- Introduction: LPVs
- Gaia DR2
- Some applications
- Towards DR3
- Conclusions
Long-period variables

- Young to old
- Bright
- Numerous
- Period-luminosity relations

Ekström et al. (2012)
Long-period variables

OGLE II + III LPVs in the LMC

\[ W_{K_S, J-K_S} = K_S - 0.686 \ (J - K_S) \]

"Miras fundamental mode pulsation"
Long-period variables

- Intermediate-age
- Bright
- Numerous
- Period-luminosity relations

O-rich and C-rich

Long-period variables: RGB + AGB

Ekström et al. (2012)

Main sequence life times

Mowlavi et al. (2012)
Example 1: Merging events in the Galaxy

C stars from Mauron et al. + others

→ Sagittarius streams

see also, e.g.,
Ibata et al. 2001 (C-rich stars)
Majewski et al. 2003 (O-rich stars)
Example 2: Age gradients throughout the Galaxy

**O-rich Miras** from ASAS+Catalina

Shorter periods $\rightarrow$ older population

*(observational suggestion of an anti-correlation between period and age in Miras)*

*see also, e.g., Catchpole et al. (2016)*
Gaia DR2 catalogue of LPVs

Variability amplitude ($G$) $> 0.2$ mag

151'761 LPV candidates
(twice the number known)
DR2: aimed at **small contamination, not completeness**

**Number of observations:** \( N_{\text{obs}}(G) \geq 12, \ N_{\text{obs}}(G_{\text{RP}}) \geq 9 \)

**Variability amplitude:** Amplitude \( (G) \) > 0.2 mag

**Color:** \( G_{BP} - G_{RP} > 0.5 \) mag

**Mag-Color correlation:** Spearman\((G, G_{BP}-G_{RP}) > 0.5\)

**Smooth variability:** Abbe\((G) < 0.8\)

**Completeness:** \( \sim 8 \rightarrow 50\% \), depending on sky position

(compared to ASAS\_SN, OGLE)

**Contamination:** \( \sim \text{few } \% \) (mainly young stellar objects in solar vicinity)
Gaia DR2 catalogue of LPVs

% time coverage in light curves

Mowlavi et al. (2018)
% time coverage in light curves

Gaia DR2 catalogue of LPVs

Gaia DR2 2007803889830622080

Gaia DR2 4056560258474612480
Color-magnitude diagram

Median $G$ vs. $G_{BP} - G_{RP}$ for the Gaia DR2 catalogue of LPVs. The data is color-coded using $QR_5(G)$. The plot shows a wide distribution of points, indicating the diversity of LPVs in the Gaia era.

Mowlavi et al. (2018)
Loops in CM diagram

Gaia DR2 catalogue of LPVs

Mowlavi et al. (2018)
Gaia DR2 catalogue of LPVs

Gaia DR2 LPV candidates – time coverage in G $\geq$ 60%

Mowlavi et al. (2018)
2 Msun, log(g) = 0, [Fe/H] = –0.5

**O-rich**

Synthetic spectra from Aringer et al. (2009)

**C-rich**

Synthetic spectra from Aringer et al. (2016)
Gaia optical + 2MASS infrared

\[ W_{KS,J-KS} = K_S - 0.686 (J - K_S) \]

\[ W_{RP,BP-RP} = G_{RP} - 1.3 (G_{BP} - G_{RP}) \]
Lebzelter et al. (2018) have identified Gaia DR2 LPVs in the LMC. They have classified these LPVs into various sub-populations based on their optical and infrared properties:

- **C-rich AGB**
- **O-rich AGB**
  - **low-mass**
  - **intermediate-mass**
- **RSG and O-rich massive AGB**
- **RGB and faint AGB**

The Gaia optical + 2MASS infrared diagram shows the distribution of these LPVs in the color-magnitude diagram. The colors correspond to different sub-populations as indicated by the legend:

\[
W_{K_{s},J-K_{s}} = K_{s} - 0.686 \left(J - K_{s}\right)
\]

\[
W_{R_{P},B_{P}-R_{P}} = G_{R_{P}} - 1.3 \left(B_{P} - G_{R_{P}}\right)
\]
Lebzelter et al. (2018) investigated Gaia optical + 2MASS infrared data to identify AGB sub-populations in the Large Magellanic Cloud (LMC).

- **O-rich AGB**: classified as low-mass, intermediate-mass, and massive.
- **C-rich**: characterized as RGB and faint AGB.
- **Extreme C-rich**: includes RSG and O-rich massive AGB.

