Ruđer Bošković's Sunspot Observations in 1777

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Ruđer Bošković (1711 - 1787)
one of the most famous Croatian scientists

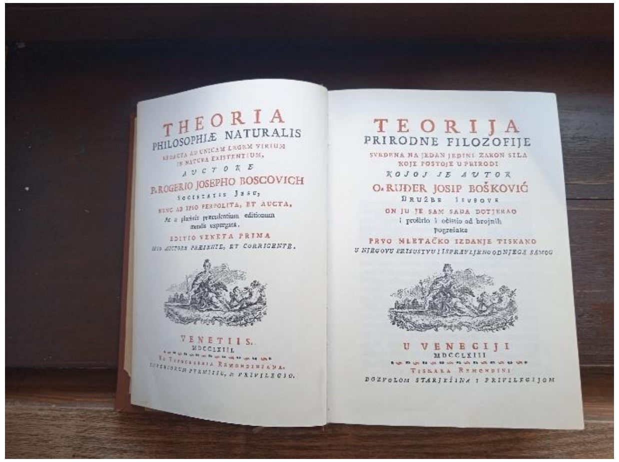
Crater named after Croatian physicist Ruđer Bošković

Croatian dinar

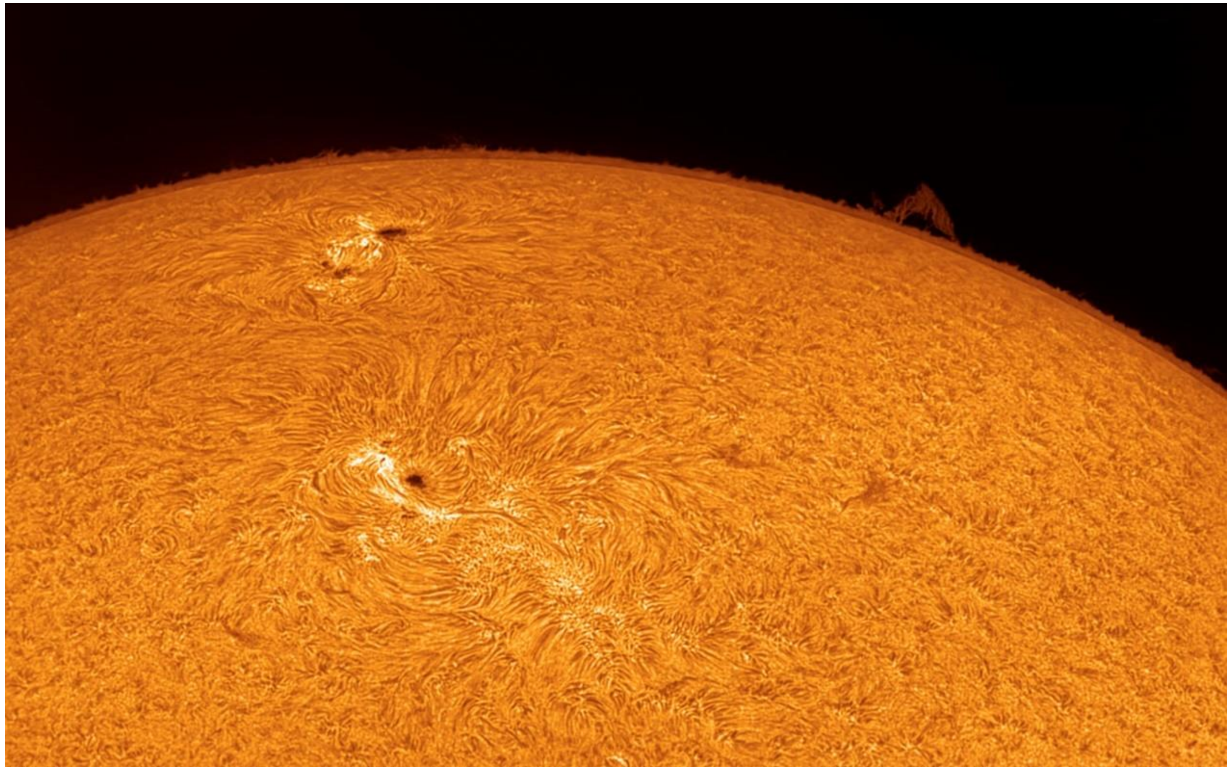
transitional currency introduced following Croatia's declaration of independence

