An Improved Model of δ Orionis A

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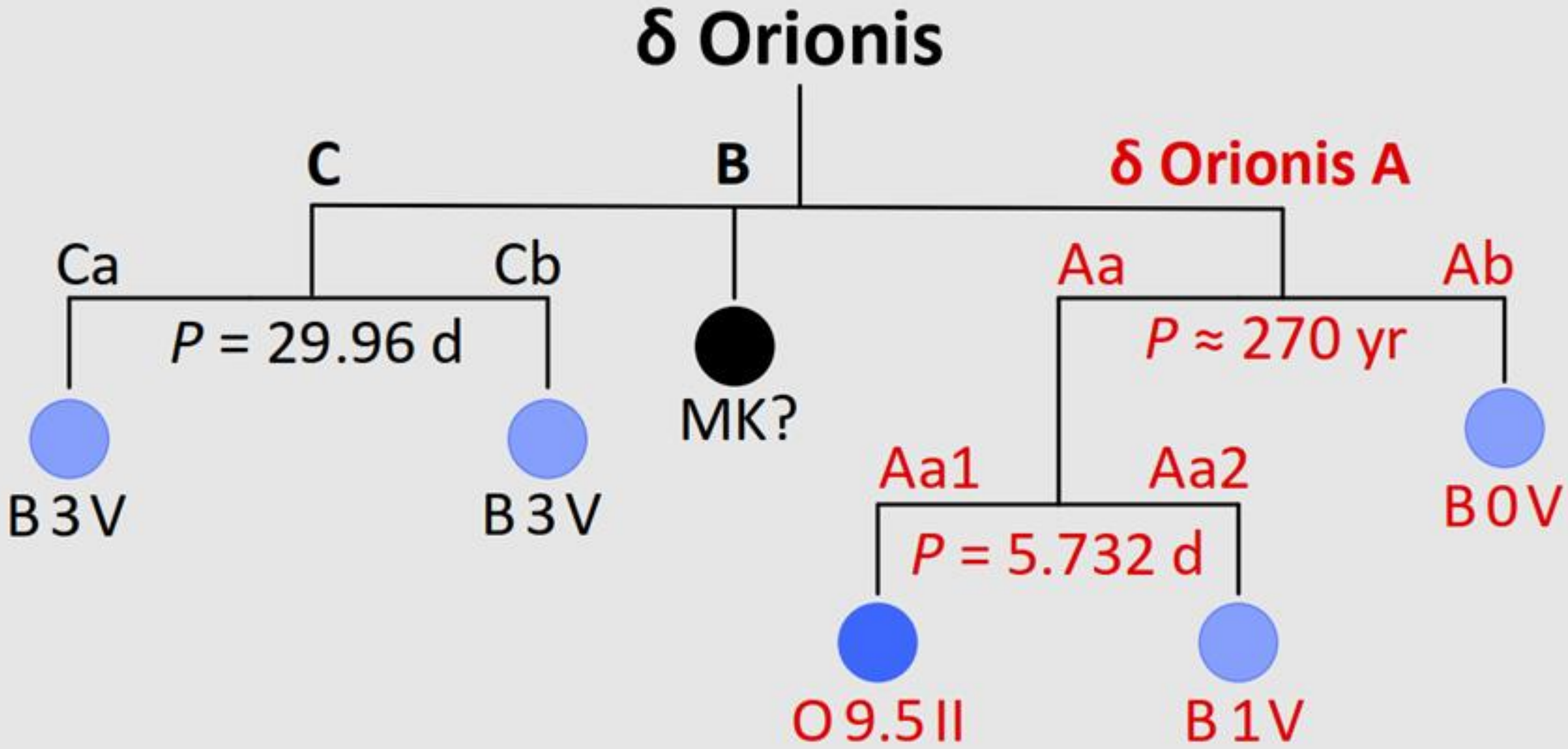
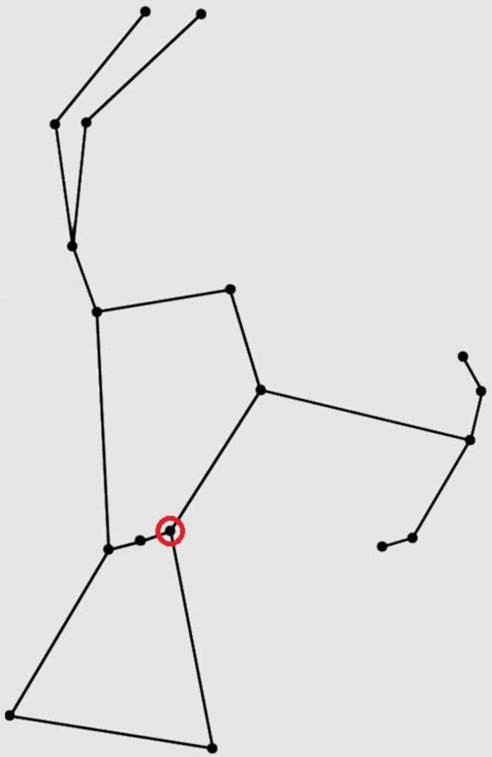
δ Orionis A

- HR 1852, HD 36486, HIP 25930
- Member of δ Orionis (Mintaka, ADS 4134)





Recent studies

- **Harvin et al. 2002**
  - Unexpectly low masses
- **Mayer et al. 2010**
  - Confusion of secondary and tertiary in Harvin's study
  - The spectral lines of the primary and tertiary dominate the optical spectra
  - Normal masses, $q \approx 0.4$
- **Harmanec et al. 2013**
  - Detection of the secondary in the red spectral region
- **Corcoran et al. 2015**
- **Nichols et al. 2015**
- **Pablo et al. 2015**
- **Shenar et al. 2015**

