Open Access Online Journal on Astronomy and Astrophysics
Acta Astrophysica Taurica
www.astrophysicatauricum.org

Acta Astrophys. Tau. 4(2), 1–5 (2023) doi:10.34898/aat.vol4.iss2.pp1-5

Sixfold enhancement of solar pulsations: 1974–2018

V.A. Kotov, V.I. Haneychuk

Crimean Astrophysical Observatory, Nauchny 298409, Crimea
e-mail: vkotov@craocrimea.ru, han@craocrimea.ru

Received 28 August 2023

ABSTRACT

Doppler observations of the Sun performed at the Crimean Astrophysical Observatory from 1974 through 2018 show that our star pulsates with the two periods, 9600.606(12) s and 9597.924(13) s. But while the first pulsation was observed during years of the enhanced amplitude only, the second one – over nearly 45 years, with a sixfold amplitude enhancement in 2018 (as compared to the average amplitude of the total 45-year dataset). The characteristic timescale of the amplitude variations, 12(1) years, coincides within the error limits with both the length of the Schwabe 11-year cycle and the sidereal period of Jupiter, 12 years. It also seems puzzling that *(a)* both periods happened to be near the 9th daily harmonic of the mean solar day, and *(b)* the beating timescale of these two periods, 398 days, coincides within the error limits with the orbital period of Jupiter, 399 days (synodic). Several evidences for a cosmic nature of the first pulsation are presented, but the true physical cause of both pulsations is not yet understood.

Key words: Sun, photosphere, pulsations, helioseismology, 11-year cycle, Jupiter

1 Introduction

Practical helioseismology began over 60 years ago when Leighton et al. (1962) discovered oscillations of the solar photosphere with periods of about five minutes (for the theory of stellar pulsations see, e.g., Rosseland, 1949; Cox, 1980, and for a review of theoretical and observational aspects of the study of normal vibrations of the solar surface, – of acoustic, p, and gravity, g, modes, – see Christensen, Gough, 1976; Fossat et al., 2017, and references therein). These dynamical data give us a new possibility to probe the interior of the Sun and thus to improve its model. The five-minute oscillations are thought to be acoustic: a superposition of normal p-modes that travel through the convective zone and the deep solar interior; they have measurable amplitudes on the solar surface, with the turning points depending on the p-mode frequency and harmonic degree (with the solar rotation taken into account, the frequencies depend on the radial order n, degree l, and azimuthal order m). The long-period g-modes (or gravity waves) propagate in the convectively stable solar interior beneath the Sun's convection zone and thus can play a key role in the investigations of the Sun's deep interior.

Problems of helioseismology were complicated by the finding of Brookes et al. (1976), Severny et al. (1976), who reported observations of oscillations of the solar surface with a period of about 9600 s, confirmed later by Grec et al. (1980), Scherrer, Wilcox (1983). The amplitude of the oscillation, being of the order of 1 m s^{-1}, happened to be near the limit of observing technology. This oscillation was detected in the whole solar disk measurements, so its degree must be small. Note, however, that although the period value is probably the most precisely known quantity, it is not yet possible to use this phenomenon to probe the solar interior. (It is remarkable that this oscillation, in the form of the solar "infra-sound wave" with a 1/9th-of-a-day period, had been predicted by Sevin (1946) long before it was actually discovered.)

2 The CrAO measurements

The measurements of the line-of-sight velocity of the solar photosphere performed at the Crimean Astrophysical Observatory (CrAO) from 1974 through 2018 were differential: the light beam from the central part of the solar disk passed through a circular polarizer, while the light from the outer portion was left unpolarized. The solar absorption spectral line Fe I λ 512.37 nm, with zero Lande factor, was used for these solar observations, and a Babcock-type solar magnetograph registered the wavelength separation between the polarized and unpolarized light beams; this separation is proportional to the difference between the mean line-of-sight velocity of the central part of the solar disk and that of its outer limb portion.

The data of the first nine years of Crimean observations, 1974–1982, fixed the period value as P_0 = 9600.606(12) s. Since 1983, the other period, close to the annual sidelobe of P_0, has become the most prominent one; the most precise value of the new period was determined to be P_1 = 9597.924(13) s (see Kotov, Haneychuk, 2020, and references therein; the uncertainties in brackets approximate standard errors).

