Multisite photometric and spectroscopic campaign of the magnetic β Cep star V2052 Ophiuchi

Handler et al. 2012, MNRAS, 424, 2380

Briquet et al. 2012, MNRAS, 427, 483

B2IV/V

vsini ~ 60 km s^{-1}

Weak magnetic field — Neiner et al. 2003, A&A, 411, 565

B_{pol} ~ 400 G — Neiner et al. 2012, A&A, 537, 148

Dominant radial mode with f = 7.145 d^{-1}

Non-radial mode with f = 6.82 d^{-1} and ℓ = 3 or 4

Rotation period P_{rot} = 3.64 d — Neiner et al. 2003, A&A, 411, 565

T_{eff} = 23000 ± 1000 K

log g = 4.0 ± 0.2

Slightly enriched in He

Mild N excess — Morel et al. 2006, A&A, 457, 651

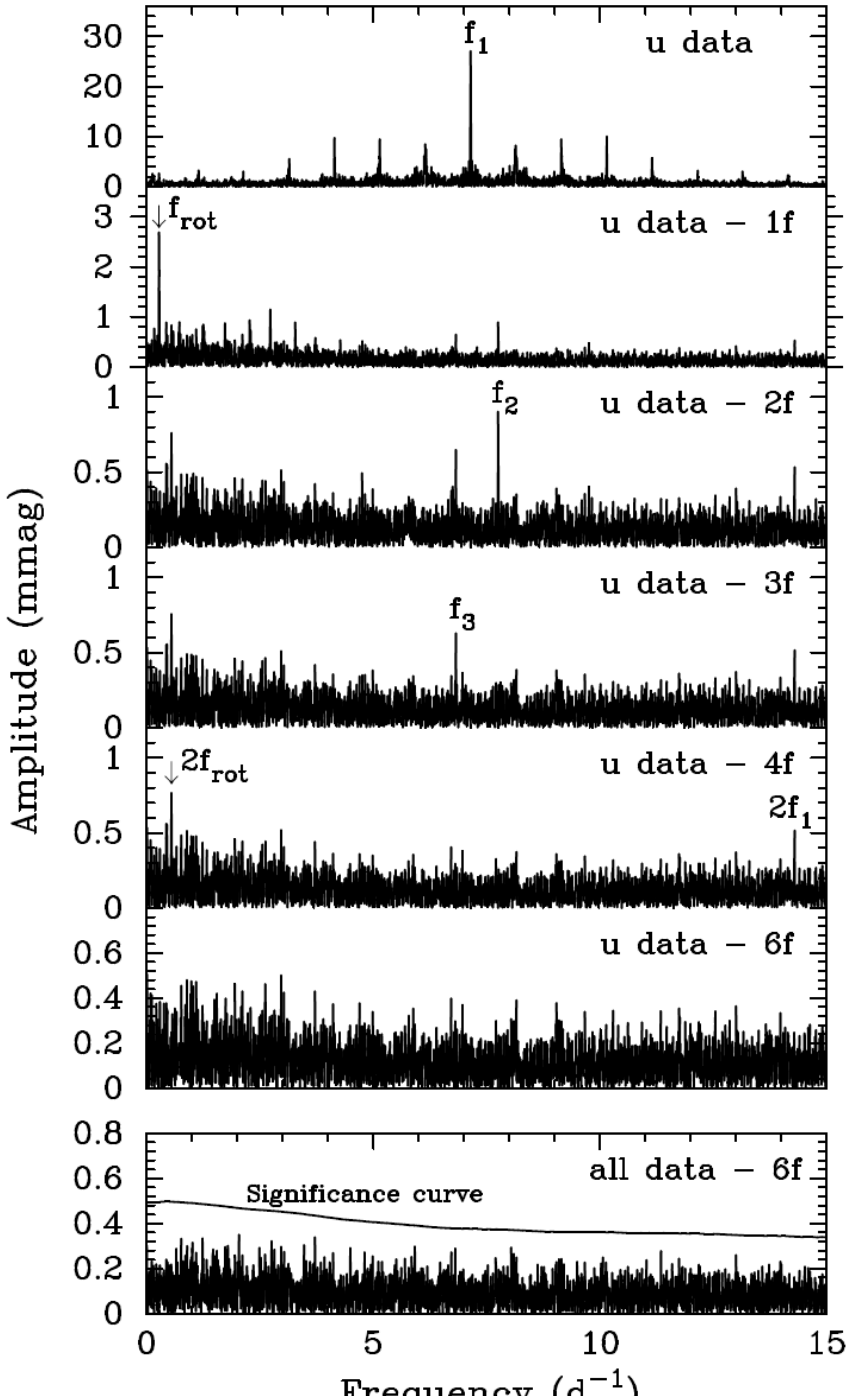
Multisite multicolour photometry

Observatory	Telescope	Amount of data Nights	hours	Filter(s)	Observer(s)
Tübitak National Observatory, Turkey	0.5m	2	6.1	V	TS
South African Astronomical Observatory	0.5m	13	50.3	uvy	EG, BN
South African Astronomical Observatory	0.75m	7	30.5	uvy	GH
South African Astronomical Observatory	0.5m	9	35.0	uV	TT
Piszkéstető Observatory, Hungary	0.5m	3	9.2	V	DL
Sierra Nevada Observatory, Spain	0.9m	4	19.7	uvby	ER
Roque de los Muchachos Observatory, Spain	1.2m Mercator	49	155.2	Geneva	KU, MB, HW, GR, AM, CB, BV
Fairborn Observatory, USA	0.75m APT	55	198.7	uvy	−−
Siding Spring Observatory, Australia	0.6m	40	168.9	uvy	RRS
Total		182	673.6		