} Series of four consecutive detailed studies

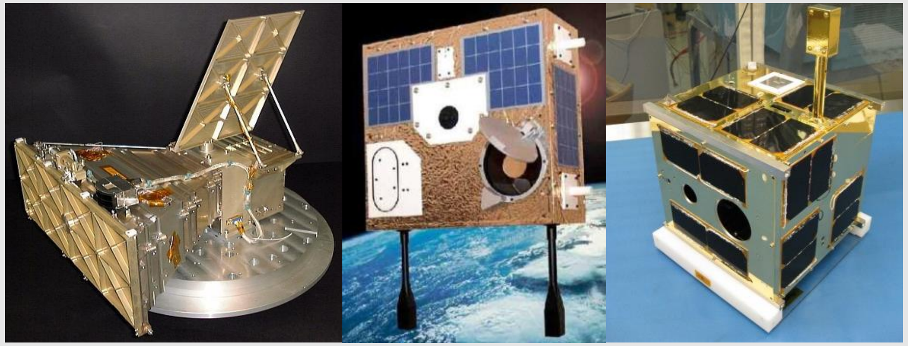
The observational material used

- Spectroscopic data

TABLE 1: Electronic spectra (blue and green spectral region):
the Ondřejov Observatory,
the Haute Provence Observatory,
the ESO LaSilla

Time interval (RJD)	No. of spectra	Detector	Wavelength range (Å)
53613.62–56003.35	70	Site-5 CCD	4753–5005
55836.57–58405.57	65	Site-5 CCD	4270–4523
50031.68–50435.40	4	Elodie	4000–6800
54136.58–54953.46	6	Feros	4000–8000

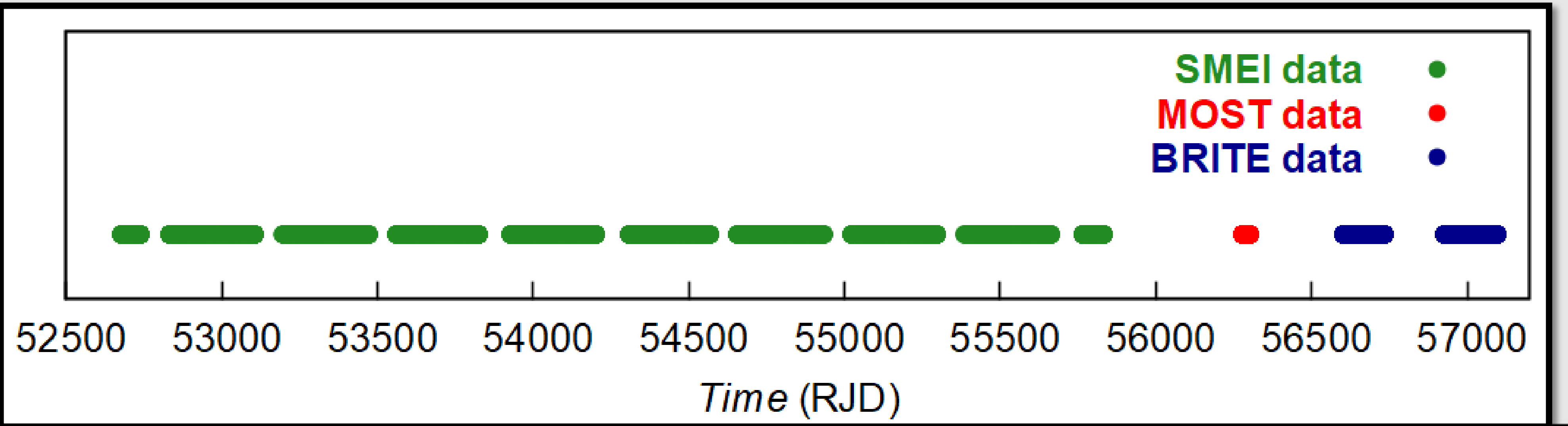
- Photometric data



SMEI MOST BRITE

TABLE 2: Information about satellites

Instrument/Satellite	Height (km)	Inclination (°)	Period (days)
SMEI (Satellite Coriolis)	840	98.7	0.07048
MOST	785	98.7	0.07041
UBr (UniBRITE)	775-790	98.6	0.06972
BAb (BRITE-Austria)	775-790	98.6	0.06972
BLb (Lem)	600-890	97.7	0.06917
BTr (BRITE-Toronto)	620-643	97.9	0.06819
BHr (Heweliusz)	612-640	98.0	0.06743



Data analysis

Reduction of spect. spectra
SPEFO[1]

Rebinning to a scale linear in RV
HEC35D[2]

Disentangling
KOREL[3]

Fitting observed and model spectra
PYTERPOL[4]

Photometric data + RV curves*
PHOEBE 1[5]

Homogenized phot. data

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[1] Krpata (2008); http://astro.troja.mff.cuni.cz/ftp/hec/SPEFO/
[2] P. Harmanec; http://astro.troja.mff.cuni.cz/ftp/hec/HEC35/
[3] Hadrava (1995, 1997, 2004, 2005); http://www.asu.cas.cz/ had/korel.html
[4] https://github.com/chrysante87/pyterpol/wiki
[5] Prša & Zwitter (2005); http://phoebe-project.org/
*Mayer et al. (2010)

