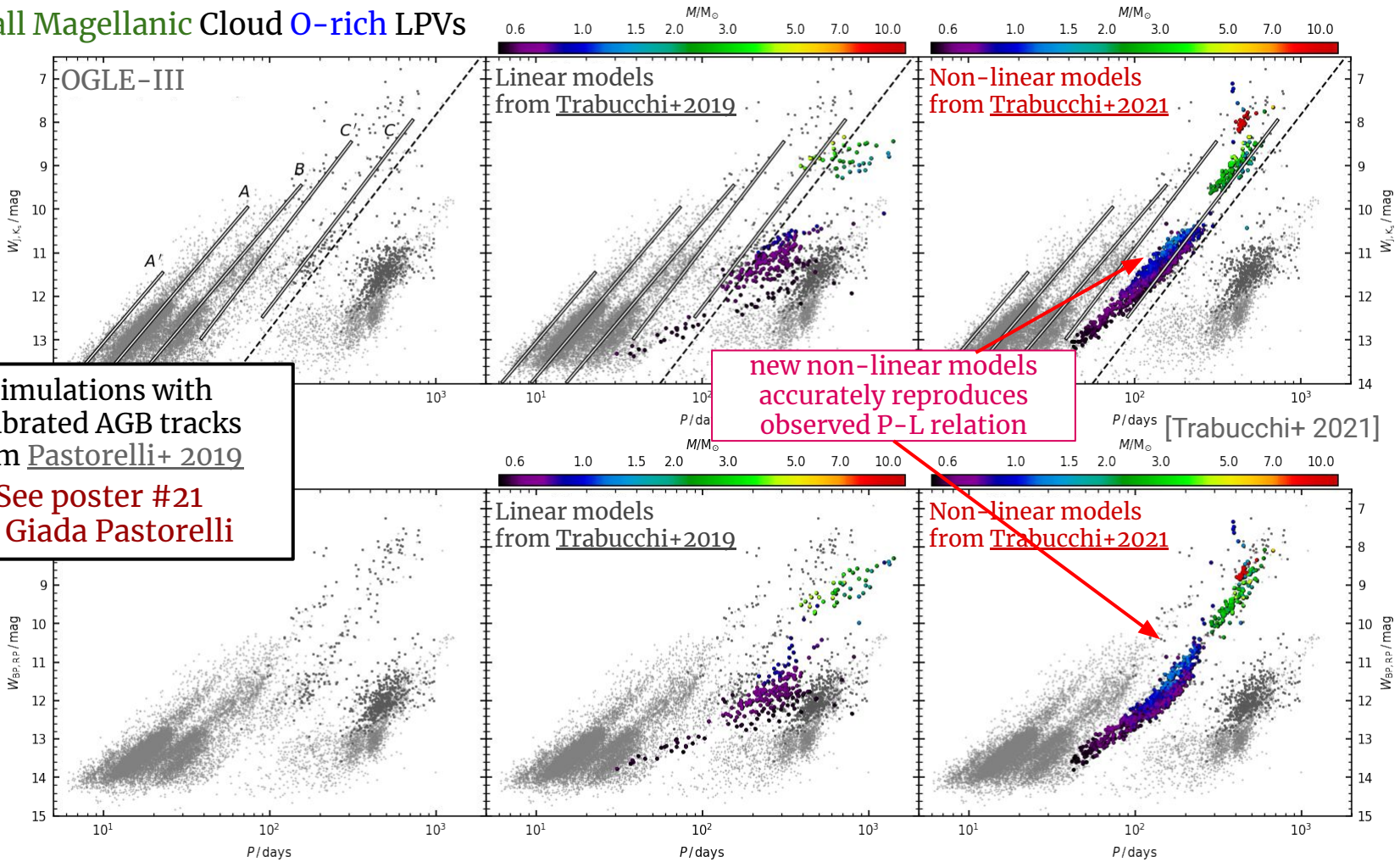
Large Magellanic Cloud O-rich LPVs



Simulations with calibrated AGB tracks from Pastorelli+ 2020

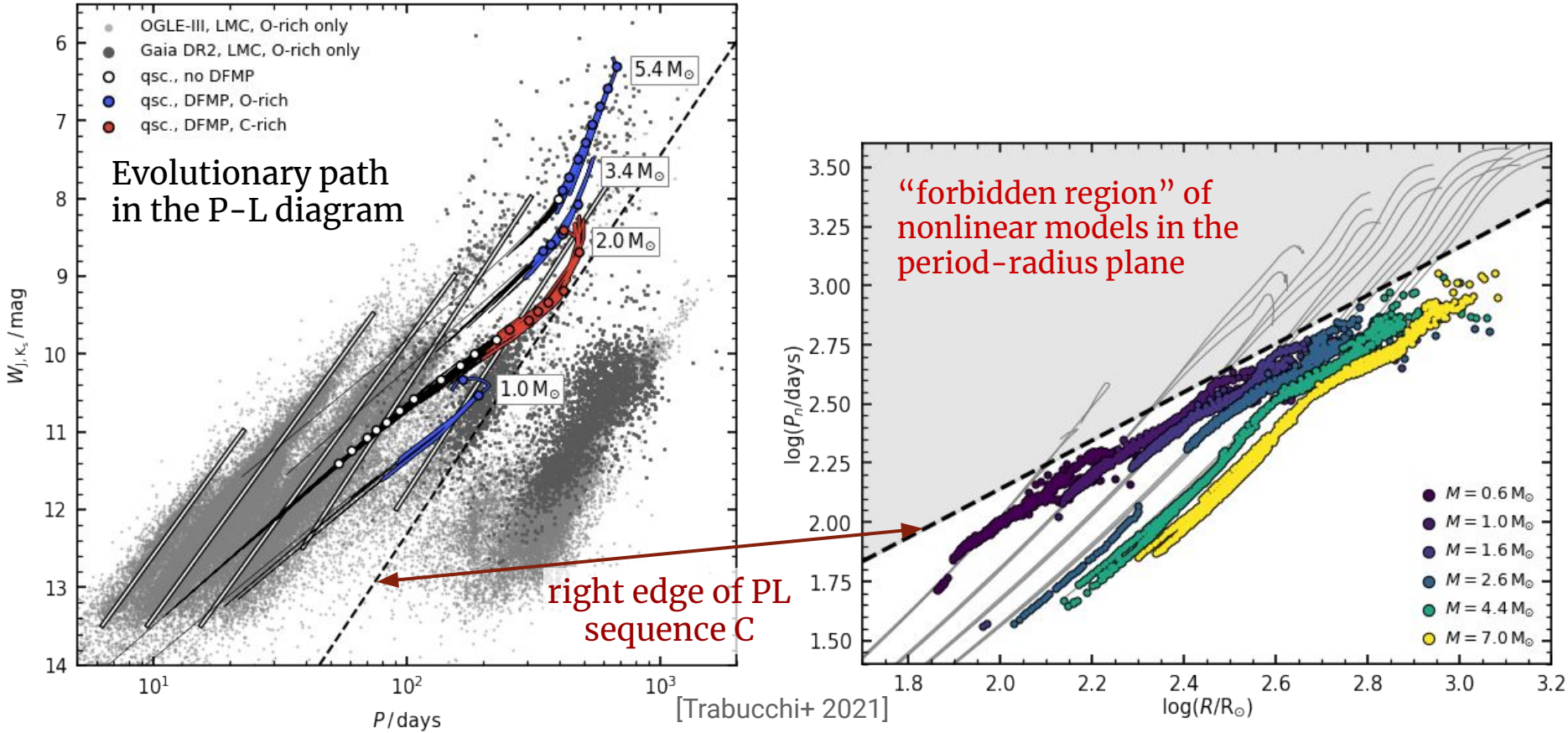
See poster #21 by Giada Pastorelli

Small Magellanic Cloud O-rich LPVs



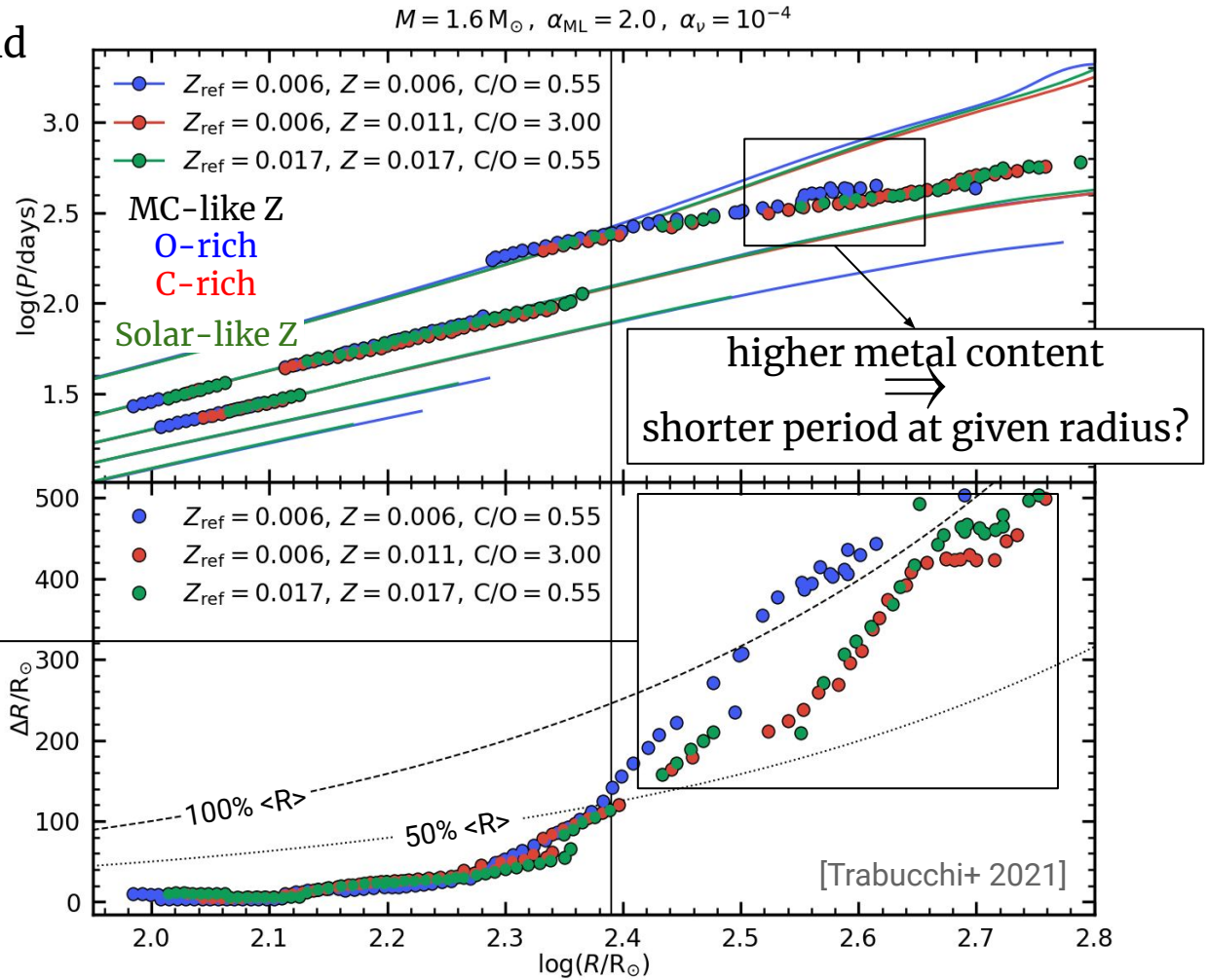
Simulations with calibrated AGB tracks from Pastorelli+ 2019

See poster #21 by Giada Pastorelli



[Trabucchi+ 2021]

Test models for C-rich and solar-metallicity cases



Different amplitude at given radius in the strongly non-linear regime:
possible effects on the shape of the PR relation?

