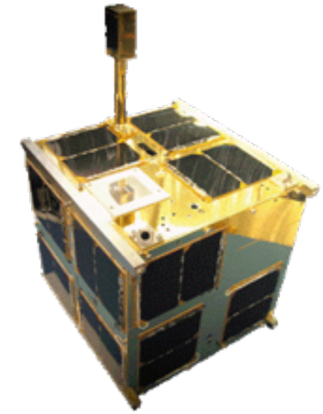


Science with nano-satellites: BRITE-Constellation

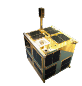
Andrzej Pigulski

Astronomical Institute

University of Wrocław, Poland

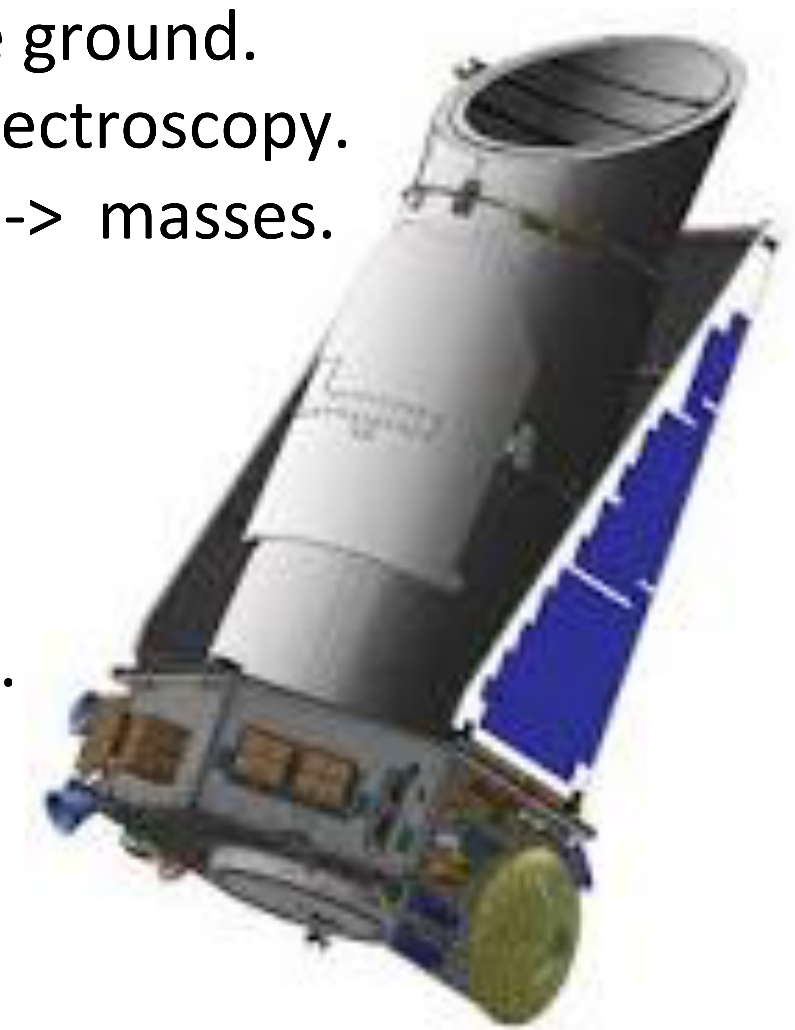
Understanding the roles of rotation, pulsation and chemical peculiarities in the upper main sequence, Lake District, Cumbria, UK, 13 September 2016

Bright star photometry with nano-satellites



Why bright stars?

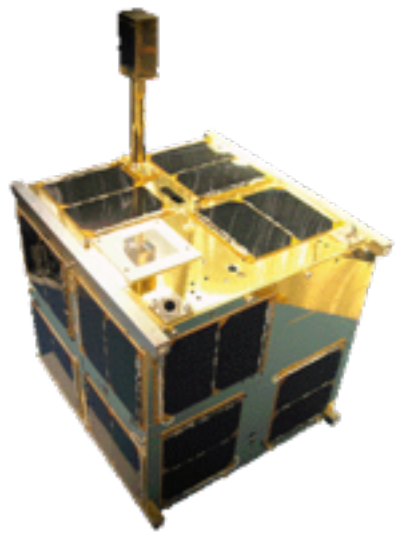
- Photometry is difficult from the ground.
- Easy or existing (time-series) spectroscopy.
- Visual + SB2 orbits for binaries -> masses.
- Accurate parallaxes.
- Low extinction & reddening.



Why nano-satellites?

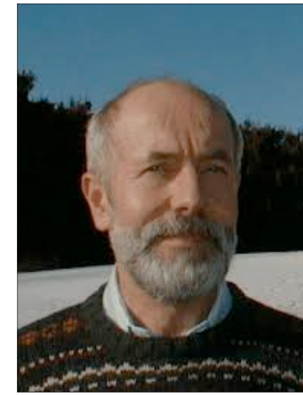
- Small telescope = small satellite.
- Low-cost.
- Testing new techniques.

BRITE



BRIght **T**arget **E**xplorer

nanosatellite
size: 20 × 20 × 20 cm
mass: 7 kg
telescope diameter: 3 cm
launched: 2013-2014
Scientific goal: variability
of bright (luminous) stars



Slavek Rucinski

Austria

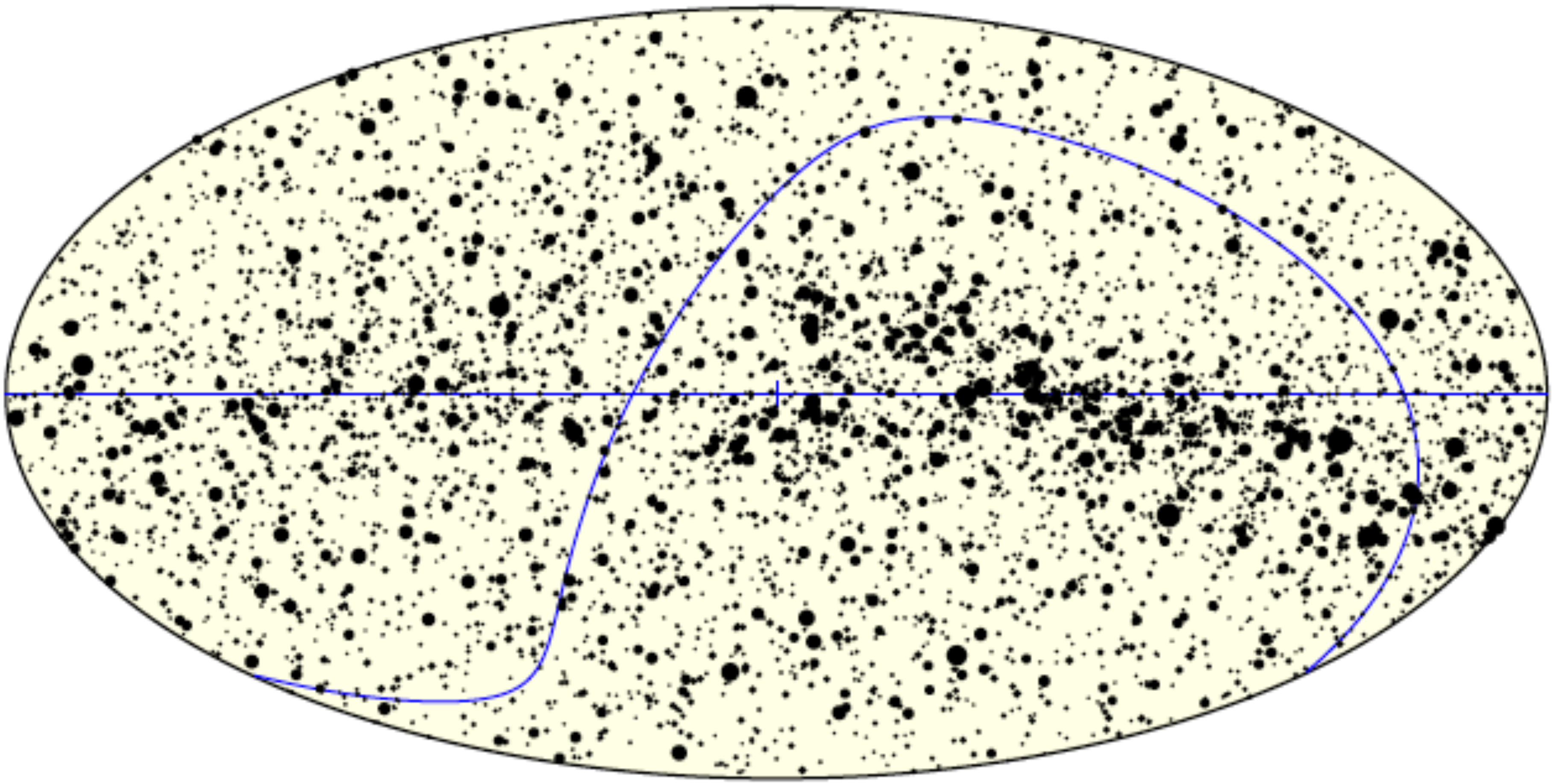
Canada

Poland

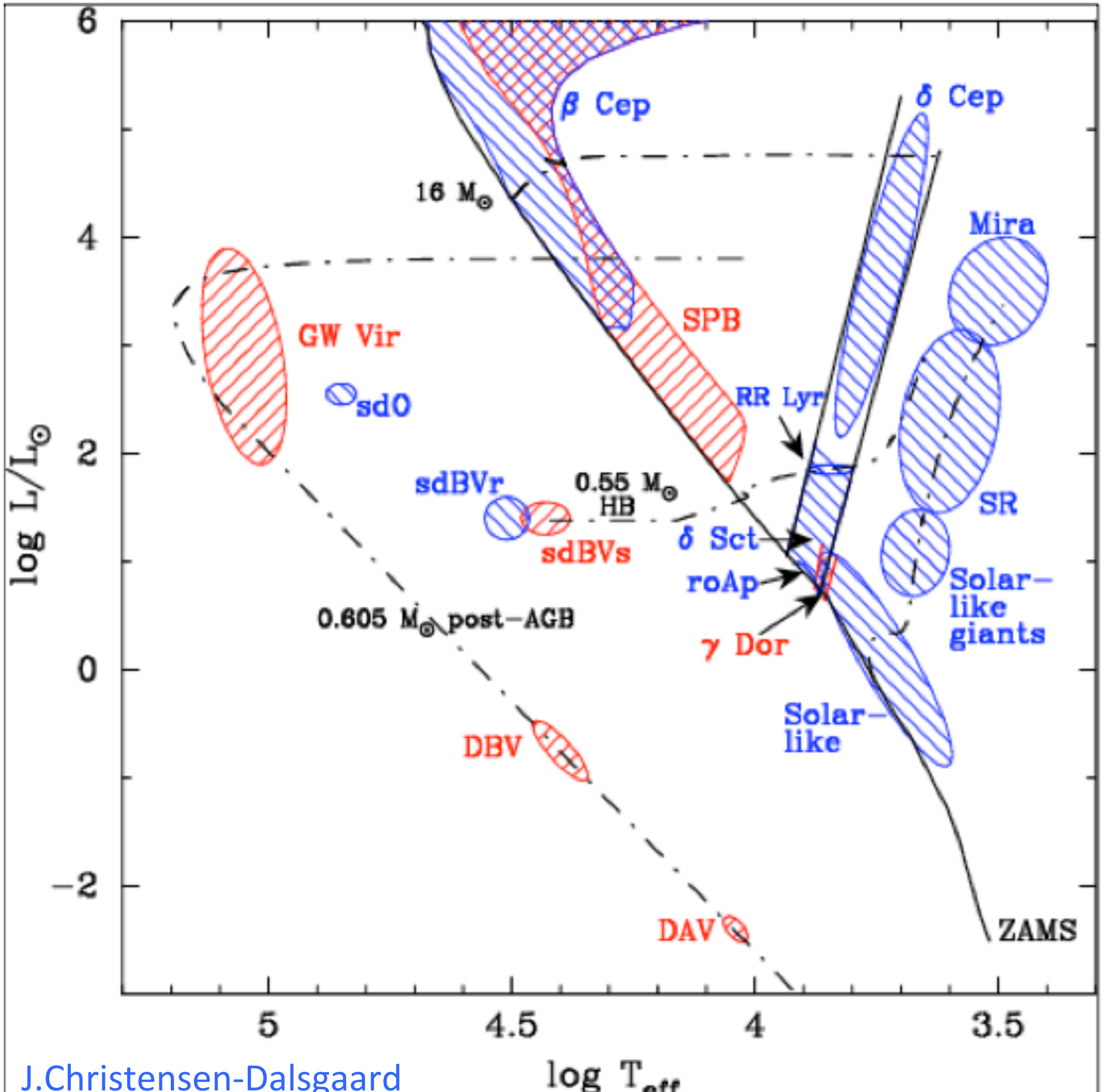
BRITE-Constellation

6 satellites, 3 equipped with red (R),
3 with blue (B) filter

BRITE sky ≈ naked-eye sky



Pulsating stars in the H-R diagram



BRITE targets:

Stars:

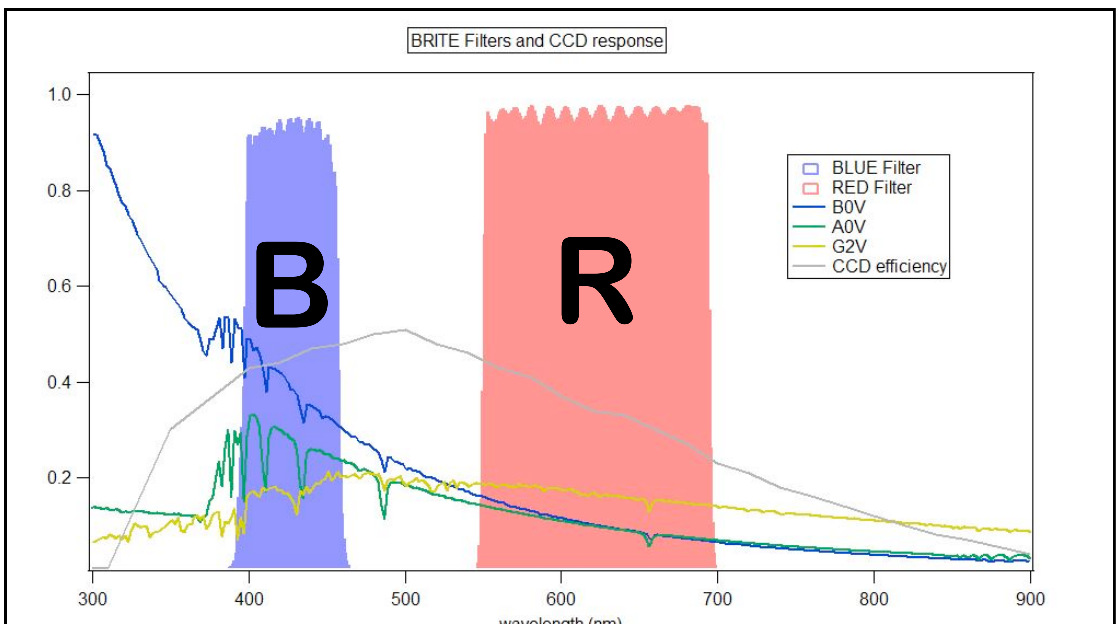
- bright,
- massive,
- young.