Application of KOREL disentangling

- Variable quality of individual spectra
  - Signal to noise ratio

$$w = \frac{(S/N)^2}{(S/N_{mean})^2}$$

- Problems in solution of this system
  - Lines of the primary and tertiary are blended
  - The primary and tertiary dominate
  - Faint secondary spectrum
  - The dependence of sum of squares on *q* is flat

Spectral disentangling in two steps

The first step

The spectra of primary and tertiary were disentangled

Residua for all individual spectra after disentangling + 1

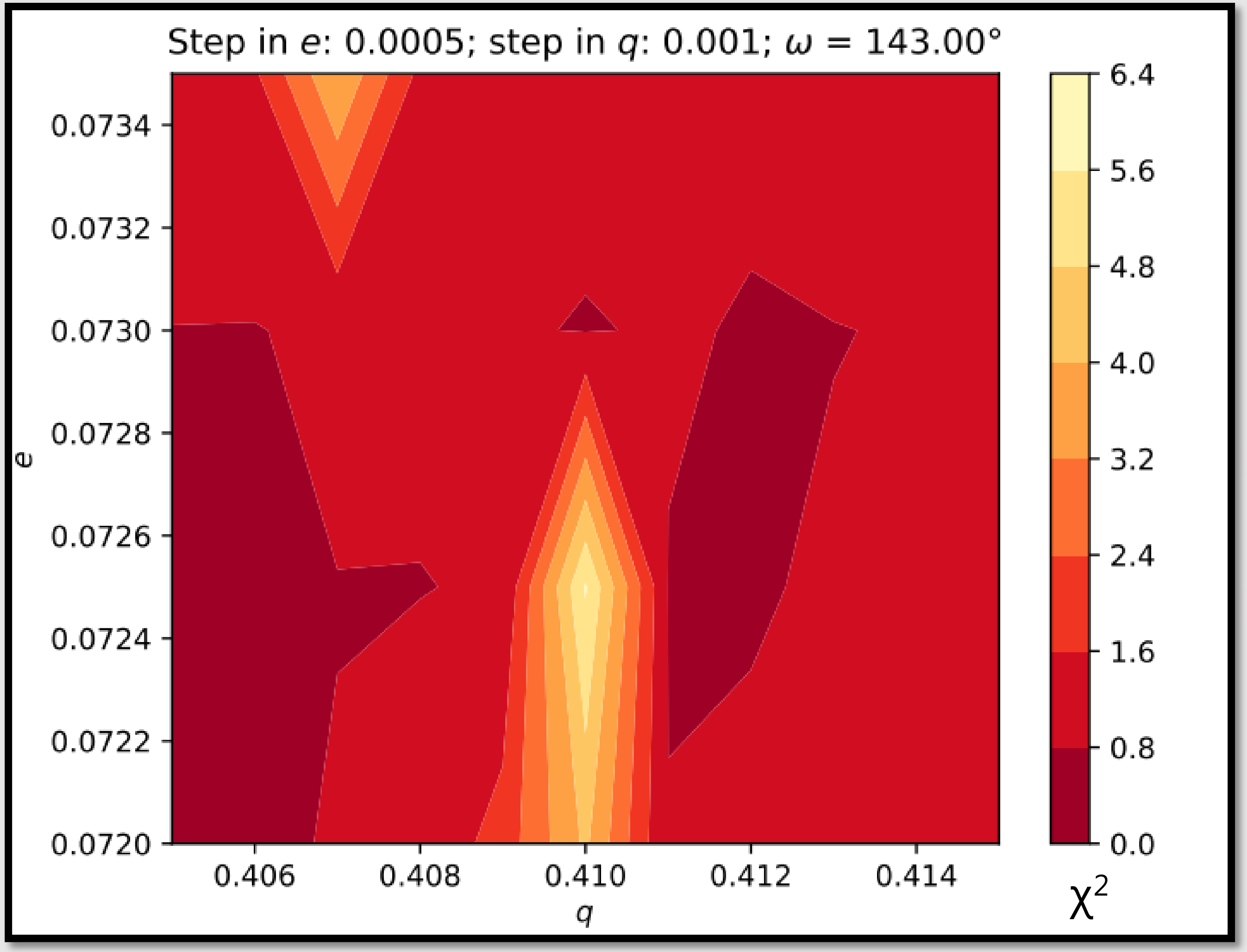
The second step

The spectrum of secondary was disentangled

KORELMAP

- Python program KORELMAP[1]

$$\omega = 143.0^\circ;\ e = 0.73;\ q = 0.41$$



[1] Written by J. A. Nemravová

KOREL chain

Disentangled:
primary and tertiary with variable intensities

Convergence of:
T_{01}, e, ω, K_1
(orbit of close pair)
T_{02}, K_2
(outer orbit)

Disentangled:
primary and tertiary with constant intensities and the secondary with variable intensity

Convergence of:
T_{01}, q
(orbit of close pair)