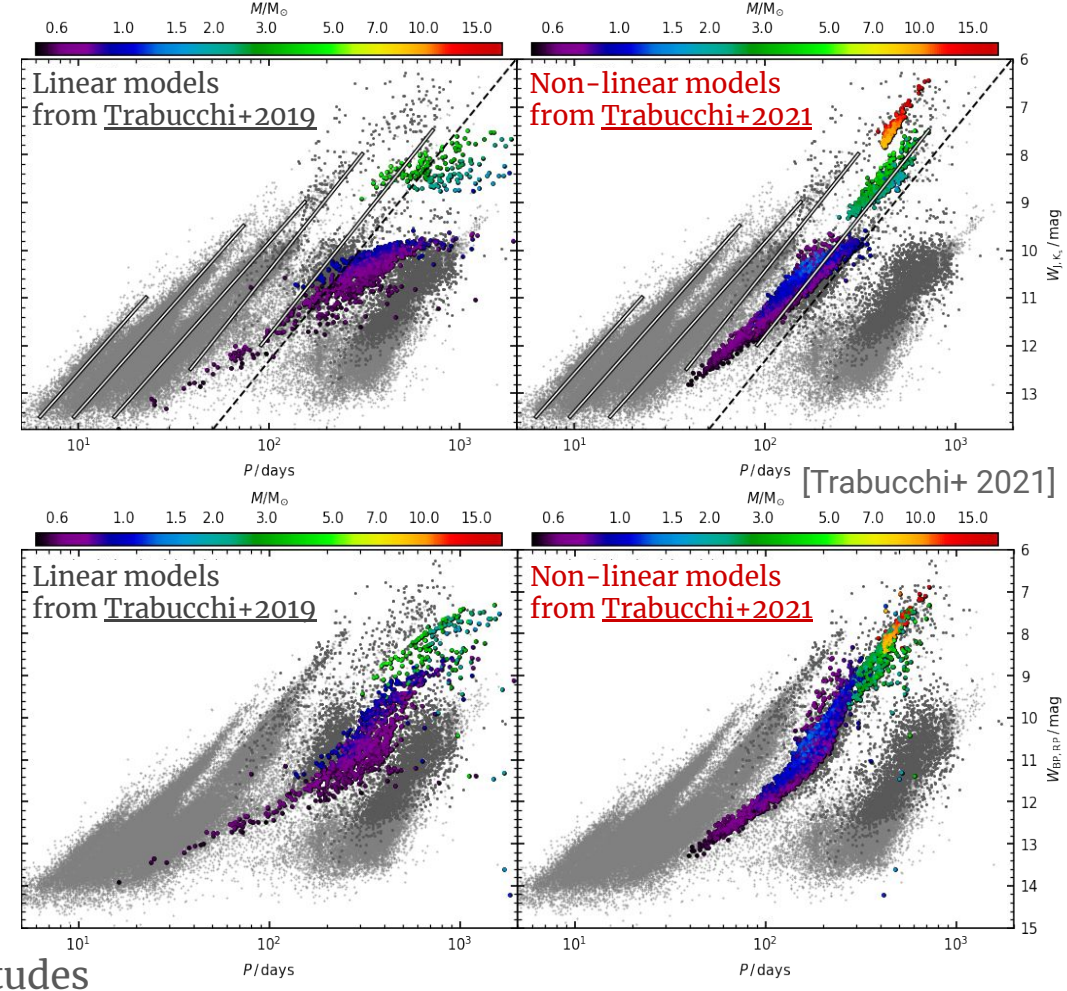
... further investigation required...

Summary

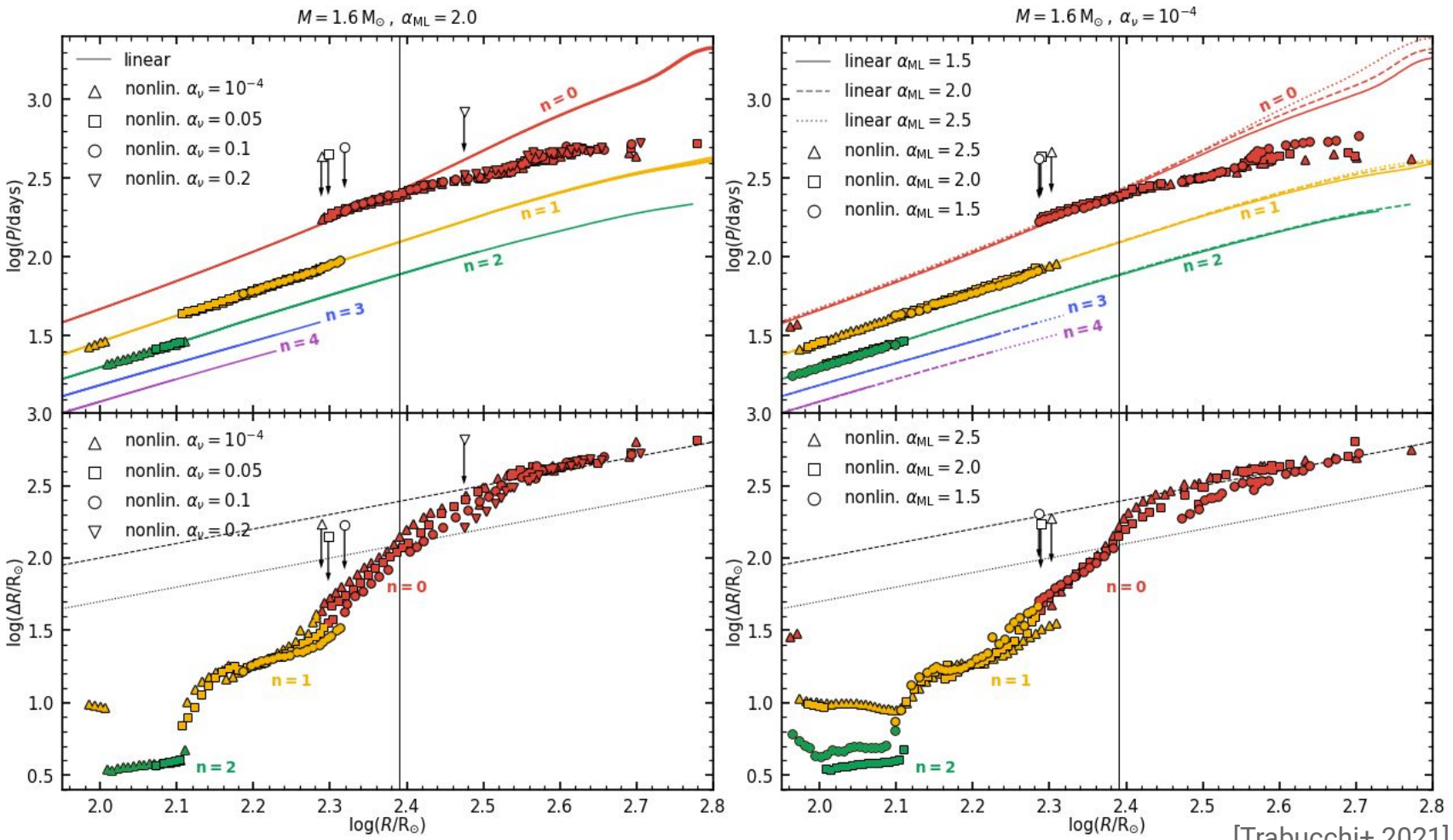
- Grid of non-linear pulsation models
- Wide coverage of AGB parameters M, L (T)
- Single composition: O-rich, MC-like Z
- Pulsation feedback on envelope structure
- Analytic best-fit P-M-R relation
- First accurate prescription for FM period
- Much better agreement with observation
- Linear overtone periods validated
- Explains right edge of Miras P-L sequence
- Possible effects of metallicity