β Cephei

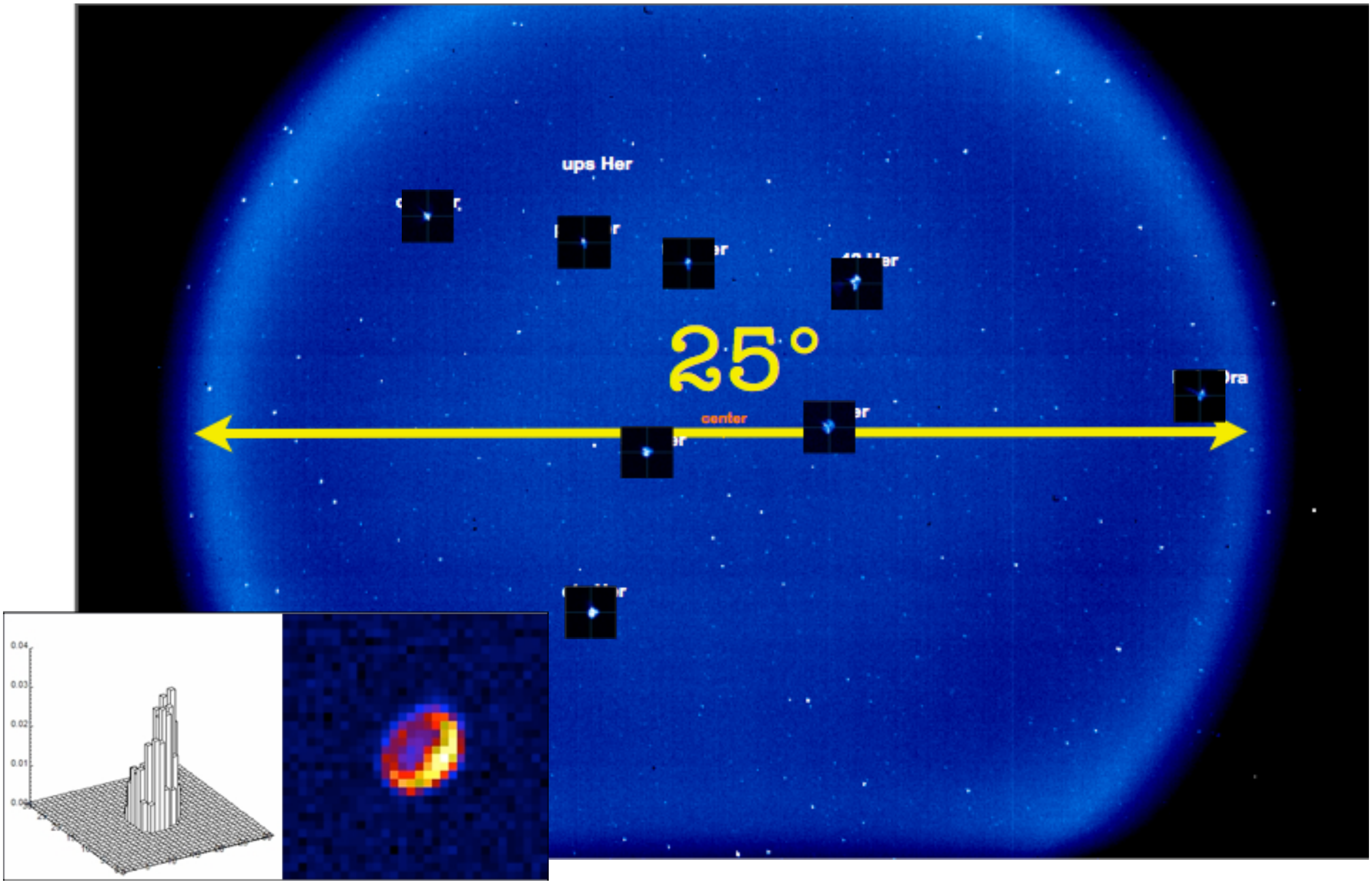
SPB

BRITE-Constellation

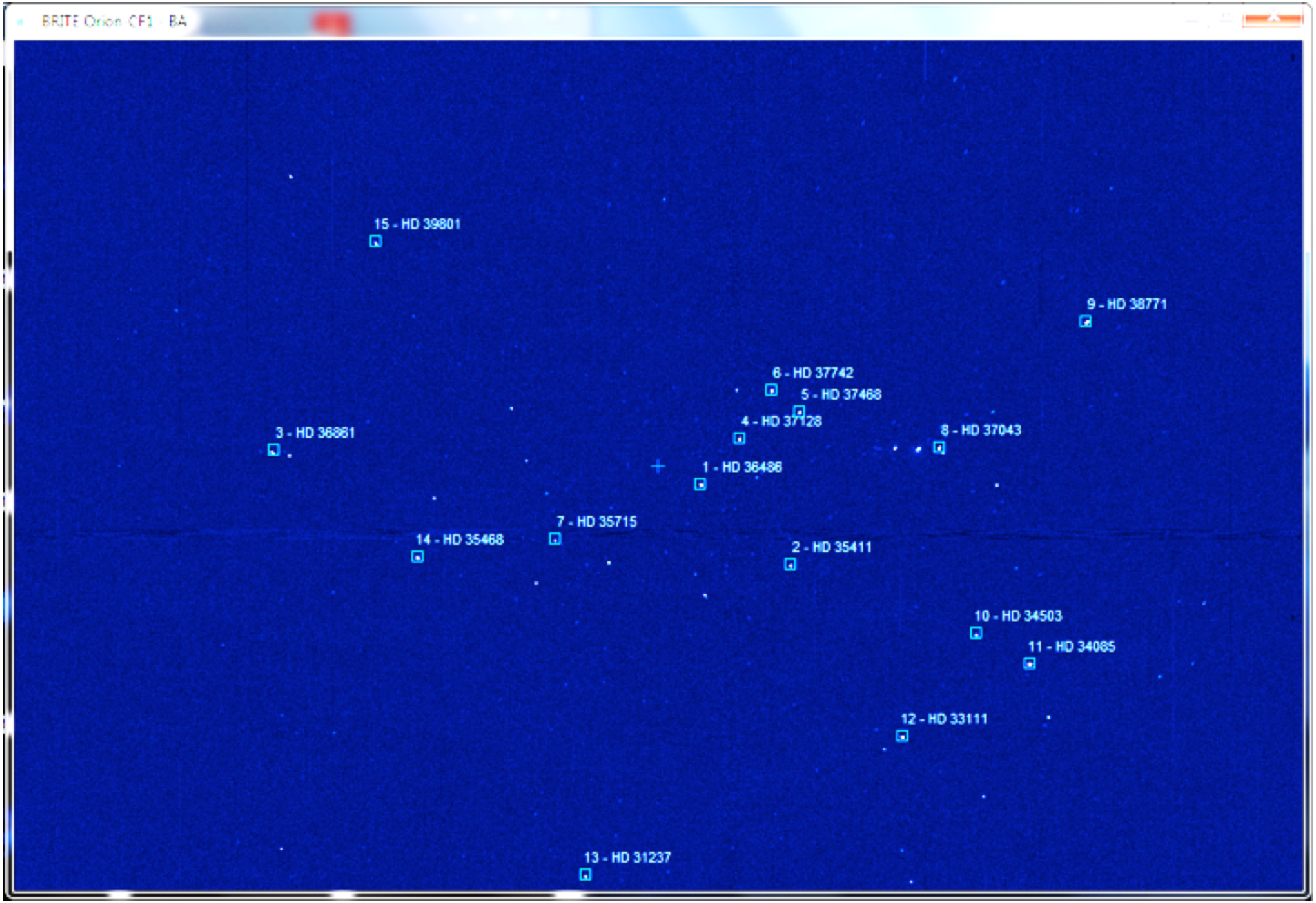
		Launch date	In space for
	**BRITE-Austria (BAb)**	**25.02.2013**	**43 months**
	UniBRITE (UBr)	**25.02.2013**	**43 months**
	**Lem (BLb)**	**21.11.2013**	**34 months**
	Heweliusz (BHr)	**19.08.2014**	**25 months**
	~~**BRITE-Montréal (BMb)**~~	**19.06.2014**	**27 months**
	BRITE-Toronto (BTr)	**19.06.2014**	**27 months**



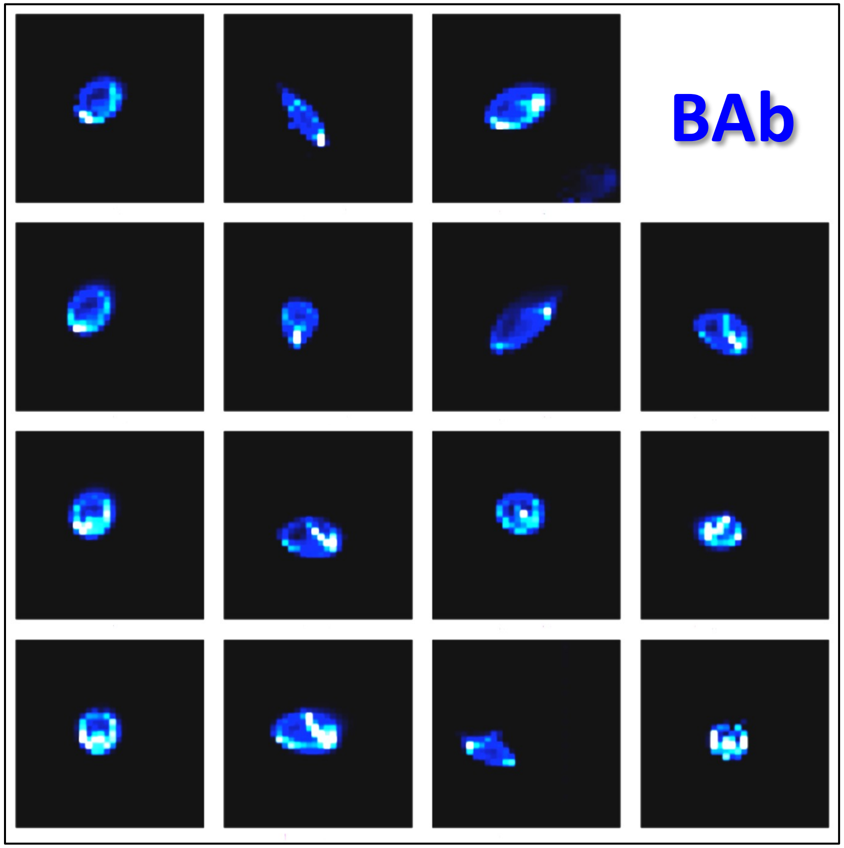
Field of view

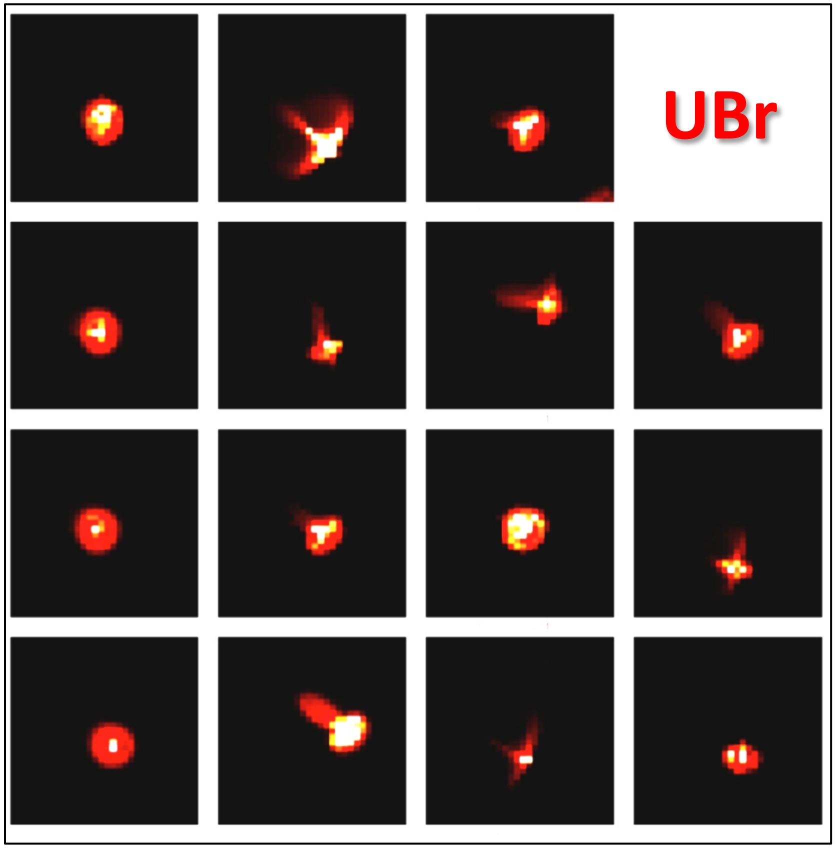


Orion field


BRITE Orion CF1 - BA
15 - HD 39801
9 - HD 38771
6 - HD 37742
5 - HD 37468
4 - HD 37128
8 - HD 37043
3 - HD 36861
1 - HD 36486
7 - HD 35715
14 - HD 35468
2 - HD 35411
10 - HD 34503
11 - HD 34085
12 - HD 33111
13 - HD 31237

BRITE photometry



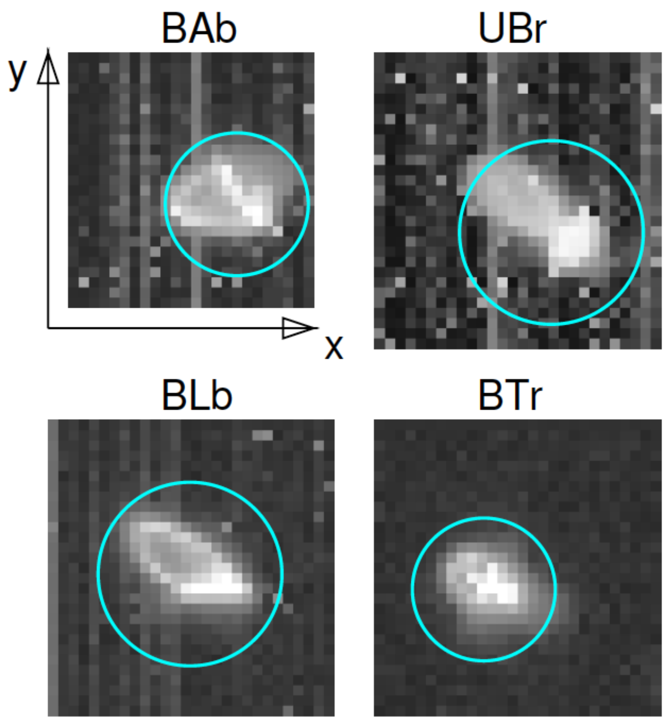


- rasters,
- defocusing,
- aperture photometry.