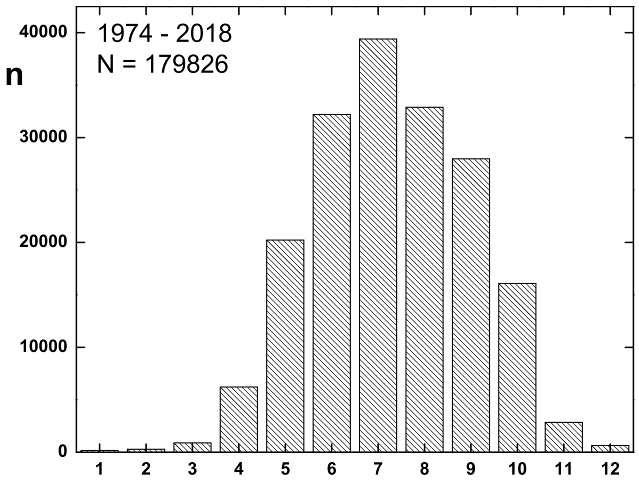

Fig. 1. Histogram of the velocity measurements, 1974–2018, during a year. The horizontal axis indicates the ordinal number of 12 intervals of a year, and the vertical one – the number n of measurements (the sum is N = 179 826).

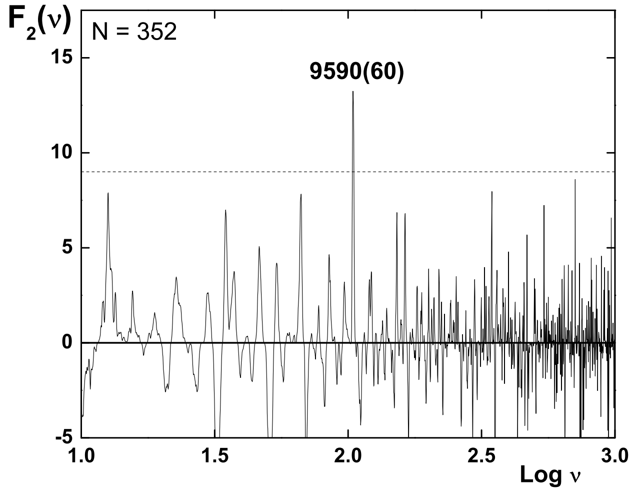

Fig. 2. Resonance spectrum $F_2(\nu)$ computed for 352 exoplanets with periods $P < 2$ days. The horizontal axis gives the logarithm of frequency ν (in μHz). The dashed line corresponds to a 3σ confidence level, and the highest peak corresponds to a timescale of P_E = 9590(60) s.

Over 45 years the measurements were performed during 2522 days (14 986 hours in all), so that the total number N of the residuals "measurement minus trend" with five-minute integration is equal to 179 826. Positive velocity corresponds to the "expansion" of the Sun, and the zero phase – to 0 UT on 1 January 1974 (note that 94% of observations were performed from May through October, see Fig. 1).

Here we *(a)* present arguments against the alleged "terrestrial effect", producing supposedly the 9th daily harmonic in the solar Doppler data, *(b)* give the facts of the existence of the P_0 periodicity in observations of other variable cosmic objects (besides the Sun, so that this new astronomical phenomenon might be called "cosmic"), and *(c)* pay a special attention to the time variations of the amplitude of the two solar oscillations.

3 Solar, terrestrial or cosmic?

Strong evidence in favor of the true solar origin of the P_0 oscillation, as observed in the line-of-sight velocity measurements of the solar photosphere, followed from the power spectrum of the Doppler data computed by Scherrer, Wilcox (1983) over a period range from 1.2 to 4.6 hours: there were no significant features except for the prominent peak near the 1/9th-of-a-day period, and there were no other noticeable daily harmonics. Moreover, the precise value of this period deviated by nearly 9.5σ from the exact daily harmonic, 9600.57(6) s, which coincides fairly well with the above P_0.

To eliminate difficulties associated with a day-night cycle and daily trends (presumably of atmospheric or instrumental origin), Grec et al. (1980) performed unique observations of the Sun from the geographic south pole. Their data showed the presence of a 9600-second wave, which fairly well matched the sinusoidal extrapolation of the average result of the CrAO and Stanford observations (see details in Grec et al., 1980; Kotov, 1985).

Despite all the above arguments for solar origin, some authors (see, e.g., Grec, Fossat, 1979; Fossat et al., 2017; Efremov et al., 2018) attributed the oscillations either to the transparency of the Earth's atmosphere or to an artifact of the observing and reduction procedures. The detailed analysis of such problems by Koutchmy et al. (1980), Severny et al. (1980) showed that neither the amplitude nor the phase behavior of the oscillation can be explained in terms of the terrestrial atmospheric influence or by the statistical treatment of data (we also emphasize that there is no any reasonable source of the Earth atmospheric perturbation that could be phase coherent over decades).