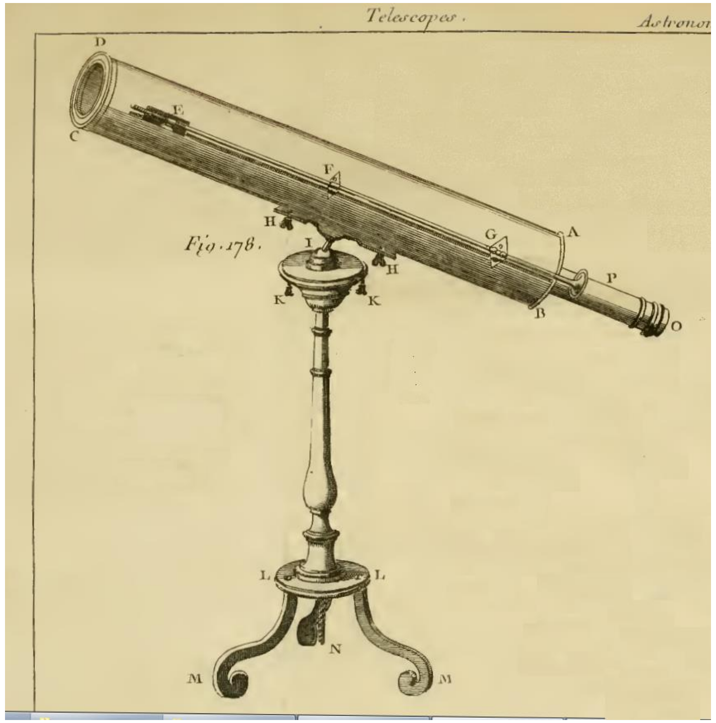
The name of our largest resarch institute in honours the Ruđer Bošković

Ruđer Bošković had broad interests and achievements in mathematics, science, civil engineering, philosophy, as well as in poetry and diplomacy



His famous work: *Philosophiæ naturalis theoria redacta ad unicam legem virium in natura existentium* (*Theory of Natural philosophy derived to the single Law of forces which exist in Nature*), containing Bošković's atomic theory and theory of forces (1. ed. Vienna 1758)





main research field was astronomy

developed several methods for the determination of the solar rotation elements and the rotational period of the Sun

De maculis solaribus (1736) (*On Sunspots*)

applied the methods to his own sunspot observations made in 1777 in Noslon near Sens, 120 km south from Paris

The main goal of this paper - analysis of a part of Bošković's observation of sunspots and calculation the elements of the Sun's rotation and period with modern methods and ephemeris data.

Significance – in addition to historical significance, also scientifically valuable data on the Sun's differential rotation, which plays a significant role in generating and maintaining solar magnetic activity.

Analysis of observational data

Derivation the expressions needed to calculate the elements of the Sun's rotation and period from observations

Processing of the Bošković's original observation

Observational data - topocentric ecliptic latitude β'_{f} and topocentric ecliptic longitude λ'_{f}