Images courtesy Rainer Kuschnig & Adam Popowicz

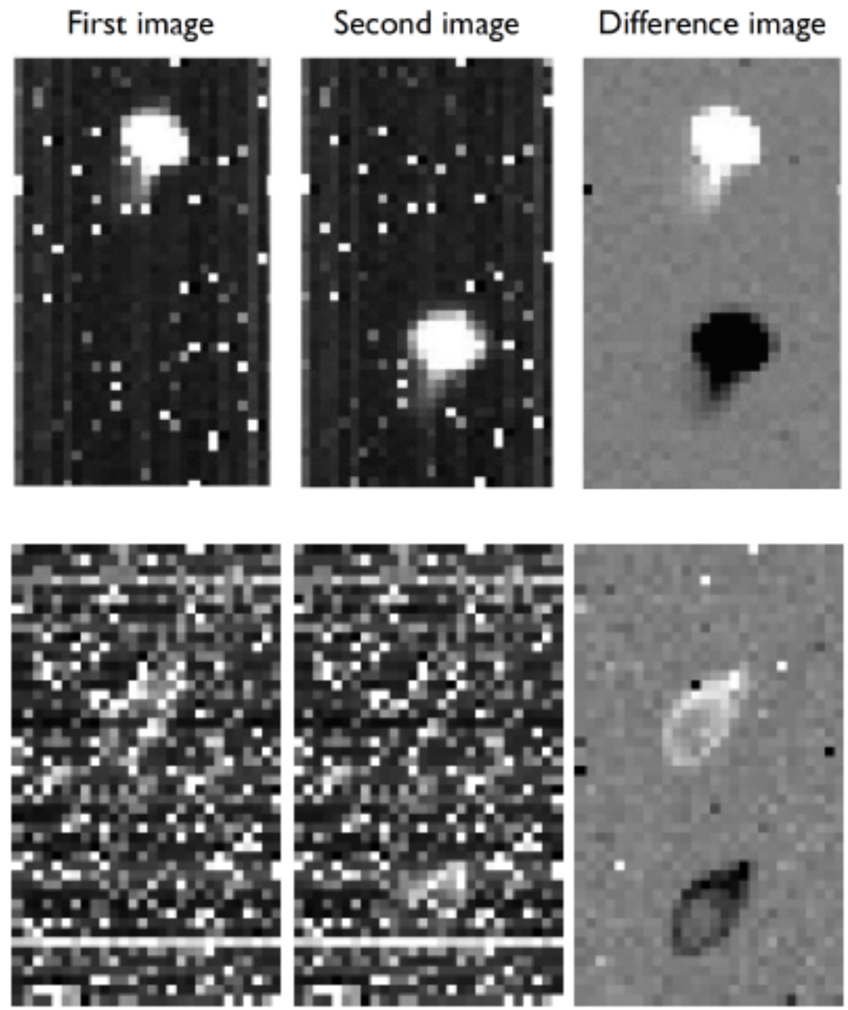
Rasters/windows, modes of observing

Normal mode



Pigulski et al. (2016)

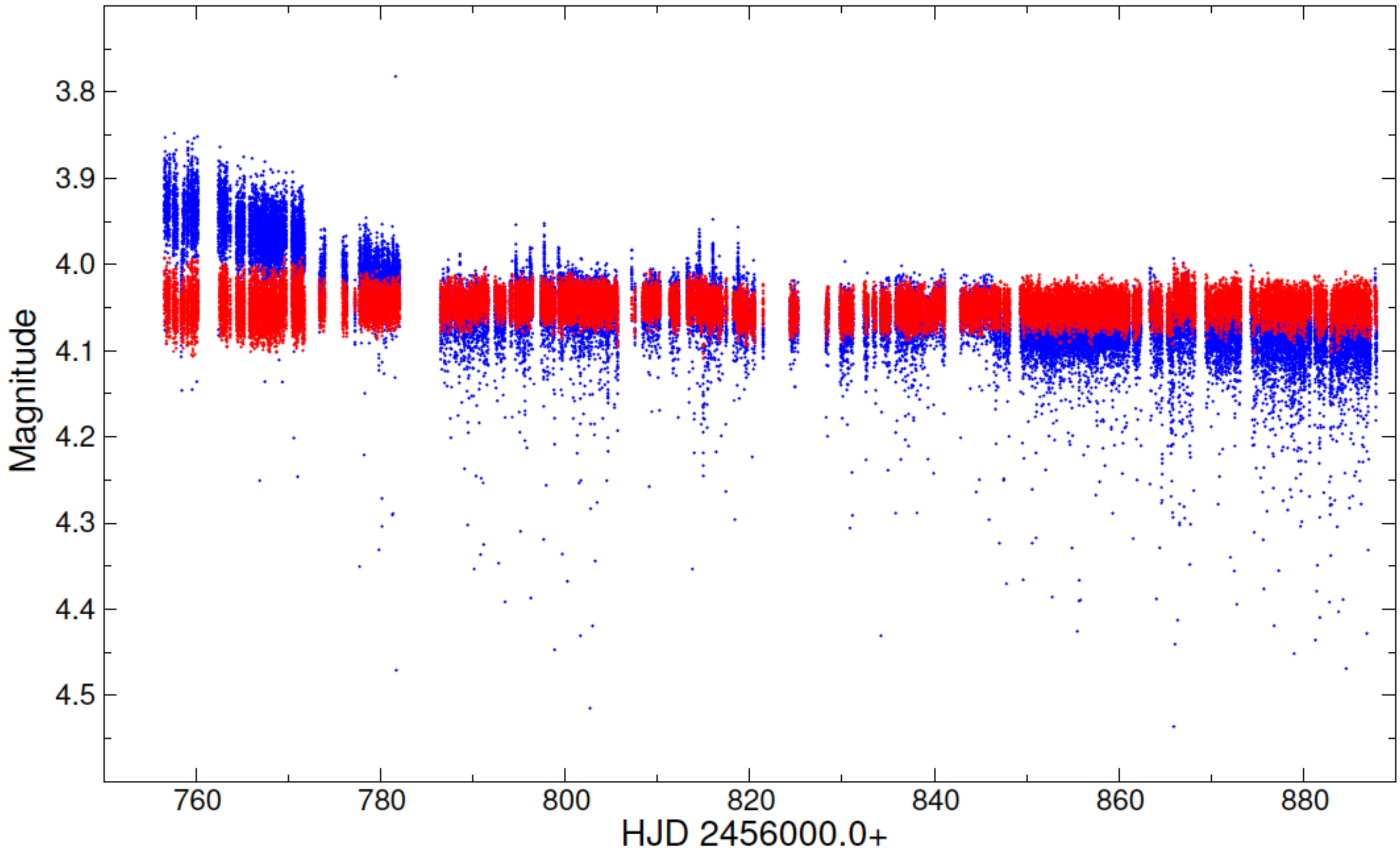
Chopping mode



Popowicz et al. (2016)

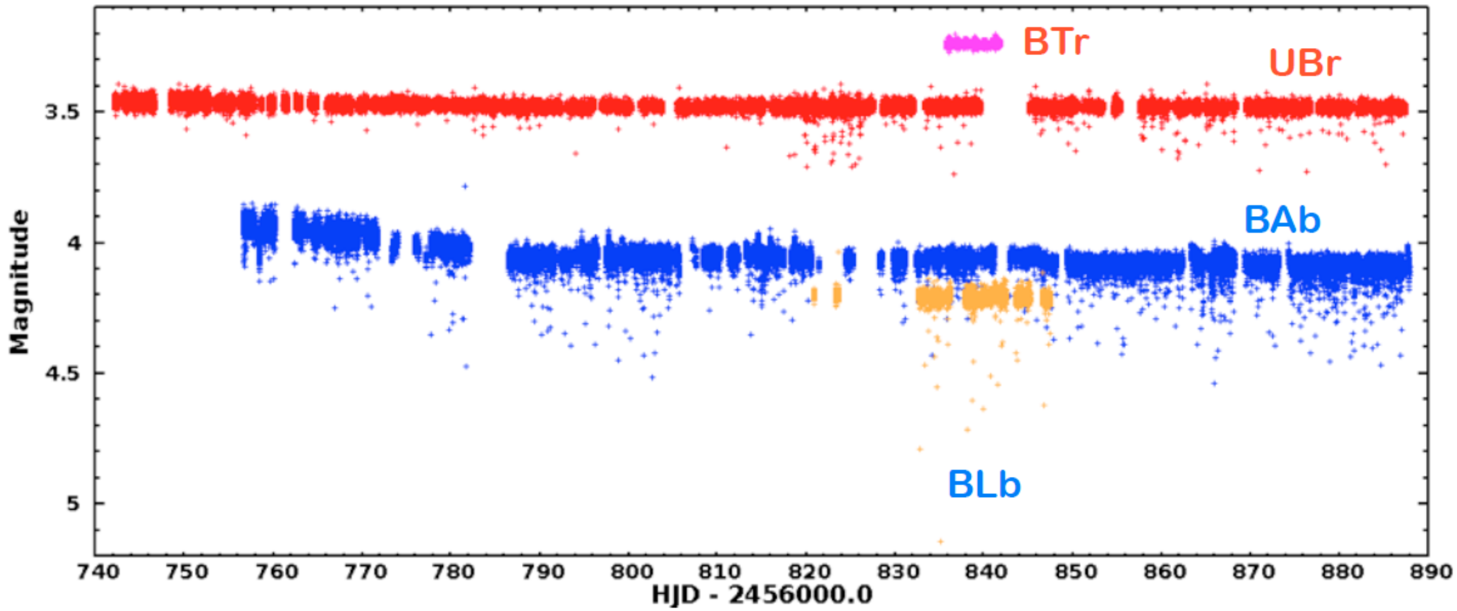
Removing instrumental effects: an example

Cen: HD 128898, BAb, 4 (α Cir)

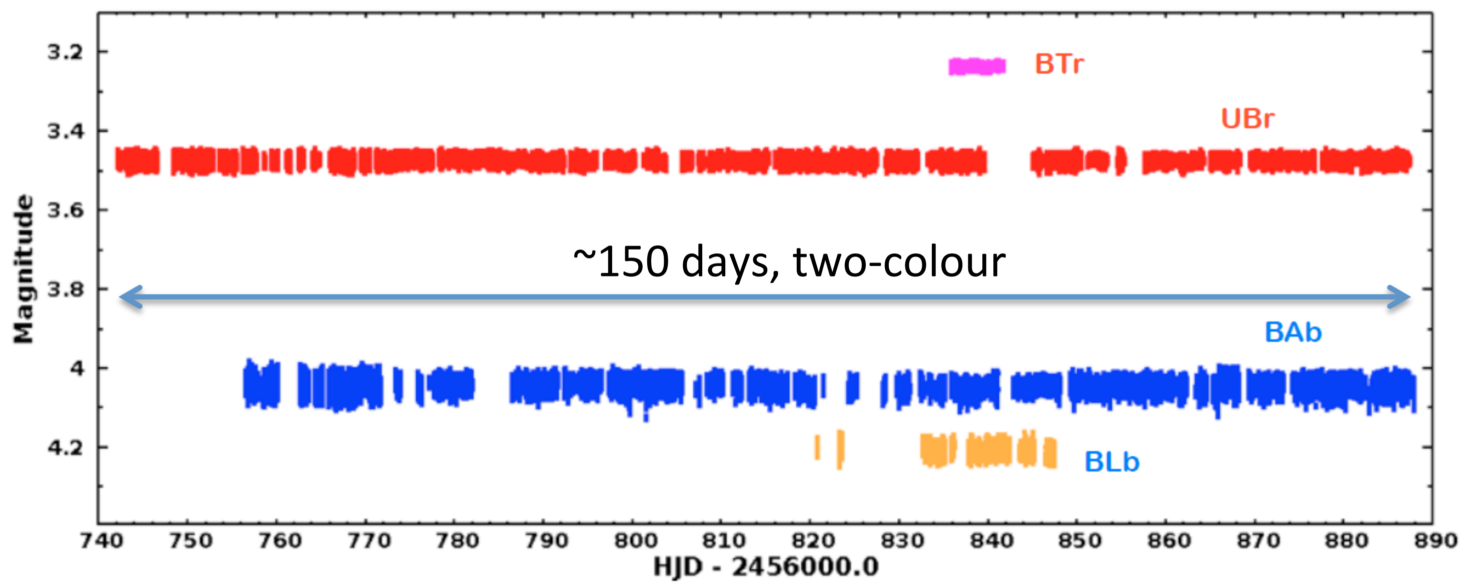


Removing instrumental effect: an example

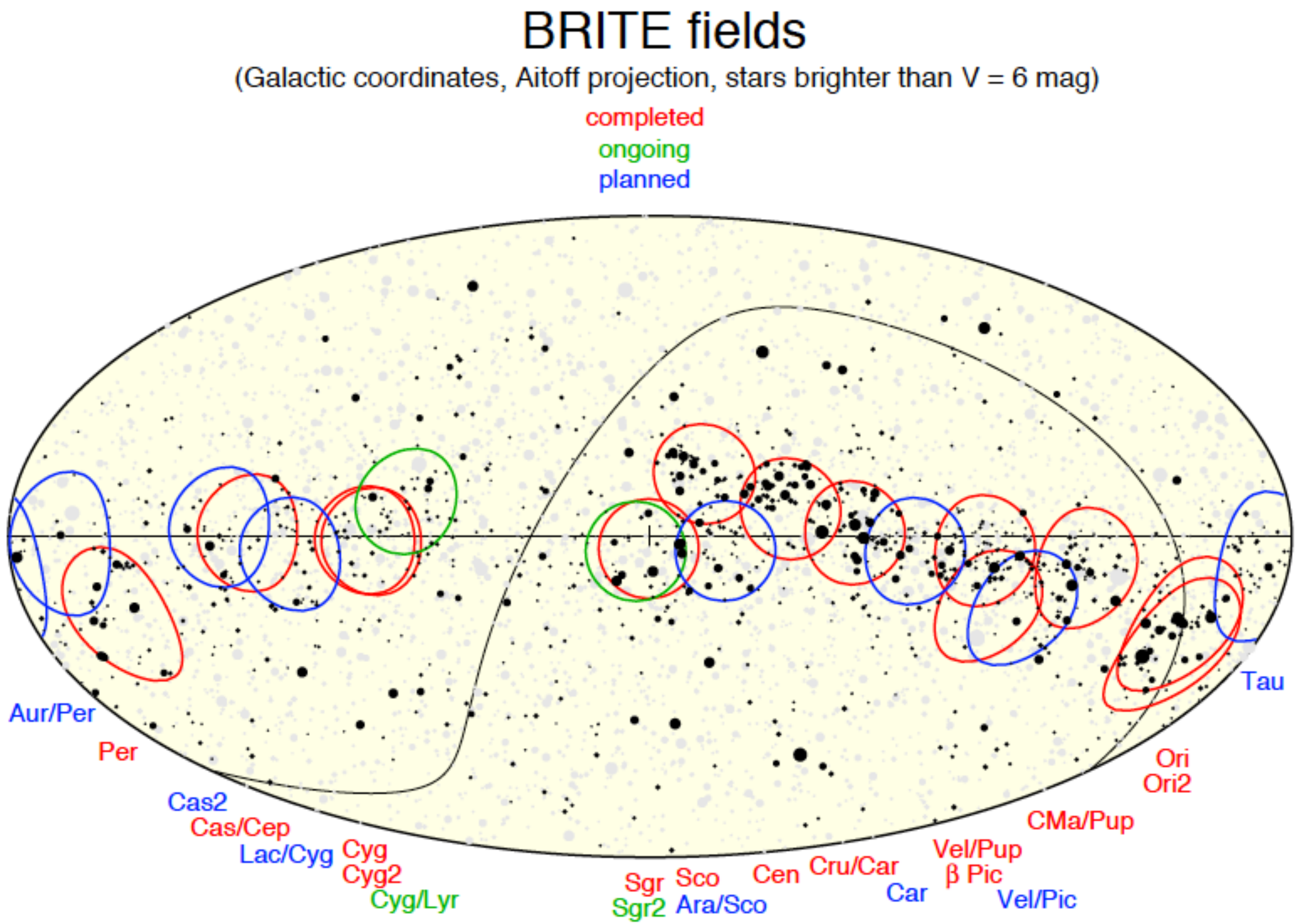
BEFORE:



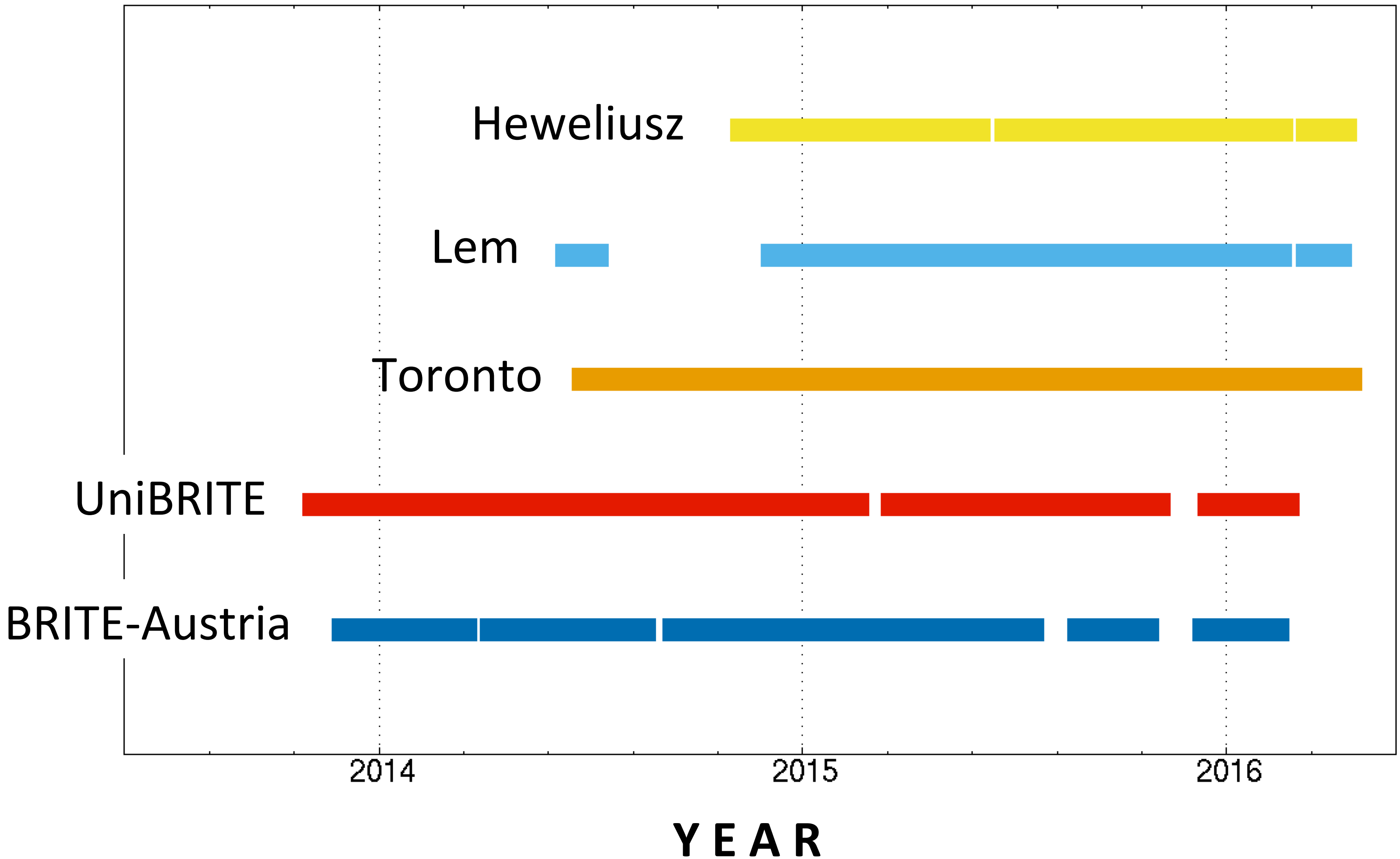
AFTER:



BRITE sky


BRITE fields
(Galactic coordinates, Aitoff projection, stars brighter than V = 6 mag)
completed
ongoing
planned
Aur/Per
Per
Cas2
Cas/Cep
Lac/Cyg
Cyg
Cyg2
Cyg/Lyr
Sgr
Sgr2
Sco
Ara/Sco
Cen
Cru/Car
Car
Vel/Pup
β Pic
Vel/Pic
CMa/Pup
Ori
Ori2
Tau

Summary of up-to-date observations



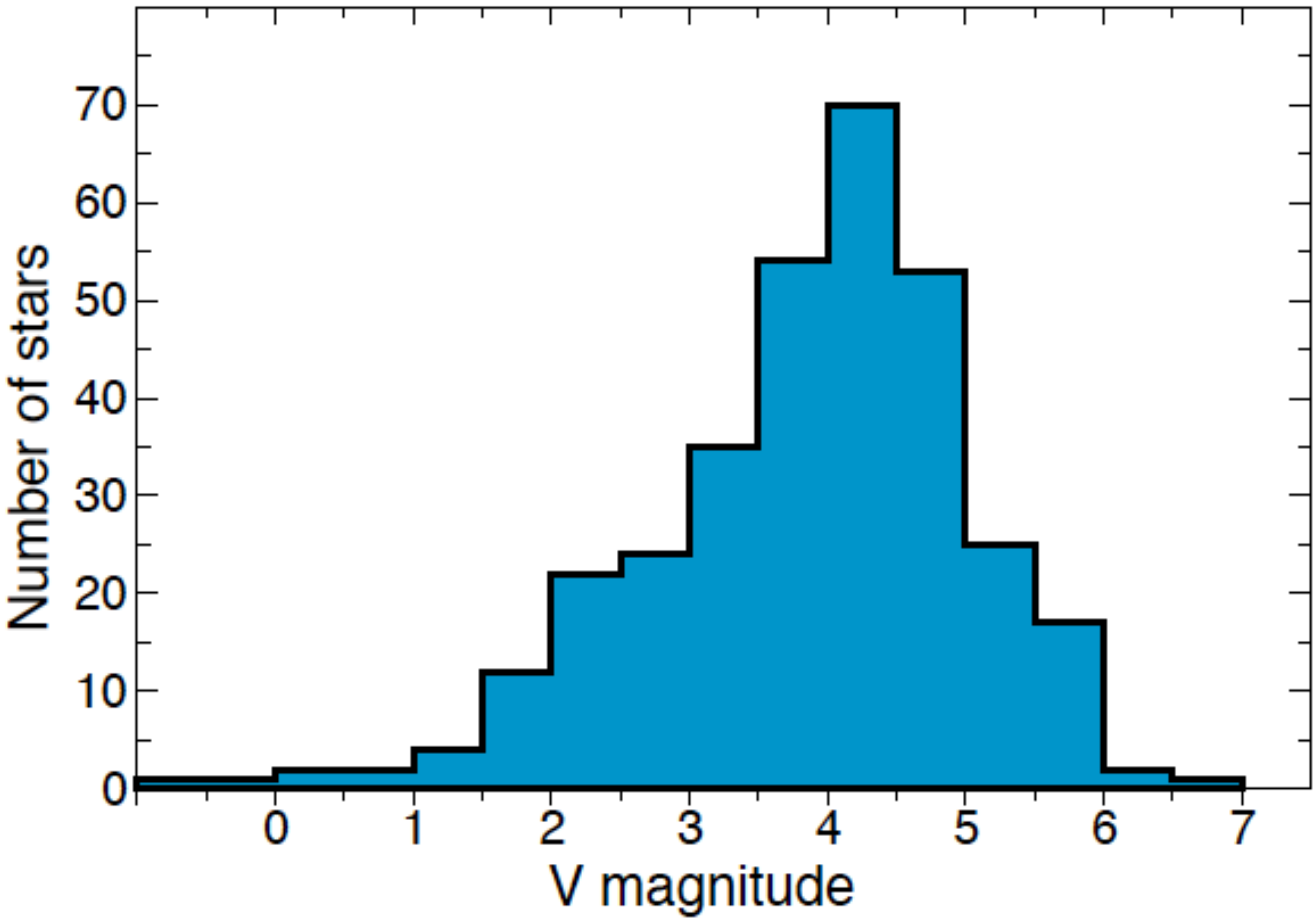
Summary of the up-to-date observations

Observations obtained for 14 fields (**337** stars).
Data delivered for 13 fields (**300** stars).
This includes 70% of all OB stars brighter than V = 4 mag.
Ongoing observations of 3 next fields.
The associated spectropolarimetric survey (~**500** stars, C.Neiner)

Two technical papers published.
The first three scientific papers published.
Two papers submitted.
Next 20 – 25 papers at different stages of preparation.

BRITE-Constellation Web page:
    http://www.univie.ac.at/brite-constellation/
BRITE-Constellation Wiki page:
    http://brite.craq-astro.ca/doku.php?id=start
BRITE-Constellation Facebook page:
    https://www.facebook.com/briteconstellation

Summary of the up-to-date BRITE targets



α Circini (HD 128898, A7 Vp SrCrEu, V = 3.19)

COMMISSION 27 OF THE I. A. U.
INFORMATION BULLETIN ON VARIABLE STARS

Number 1987

Konkoly Observatory
Budapest
1981 July 7

HU ISSN 0374-0676

THE DISCOVERY OF 6.8 MINUTE OSCILLATIONS IN α Cir

Kurtz & Cropper (1981)

COMMISSION 27 OF THE I. A. U.
INFORMATION BULLETIN ON VARIABLE STARS

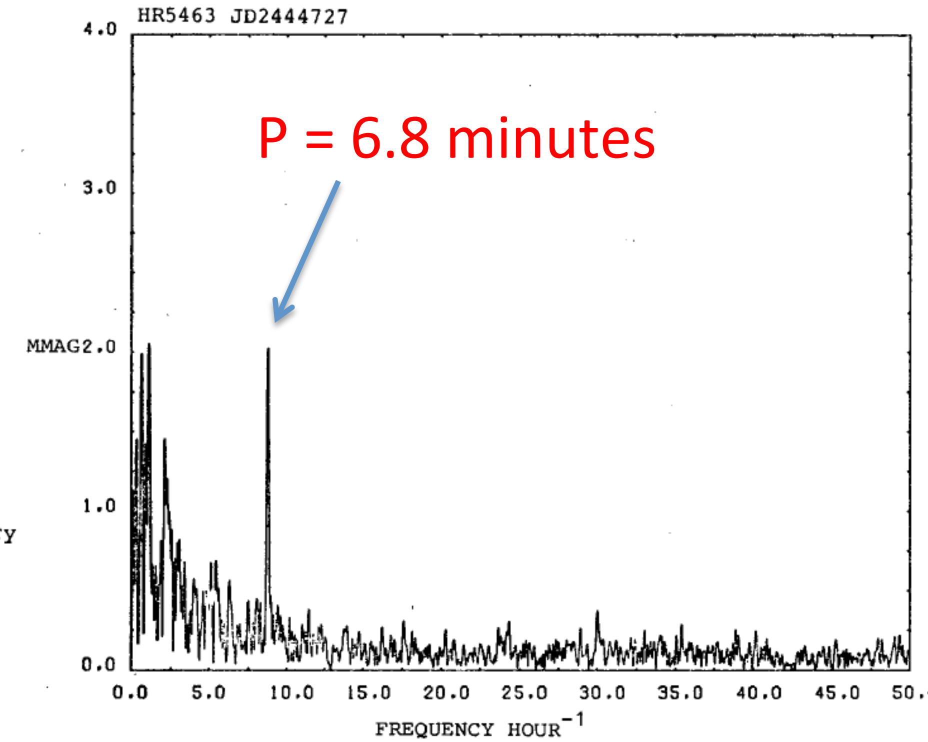
Number 2033

Konkoly Observatory
Budapest
1981 October 30

HU ISSN 0374-0676

THE PRINCIPAL FREQUENCY OF THE RAPIDLY OSCILLATING
Ap STAR α Cir

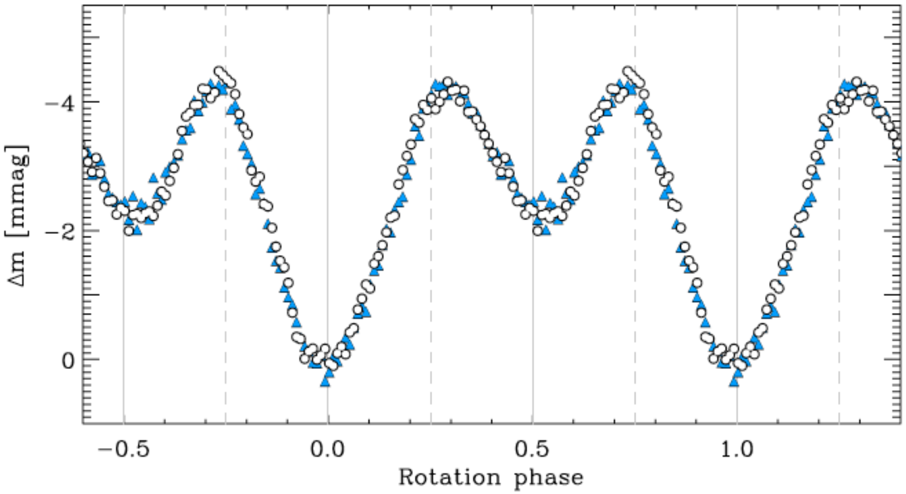
Kurtz et al. (1981)



α Circini from WIRE

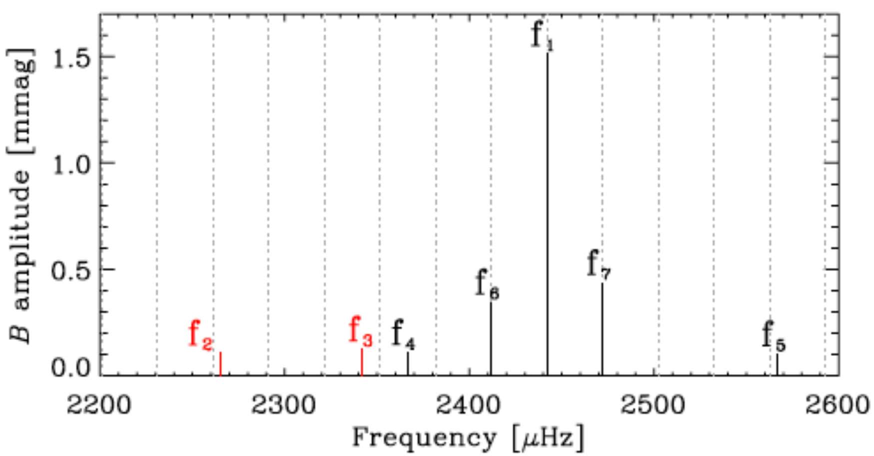
Asteroseismic analysis of the roAp star *α* Circini: 84 d of high-precision photometry from the *WIRE* satellite★

H. Bruntt,[1]† D. W. Kurtz,[2] M. S. Cunha,[3] I. M. Brandão,[3,4] G. Handler,[5] T. R. Bedding,[1] T. Medupe,[6,7] D. L. Buzasi,[8] D. Mashigo,[6] I. Zhang[6] and F. van Wyk[7]