Disentangled:
all three components with constant intensities

$q = 0.41549$; $e = 0.07583$

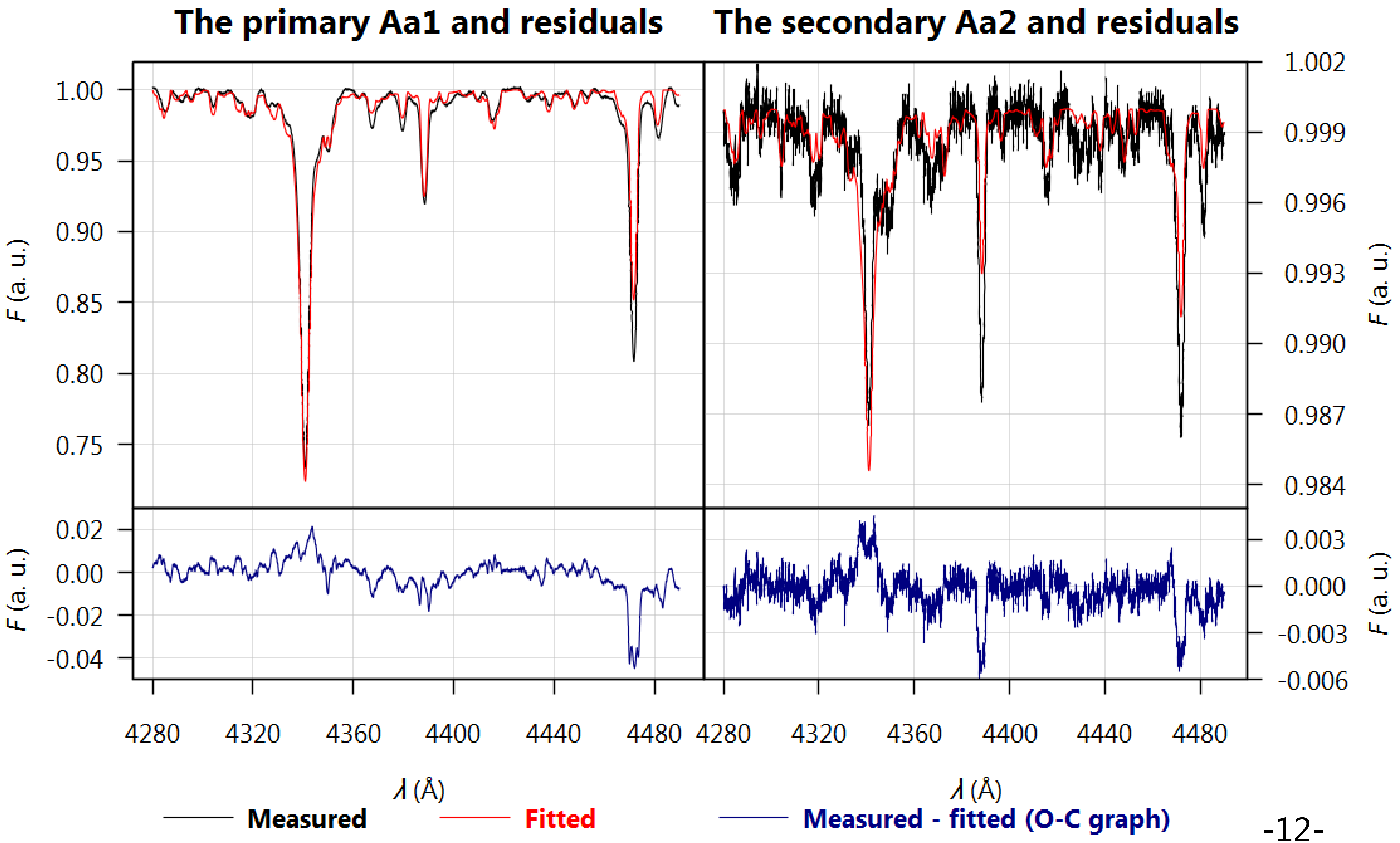
Convergence of:
T_{01}, e, ω, q, K_1
(orbit of close pair)
T_{02}, K_2
(outer orbit)

PYTERPOL

- For instance: T_{eff}, log g , v sin i, L_R
- Finds fit between observed spectra and interpolated model
    - Simplex minimization technique

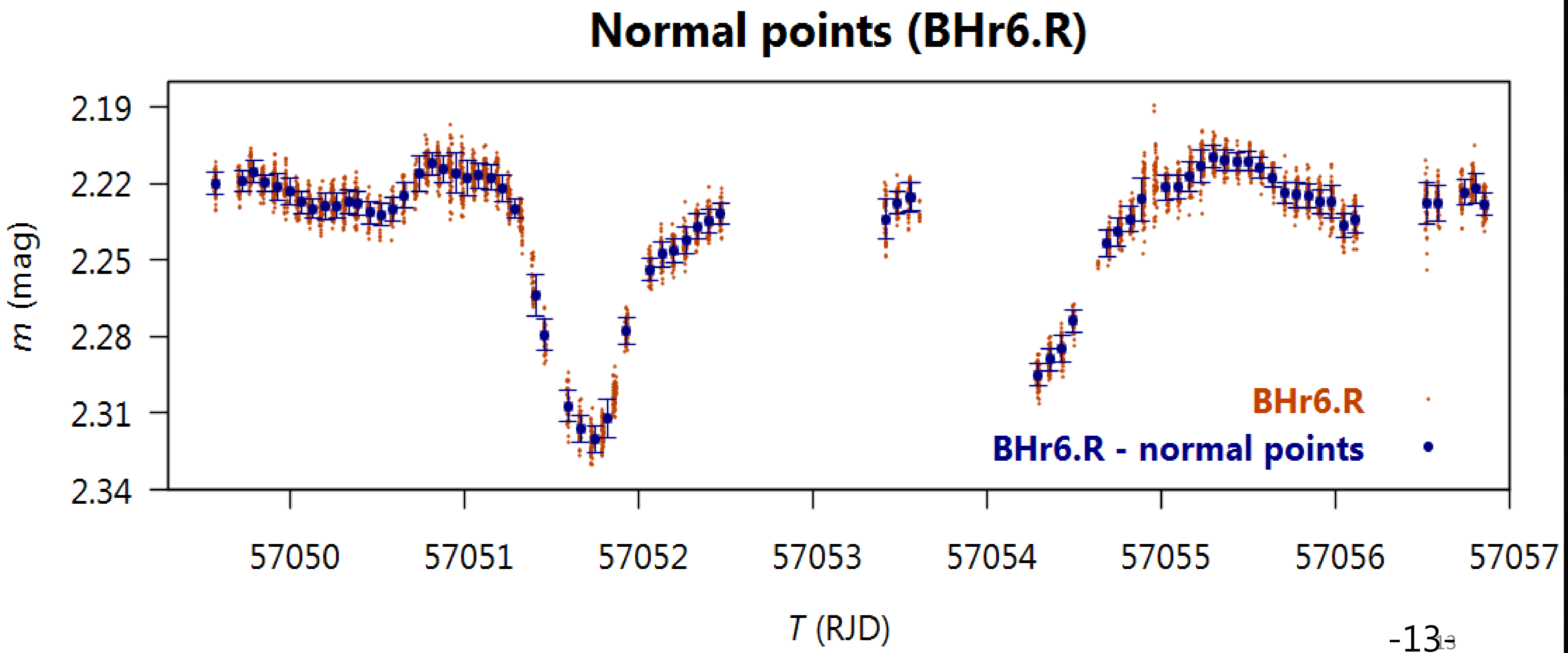
TABLE 3: Parameters derived with PYTERPOL