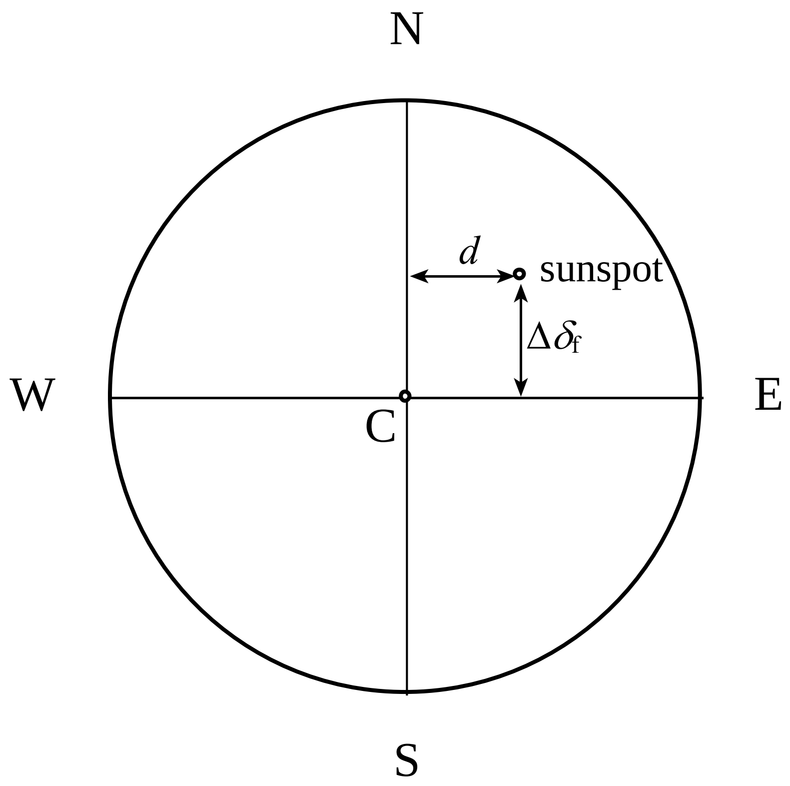


Figure 1: drawing of a solar disk with the position of a single spot. Line WE is parallel to the plane of the equator and is easily determined from observations.

optical micrometre – determination of the declination (difference between the declination of the sunspot (δ_{f}) and the declination (δ_{S}) of the centre of the solar disk)

pendulum for time measurement – determination the right ascension of the sunspot (α_{f})

$$\alpha_{\mathrm{f}} = \alpha_{\mathrm{S}} + \frac{d}{\cos\delta_{\mathrm{f}}}$$

From the α and δ, we can easily calculate topocentric ecliptic coordinates of the sunspot (topocentric ecliptic latitude β'_{f} and topocentric ecliptic longitude λ'_{f}):

$$\sin\beta'_{\mathrm{f}} = \cos\varepsilon\sin\delta_{\mathrm{f}} - \sin\varepsilon\cos\delta_{\mathrm{f}}\sin\alpha_{\mathrm{f}}\,,$$
$$\cos\beta'_{\mathrm{f}}\cos\lambda'_{\mathrm{f}} = \cos\delta_{\mathrm{f}}\cos\alpha_{\mathrm{f}}\,,$$
$$\cos\beta'_{\mathrm{f}}\sin\lambda'_{\mathrm{f}} = \sin\delta_{\mathrm{f}}\sin\varepsilon + \cos\delta_{\mathrm{f}}\cos\varepsilon\sin\alpha_{\mathrm{f}}\,,$$

where ε is the obliquity of the ecliptic.

Expressions needed to find the elements of the Sun's rotation and period from observations

1. Transformation topocentric ecliptic coordinates of the sunspot (λ'_f, β'_f) to heliocentric ecliptic coordinates (λ_S, β_S)

The apparent angular and rectangular topocentric coordinates of the Sun ((λ'_S, β'_S) and (x_S, y_S, z_S)) as well as the current distance to the Sun can be determined using some of the ephemeris.

