VARIABILITY OF GAMMA CAS

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Outline

- **Spectroscopy (Ground)**
  - Be Star Spectra

- **Photometry**
  - SMEI
  - BRITE

- **Spectroscopy (Space)**
  - HST
SPECTROSCOPY

Ground based
BeSS Database

• **Be Star Spectra**

• Professional and amateur observers

• Ground based

• 371 spectra over 11 years (2006-2017)

• High resolution ~15 000

Neiner et. al. 2011
http://basebe.obspm.fr
BeSS – Binned profile
Orbital period (203.5 days): Nemravová+2012

BESS - POWER SPECTRUM

Orbital frequency + 1 c/y

Orbital frequency

1 c/y

Orbital frequency – 1 c/y
DISK STRUCTURE

The presence of a companion can create spiral structure in the disk.

Credit: D. Panoglou+2016 (fig.4)
PHOTOMETRY
Space – SMEI & BRITE
SMEI
Solar Mass Ejection Imager
SMEI SATCHELITE

- **Solar mass ejection imager (2003-2011/UK/USA)**
- **Three cameras of** $3 \times 60 \text{ deg}^2$
- **Combined field of view of** $3 \times 160 \text{ deg}^2$
- **Observes full sky every** $\sim 102 \text{ min}$
- **Long baseline of 8 years** Very noisy data
TIME SERIES - SMEI

SMEI data before reduction

SMEI data after reduction
POWER SPECTRUM - SMEI

Period from this work: \(1.2162(1)\) days or \(0.82224(7)\) c/d
Period from Henry+2012: \(1.215811(30)\) days

Separate cameras

Full SMEI dataset
VARIATION - HENRY+2012

Credit: G. Henry & M. Smith 2012
AMPLITUDE VARIATION 0.82 C/D

HENRY+2012

SMEI

2003-2007

2008-2011

Credit: G. Henry & M. Smith 2012 (fig 6.)
BRITE CONSTELLATION

- **BRIGHT Target Explorer (2015-/at/ca/pl)**
- **5 Nano satellites - 20 x 20 cm**
- **2 with blue filter, 3 with red filter**
- **Orbital period of ~100 min**
- **Very detailed but only half year light curves**

Image credit: TU Graz
Period of 2.480(4) c/d or ~9.7 hours
FIT RESULTS - BRITE

Average period of 9.677(15) hours or 2.480(4) c/d
PHASE FOLDED TIME SERIES - BRITE

2.48 c/d or 9.7 hours
HUBBLE SPACE TELESCOPE

GODDARD HIGH-RESOLUTION SPECTROGRAPH (GHRS)

MARCH 1996
Example of time series of wavelength bin

For more detailed analysis see: Smith+1999
CROSS CORRELATION

BRITE: 2.48 c/d
CROSS CORELATION

BRITE: 2.48 c/d  Random 2.76 c/d
POWER SPECTRA COMPARISON
FREQUENCY COMPARISON

Ratio: \[ \frac{2.480(4)}{0.82224(7)} = 3.016(5) \]
Doppler shift due to Be or WD is not distinguishable

ORIGIN OF VARIABILITY

Power spectrum for BAb2017
CONCLUSION

- Spectroscopy
  - Binary period of 203.5 days confirmed
  - Convex/concave asymmetry of spiral arm

- Photometry
  - 0.82 c/d period and fading confirmed with SMEI
  - New 2.48 c/d period found with varying amplitude
    - Cannot be rotation
    => Impacts interpretation of 0.82 c/d being rotation
Gamma Cas (1997–2017)
B Filter, Normalized, 3–Sigma Filter
(Search for BRITE 2.4718 c/d Freq.)

\[ N_{\text{obs}} = 5371 \quad \text{Mean} = -4.38907 \quad \sigma = .00753 \]

\[ f = 2.4794500 \pm .0000015 \text{ c/d} \]
\[ P = .4033153 \pm .0000002 \text{ days} \]

\[ T_{\text{min}} = 50711.7173 \quad \text{Mean} = -4.38910 \quad \text{Period} = .403315 \]
\[ \text{Full Amp} = .00169 \pm .00029 \text{ (5.8)} \quad \text{rms} = .00691 \]
Gamma Cas (1997–2017)
V Filter, Normalized, 3–Sigma Filter
(Search for BRITE 2.4718 c/d Freq.)

\[ N_{\text{obs}} = 5329 \quad \text{Mean} = -3.63712 \quad \sigma = 0.00853 \]

\[ f = 2.4794650 \pm 0.0000015 \, \text{c/d} \]
\[ P = 0.4033128 \pm 0.0000002 \, \text{days} \]

\[ T_{\text{min}} = 50719.0161 \quad \text{Mean} = -3.63718 \quad \text{Period} = 0.403313 \]

\[ \text{Full Amp} = 0.00153 \pm 0.00033 \, (4.6) \quad \text{rms} = 0.00783 \]
Gamma Cas (1997–2004)
B Filter, Normalized, 3–Sigma Filter
(Search for BRITE 2.4718 c/d Freq.)