Parameters	Primary Aa1	Secondary Aa2
χ^2_N	2.562	1.769
T_{eff} (K)	31401	25442
$\log g$ (cgs)	3.549	3.476
$v \sin i$ (km s^{-1})	114.280	89.506
L_{R_3}	0.692	0.035
RV (km s^{-1})	26.25	36.44


The primary Aa1 and residuals
The secondary Aa2 and residuals
1.00
0.95
0.90
0.85
0.80
0.75
F (a. u.)
0.02
0.00
-0.02
-0.04
1.002
0.999
0.996
0.993
0.990
0.987
0.984
0.003
0.000
-0.003
-0.006
4280
4320
4360
4400
4440
4480
λ (Å)
Measured
Fitted
Measured - fitted (O-C graph)

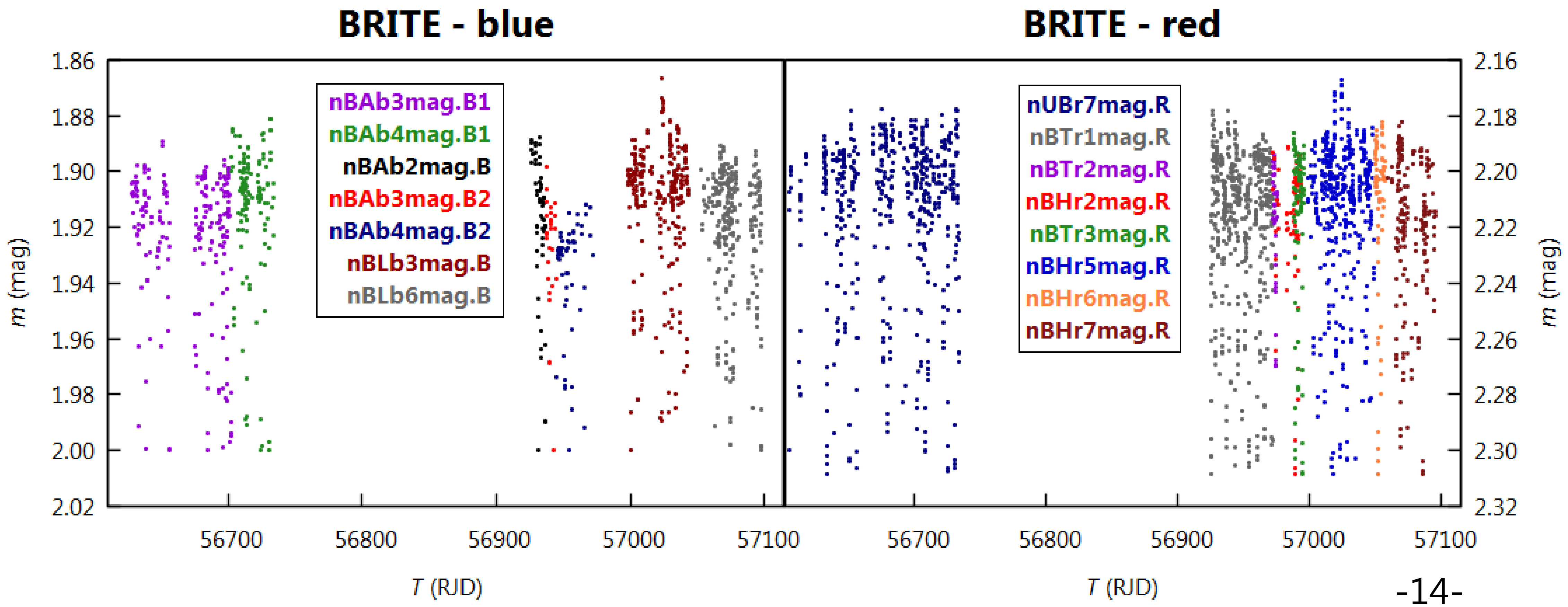
PHOEBE 1 - data

- Homogenization of photometric data
    - Normal points



PHOEBE 1 - data

- Homogenization of photometric data
  - Normal points
  - Interpolating maxima by Hermite polynomial