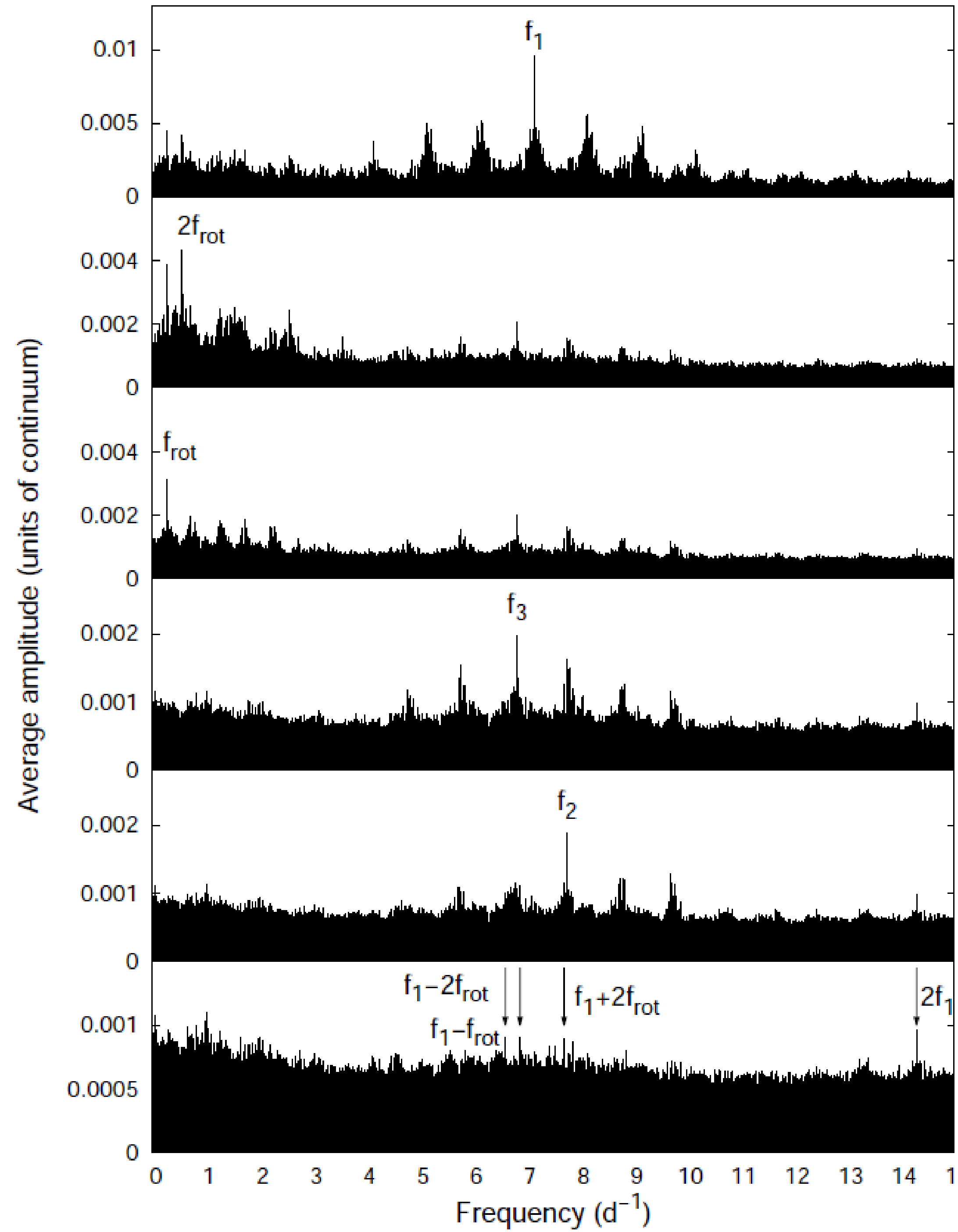
Multisite high-resolution high S/N spectroscopy

Observatory (Name of the instrument; resolution; wavelength range in Å)	Telescope	Julian Date Begin	End	Data amount and quality ΔT	N	S/N	Observer(s)
2000-2004		−2450000					
Pic du Midi, France (MUSICOS; 35 000; 4489–6619)	2.0-m TBL	1730	3186	1457	161	165	CN, HH, VG, AH, AT
2004		−2450000					
Pico dos Dias Observatory, Brazil (Esp Coudé; 30 000; 4479–4644)	1.6-m	3200	3201	2	20	290	AB
Complejo Astronómico El Leoncito Observatory, Argentina (EBASIM; 40 000; 3826–5759)	2.1-m	3219	3221	3	20	103	OP
Bohyunsan Astronomical Observatory, Korea (BOES; 50 000; 3751–9803)	1.8-m	3133	3161	29	37	186	DM, BL
Dominion Astrophysical Observatory, Canada (45 000; 4457–4603)	1.2-m	3134	3197	64	53	213	SY
McDonald Observatory, USA (Coudé; 60 000; 3619–10274)	2.7-m	3195	3198	4	105	215	GH, ME
Okayama Astrophysical Observatory, Japan (HIDES; 68 500; 3991–4815)	1.88-m	3202	3228	27	119	144	EK
Thüringer Landessternwarte Tautenburg, Germany (67 000; 3700–5416)	2-m	3142	3219	77	215	116	HL
La Silla Observatory, Chile (CORALIE; 50 000; 3876–6820)	1.2-m Euler	3072	3282	211	60	104	KU, KL, JV
Mount John University Observatory, New Zealand (HERCULES; 70 000; 4456–7150)	1.0-m	3154	3193	40	88	152	DW
Observatorio Astronómico Nacional at San Pedro Mártir, México (Echelle Spectrograph; 20 000; 3781–6893)	2.1-m	3205	3211	7	637	282	RC, JE
2007-2010		−2450000					
Pic du Midi, France (NARVAL; 65 000; 3694–10484)	2.0-m TBL	4286	5403	1118	44	389	YF, CM, OT
Total				3674	1559		