heliocentric angular distance between the sunspot and observer is:

$$\sigma' = 180° - \sigma - \frac{d_{\text{observer-S}}}{r_S}\sin\sigma$$

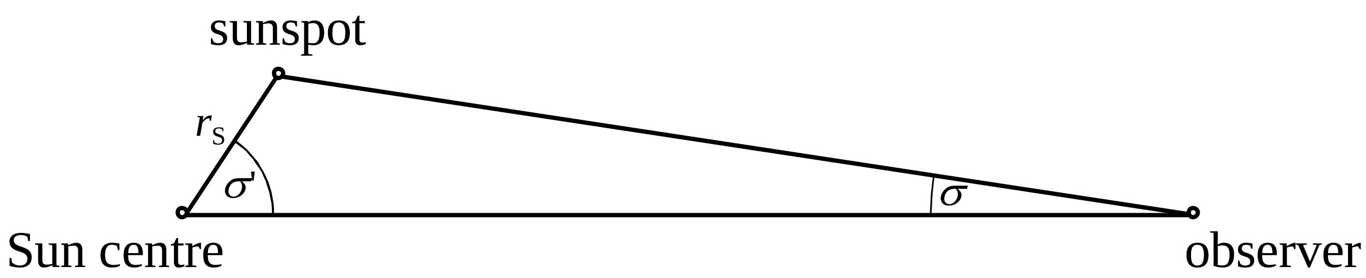


Figure 2: with known distance between observer and the Sun ($d_{\text{observer-S}}$), apparent angular distance between centre of the Sun and sunspot (σ) and Solar radius (r_S), angle (σ') can be determined, as well as heliocentric coordinates of sunspot.

heliocentric rectangular ecliptic coordinates of the sunspot (x_f, y_f, z_f) are:

$$x_f = d_{\text{f-S}}\cos\lambda'_f\cos\beta'_f - x_S$$
$$y_f = d_{\text{f-S}}\sin\lambda'_f\cos\beta'_f - y_S$$
$$z_f = d_{\text{f-S}}\sin\beta'_f - z_S$$

heliocentric ecliptic coordinates of the sunspot (λ_S, β_S):

