The roles of rotation and pulsation in the new B- and A-type periodic variables in NGC3766

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* New variable stars in NGC 3766: Reminder
  → Mowlavi et al. (2013, Paper I)

* VLT spectra: New insight
  → Mowlavi et al. (2016, submitted)
Stellar pulsation in the HR diagram

\[ \log T_{\text{eff}} \]

- **β Cep stars**: 0.1-0.6 d
- **SPB stars**: 0.5 - 5 d
- **δ Sct stars**: 0.02-0.25 d
- **γ Dor stars**: 0.3-1.7 d

Christensen-Dalsgaard (2004)
Stellar pulsation in the HR diagram

Christensen-Dalsgaard (2004)

No pulsation
Open cluster NGC 3766

14 - 30 My

Photom. survey 2002-2009
(1.2m Euler telescope, La Silla)

→ 2545 images in V'
  430 images in B'
  376 images in U'

ESO Press Release 1326 (2013)
Photom. survey 2002-2009
(1.2m Euler telescope, La Silla)

Open cluster NGC 3766
14 - 30 My

Mowlavi et al. (2013)
Previously reported periodic variables in the gap?

**Before Paper I** (not exhaustive)

* Maia stars (?)  
  Struve (1955), ... , Scholz et al. (1998)

* Individual stars  

* CoRoT  
  Yes, pulsation proposed (Degroote et al. 2009)

* Kepler  
  Yes, spots proposed (Balona 2013)

* NGC 7654  
  Yes, but not recognized as such (Luo et al 2012)

**Since 2013** (not exhaustive)

- Lata et al. (2014) “Main-sequence variable stars in young open cluster NGC 1893”
- Lata et al. (2016) “Variable stars in young open star cluster NGC 7380”
- Balona et al. (2016) “The hot γ Doradus and Maia stars"
Properties of the new group

Mowlavi et al. (2013)

**Period**

0.1 – ~0.5 d

**Amplitude**

<1 – ~5 mmag

Shorter than SPBs and longer than δ Scts

Limited by photometric precision → extends below mmag
Origin of variability?

Binary stars?
Role of rotation?

← multi-epoch $V_r$
← $v \times \sin(i)$
Origin of variability?

**Binary stars?**

**Role of rotation?**

\[ \leftarrow \text{multi-epoch } V_r \]

\[ \leftarrow v \sin(i) \]

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**Spectra** taken with VLT/Girafe (LR02 mode) for

- *all new variables*
- *SPB stars*
- *Many non-periodic stars* in same mag range

**Multi-epoch:** for each star, several spectra each night during three consecutive nights
Result 1: New variables form 2 groups
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**Group 1**
- \( P_1 > 0.55 \) d
- Small \( v \sin(i) \)

**Group 2**
- \( P_1 < 0.55 \) d
- Fast-rotators

**Rotation rates**

**Number of stars**

- \( P_1 > 0.55 \) d
- \( P_1 < 0.55 \) d

**Binaries**

**SPB**

**Hybrid**

Mowlavi et al. (2016)
Result 1: New variables form 2 groups

Mowlavi et al. (2016)

NGC 3766

Rotation rates

SPB

FaRPB

δ Scuti

γ Dor

Mowlavi et al. (2016)
Result 1: New variables form 2 groups

Rotation rates

Mowlavi et al. (2016)

NGC 3766

SPB

FaRPB

δ Scuti

γ Dor

Fast Rotating Periodic B-type

$P_{\text{phot}}$(d)

$V'(\text{mag})$

$\nu_{\text{phot}}$(d)

$\nu\sin(i)$(km/s)

small $\nu\sin(i)$

Mowlavi et al. (2016)
Expected amplitude of RV variations

SPBs: $A_{\nu r} \leq 7 \text{ km/s}$

$\beta$ Ceps: $A_{\nu r} \leq 20 \text{ km/s}$

→ Binary if $A_{\nu r} \geq 20 \text{ km/s}$

Identification of binaries

$V_r \rightarrow \text{Binarity?}$

de Cat (2002)