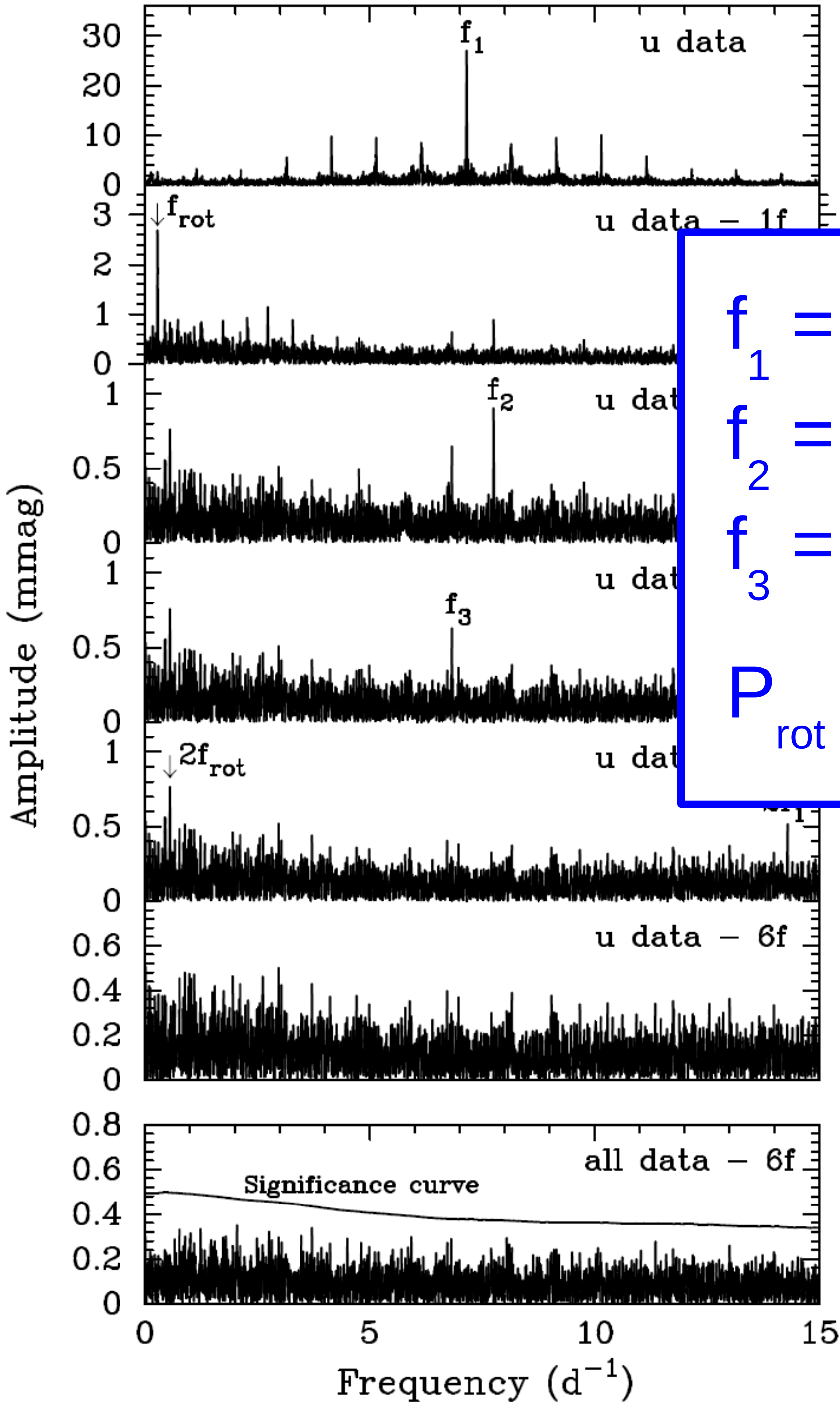
Photometry



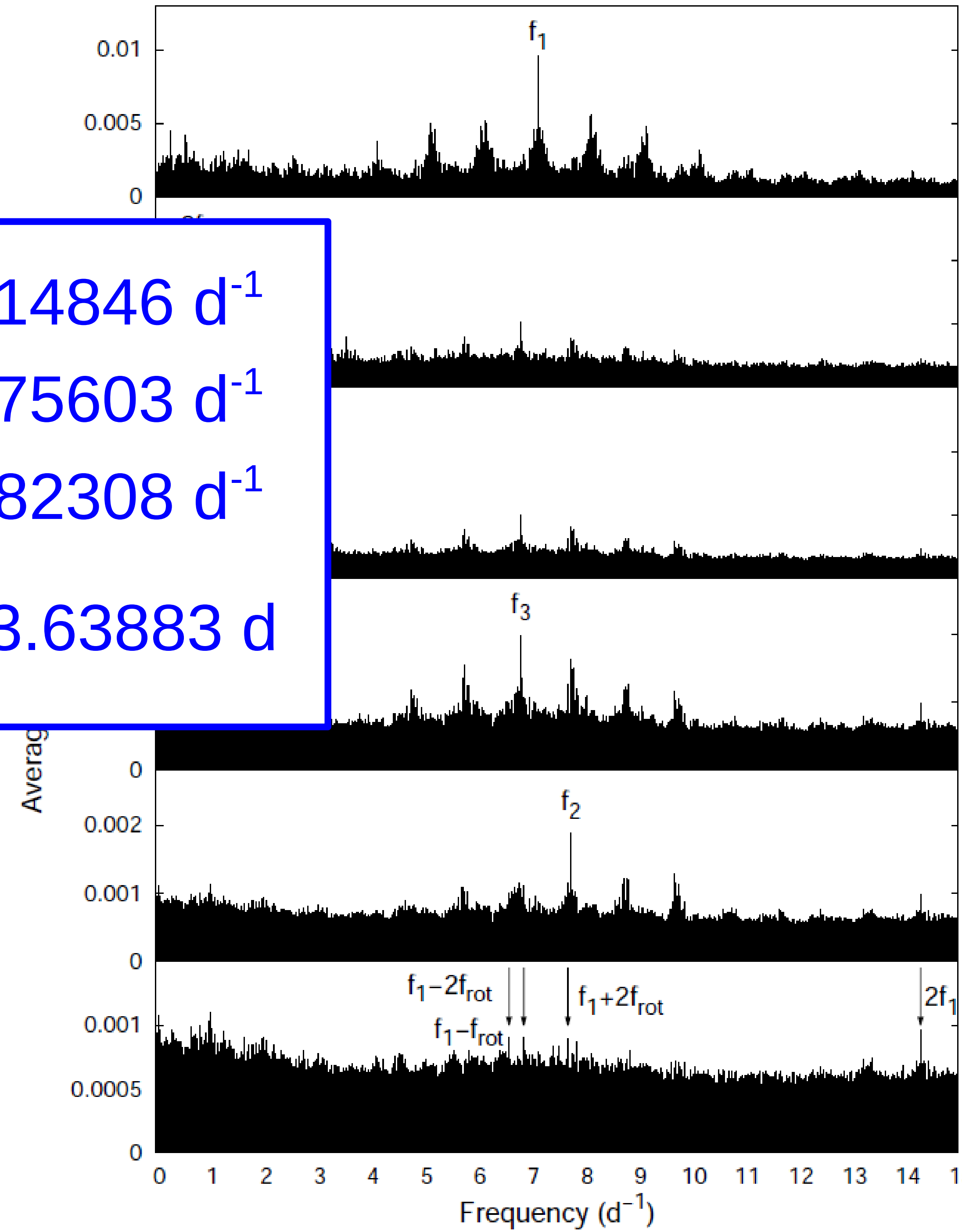
Spectroscopy



Photometry



Spectroscopy



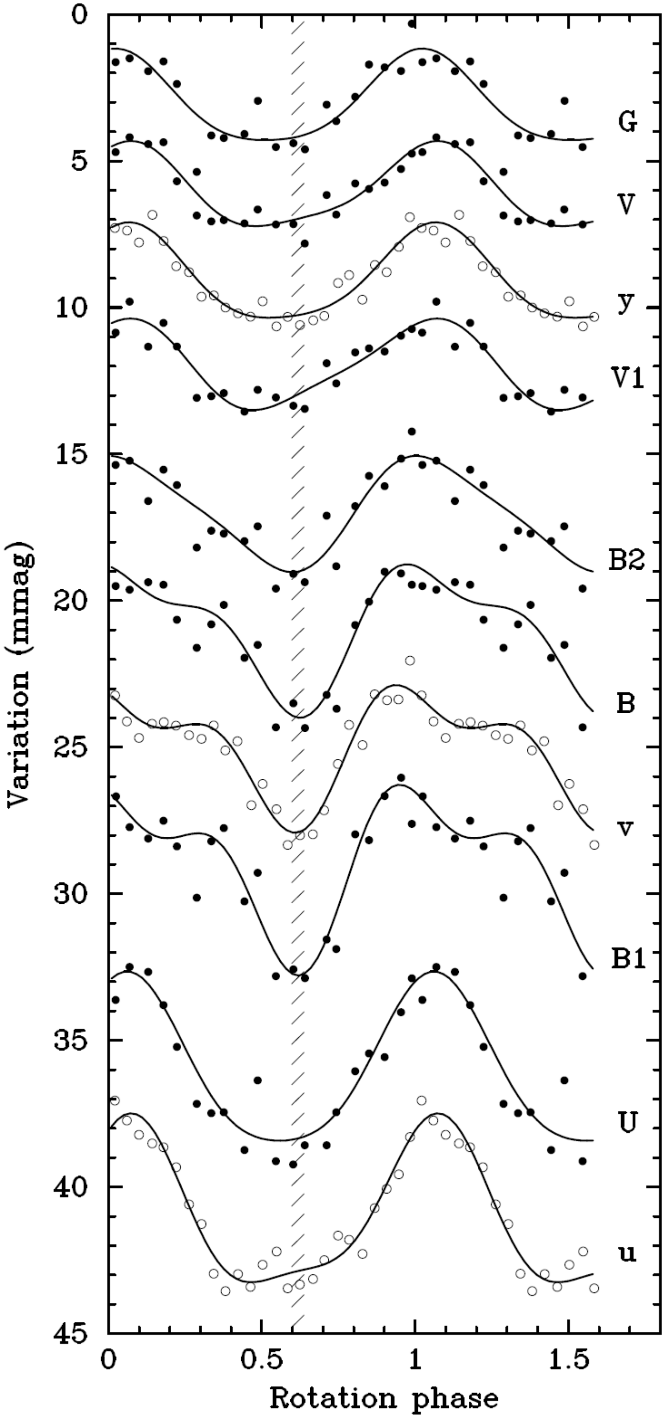
$f_1 = 7.14846\ d^{-1}$

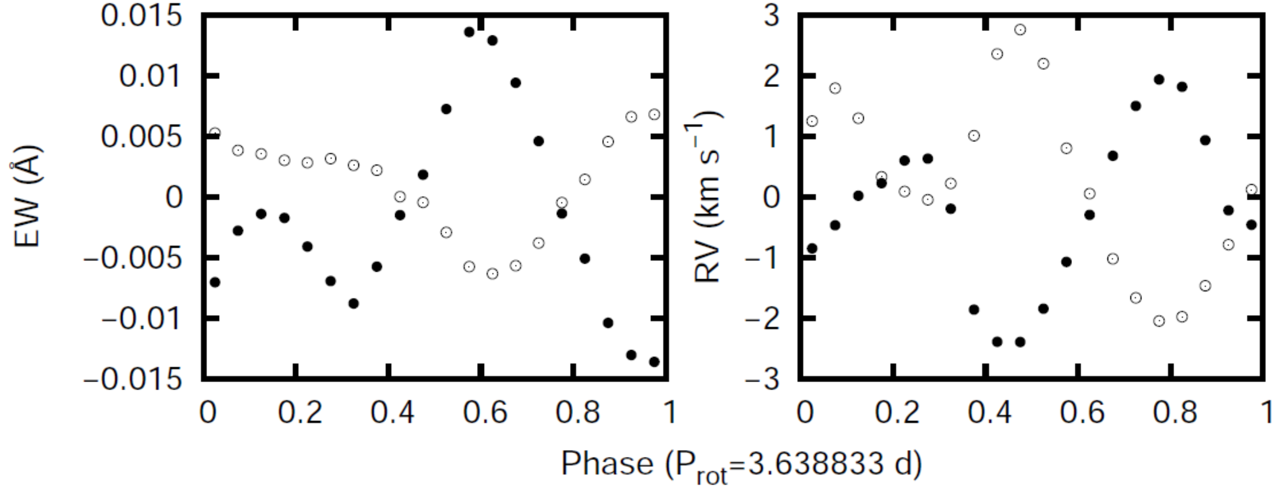
$f_2 = 7.75603\ d^{-1}$

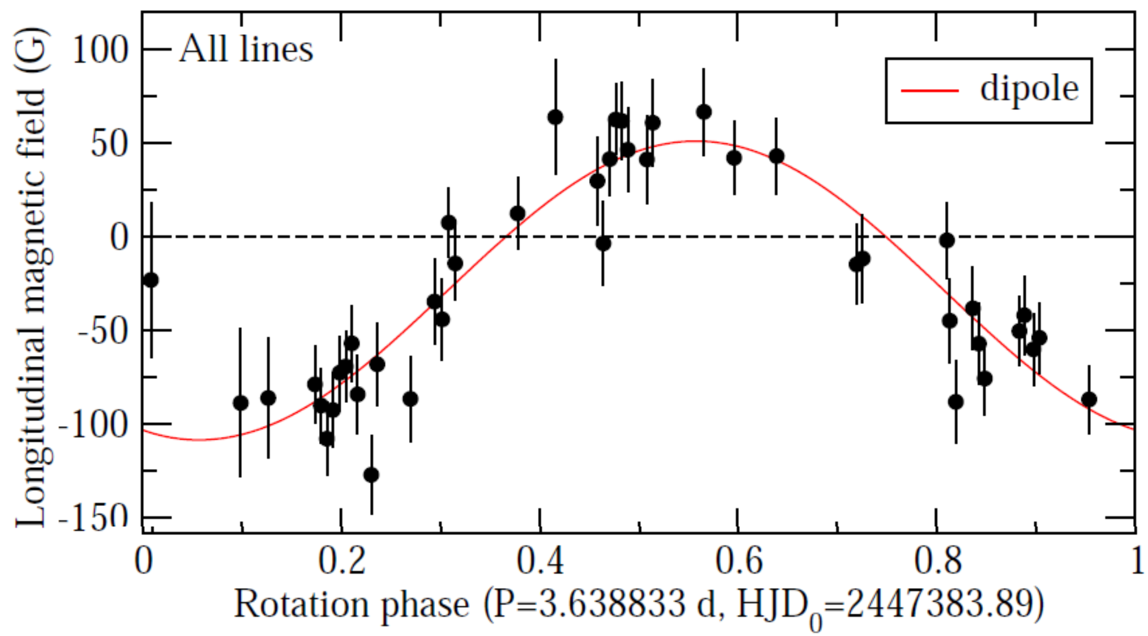
$f_3 = 6.82308\ d^{-1}$

$P_{rot} = 3.63883\ d$

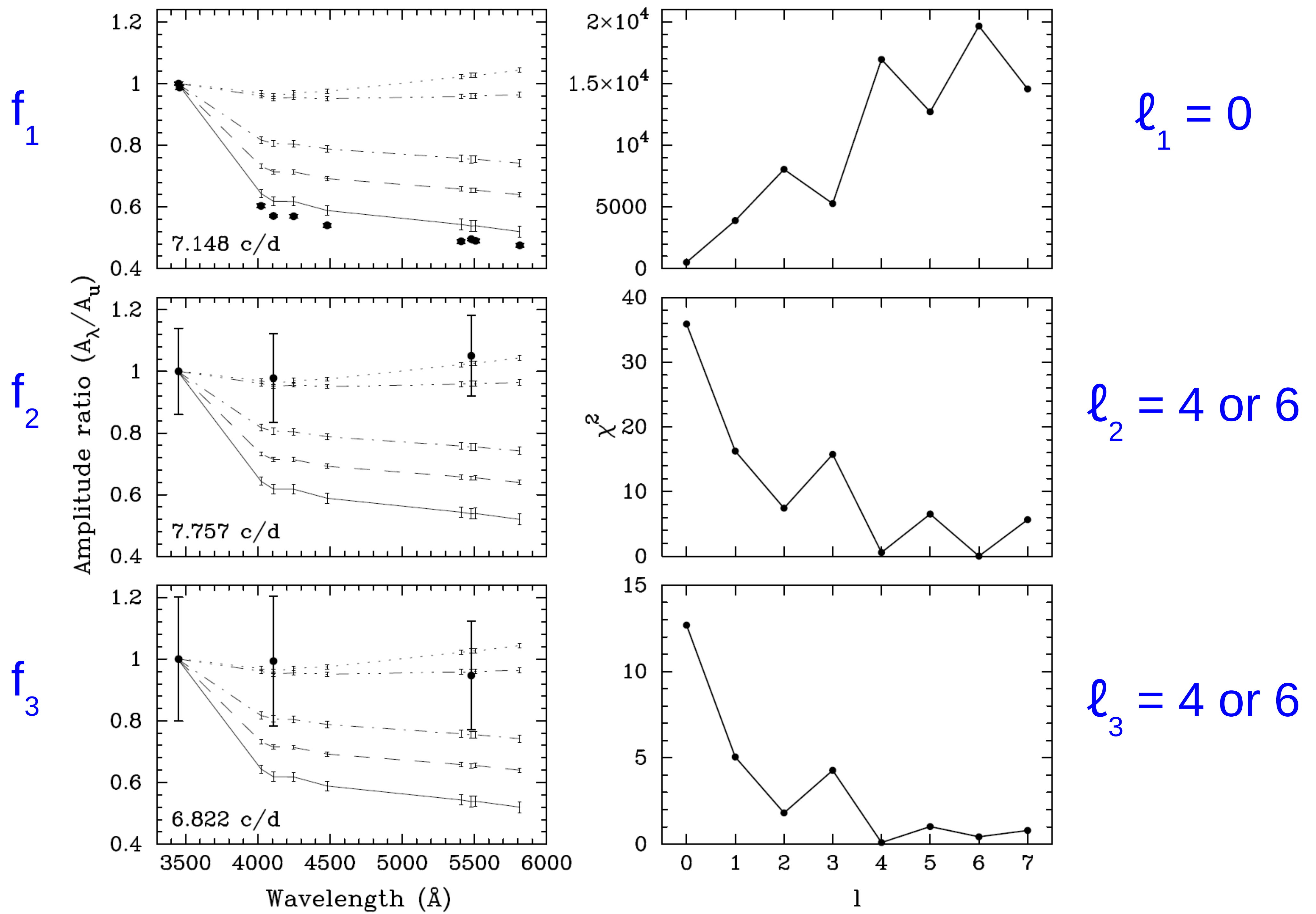