$$\beta_f = \arcsin\frac{z_f}{r_S}$$

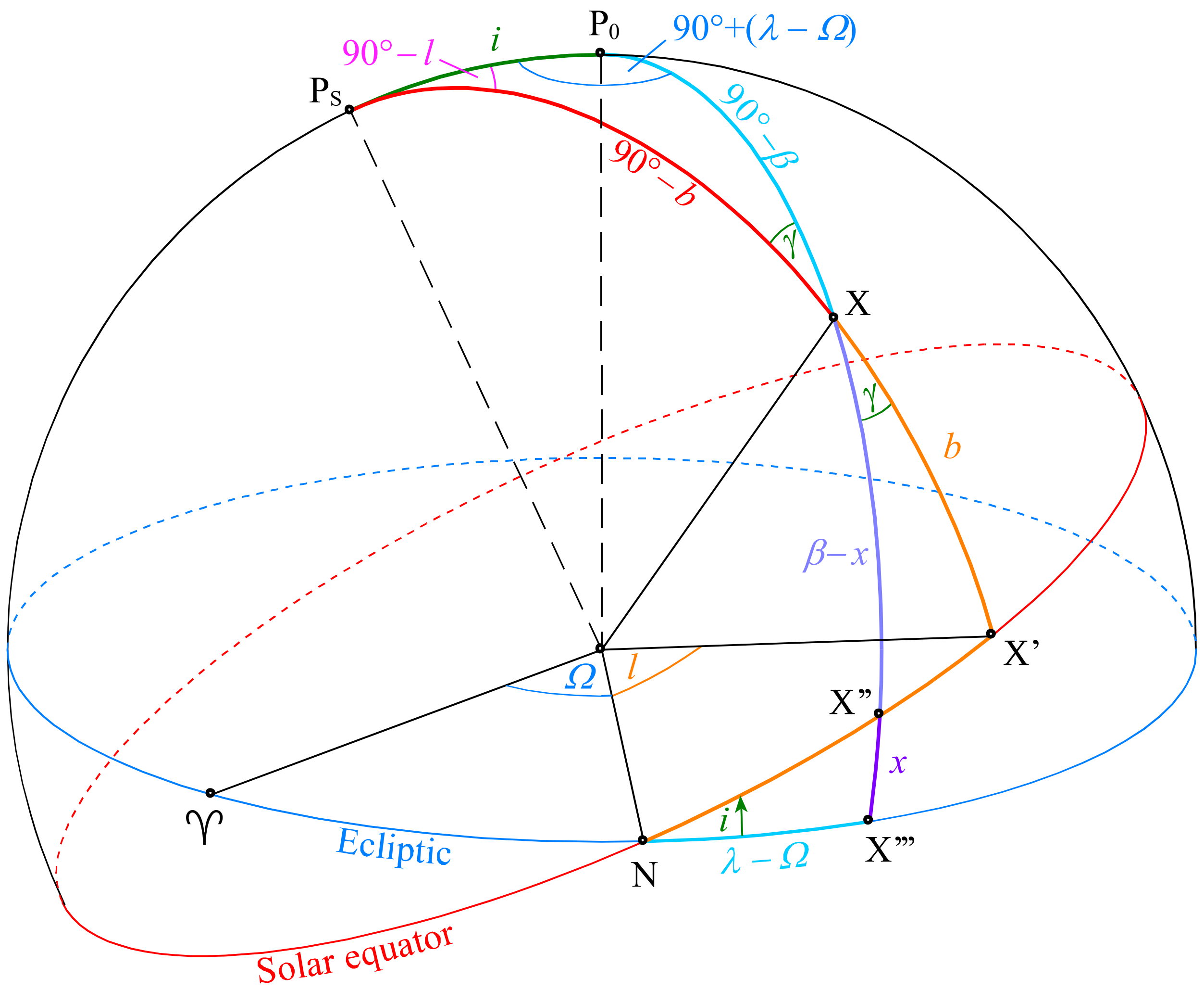
$$\lambda_f = \arctan\frac{x_f}{y_f}$$

2. Transformation heliocentric ecliptic coordinates (λ_S, β_S) to heliographic (b, l)
Determination of the solar rotation elements and period

The direction of the solar axis in space is determined by:

inclination (i) - the angle between the ecliptic plane and the solar equatorial plane and

ecliptic longitude (Ω) of the ascending node of the solar equator - the angle, in the ecliptic plane, between the equinox direction and the direction where the solar equator intersects the ecliptic from the South, i.e. in the sense of rotation.



$$X + Y\cos\beta\sin\lambda - Z\cos\beta\cos\lambda = \sin\beta$$

$$X = \sin b/\cos i,\ Y = \cos\Omega\tan i \text{ and } Z = \sin\Omega\tan i$$

we need to have at least three observations of a sunspot

$$b = \arcsin\left(X\cos i\right)$$

$$\Omega = \arctan\left(\frac{Z}{Y}\right)$$

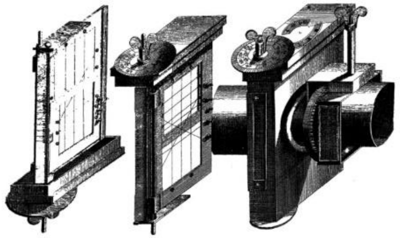
$$i = \arctan\left(\sqrt{Y^2 + Z^2}\right)$$

$$\tan l = \frac{\sin i\tan\beta}{\cos\left(\lambda - \Omega\right)} + \cos i\tan\left(\lambda - \Omega\right).$$

Bošković's measurements

Right ascension is directly given by measured time of contacts (time that elapsed from the moment when Sun was in upper culmination in Sens, France.)

Distance in declination from northern edge of the Sun was measured by use of micrometer



6 days of observations (between 12 and 19 September 1777) of the same sunspot with set of 5 measurements each day of observation

solar rotation elements:
$b = 26.43°$, $\Omega = 65.61°$, $i = 7.88°$

sidereal period (using least square method) is P = (26.696 ± 0.044) days (ω = (13.485 ± 0.022) °/day) which corresponds to mean value of the synodic period of P = 28.780 days (ω = 12.508 °/day).
In calculation of the sidereal period from synodic we used mean angular heliocentric velocity of the Earth (0,9765°/day) during period between 12 and 19 September 1777.
Bošković's results for sidereal period is 26.77 days and it is close to the our result.