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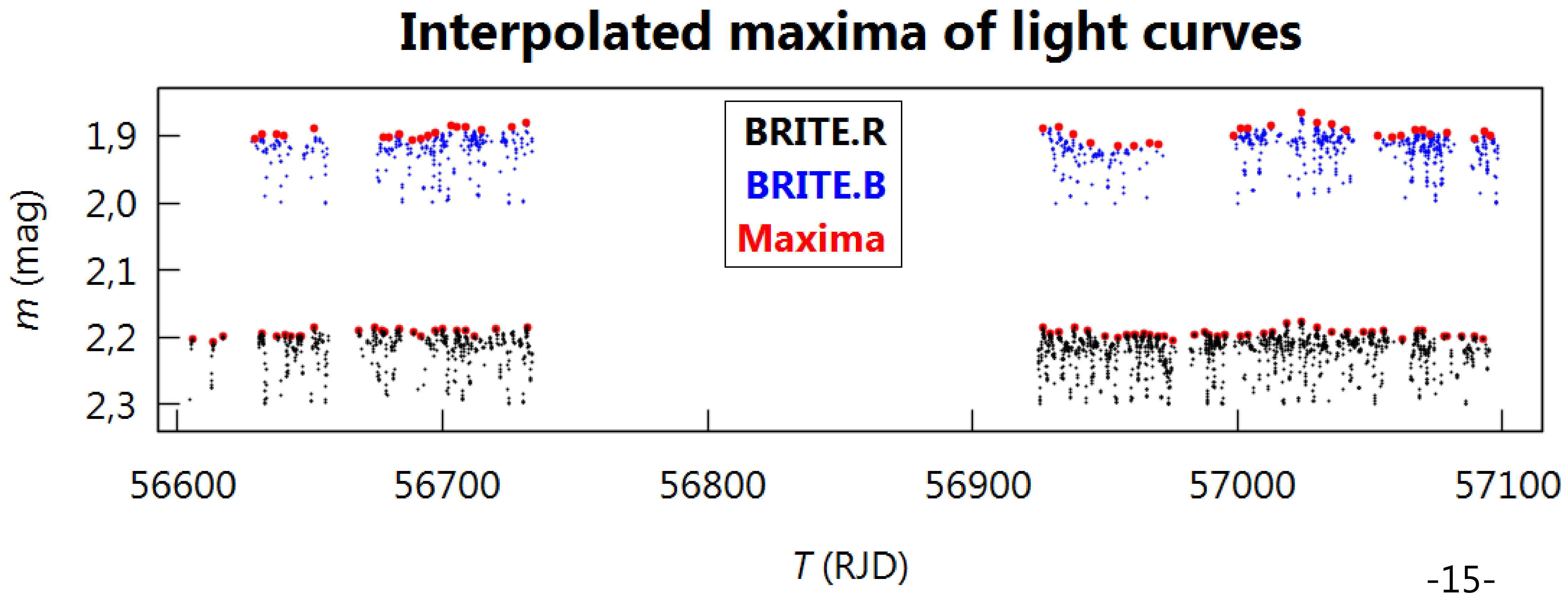

PHOEBE 1 - data

- Homogenization of photometric data
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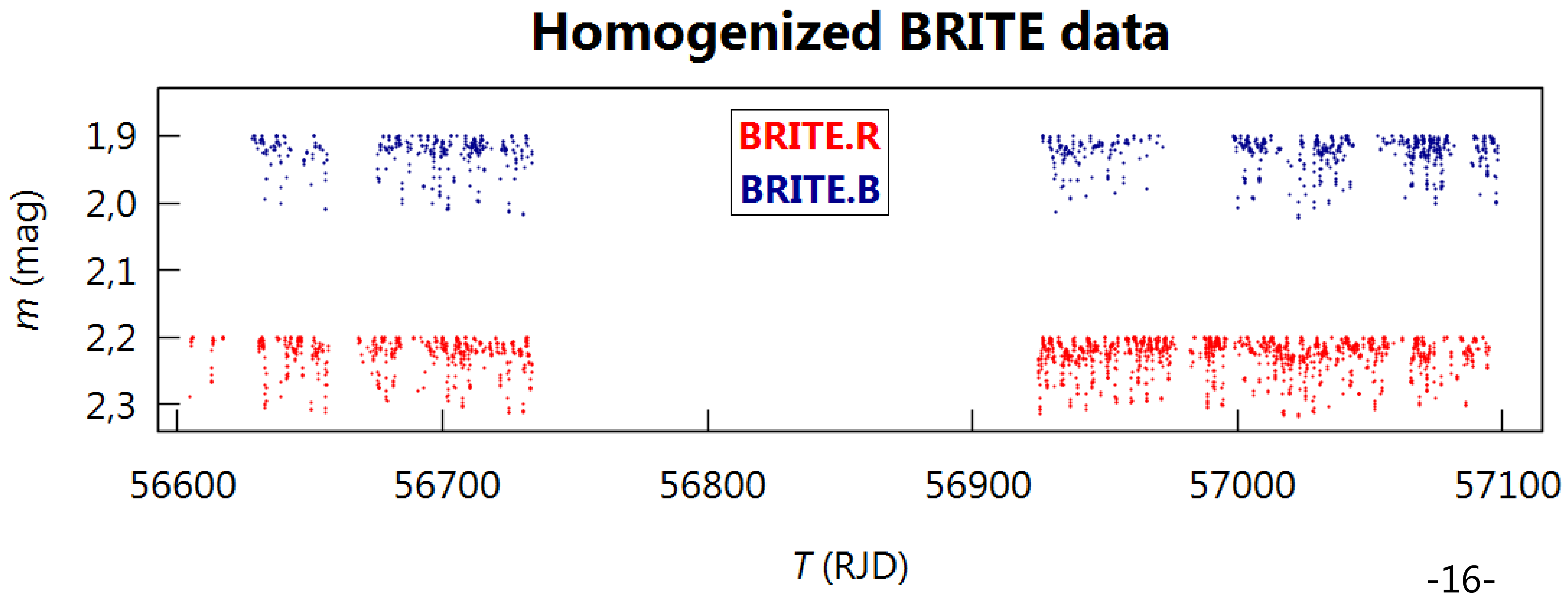