Next steps

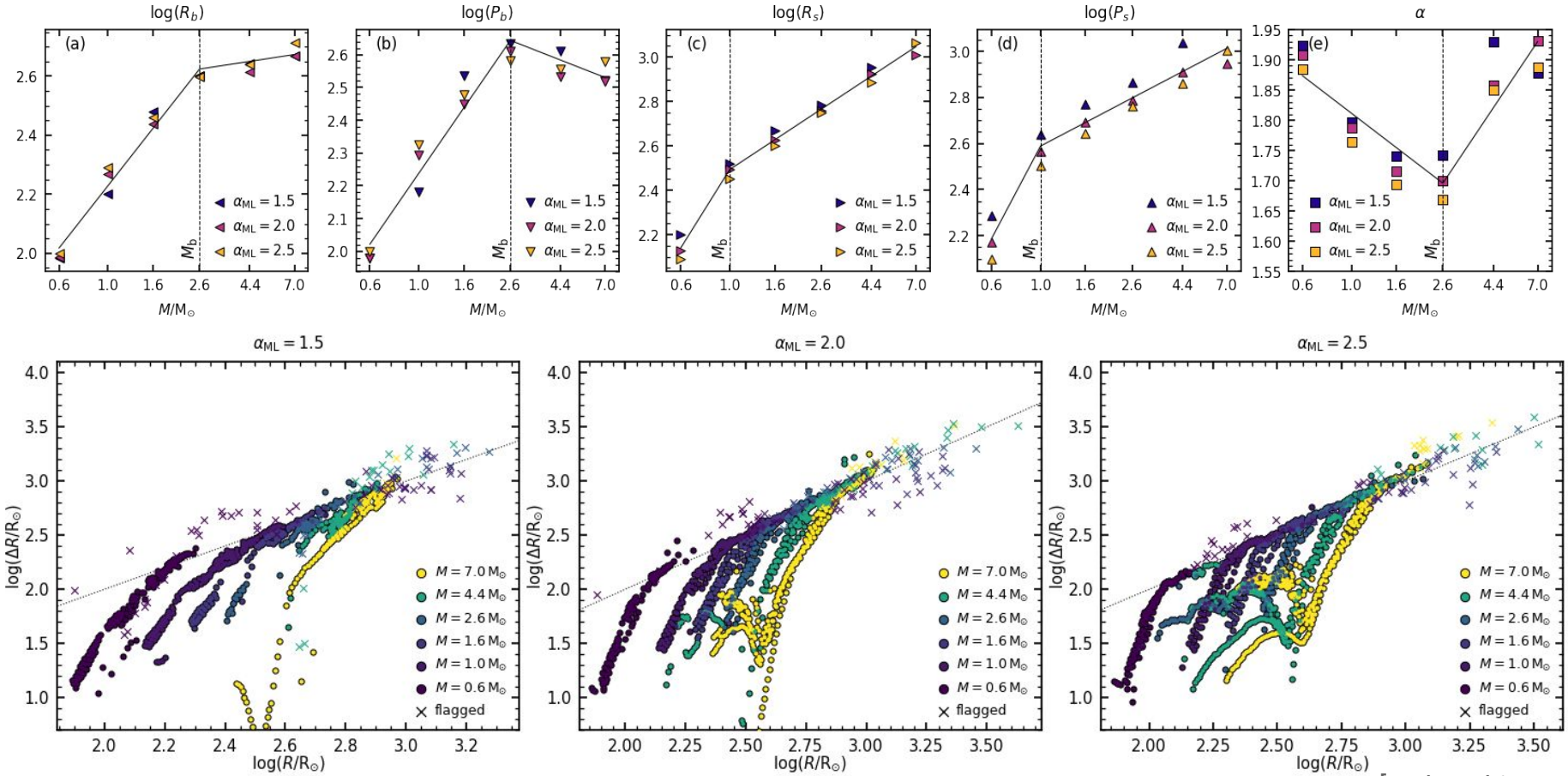
- Extend to C-rich, higher/lower Z
- Investigate multi-periodicity
- Mode shifting and dependence on M,T,Z...
- Synthetic light curves, photometric amplitudes



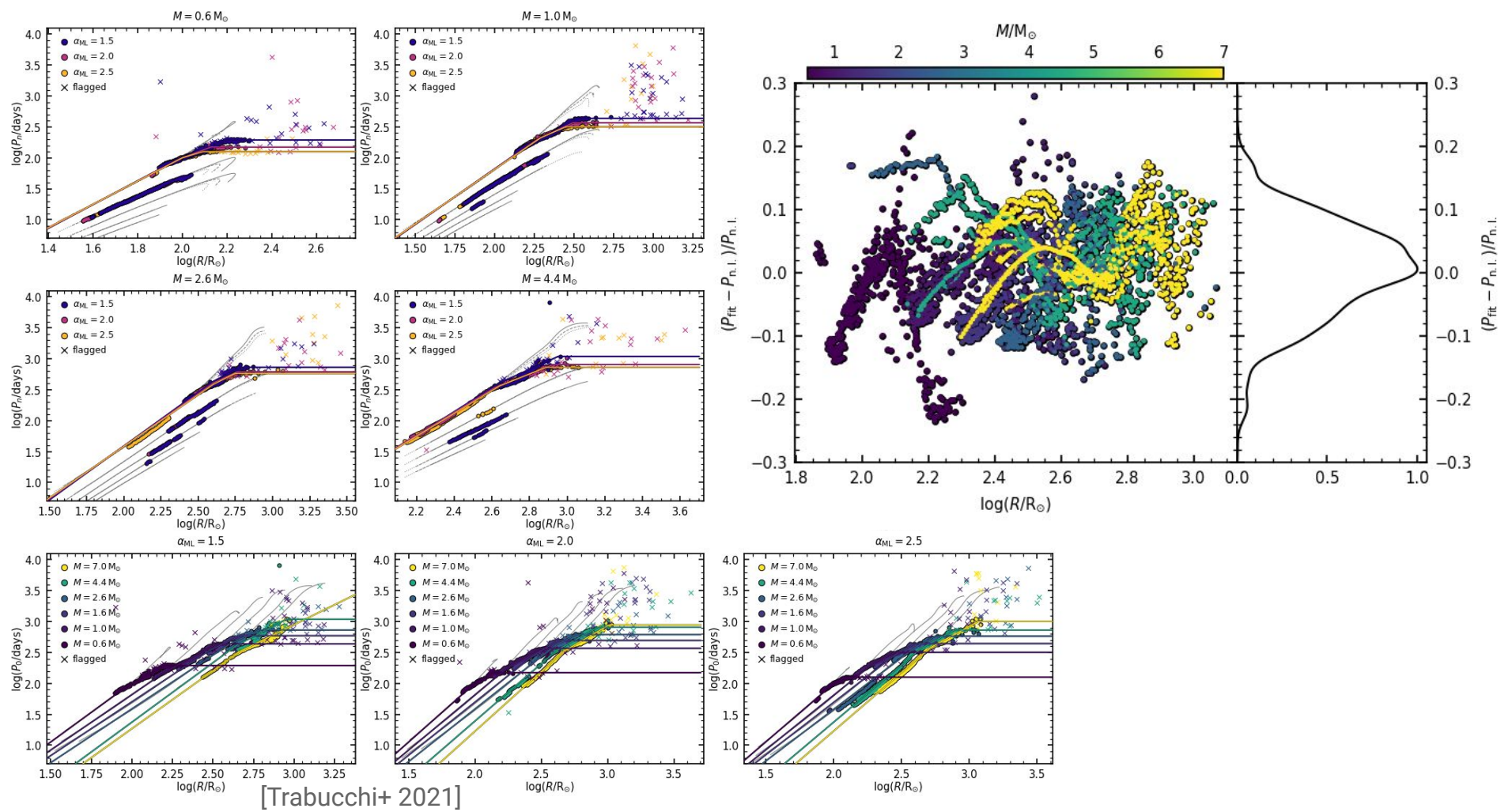
[Trabucchi+ 2021]