Rotational modulation



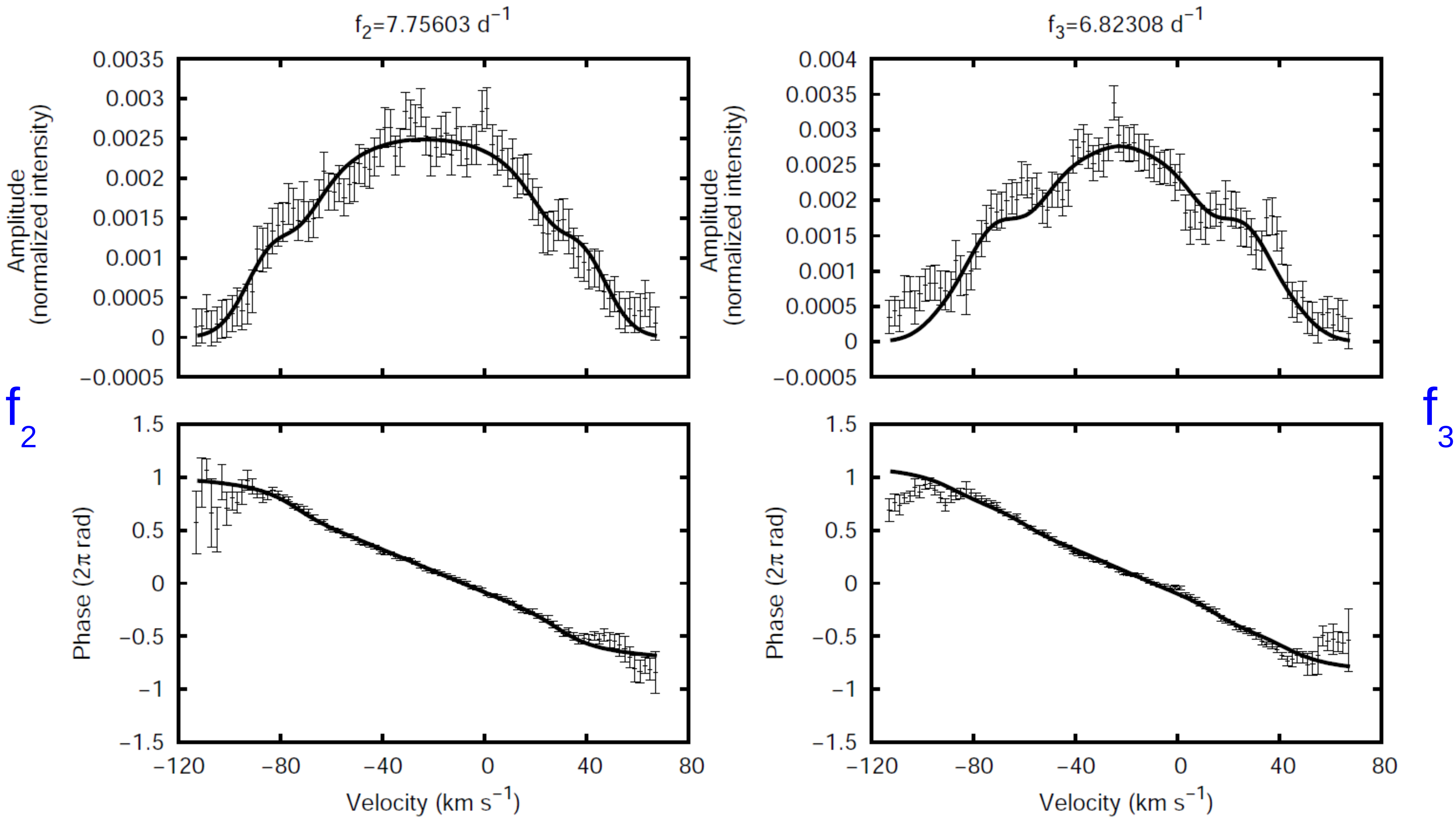




Photometric mode identification



Spectroscopic mode identification



ℓ = 3 or 4 or 5

Spectroscopic mode identification

ID	χ^2	(ℓ_2, m_2)	(ℓ_3, m_3)	i ($^\circ$)	$v_{\rm eq}$ (km s^{-1})
1	1.16	(4, 3)	(4, 2)	59.7±2.1	75.0±1.6
2	1.23	(4, 3)	(4, 4)	33.6±1.9	118.2±5.1
3	1.31	(4, 3)	(4, 3)	81.6±0.7	65.3±0.5
4	1.42	(4, 2)	(4, 2)	53.9±3.1	80.2±3.5