LC solution

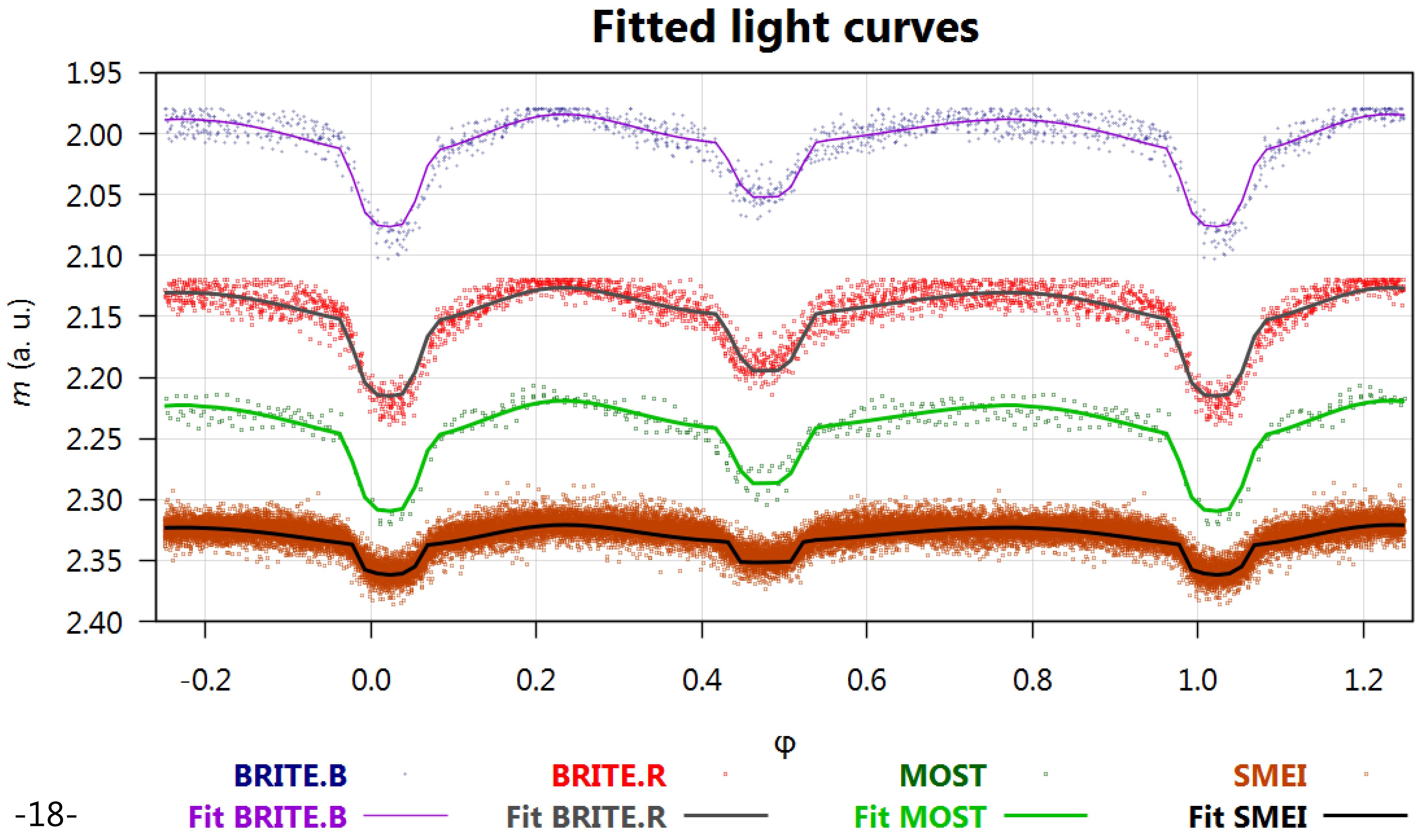
$$F_k = P_{orb} \frac{v_k \sin i}{50.59273 R_k^e \sin i}$$