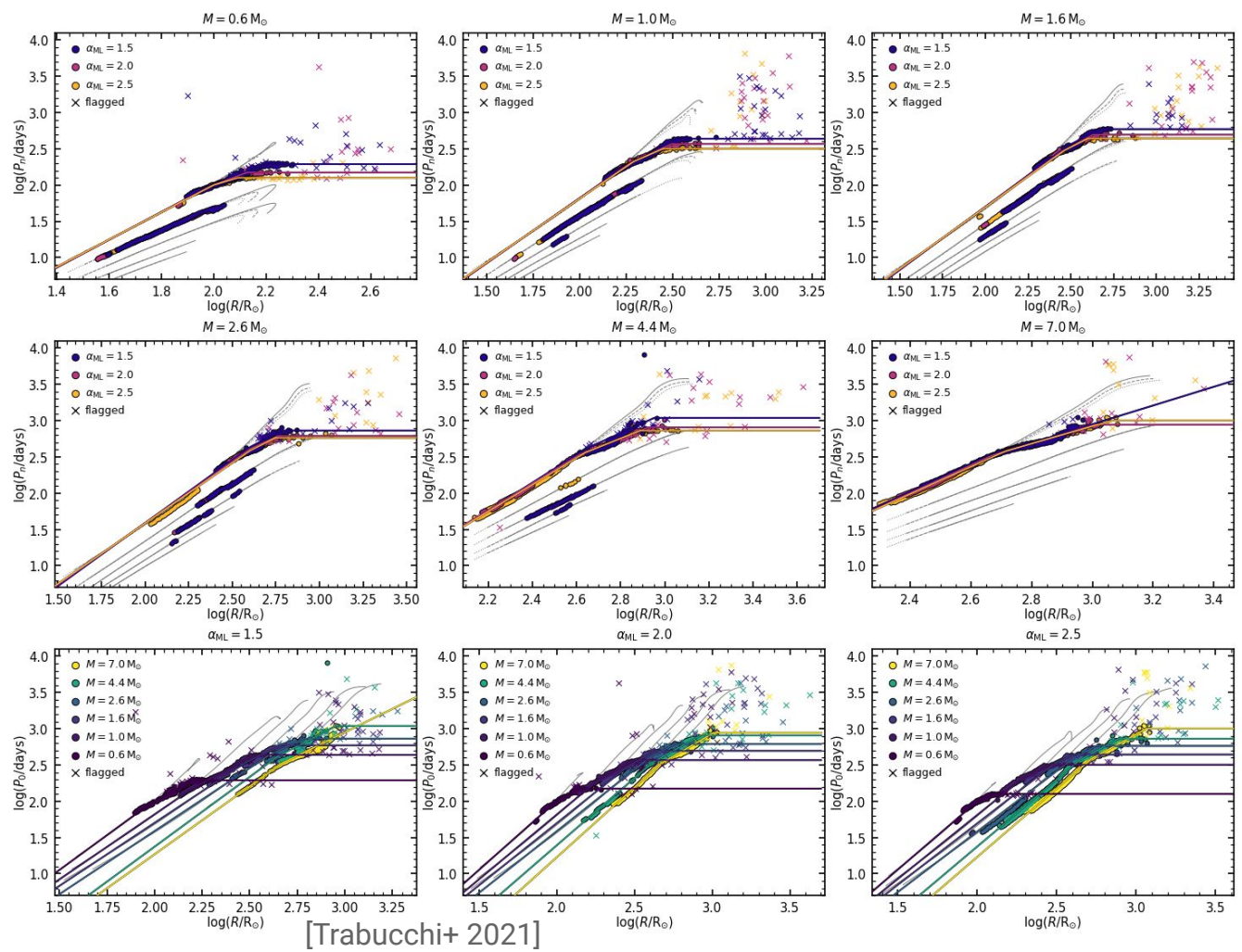
[Trabucchi+ 2021]



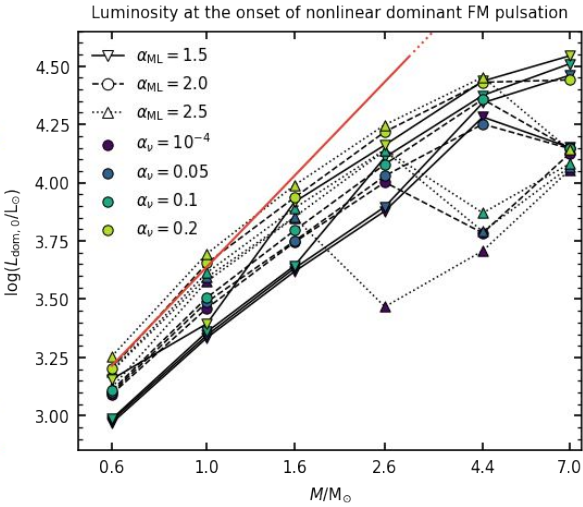
[Trabucchi+ 2021]