12.	Sept.	1777.																Comment:
bord boreal			561			555			559			563			559	Milieu	559.4	A
	h	'	"	h	'	"	h	'	"	h	'	"	h	'	"			
1 bord..	2	59	9	3	6	42	3	10	32	3	14	27	3	22	3			t_1
tache..	3	0	55	3	8	29	3	12	20	3	16	14	3	23	51			t_t
2 bord..	3	1	16	3	8	50	3	12	40	3	16	35	3	25	12			t_2
Différence			42.5			43.0			44.0			43.0			43.5	milieu	43.2	B
13.	Sept.	1777.																
bord boreal			526			524			521			527			524	Milieu	524.4	
	h	'	"	h	'	"	h	'	"	h	'	"	h	'	"			
1 bord..	2	33	4	2	35	44	2	39	48	2	42	33	2	50	11			
tache..	2	34	41	2	37	21	2	41	25	2	44	11	2	51	49			
2 bord..	2	35	11	2	37	52	2	41	56	2	44	41	2	52	21			
Différence			33.5			33.0			33.0			34.0			33.0	milieu	33.3	
15.	Sept.	1777.																
bord boreal			440			440			440			440			440	Milieu	440.0	
	h	'	"	h	'	"	h	'	"	h	'	"	h	'	"			
1 bord..	3	6	42	3	14	8	3	17	45	3	20	48	3	34	16			
tache..	3	7	57	3	15	23	3	19	0	3	22	4	3	25	32			
2 bord..	3	8	50	3	16	15	3	19	53	3	22	56	3	26	24			
Différence			11.0			11.0			11.0			12.0			12.0	milieu	11.4	
16.	Sept.	1777.																
bord boreal			388			388			389			390			388	Milieu	388.6	
	h	'	"	h	'	"	h	'	"	h	'	"	h	'	"			
1 bord..	3	42	35	3	45	29	3	48	22	3	51	19	3	54	3			
tache..	3	43	39	3	46	33	3	49	25	3	52	23	3	55	8			
2 bord..	3	44	43	3	47	37	3	50	30	3	53	27	3	56	12			
Différence			0.0			0.0			-1.0			0.0			1.0	milieu	0	
17.	Sept.	1777.																
bord boreal			331			332			334			334			331	Milieu	332.4	
	h	'	"	h	'	"	h	'	"	h	'	"	h	'	"			
1 bord..	3	18	0	3	24	23	3	28	12	3	31	21	3	35	12			
tache..	3	18	53	3	25	16	3	29	6	3	32	15	3	36	7			
2 bord..	3	20	7	3	26	30	3	30	19	3	33	29	3	37	20			
Différence			-10.5			-10.5			-9.5			-10.0			-9.0	milieu	-9.9	
19.	Sept.	1777.																
bord boreal			239			241			240			240			240	Milieu	240.0	
	h	'	"	h	'	"	h	'	"	h	'	"	h	'	"			
1 bord..	2	34	26	2	37	14	2	41	51	2	43	47	2	46	43			
tache..	2	35	3	2	37	50	2	42	26	2	44	23	2	47	19			
2 bord..	2	36	34	2	39	22	2	43	59	2	45	55	2	48	51			
Différence			-27.0			-28.0			-29.0			-28.0			-28.0	milieu	-28	

Conclusions

This paper presents an analysis of a part of Bošković's observations of sunspots with a presented mathematical approach and with the use of modern ephemeris parameters. The obtained values for the solar rotation parameters and the rotation period are close to Bošković's results, which indicates the accuracy of Bošković's methods. Furthermore, we plan to extend the processing to all of Bošković's observations and compare them with the results of other historical and modern measurements.