5	1.57	(4, 2)	(4, 4)	46.9±2.4	89.1±3.4
6	1.63	(4, 2)	(4, 3)	55.3±7.9	78.0±7.7
7	1.81	(4, 4)	(4, 2)	45.8±2.6	90.5±3.5
8	1.86	(4, 4)	(4, 3)	28.5±3.3	136.1±14.9
9	2.01	(4, 4)	(4, 4)	27.5±1.1	141.2±5.5

Prograde modes with (ℓ, m) = (4,2) or (4,3) or (4,4)

Observational constraints

f_1 = 7.14846 d^{-1} $(\ell_1, m_1)=(0,0)$
f_2 = 7.75603 d^{-1} $(\ell_2, m_2)=(4,2)$ or $(4,3)$ or $(4,4)$
f_3 = 6.82308 d^{-1} $(\ell_3, m_3)=(4,2)$ or $(4,3)$ or $(4,4)$

P_{rot} = 3.63883 d

T_{eff} = 23000 ± 1000 K
log g = 4.0 ± 0.2

↕

CLES models + LOSC pulsation frequencies

Mass: 7.6, 7.7, …, 19.9, 20.0 $M_\odot$
X: 0.68, 0.70, 0.72, 0.74
Z: 0.010, 0.012, 0.014, 0.016, 0.018
α_{ov}: 0.00, 0.05, …, 0.45, 0.50
ZAMS – TAMS

OP opacities
Asplund et al. mixture

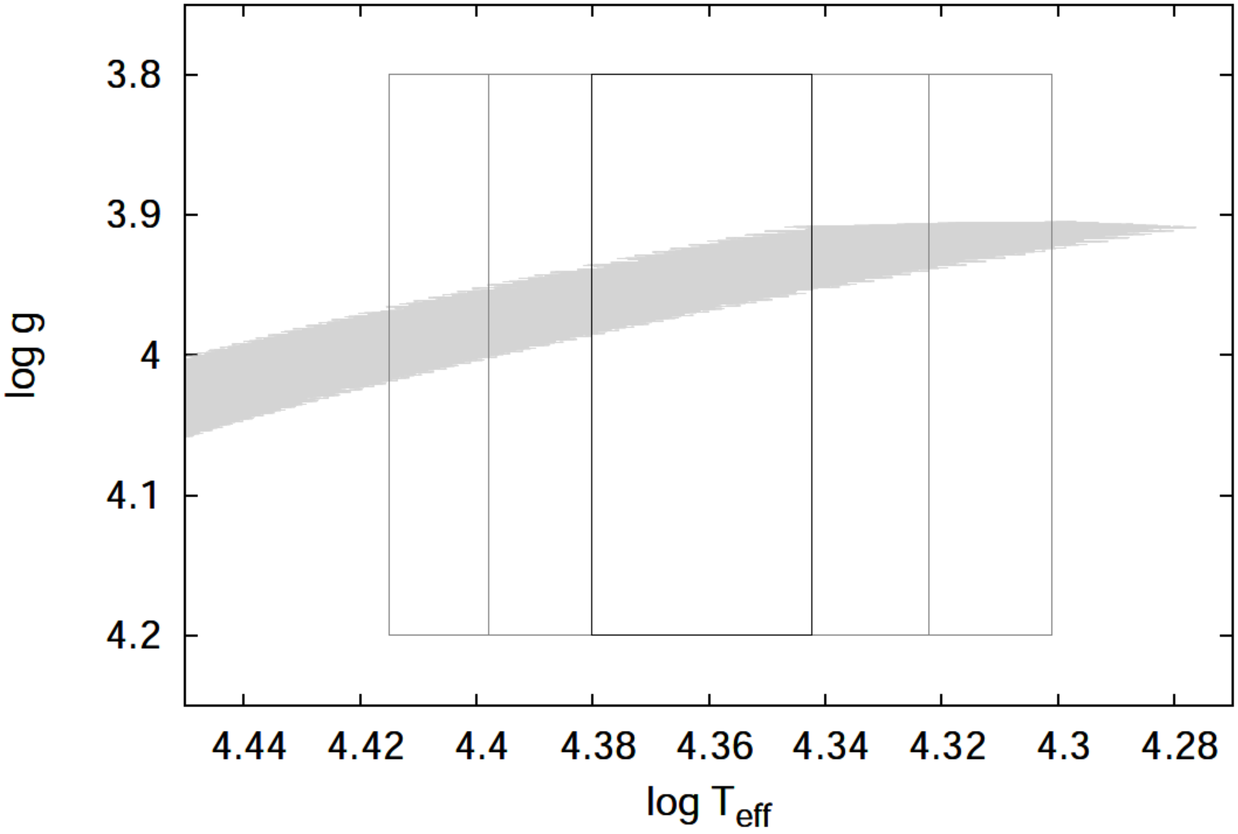
Fundamental radial mode:

Model radius + observed P_{rot} + v_{eq}sini
→ stellar inclination angle in [54, 66]°

Modelling the magnetic field data
→ stellar inclination angle in [53, 77]°

→ v_{eq} in [71, 75] km s^{-1}

Models which match f_1, as fundamental, within 0.05 d^{-1}



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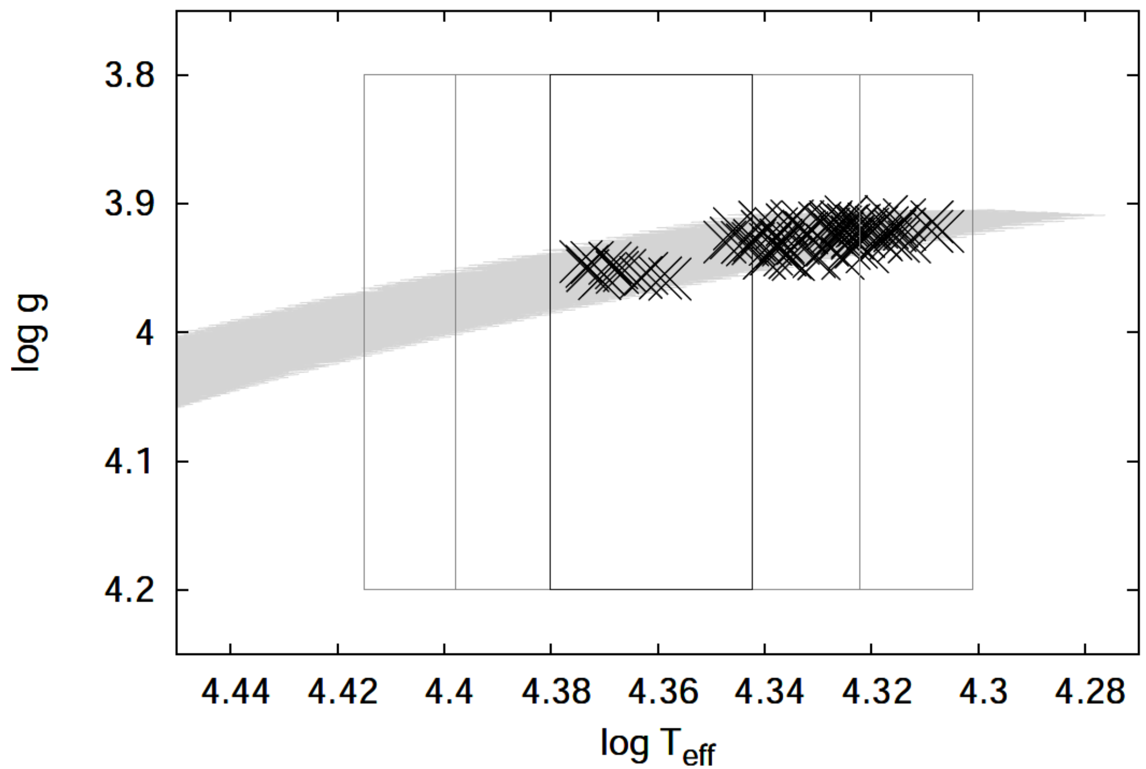

$n_1 = 1$, $n_2 = -3$ and $n_3 = -2$

Observed frequencies predicted to be excited

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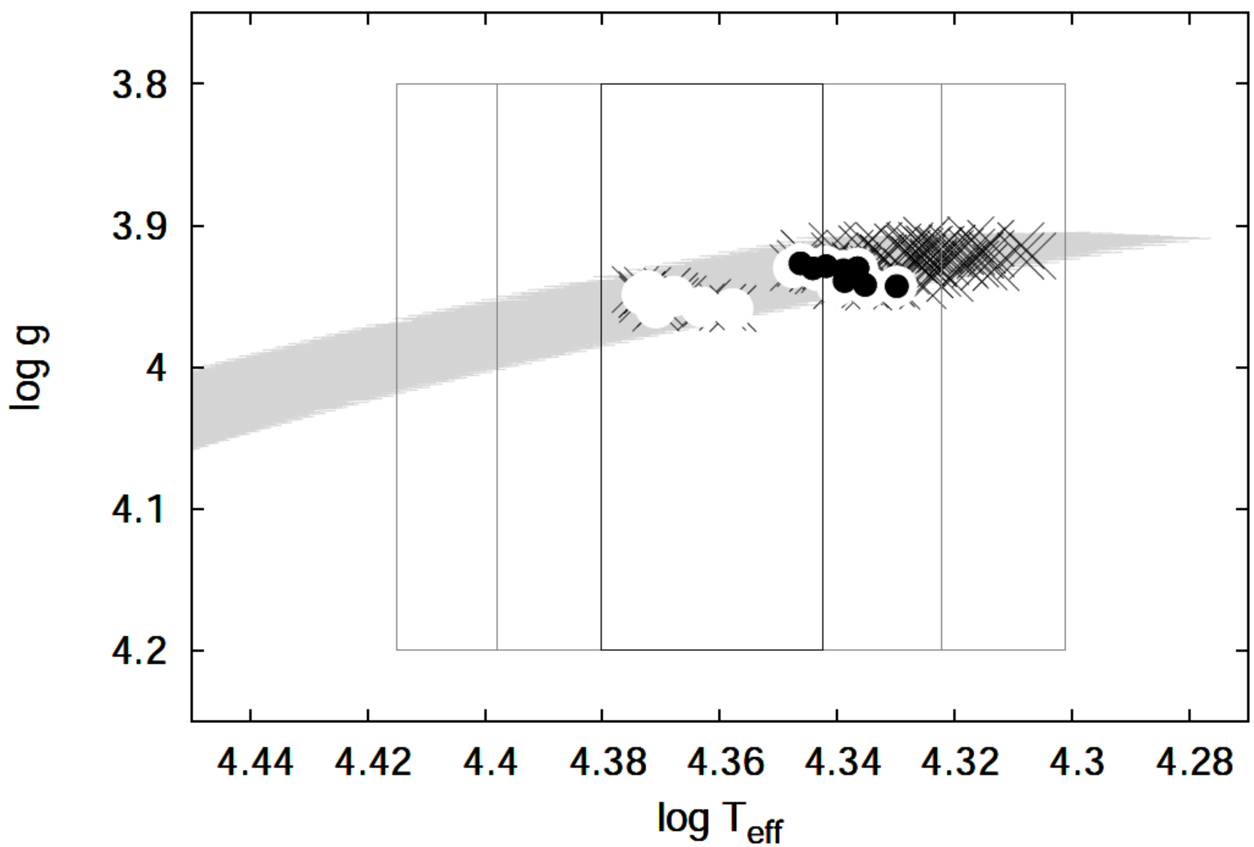