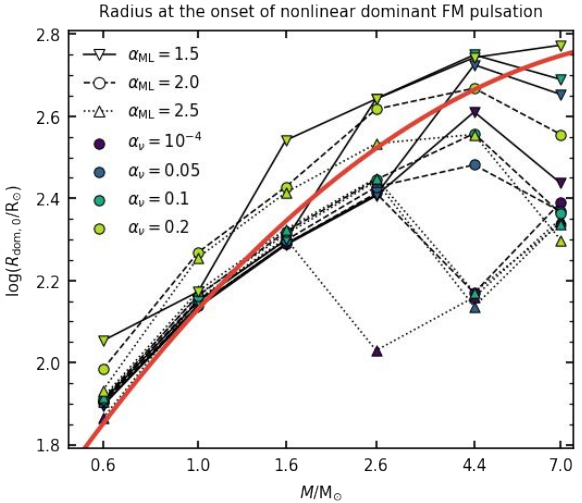


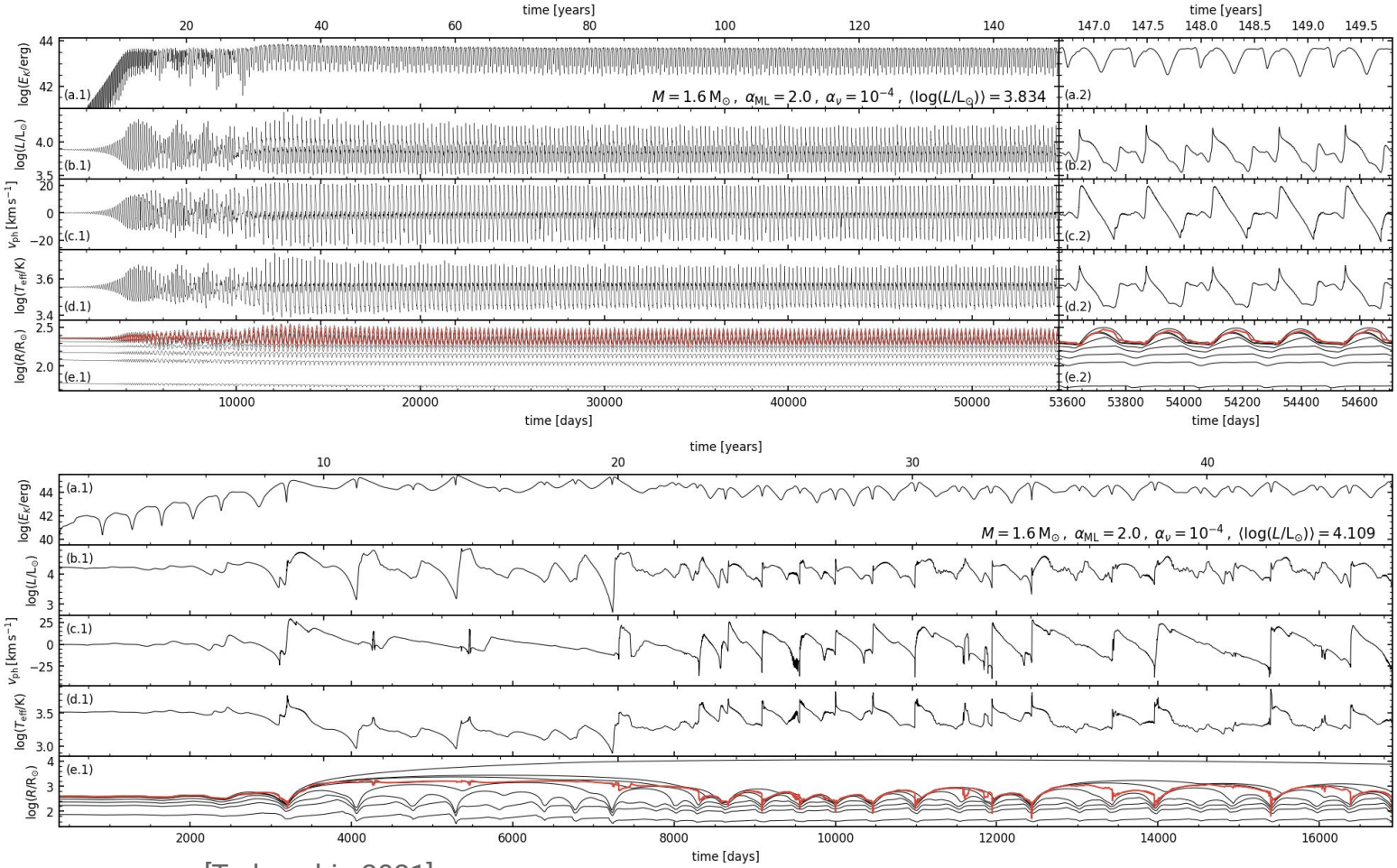
[Trabucchi+ 2021]



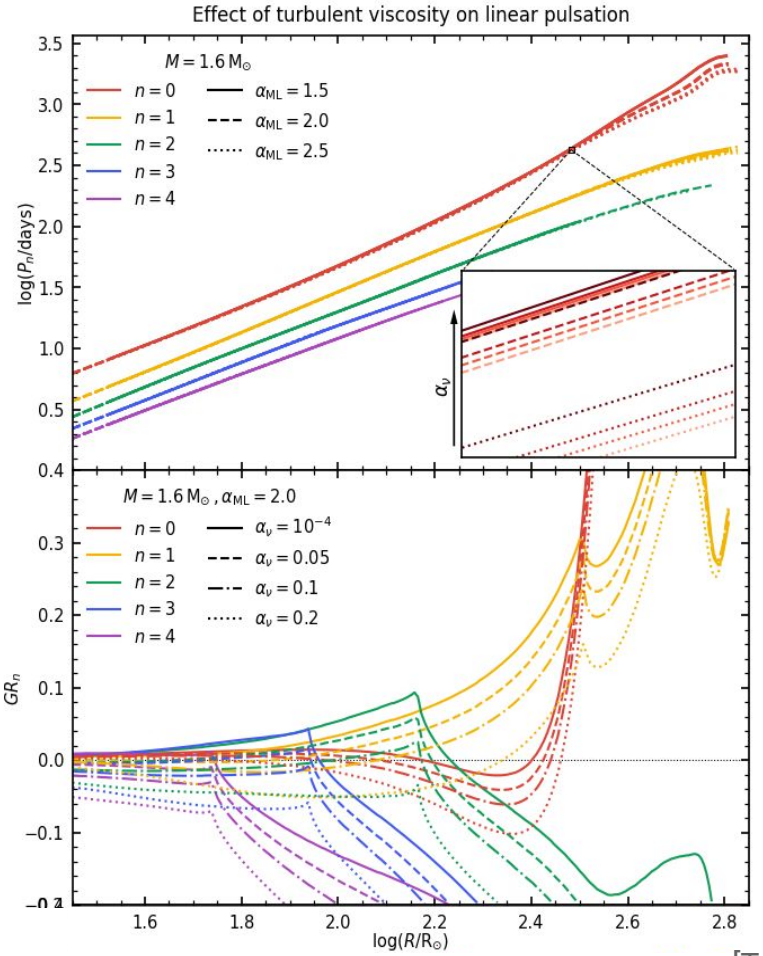
[Trabucchi+ 2021]