$N_{\text{obs}} = 2846$, Mean = $-4.38920$, $\sigma = .00786$

$\Delta \text{Mag}$

HJD - 2,400,000 (UTC)

$f = 2.4766050 +/-.0000040 \text{ c/d}$
$P = .4037786 +/-.0000007 \text{ days}$

Reduction Factor

Trial Frequency (c/d)

$T_{\text{min}} = 50712.0261$, Mean = $-4.38926$, Period = $.403779$

$\Delta \text{Mag}$

Photometric Phase

Full Amp = $0.00210 +/-.00041 \text{ (5.1)}$, rms = $0.00721$
Gamma Cas (2012–2017)
B Filter, Normalized, 3–Sigma Filter
(Search for BRITE 2.4718 c/d Freq.)

\[ \Delta \text{Mag} \]

\[ N_{\text{obs}} = 632 \quad \text{Mean} = -4.38922 \quad \sigma = .00595 \]

\[ \text{HJD} - 2,400,000 \text{ (UTC)} \]

\[ f = 2.4794480 \pm .0000110 \text{ c/d} \]
\[ P = .4033156 \pm .0000018 \text{ days} \]

\[ \text{Reduction Factor} \]

\[ T_{\text{min}} = 56077.0336 \quad \text{Mean} = -4.38920 \quad \text{Period} = .403316 \]

\[ \text{Full Amp} = .00326 \pm .00066 \quad (5.0) \quad \text{rms} = .00539 \]

\[ \Delta \text{Mag} \]

\[ \text{Photometric Phase} \]
Gamma Cas (2012–2017)
V Filter, Normalized, 3-Sigma Filter
(Search for BRITE 2.4718 c/d Freq.)

$N_{\text{obs}} = 601$, $\text{Mean} = -3.63777$, $\sigma = .00638$

\[ \Delta \text{Mag} \]

\[ \text{HJD} - 2,400,000 \ (\text{UTC}) \]

\[ f = 2.4793850 +/-.0000120 \ \text{c/d} \]
\[ P = .4033258 +/-.0000020 \ \text{days} \]

\[ \rightarrow \]

\[ \text{Reduction Factor} \]

\[ \text{Trial Frequency (c/d)} \]

\[ T_{\min} = 56076.9779 \quad \text{Mean} = -3.63782 \quad \text{Period} = .403326 \]

\[ \Delta \text{Mag} \]

\[ \text{Photometric Phase} \]

\[ \text{Full Amp} = .00363 +/-.00072 \ (5.0) \quad \text{rms} = .00577 \]
Gamma Cas (2005–2011)
B Filter, Normalized, 3–Sigma Filter
(Search for BRITE 2.4718 c/d Freq.)

\[ \Delta M_{\text{ag}} \]

-4.42
-4.4
-4.38
-4.36

HJD - 2,400,000 (UTC)

\[ N_{\text{obs}} = 1857 \quad \text{Mean} = -4.38883 \quad \sigma = 0.00705 \]

\[ f = 2.4797450 \pm 0.0000050 \text{ c/d} \]
\[ P = 0.4032673 \pm 0.0000008 \text{ days} \]

\[ T_{\text{min}} = 53527.3302 \quad \text{Mean} = -4.38885 \quad \text{Period} = 0.403267 \]

\[ \text{Full Amp} = 0.00248 \pm 0.00046 \text{ (5.4)} \quad \text{rms} = 0.00645 \]

\[ \Delta M_{\text{ag}} \]

-4.42
-4.4
-4.38
-4.36

Photometric Phase

0.0 0.2 0.4 0.6 0.8 1.0 0.0 0.2 0.4 0.6 0.8 1.0
Gamma Cas (2005–2011)
V Filter, Normalized, 3–Sigma Filter
(Search for BRITE 2.4718 c/d Freq.)

\( N_{\text{obs}} = 1829 \quad \text{Mean} = -3.63708 \quad \sigma = .00781 \)

\[ f = 2.4797790 \pm .0000050 \text{ c/d} \]
\[ P = .4032617 \pm .0000008 \text{ days} \]

\[ T_{\text{min}} = 53527.3401 \quad \text{Mean} = -3.63713 \quad \text{Period} = .403262 \]

\( \Delta \text{Mag} \)

\[ \text{Full Amp} = .00214 \pm .00052 (4.1) \quad \text{rms} = .00717 \]
POWER SPECTRUM

\[ P_i = A_i^2 = \alpha^2 + \beta^2 \]

\[ \alpha = (sc_2 - cx)/(s_2c_2 - x^2) \]
\[ \beta = (cs_2 - sx)/(s_2c_2 - x^2) \]

\[ c = \sum w_j x_j \cos(\omega_i t_j) \]
\[ s = \sum w_j x_j \sin(\omega_i t_j) \]
\[ c_2 = \sum w_j \cos^2(\omega_i t_j) \]
\[ s_2 = \sum w_j \sin^2(\omega_i t_j) \]
\[ x = \sum w_j \sin(\omega_i t_j) \cos(\omega_i t_j) \]

\((t_j, x_j)\) are the data points, \(w_j\) the corresponding weight and \(\omega_i\) the frequency.

See Kjeldsen 1992 and Frandsen+1995
AMPLITUDE DECLINE - SMEI

[Graph showing amplitude decline with time and frequency]
BRITE FOLDED WITH 1.21 DAYS