As to a plausible cosmic nature of the P_0 oscillation, we refer here to the following robust observational facts:

(a) the most resonant, or "synchronizing", timescale for the pulsation periods of the δ Sct stars occurs to be, within the error limits, the same P_0 period, see Kotov, Kotov (1997);

(b) the best commensurable timescale for the spin periods of the largest and fastest rotators of the Solar system appears to be a period of 9594(65) s, coinciding fairly well with P_0 again, see Kotov (2018);

(c) a substantial part of superfast exoplanets move with periods that tend to be near-commensurate with timescales P_0 and/or $2P_0/\pi$ (the probability that two timescales – P_0 and the P_E feature in Fig. 2 – would coincide by chance is near 3×10^{-4}; see also Kotov, 2019);

(d) the best commensurable timescale of the orbital periods of cataclysmic variables and related objects is equal to $2P_0/\pi$, where the factor two takes into account that one part of the orbit repeats the other one, and the π number stands for the best stability factor for a binary motion (with respect to an outer/inner periodic perturbation of unknown nature; Kotov, 2008; Kotov, 2019);

(e) orbital periods of close binary stars with periods less than five days tend to be commensurable with $2\pi P_0$ and/or

$2P_0/\pi$ at about 6σ significance of the overall best commensurability effect (Kotov, 2008);

(f) luminosity of some extragalactic objects oscillates with the P_0 period (Kotov et al., 1997b, 2012).

It seems impossible to accept the suggestion of some opponents about some "mysterious" terrestrial P_0 phenomenon supposedly affecting the observations made from Earth of other, besides the Sun, cosmic objects, and thus appearing to be "cosmological" (one should note, in particular, the presence of the transcendental number π in the analysis of the period distribution of close binary stars and superfast exoplanets: this circumstance excludes artifacts encountered in mathematical operations with rational numbers).

4 Amplitude variations

The harmonic amplitude A_h of the best-fit sinusoid with the P_1 period was determined for each successive two-year dataset of the CrAO Doppler measurements, and the resultant time behavior of A_h is shown in Fig. 3a, where one observes that the P_1 oscillation, after the 1974–1975 discovery, exceeded the mean level, 0.45 m s^{-1}, over 1979–1982 years, then significantly enhanced its amplitude during the intervals of 1993–1995, 2004–2006, and 2016–2018. The average timescale of those "amplifications", 12(1) years, agrees well with both the mean duration of the Schwabe cycle, 11.1 years, and the sidereal period of Jupiter, 11.9 years.

Note that the similar changes of A_h are displayed by the P_0 oscillation as well, since the tiny difference $P_0 - P_1$ is negligible for the above two-year samples, and that the 2017–2018 data exhibit the strongest amplitudes of both oscillations. For instance, the amplitude A_h = 1.69 m s^{-1} of the P_1 oscillation in 2018 occurred to be six times larger than its mean value, 0.27 m s^{-1}, of the total 45-year dataset (see the mean P_1 curve in Section 5).

From the run of the yearly mean Wolf number W shown in Fig. 3b, one can conclude that the enhancements of both oscillations were delayed by about three years with respect to the W-maximum epochs, while the minimum epochs of both the amplitude A_h and the sunspot number W reveal a tendency to be coincident with each other.

The P_1 amplitude, at first sight, does not seem to have a distinctive relationship with time changes of the sunspot number (see Fig. 3). But the characteristic timescale of the amplitude variation, 12(1) years, justifies our suggestion about a possible connection between these two variables. Such statement, however, needs further verification by the new Doppler observations of the solar photosphere. Note also that *(a)* the quality and the amount of the data plotted in Fig. 3a are not yet sufficient to make a special correlation analysis of A_h and W, *(b)* many studies which show a decrease of the oscillation amplitude with growing magnetic activity of the Sun have already been published, but none of them is connected with the long-period g-mode solar oscillations or "enigmatic" P_0 pulsation, and *(c)* since the difference P_0–P_1 is very small, the plot for the P_0 oscillation amplitude (not shown here) occurred to be nearly the same as that for the P_1 oscillation in Fig. 3a.

The question arises as well: why are the pulsation periods not identified in the total datasets/years? We believe this is hardly caused by the bad data quality during some years or