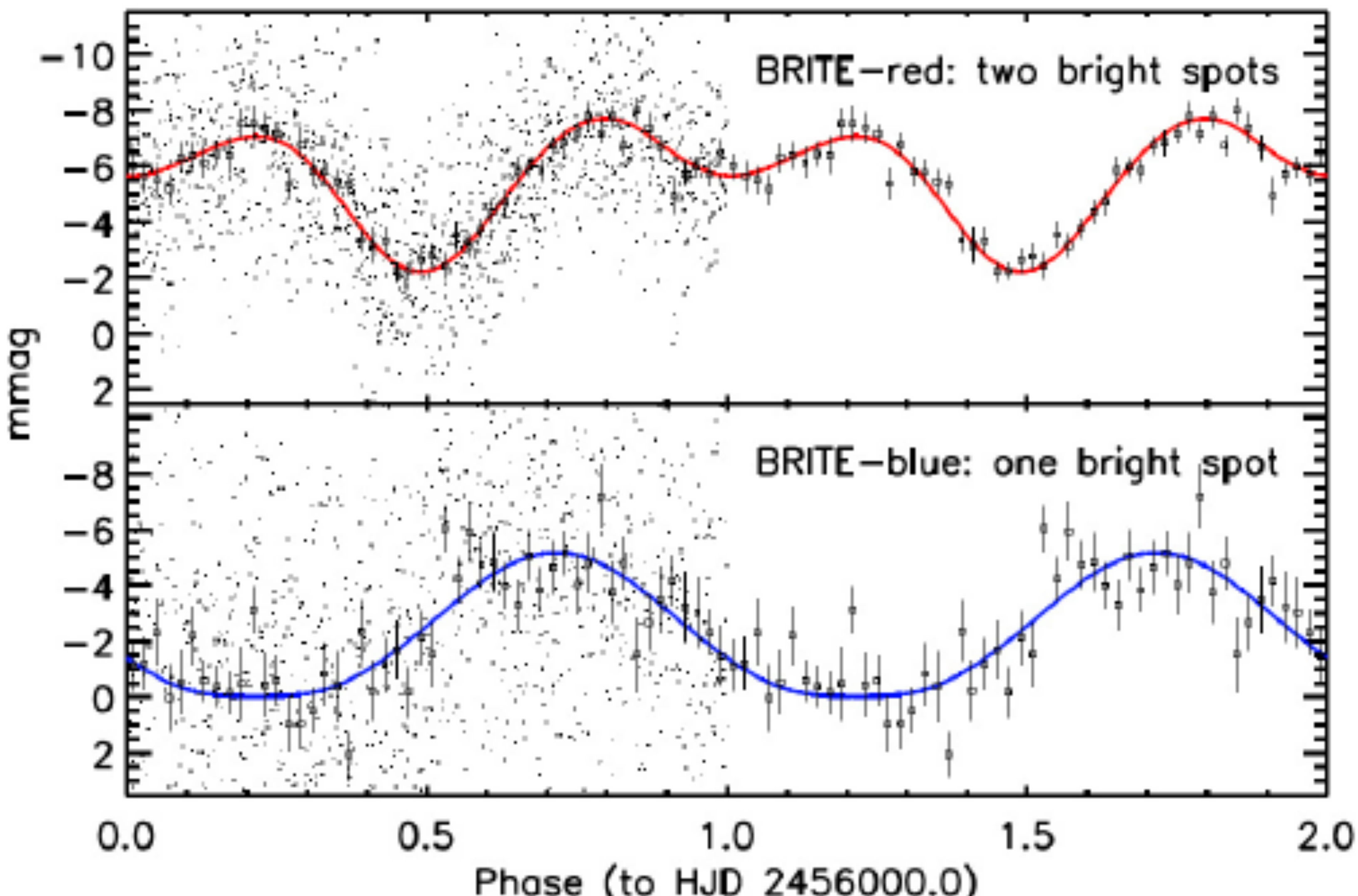
rotation

pulsations



Bruntt, Kurtz, et al. (2009)

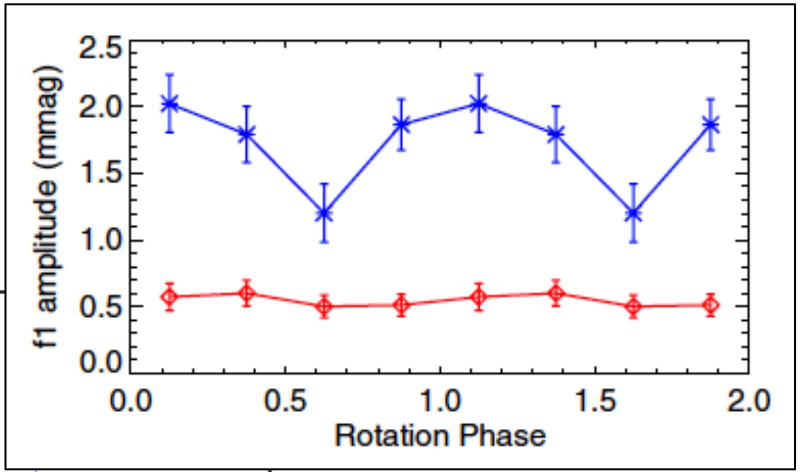
α Circini from BRITE: rotation

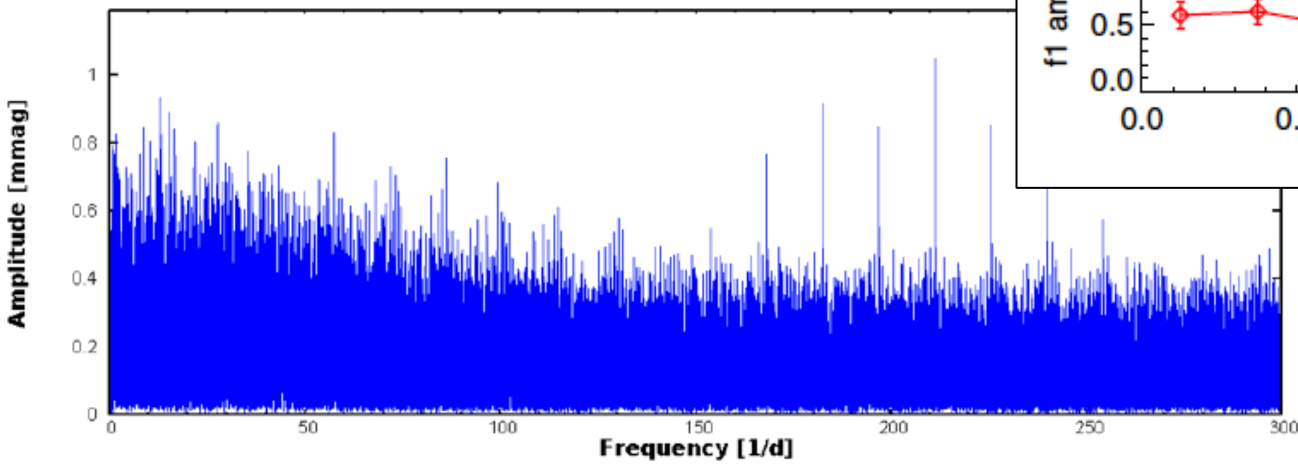


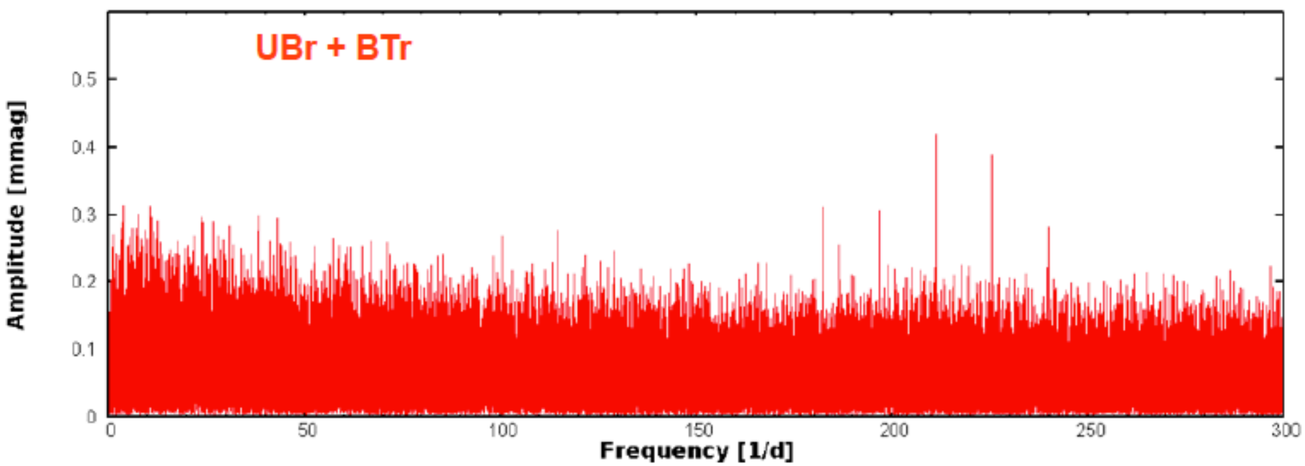
Weiss et al. (2016)

α Circini from BRITE: pulsations

f_1 and f_7 (marginally) detected

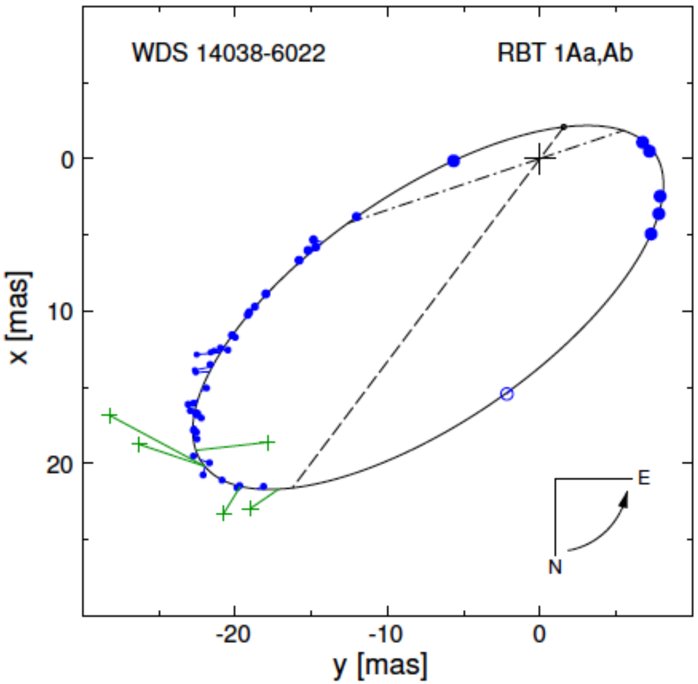


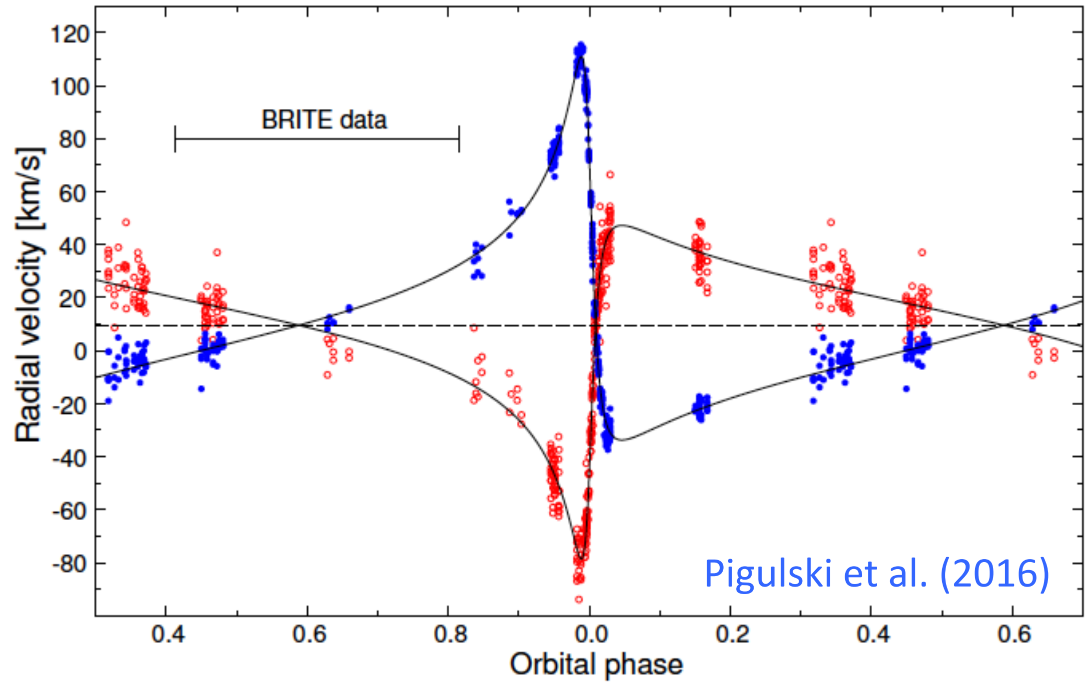




Weiss et al. (2016)

β Centauri (HD 122451 = Agena, B1 V + B + ..., V = 0.6)





Parameter	Visual orbit	Spectroscopic orbit	Combined orbits
Orbital period, $P_{\rm orb}$ [yr]	$0.9788^{+0.0008}_{-0.0014}$	$0.97719^{+0.00005}_{-0.00005}$	$0.97720^{+0.00004}_{-0.00004}$
Orbital period, $P_{\rm orb}$ [d]	$357.49^{+0.31}_{-0.51}$	$356.911^{+0.018}_{-0.018}$	$356.915^{+0.015}_{-0.015}$
Eccentricity, e	$0.8201^{+0.0031}_{-0.0021}$	$0.8237^{+0.0011}_{-0.0011}$	$0.8245^{+0.0006}_{-0.0006}$
Longitude of periastron, ω [°]	$60.1^{+0.5}_{-0.4}$	$61.13^{+0.36}_{-0.34}$	$60.87^{+0.26}_{-0.25}$
Time of periastron passage, T_0 [Besselian epoch]	$2000.1509^{+0.0010}_{-0.0010}$	$2000.15209^{+0.00012}_{-0.00013}$	$2000.15202^{+0.00011}_{-0.00010}$
Inclination, i [°]	$66.76^{+0.30}_{-0.33}$	—	$67.68^{+0.12}_{-0.12}$
Position angle of the line of nodes, Ω [°]	$108.69^{+0.22}_{-0.37}$	—	$108.80^{+0.14}_{-0.15}$
Angular semimajor axis of the relative orbit, a'' [mas]	$24.71^{+0.19}_{-0.16}$	—	$25.15^{+0.09}_{-0.08}$
Systemic velocity, γ [km s^{-1}]	—	$9.61^{+0.23}_{-0.21}$	$9.59^{+0.23}_{-0.21}$
Half-range of radial-velocity for primary, K_1 [km s^{-1}]	—	$62.9^{+0.6}_{-0.6}$	$62.9^{+0.6}_{-0.6}$
Half-range of radial-velocity for secondary, K_2 [km s^{-1}]	—	$72.36^{+0.31}_{-0.28}$	$72.35^{+0.30}_{-0.29}$

Aa – Ab system

β Centauri: A-B system

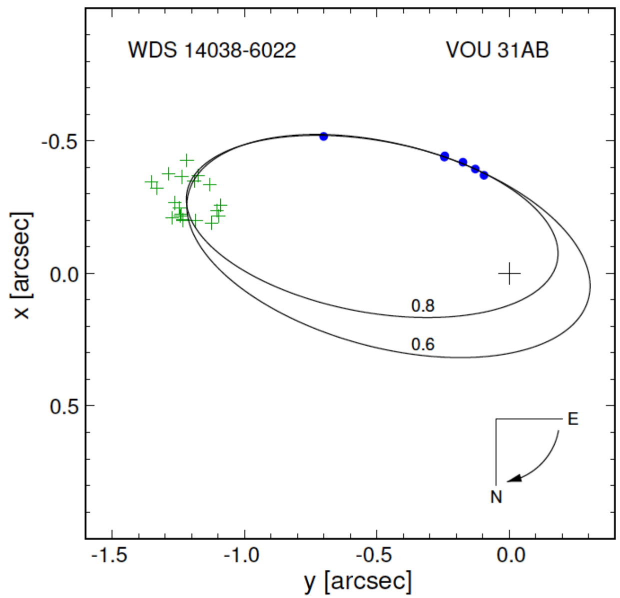
Table 2. Other parmeters of β Cen.