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ID	mass ($M_\odot$)	radius ($R_\odot$)	Z	α_{ov}	T_{eff} (K)	$\log g$	$\log(L/L_\odot)$	age (Myr)	X_c
1	[8.2, 9.0]	[5.16, 5.31]	[0.012, 0.016]	[0.00, 0.15]	[21370, 22190]	[3.93, 3.94]	[3.72, 3.76]	[19.9, 23.7]	[0.28, 0.32]
2	no model								
3	[8.9, 9.6]	[5.26, 5.38]	[0.010, 0.012]	[0.00, 0.10]	[22790, 23570]	[3.95, 3.96]	[3.85, 3.89]	[17.3, 18.3]	[0.27, 0.31]
4	[8.3, 9.0]	[5.17, 5.30]	[0.012, 0.016]	[0.00, 0.10]	[21600, 22250]	[3.93, 3.94]	[3.73, 3.77]	[19.2, 21.9]	[0.27, 0.30]
5	no model								
6	[9.0, 9.1]	[5.27, 5.29]	0.010	0.05	[23320, 23620]	3.95	[3.89, 3.87]	[16.9, 18.0]	[0.25, 0.27]
~~7~~	~~[8.1, 9.0]~~	~~[5.15, 5.31]~~	~~[0.016, 0.018]~~	~~[0.00, 0.15]~~	~~[20550, 21720]~~	~~[3.92, 3.94]~~	~~[3.64, 3.74]~~	~~[18.7, 26.5]~~	~~[0.30, 0.35]~~
~~8~~	~~[7.8, 9.6]~~	~~[5.10, 5.39]~~	~~[0.010, 0.018]~~	~~[0.00, 0.35]~~	~~[20260, 23680]~~	~~[3.91, 3.96]~~	~~[3.61, 3.90]~~	~~[15.6, 28.9]~~	~~[0.28, 0.37]~~
~~9~~	~~[7.7, 8.2]~~	~~[5.10, 5.19]~~	~~[0.014, 0.018]~~	~~[0.25, 0.40]~~	~~[20350, 21620]~~	~~[3.91, 3.92]~~	~~[3.62, 3.71]~~	~~[24.5, 30.1]~~	~~[0.33, 0.38]~~
	[8.2, 9.6]	[5.16, 5.38]	[0.010, 0.016]	[0.00, 0.15]	[21370, 23620]	[3.93, 3.96]	[3.72, 3.89]	[16.9, 23.7]	[0.25, 0.32]

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~~9~~	~~2.01~~	~~(4, 4)~~	~~(4, 4)~~	~~27.5±1.1~~	~~141.2±5.5~~

(ℓ,m) = (4,2) or (4,3) for both non-radial modes detected

ID	mass ($M_\odot$)	radius ($R_\odot$)	Z	α_{ov}	T_{eff} (K)	$\log g$	$\log(L/L_\odot)$	age (Myr)	X_c
1	[8.2, 9.0]	[5.16, 5.31]	[0.012, 0.016]	[0.00, 0.15]	[21370, 22190]	[3.93, 3.94]	[3.72, 3.76]	[19.9, 23.7]	[0.28, 0.32]
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Stellar models with no or mild core overshooting

Parameter	θ Oph	V2052 Oph
$T_{\rm eff}$ (K)	22260±280	22500±1100
$\log g$ (dex)	3.95±0.01	3.95±0.02
M ($M_\odot$)	8.2±0.3	8.9±0.7
X_c	0.38±0.02	0.29±0.04
Z	[0.009, 0.015]	[0.010, 0.016]
$\alpha_{\rm ov}$	0.44±0.07	0.07±0.08
$v_{\rm eq}$ (km s^{-1})	29±7	73±2
$\Omega/\Omega_{\rm crit}$	0.09±0.03	0.23±0.01

Parameter	θ Oph	V2052 Oph
$T_{\rm eff}$ (K)	22260±280	22500±1100
$\log g$ (dex)	3.95±0.01	3.95±0.02
M ($M_\odot$)	8.2±0.3	8.9±0.7
X_c	0.38±0.02	0.29±0.04
Z	[0.009, 0.015]	[0.010, 0.016]
$\alpha_{\rm ov}$	0.44±0.07	0.07±0.08
$v_{\rm eq}$ (km s^{-1})	29±7	73±2
$\Omega/\Omega_{\rm crit}$	0.09±0.03	0.23±0.01

No magnetic field — Magnetic

Parameter	θ Oph	V2052 Oph
$T_{\rm eff}$ (K)	22260±280	22500±1100
$\log g$ (dex)	3.95±0.01	3.95±0.02
M ($M_\odot$)	8.2±0.3	8.9±0.7
X_c	0.38±0.02	0.29±0.04
Z	[0.009, 0.015]	[0.010, 0.016]
$\alpha_{\rm ov}$	0.44±0.07	0.07±0.08
$v_{\rm eq}$ (km s^{-1})	29±7	73±2
$\Omega/\Omega_{\rm crit}$	0.09±0.03	0.23±0.01

No magnetic field Magnetic

Magnetic field inhibits mixing in the interior of V2052 Oph

Gathering of intensive asteroseismic data of β Cep stars with a magnetic field detected

Search for a magnetic field in β Cep stars with a lot of pulsational constraints

e.g. hybrid β Cep/SPB CoRoT target HD 43317 (Pápics et al. 2012, A&A, 542, 55) is magnetic

Multisite photometric and spectroscopic campaign of the magnetic β Cep star V2052 Ophiuchi

Handler et al. 2012, MNRAS, 424, 2380
Briquet et al. 2012, MNRAS, 427, 483