TABLE 4: Fixed parameters

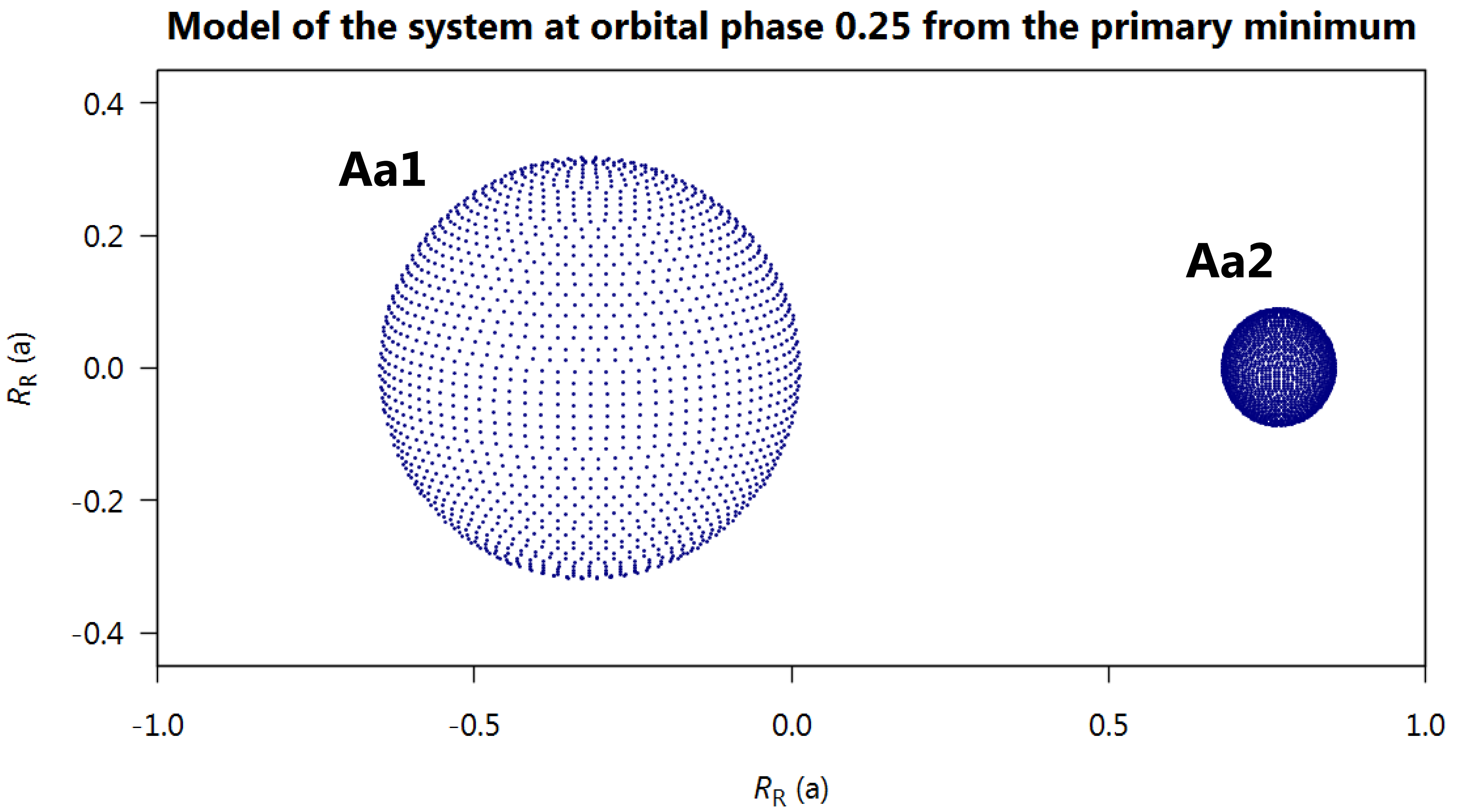
Parameters	Values
P (d)	5.732436
$\dot{\omega}$ (°/d)	0.004220
$q = M_1/M_2$	0.41549
e	0.07583
T_{eff_1} (K)	31401
T_{eff_2} (K)	25442
L_{R_3}	0.273

TABLE 5: Solution

Parameters	SMEI	MOST + BRITE
a ($\mathcal{R}_\odot^N$)	40.71 ± 0.21	41.91 ± 0.18
ω (°)	158.37 ± 0.71	148.73 ± 1.49
γ (km s^{-1})	22.28 ± 0.41	21.96 ± 0.33
i (°)	91.6 ± 0.4	78.1 ± 0.3
M_1 ($\mathcal{M}_\odot^N$)	19.4	21.1
M_2 ($\mathcal{M}_\odot^N$)	8.1	8.8
R_1 ($\mathcal{R}_\odot^N$)	10.4	13.6
R_2 ($\mathcal{R}_\odot^N$)	1.71	3.7
M_{bol_1} (mag)	-7.69	-8.28
M_{bol_2} (mag)	-2.87	-4.55
L_{R_1}	0.712	0.690
L_{R_2}	0.014	0.037
$\log g_1$ (cgs)	3.70	3.50
$\log g_2$ (cgs)	4.88	4.24
Cost function χ^2_N	1.008	11.389



Fitted light curves
1.95
2.00
2.05
2.10
2.15
2.20
2.25
2.30
2.35
2.40
m (a. u.)
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
φ
BRITE.B
BRITE.R
MOST
SMEI
Fit BRITE.B
Fit BRITE.R
Fit MOST
Fit SMEI



Model of the system at orbital phase 0.25 from the primary minimum
Aa1
Aa2
0.4
0.2
0.0
-0.2
-0.4
R_R (a)
-1.0
-0.5
0.0
0.5
1.0
R_R (a)

Results

TABLE 6: Comparison of results

	Star	Spectral type	M ($\mathcal{M}_\odot^{\mathrm{N}}$)	R ($\mathcal{R}_\odot^{\mathrm{N}}$)
BRITE, MOST		O 9.5 II	21.1	13.6
SMEI	del Ori Aa1		19.4	10.4
Martins et al. (2005)		O 9.5 III	21.04	13.37
BRITE, MOST			8.8	3.7
SMEI	del Ori Aa2	B 1 V	8.1	1.7
Harmanec (1988)			10.41	4.75

Conclusion

- Analysis of a triple star delta Orionis A
  - Multiple star system delta Orionis
  - An eclipsing binary and a distant tertiary
- Spectroscopic data
  - Disentangling the spectral lines of the secondary
  - Mass ratio: q = 0.415
- Photometric data – satellites SMEI, MOST, BRITE
  - Light-curve solution
  - Improved physical elements

Thank you for your attention