Parameter	Value
Primary's mass, M_1	$12.02 \pm 0.13\ M_\odot$
Secondary's mass, M_2	$10.58 \pm 0.18\ M_\odot$
Semimajor axis, a	2.782 ± 0.011 AU
Distance, D	110.6 ± 0.5 pc
Parallax, π	9.04 ± 0.04 mas
Primary's absolute magnitude, $M_{V,1}$	-4.03 ± 0.10 mag
Secondary's absolute magnitude, $M_{V,1}$	-3.88 ± 0.10 mag

8.32 ± 0.50

(van Leeuwen 2007)

A – B system



$e = 0.6 - 0.8$

$P_{orb} = 125 - 220$ lat

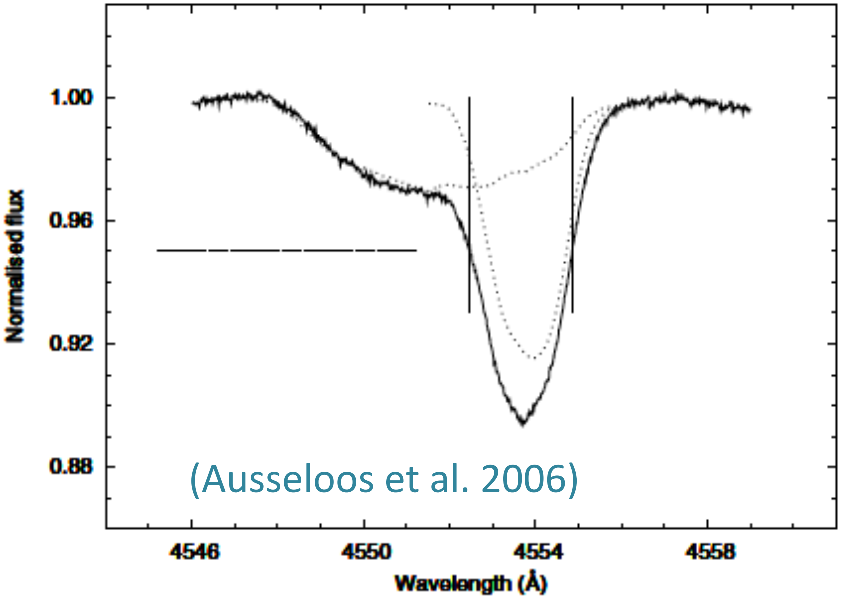
$\omega = 150 - 240°$

$T_0 = 2024 - 2032$

$\Omega = 67 - 110°$

$i = 118 - 130°$

β Centauri: two massive components



V_{rot} sin i:

Aa: 200 - 250 km/s

Ab: 70 - 120 km/s

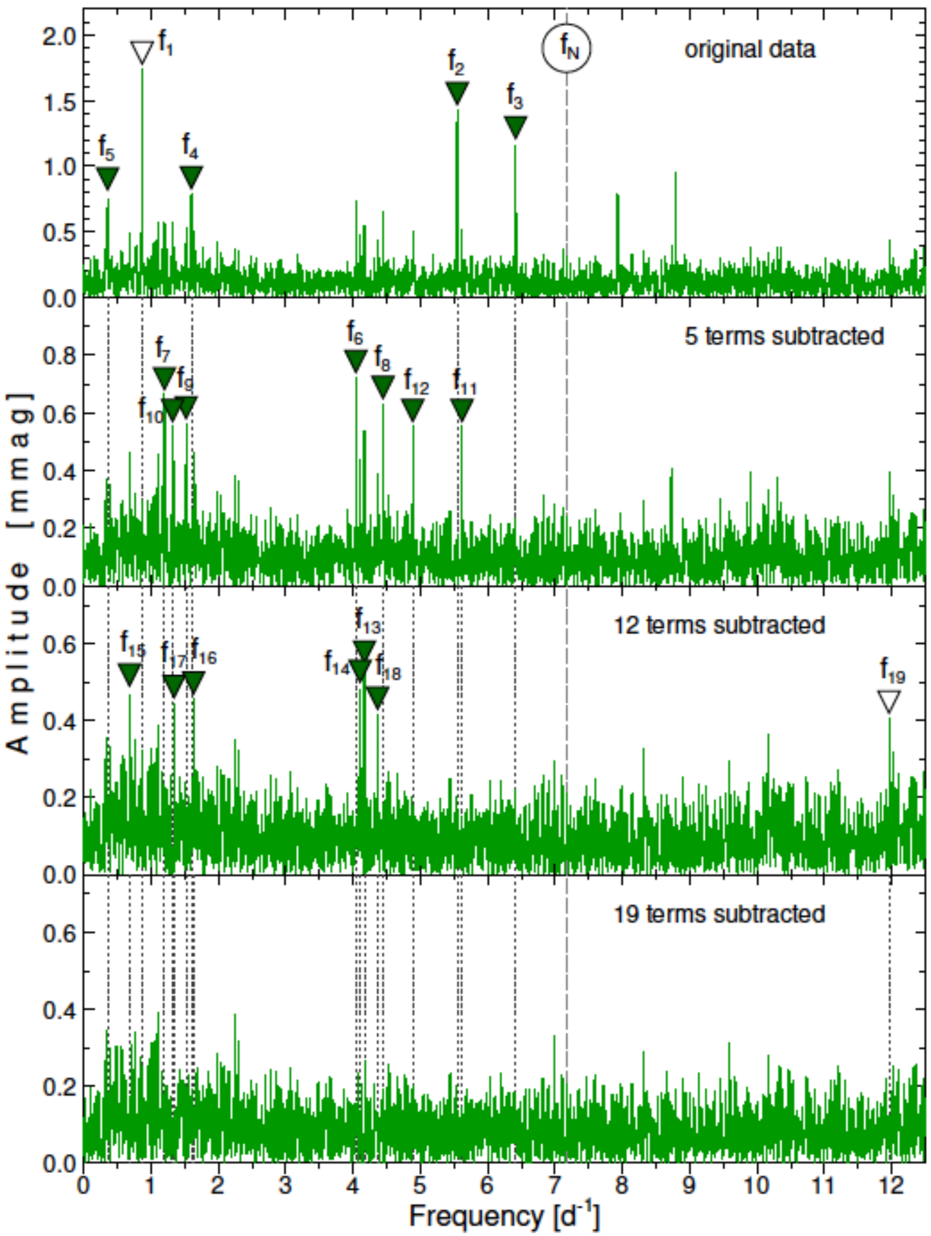
Source	Freq. $[d^{-1}]$	Identification
Breger (1967)	7.59	$f_2 + 2\ d^{-1}$
Shobbrook & Robertson (1968)	7.418	$f_3 + 1\ d^{-1}$
Lomb (1975)	6.37	f_3
Robertson et al. (1999)	5.59	f_2
	6.28	possibly f_3
Ausseloos et al. (2002)	6.51481	$f_2 + 1\ d^{-1}$ $-1\ mo^{-1}$
	6.41356	f_3
	6.49521	—
Ausseloos et al. (2006)	7.415	$f_3 + 1\ d^{-1}$
	4.542	$f_2 - 1\ d^{-1}$
Balona (1977)	3.33	—

Ground-based observations:

f_2, f_3 or their aliases (spectroscopy)

nothing reliable from photometry

β Centauri: BRITE, frequency spectrum

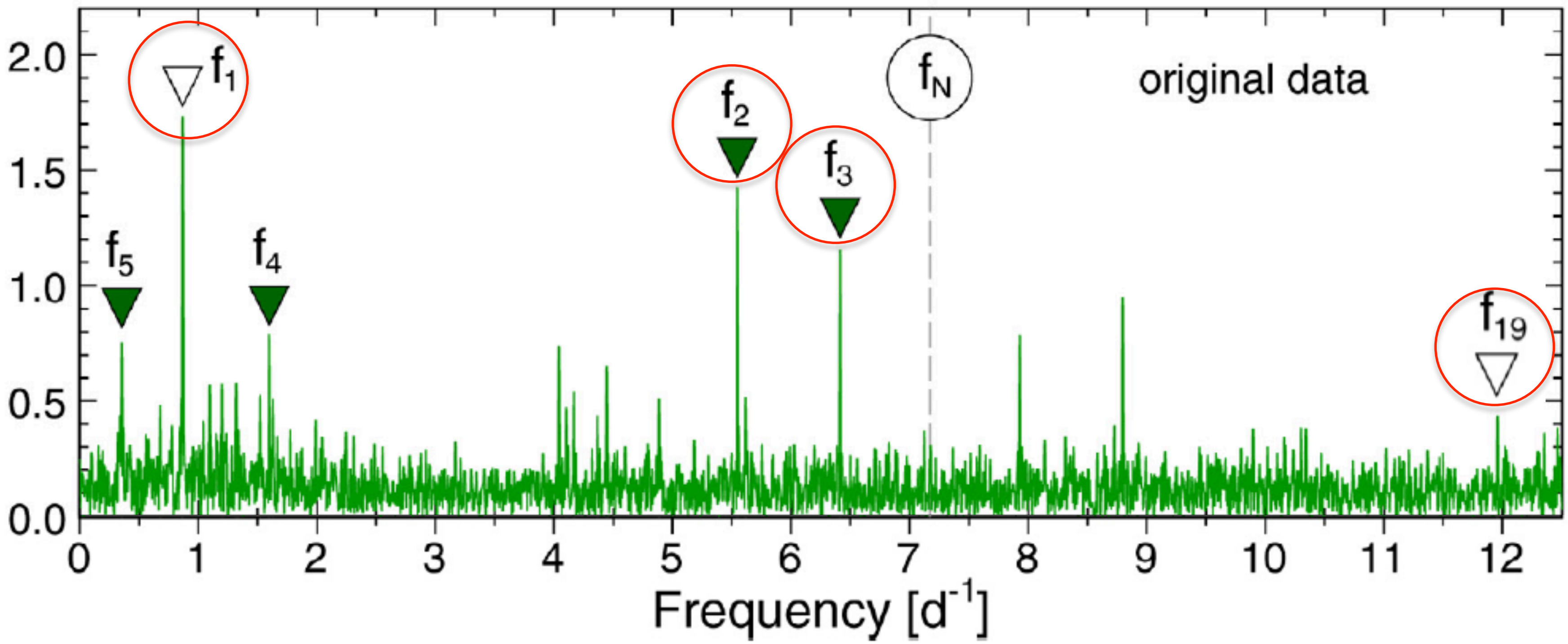


8 *g* modes
9 *p* modes
2 combinations

another
β Cep/SPB hybrid

Pigulski et al. (2016)

β Centauri: BRITE, frequency spectra

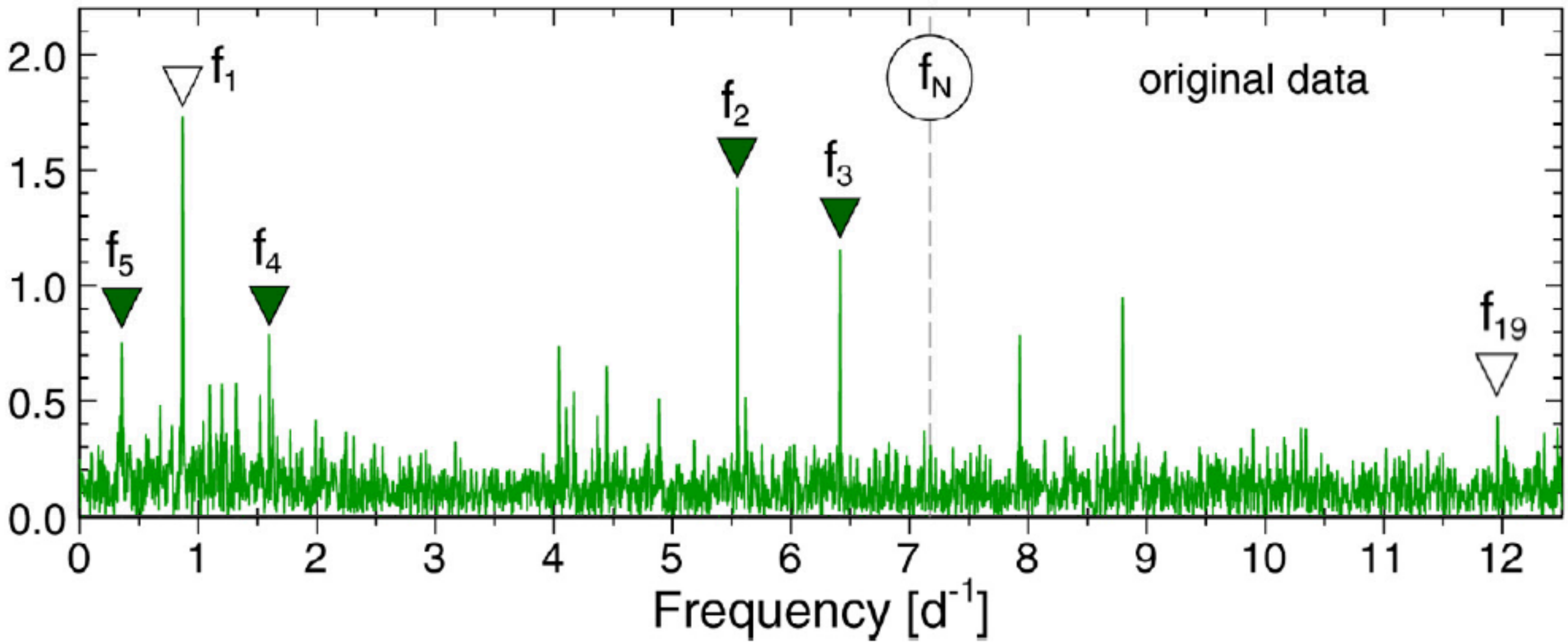


1. f_1 & f_2 are intrinsic, $f_3 = f_1 + f_2$, $f_{19} = f_1 + 2f_2$
2. f_2 & f_3 are intrinsic, $f_1 = f_3 - f_2$, $f_{19} = f_2 + f_3$

A unifying explanation of complex frequency spectra of γ Dor, SPB and Be stars: combination frequencies and highly non-sinusoidal light curves

Donald W. Kurtz[1], Hiromoto Shibahashi[2], Simon J. Murphy[3,4], Timothy R. Bedding[3,4], Dominic M. Bowman[1]