The diagrams illustrate color-magnitude relations with the following equations:

- \( W_{Ks,J-Ks} = K_s - 0.686 (J - K_s) \)
- \( W_{RP,BP-RP} = G_{RP} - 1.3 (G_{BP} - G_{RP}) \)
From **FULL** Gaia DR2

*Gaia* LPVs in **LMC** with $A_{\text{proxy}}(G) > 0.06$ from full DR2 archive

20'486 sources
10'989 in DR2 LPVs

Mowlavi et al. (2019)
AGB sub-populations

Metallicity dependence

From FULL Gaia DR2

Gaia LPVs in SMC with $A_{\text{proxy}}(G) > 0.06$ from full DR2 archive

3’208 sources

$K_s - 18.96$ [mag]

$W_{RP,BP-RP} - W_{K_s,J-K_s}$ [mag]

$A_{\text{proxy}}(G)$ [limited color scale]

→ Relatively more C-rich AGB stars in SMC than LMC

Mowlavi et al. (2019)
From FULL Gaia DR2

Gaia LPVs in Galaxy with $A_{\text{proxy}}(G) > 0.06$ from full DR2 archive

4'803 sources

→ Relatively less C-rich AGB stars in Galaxy than in LMC

Mowlavi et al. (2019)
AGB sub-populations

Metallicity dependence

From FULL Gaia DR2

Gaia LPVs in Galaxy with $A_{\text{proxy}}(G) > 0.06$ from full DR2 archive

12,820 sources

parallax better than 15%

$\rightarrow$ Relatively less C-rich AGB stars in Galaxy than in LMC

Mowlavi et al. (2019)
Period-Luminosity relations

**Gaia DR2 LPVs**

**O-rich AGBs**

in the LMC

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**Lebzelter et al. (2019)**

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Gaia advantage:
- wide luminosity range
  → intermediate-mass AGBs in the Clouds

**Higher masses**
- → shorter periods
  → but also higher \( T_{\text{eff}} \)

**In optical, TiO bands sensitive to \( T_{\text{eff}} \)**
- (not in infrared)
  → larger \( W_{\text{BP,RP}} \), compensating higher \( T_{\text{eff}} \)
- **DR2**: doubled the number of known large-amplitude LPVs

  N. Mowlavi, I. Lecoeur-Taïbi, T. Lebzelter et al., A&A 618, A58 (201)

- **What is expected for DR3?** *(to be confirmed…)*
  
  - **Higher completeness** while keeping small contamination
  
  - **Improved periods**
    
    → *multi-periodic characterization*
  
  - **C-rich identification**
    
    → *Gaia Image of the Week 15/11/2018* ([https://www.cosmos.esa.int/web/gaia/iow_20181115](https://www.cosmos.esa.int/web/gaia/iow_20181115))
O-rich versus C-rich giant stars

Andrae et al. (2018)
Towards DR3

Using *Gaia* **epoch** RP spectra

**T Aqr (O-rich)**  \( P = 203 \text{d} \)

*Gaia* Image of the Week
15/11/2018

![Graph showing TiO molecular bands](image)

- **Flux [e⁻ / s / sample]**
- **Pseudo-wavelength**
  - \((\sim 640 \text{ nm} \rightarrow \sim 1100 \text{ nm})\)
- **TiO molecular bands**

Nami Mowlavi, 2019-09-16

*LPVs in the Gaia era*
Towards DR3

Using *Gaia* **epoch** RP spectra

**RU Vir (C–rich)  P = 425d**

*Gaia* Image of the Week  
15/11/2018

O–rich versus C–rich giant stars

CH, C₂ molecular bands

Nami Mowlavi, 2019-09-16

LPVs in the Gaia era
C-star identification based on: **Gaia** optical + **2MASS** infrared
C-star identification based on: **Gaia ONLY!**

**Gaia Image of the Week (15/11/2018)**

- **O-rich versus C-rich giant stars**
- **Towards DR3**

**O-rich versus C-rich giant stars**

**Gaia DR2 LPVs in the LMC**

- **O-rich**
- **C-rich**

- **median($\Delta \lambda^*$) $\geq$ 7**
- **median($\Delta \lambda^*$) $\leq$ 7**

- **C-star identification based on: Gaia ONLY!**
Towards DR3

C-rich Mira RU Vir, period: 425 days

Towards DR3

Credit Animation: M. Trabucchi
Credit Data: ESA/Gaia/DPAC, the Gaia CU5 Cambridge and CU7 Geneva teams

O-rich versus C-rich giant stars

Animation available at: https://zenodo.org/record/3269780
- **DR2: 151’761 LPV candidates** with $G$ amplitudes > 0.2 mag
  → N. Mowlavi, I. Lecoeur-Taïbi, T. Lebzelter et al., A&A 618, A58 (201)

- Some developments based on *Gaia* DR2:
  - **Gaia + 2MASS: AGB sub-groups** identification
  - **Period-luminosity** relations, for *distance determinations*
  - **LPVs:** Powerful tool for *stellar population studies*
    → Studies in preparation…

- Towards DR3: **more LPVs, C&O-rich, additional attributes**
  → *work in progress within the Gaia consortium*