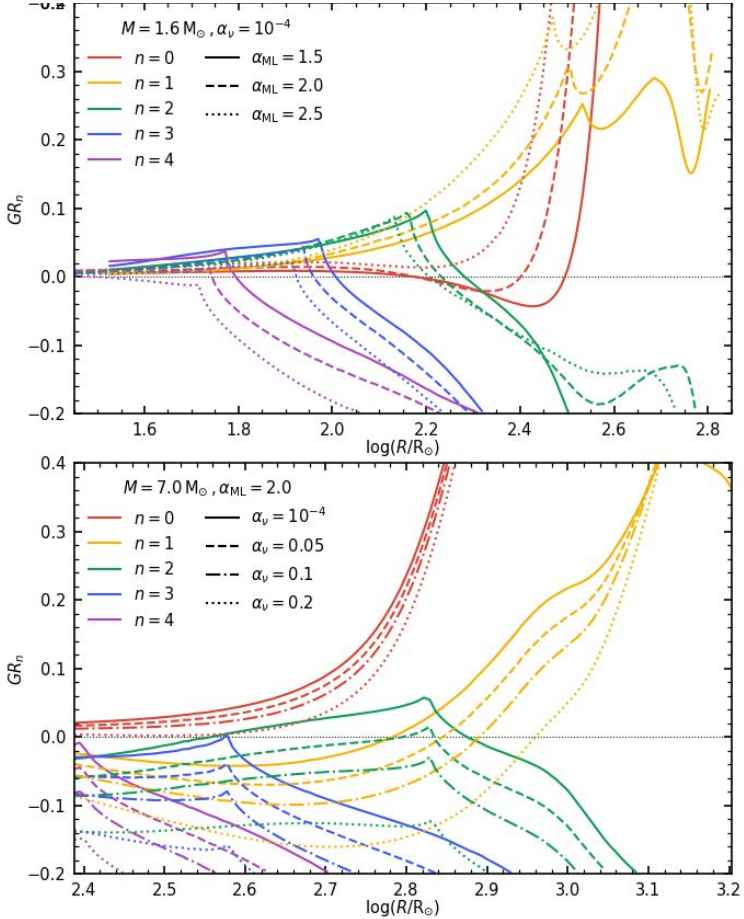




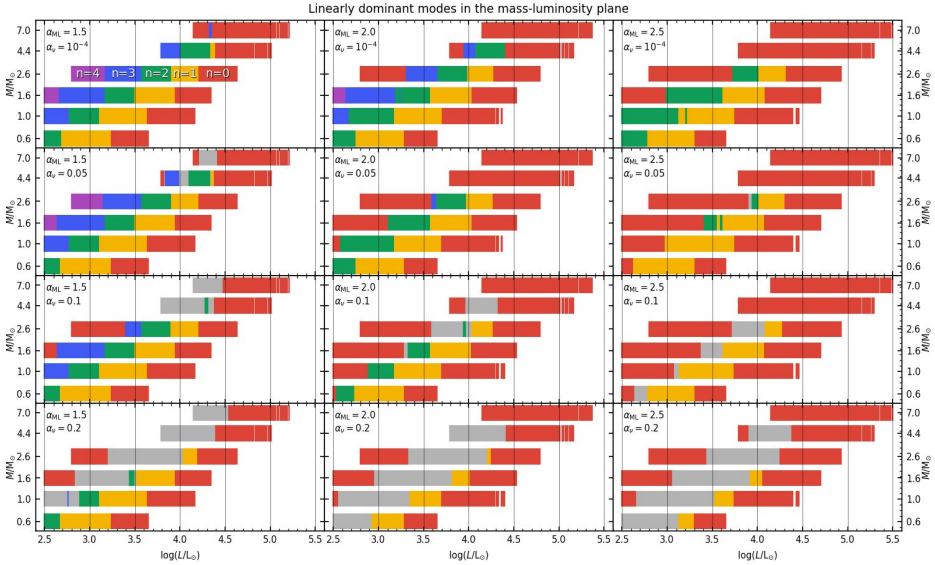


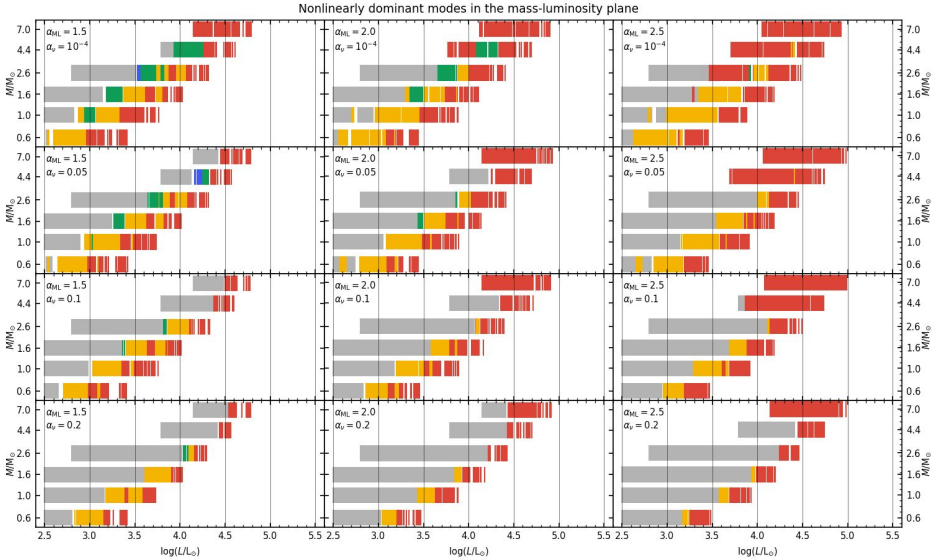
[Trabucchi+ 2021]