SPBs

\[ A_{H_p} \text{ (mmag)} \]
\[ A_{\nu r} \text{ (km/s)} \]

\[ A_{H_p} \text{ (mmag)} \]
\[ A_{\nu r} \text{ (km/s)} \]
Identification of binaries

NGC 3766

Mowlavi et al. (2016)

Binary stars

\( Q_{RV} \) (km/s)

\( \nu_{sin i} \) (km/s)

Binar

ies

Mowlavi et al. (2016)
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NGC3766–154: $P_{\text{phot}} = 0.80672$ d [ $P_{\text{orb}} \gg 3$ d ]

NGC3766–278: $P_{\text{phot},1} = 0.62115$ d, $P_{\text{phot},2} = 0.199088$ d [ $P_{\text{orb}} = 2P_{\text{phot},1}$ ]

NGC3766–364: $P_{\text{phot}} = 0.91772$ d [ $P_{\text{orb}} = 2P_{\text{phot}}$ ]

NGC3766–107: $P_{\text{phot}} = 4.536$ d [ $P_{\text{orb}} = P_{\text{phot}}$ ]

Identification of binaries

Mowlavi et al. (2016)
Result 1: New variables form 2 groups

Rotation rates

Mowlavi et al. (2016)

NGC 3766

SPB

FaRPB

γ Dor

δ Scuti

Mowlavi et al. (2016)
Result 2: New Period-Luminosity relation

\[
\log(P_{\text{phot}}) = (-0.11 \pm 0.01) (V - 12) - (0.449 \pm 0.006)
\]
(solid line)
Result 2: New Period-Luminosity relation

Cepheid-like pulsation mechanism?

\[ P_{\text{puls}} \propto \frac{1}{\sqrt{\rho}} \quad L \propto M^\alpha \quad R \propto M^\beta \quad V \approx 0.6M_{\text{bol}} + \text{cte} \]

\[ \log(P_{\text{puls}}) \approx -\frac{3\beta - 1}{3\alpha} V + \text{cte} \approx -0.044 V + \text{cte} \]

(dotted line)

Marginal agreement

\( P_{\text{phot}} \) (d) vs. \( V' \) (mag)

NGC 3766

FaRPB stars with \( v \sin i \geq 250 \text{ km/s} \)
Result 2: New Period-Luminosity relation

Rotation-related?

\[ P_{\text{rot}} = \frac{2 \pi R_{\text{eq}}}{v} \]

\[ L \propto M^\alpha \]

\[ R \propto M^\beta \]

\[ V \approx 0.6 M_{\text{bol}} + \text{cte} \]

\[ \alpha \approx 3.8, \beta \approx 0.5 \]

\[ \Rightarrow \log(P_{\text{rot}}) \approx -\frac{2}{3} \beta V + \text{cte} \approx -0.088 V + \text{cte} \]

(dashed line)

Better agreement

+ factor of 2 between the two sequences
Result 2: New Period-Luminosity relation

Rotation rates from model predictions

Geneva isochrones

$\log(\text{age}[\text{y}]) : 7.4$  
$d = 2.3 \text{ kp}$

NGC 3766

FaRPB stars

$P_{\text{phot}} (d)$

$v \sin i$ (km/s)

$V'$ (mag)
\[ \omega_{\text{obs}} \approx \omega_{\text{corot}} - m\Omega \quad (m: \text{azimuthal order}) \]

Fast-rotating stars:
\[ \omega_{\text{corot}} \ll \Omega \quad \text{for prograde sectoral modes (} m = -\ell \text{)} \]
(e.g. Townsend 2005, Salmon et al. 2014)

\[ \rightarrow \omega_{\text{obs}} \approx -m\Omega \]
Result 2: New Period-Luminosity relation

Origin: Pulsation in fast rotating stars?

FaRPB stars = Fast Rotating Periodic B-type stars

Pulsating
Conclusions

- All new variables with $P < 0.5\,\text{d}$ are fast rotators
  $\rightarrow$ **FaRPB stars** (**Fast Rotating Pulsating B-type**) stars

- They obey a **new P-L relation**
  $\rightarrow$ 2 sequences (maybe 3)
    Most probably prograde sectoral modes at $\ell = 1$ and 2

Details in Mowlavi et al. (2016, submitted)