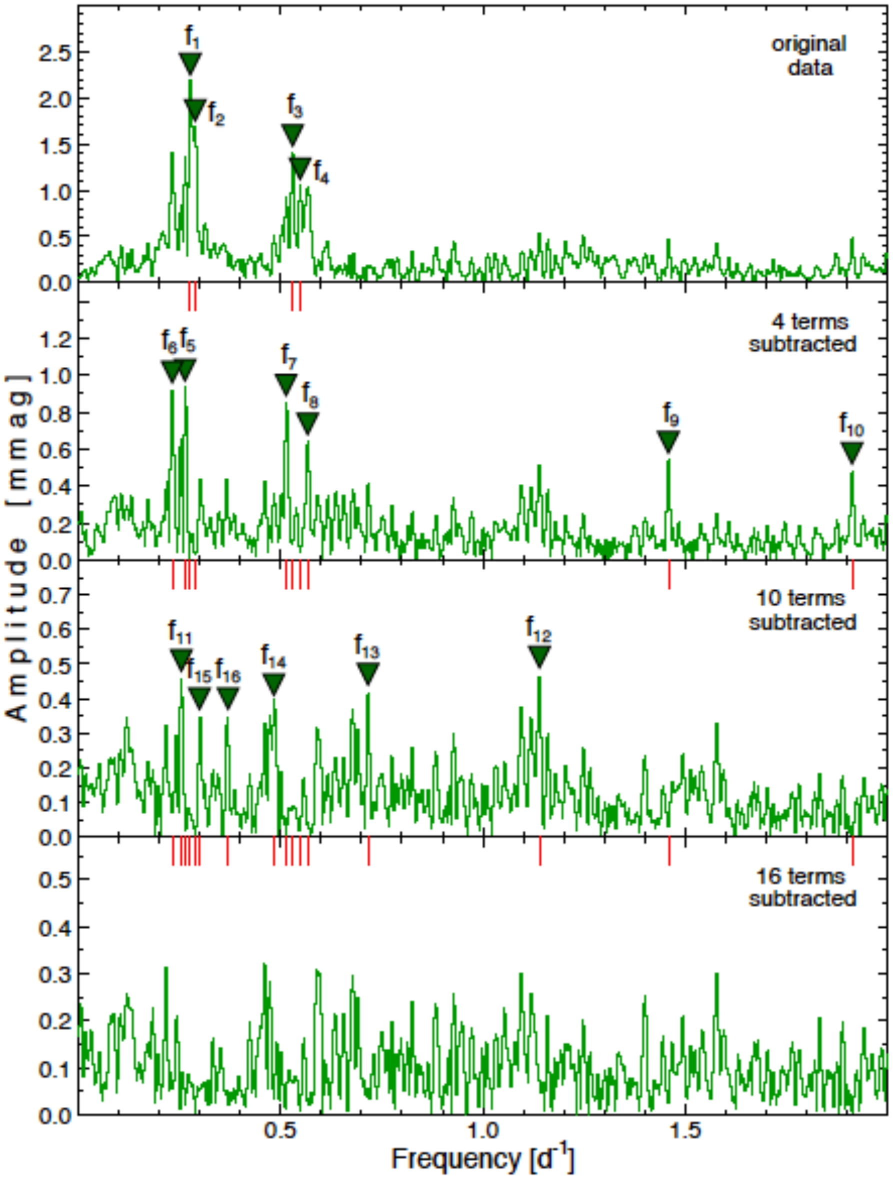
β Centauri: BRITE, frequency spectra



An algorithm for significantly reducing the time necessary to compute a Discrete Fourier Transform periodogram of unequally spaced data

D. W. Kurtz *Department of Astronomy, University of Cape Town, Rondebosch 7700, South Africa*

β Lupi (HD 132058, B2 IV, V = 2.7)

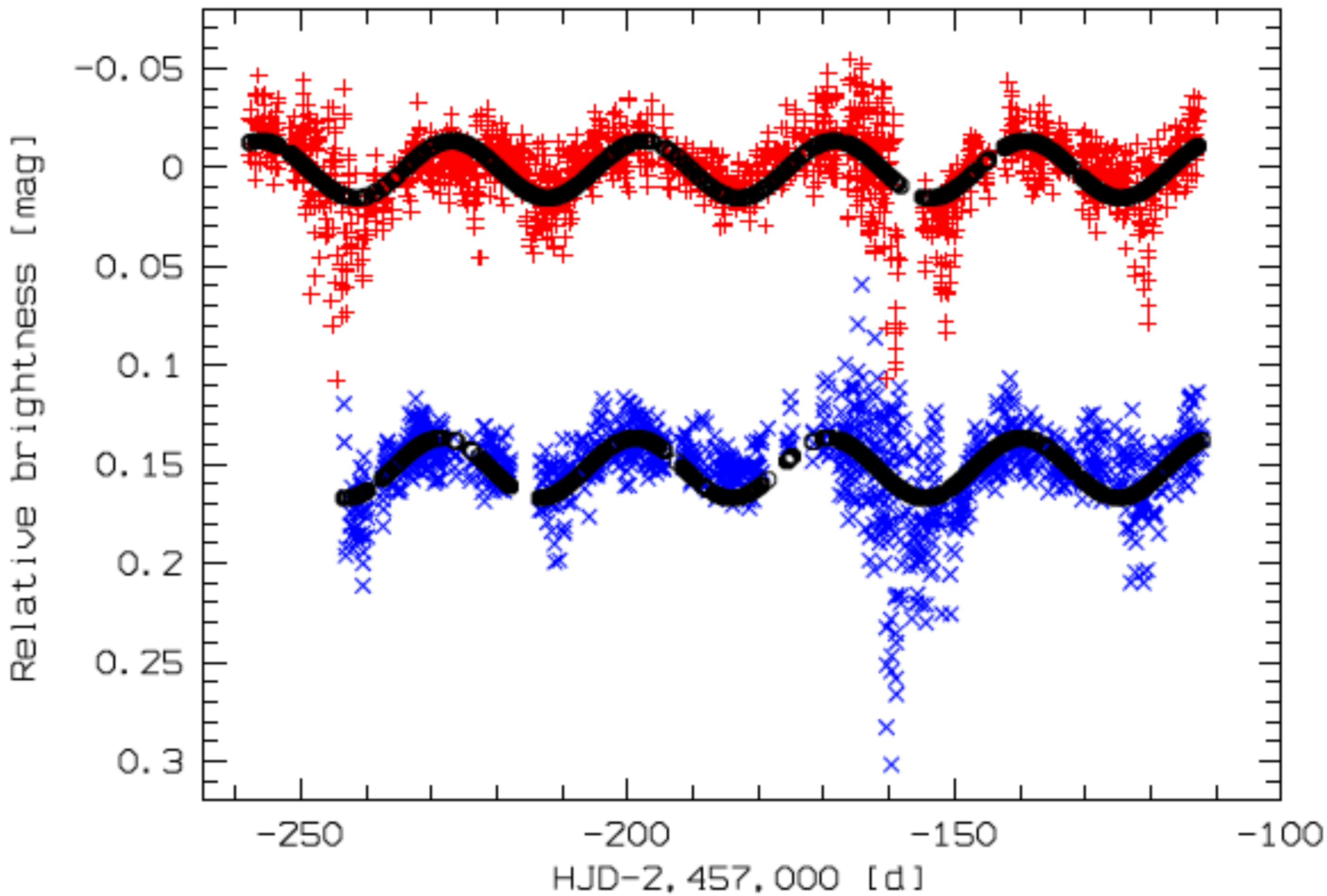


15 *g* modes

Cugier et al. (in prep.)

η Centauri (HD 127973, B1.5 Vne, V = 2.3)

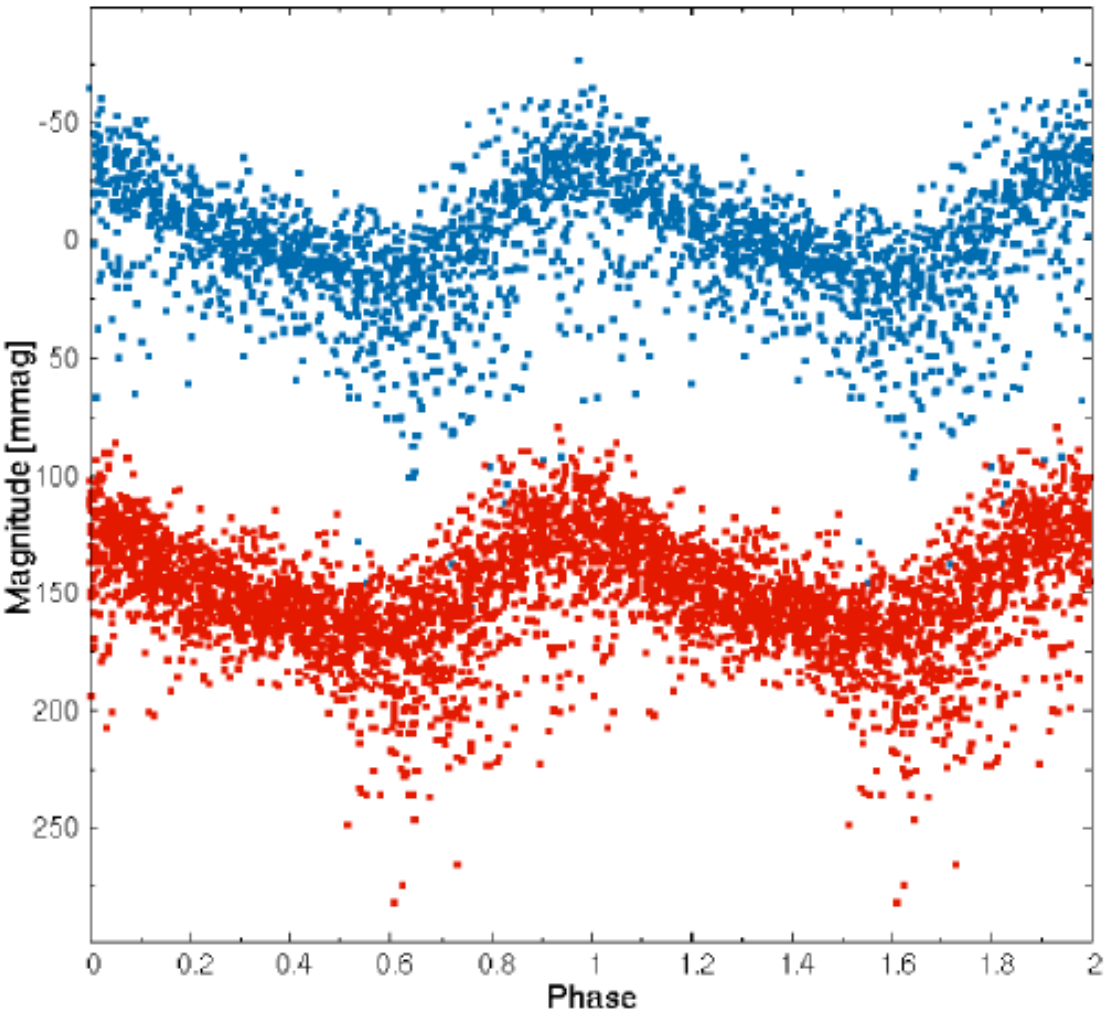
long-term variability, P ≈ 29.4 d



Baade et al. (2016)

η Centauri (HD 127973, B1.5 Vne, V = 2.31)

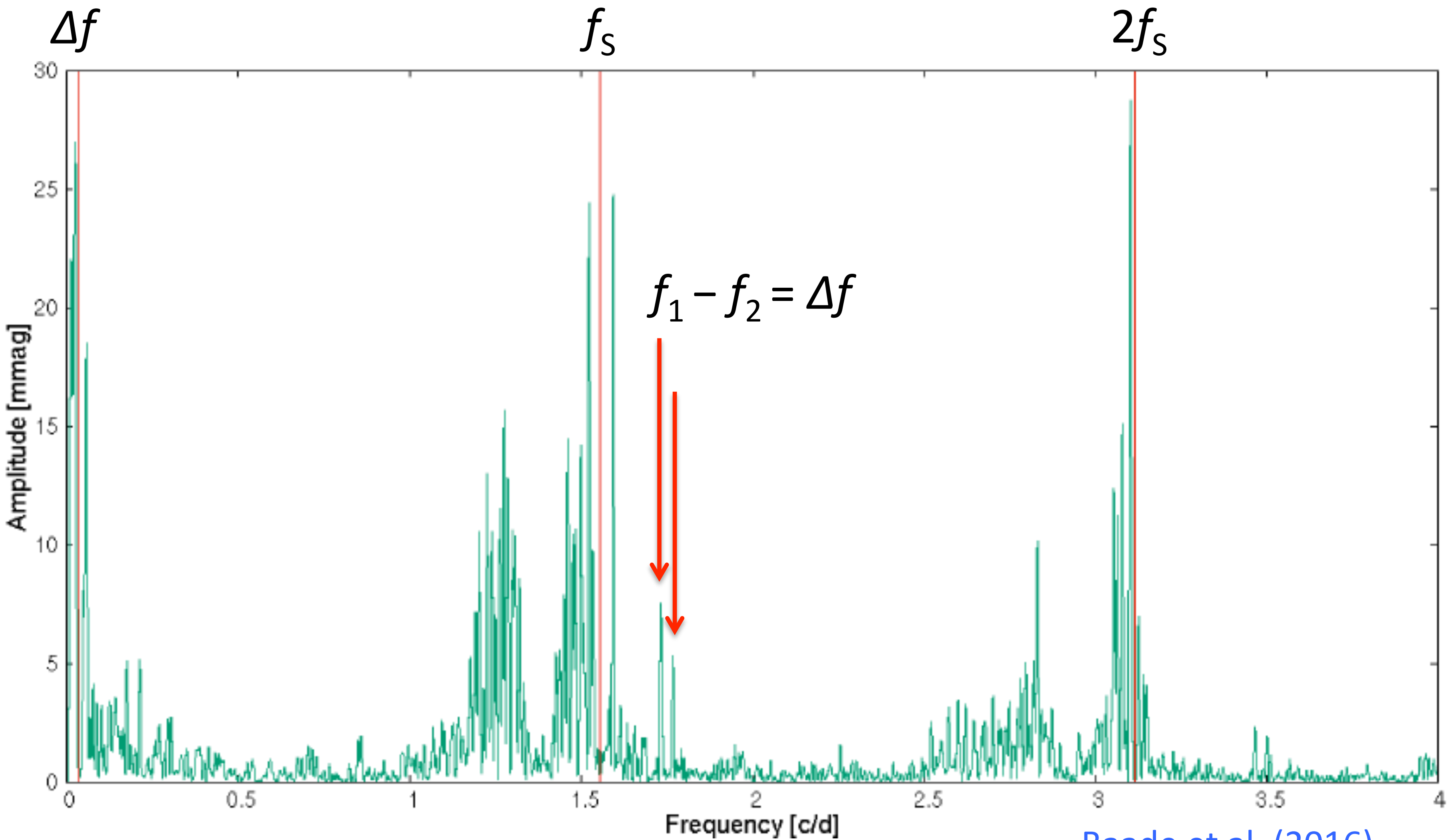
Štefl frequency, $f_S \approx 1.556\ \mathrm{d}^{-1}$



Baade et al. (2016)

η Centauri (HD 127973, B1.5 Vne, V = 2.31)