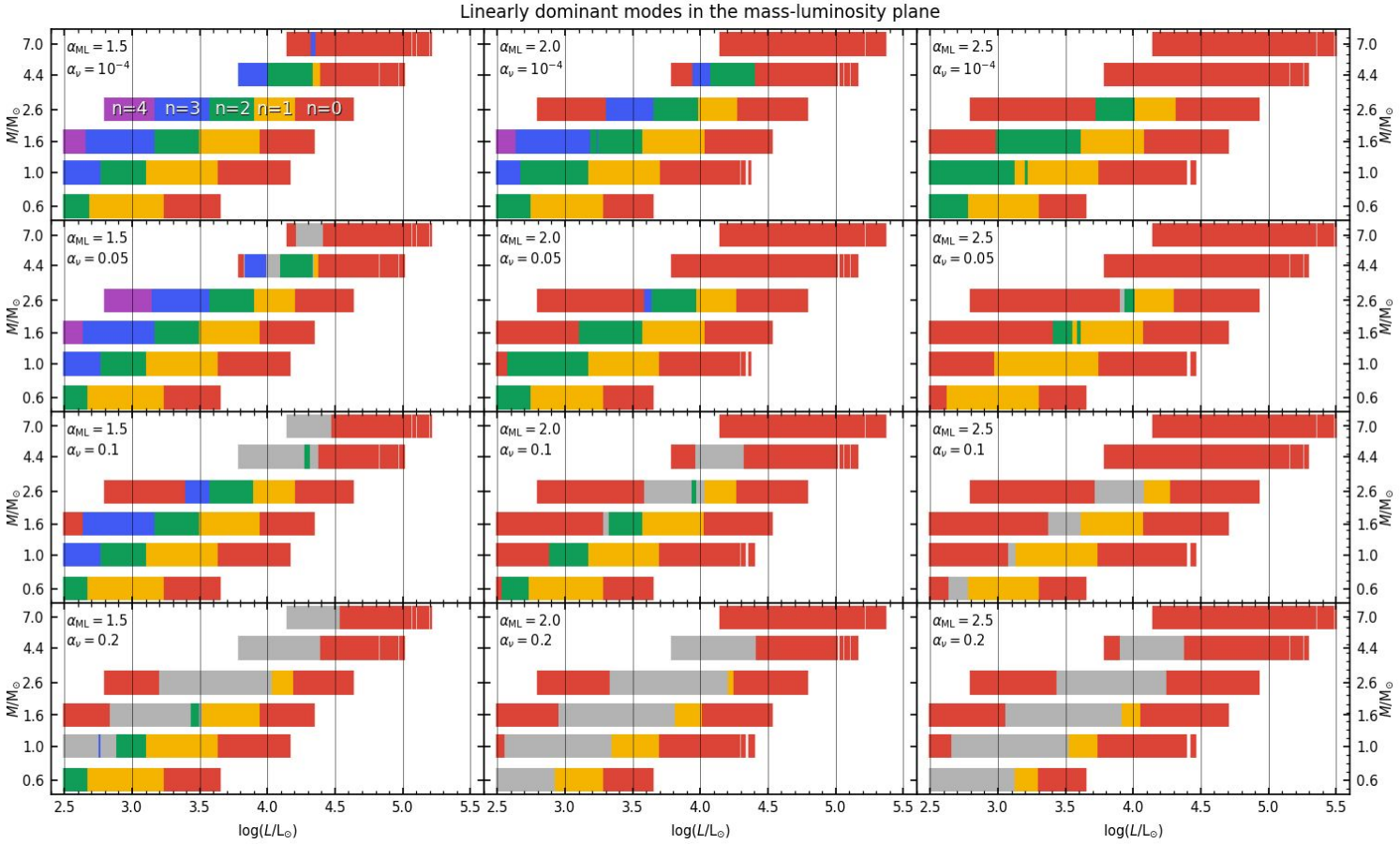


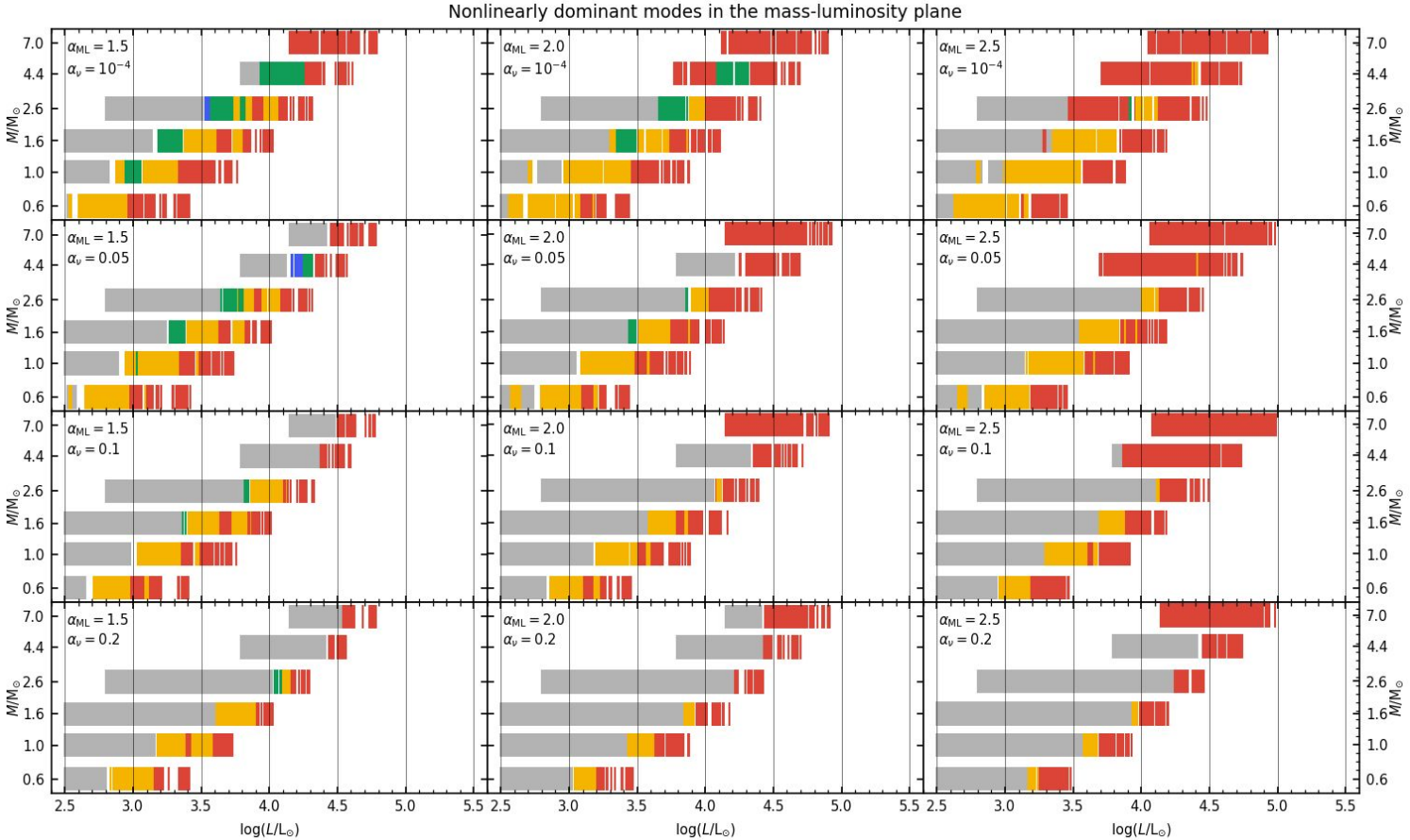
[Trabucchi+ 2021]





[Trabucchi+ 2021]


Linearly dominant modes in the mass-luminosity plane
$\alpha_{ML} = 1.5$
$\alpha_\nu = 10^{-4}$
n=4 n=3 n=2 n=1 n=0
$\alpha_{ML} = 2.0$
$\alpha_\nu = 10^{-4}$
$\alpha_{ML} = 2.5$
$\alpha_\nu = 10^{-4}$
$\alpha_{ML} = 1.5$
$\alpha_\nu = 0.05$
$\alpha_{ML} = 2.0$
$\alpha_\nu = 0.05$
$\alpha_{ML} = 2.5$
$\alpha_\nu = 0.05$
$\alpha_{ML} = 1.5$
$\alpha_\nu = 0.1$
$\alpha_{ML} = 2.0$
$\alpha_\nu = 0.1$
$\alpha_{ML} = 2.5$
$\alpha_\nu = 0.1$
$\alpha_{ML} = 1.5$
$\alpha_\nu = 0.2$
$\alpha_{ML} = 2.0$
$\alpha_\nu = 0.2$
$\alpha_{ML} = 2.5$
$\alpha_\nu = 0.2$
$M/M_\odot$
7.0
4.4
2.6
1.6
1.0
0.6
2.5
3.0
3.5
4.0
4.5
5.0
5.5
$\log(L/L_\odot)$



[Trabucchi+ 2021]