Frequency spectrum of residuals

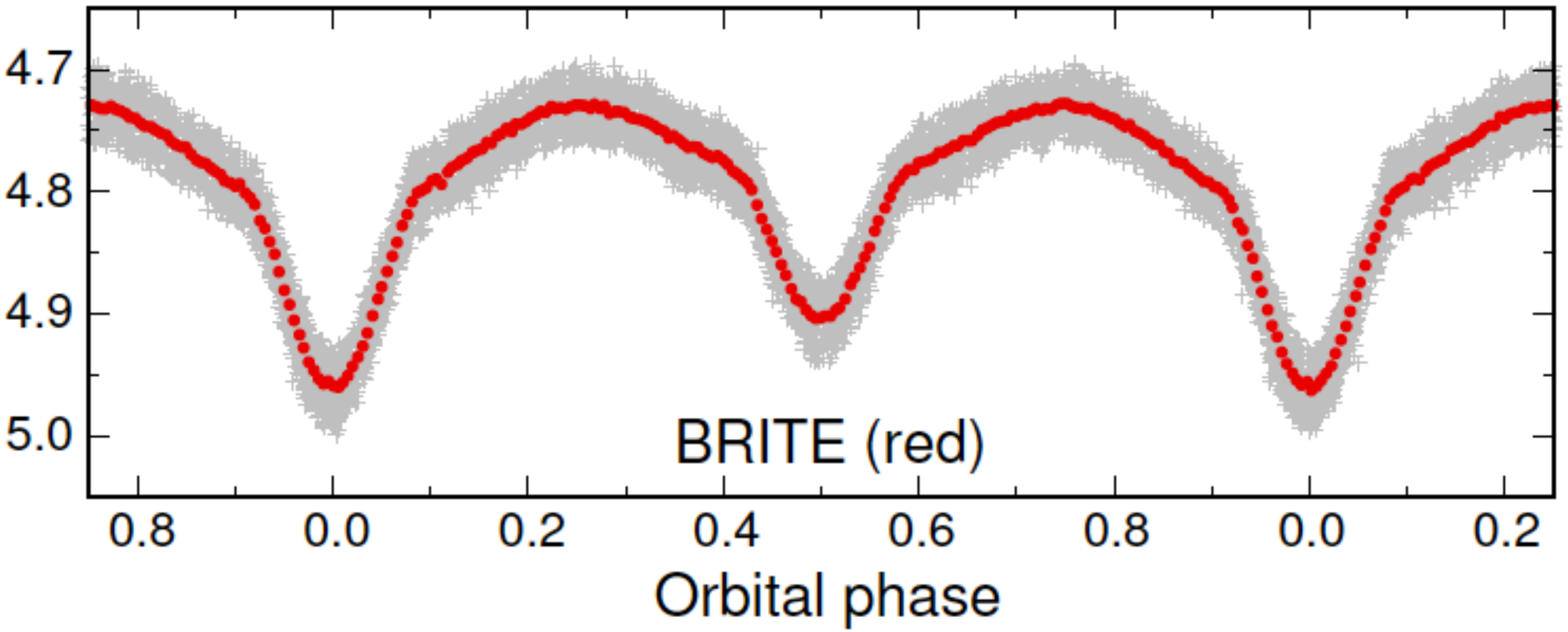


Baade et al. (2016)

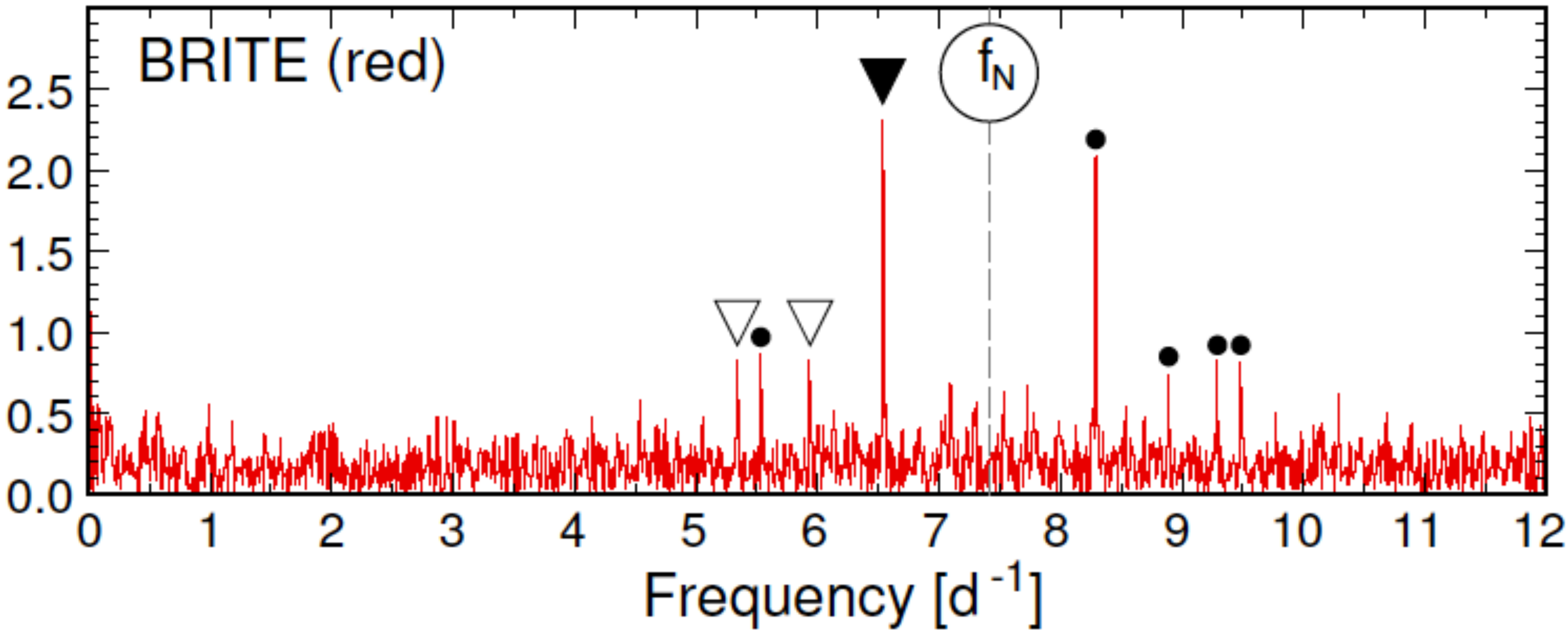
δ Pictoris (HD 42933, B0 III)

BRITE data
(Heweliusz)

P_{orb} = 1.67254 d

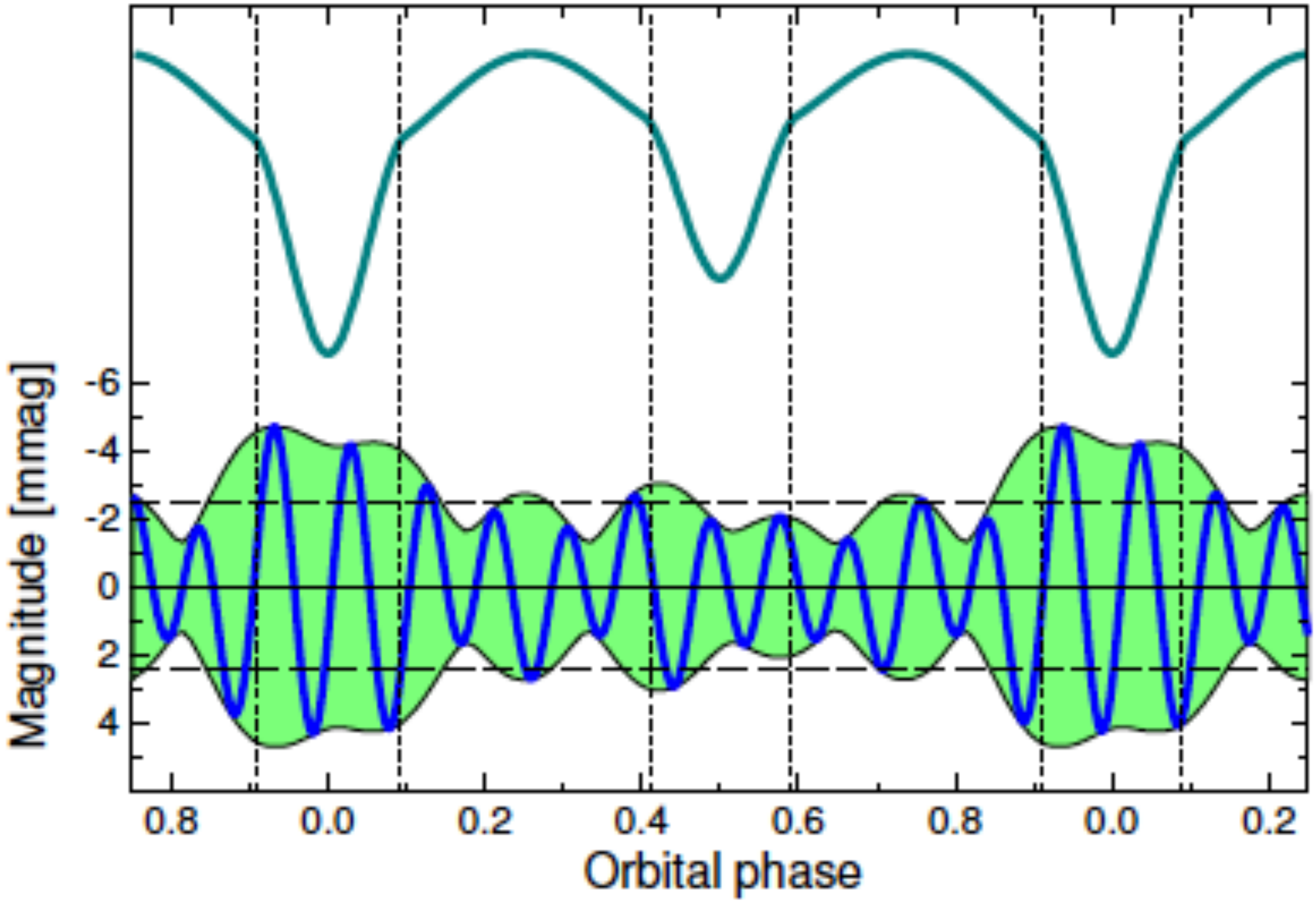


δ Pictoris (HD 42933, B0 III)

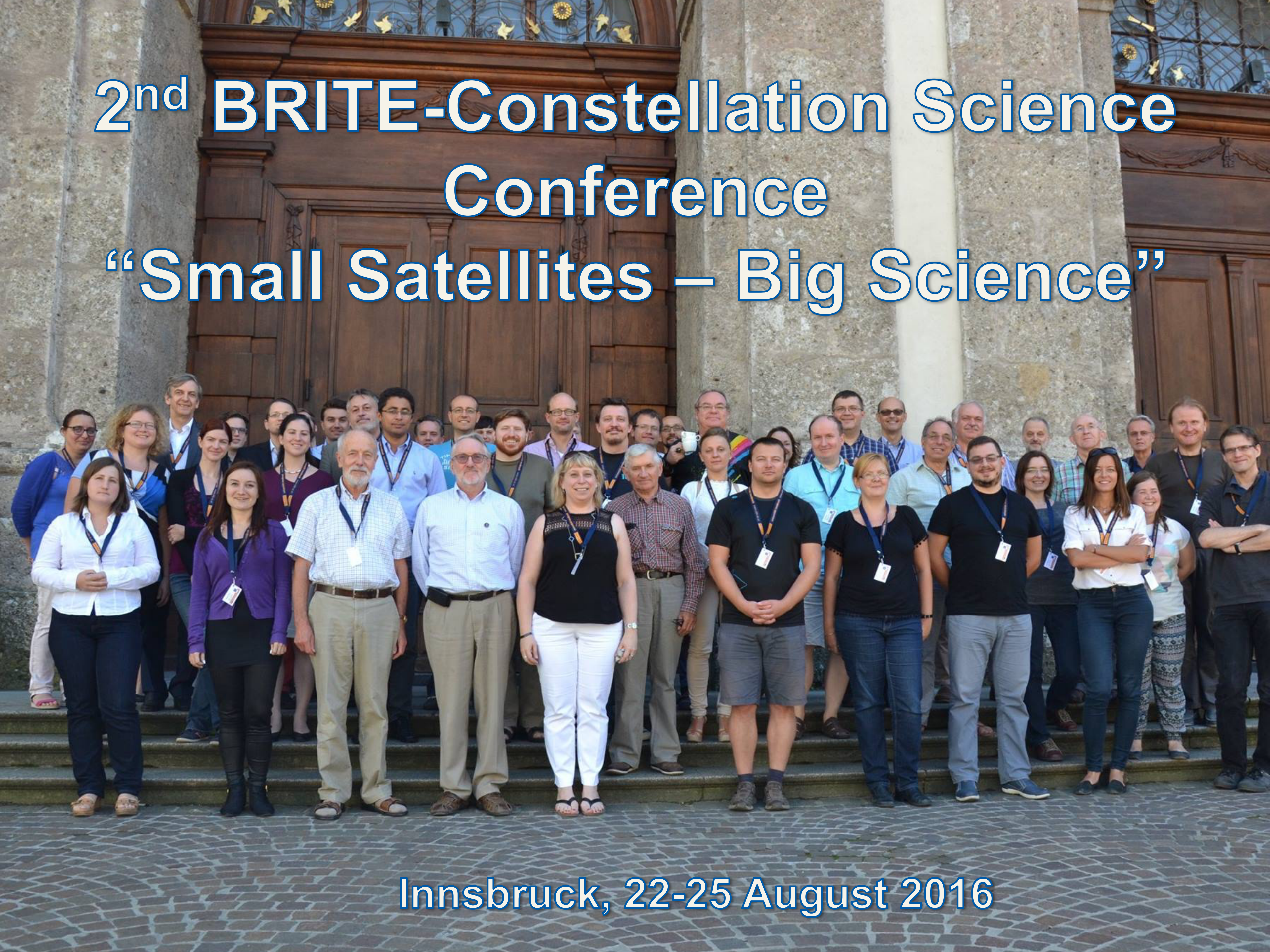


Frequency	Semi-ampl. [mmag]	Phase [rad]	S/N
f_1	2.43 ± .08	4.691 ± .033	16.5
$f_1 - f_{orb}$	0.84 ± .08	0.601 ± .096	5.7
$f_1 - 2f_{orb}$	0.75 ± .08	2.357 ± .101	5.1
$f_1 - 6f_{orb}$	0.62 ± .08	1.377 ± .133	4.2
$f_1 - 4f_{orb}$	0.43 ± .08	6.042 ± .187	2.9
$f_1 - 3f_{orb}$	0.42 ± .08	4.821 ± .187	2.8

δ Pictoris (HD 42933, B0 III)



Pulsations originate in the primary star !


2nd BRITE-Constellation Science
Conference
“Small Satellites – Big Science”
Innsbruck, 22-25 August 2016

Conclusions

1. **BRITE data are as good as expected.**
   Periodic variability with amplitudes down to 0.2 – 0.3 mmag can be detected. This proves that nano-satellites can be used for science.

2. BRITEs will allow asteroseismology of a large sample of Beta Cep/SPB stars with a significant number of modes (10 – 20).

3. Beta Cep/SPB hybridity seems to be widespread.

4. Observations of a large sample of Be stars may bring a breakthrough in understanding the role of pulsations in transferring matter to circumstellar disk.

5. Precise masses and radii of many massive stars will be determined.

Thank you, Don, for your excellent work and for inspiring many colleagues with new ideas.

Have a lot of fun continuing work on stars...

With best greetings from
(non-rapidly oscillating) AP