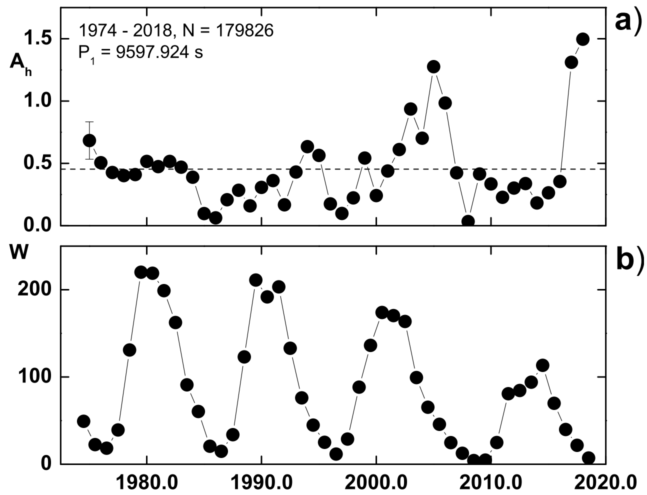

Fig. 3. (a) Time variation of the amplitude A_h plotted with the P_1 period for the two-year samples of the velocity data (1974–2018, N = 179 826; dots connected by straight lines). The horizontal axis gives years, the vertical bar indicates a typical 1σ error, and the horizontal dashed line shows the mean A_h level, 0.45 m s^{-1}. (b) The run of the yearly mean Wolf sunspot number W, 1974–2018 (according to *NGDC.NOAA.gov*).

extended gaps in the corresponding time series: all observations were performed using the same instrument and with the identical (rather random) distribution of gaps, leaving apart the natural sampling effects due to the day-night cycle and the quasi-annual gaps (see Fig. 1).

5 Phase diagrams and mean curves

The phase diagram O–C ("observation minus calculation") plotted in Fig. 4a for the folding period 9597.600 s indicates that the true period is equal to 9597.924(9) s (the best value determined by the phase diagram and the power spectrum is P_1 = 9597.924(13) s, see Kotov, Haneychuk, 2020).

One should note that the amplifications of the P_1 oscillation might be caused by the presence of the primary P_0 oscillation during some years. To clarify this point, the other phase diagram, with a trial period of 9600.000 s and for yearly samples of data, was constructed for the following time intervals: 1974–1982 (N = 32 630, with the evident existence of the P_0 oscillation), 1993–1995 (N = 12 898), 2001–2006 (N = 18 682), and 2016–2018 (N = 6740) – four samples with the enhanced amplitude, see Fig. 3a (N = 70 950 in all). The result is shown in Fig. 4b, where the linear regression line corresponds to a period of 9600.626(13) s, which agrees well within the error limits with P_0 = 9600.606(12) s. We conclude that the P_0 oscillation seemingly existed in the Sun over 45 years (disappearing, however, during some years) is an apparent result of both the beating with the secondary P_1 oscillation and the sampling of the data, see Fig. 1).

Figure 5 shows the two mean curves plotted with the folding periods P_0 and P_1 for 45 years of observations (the first curve is obtained for four intervals with the presence of the P_0 oscillation, and the second one – for the total dataset). The

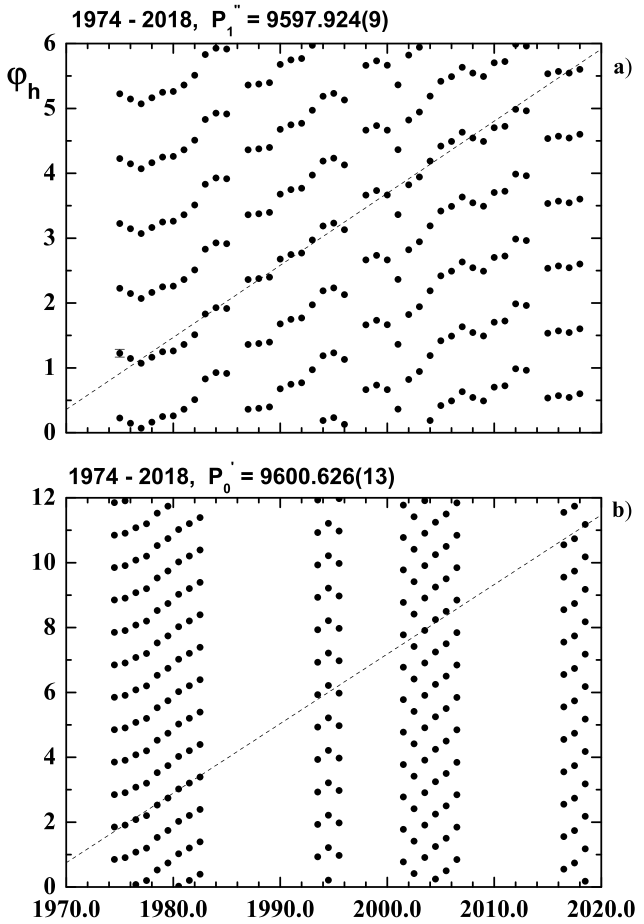

Fig. 4. (a) Phase diagram constructed with the trial period 9597.600 s for the total dataset 1974–2018, N = 179 826 (the vertical line is a typical error bar compared with the size of a dot). The horizontal axis indicates a year, and the vertical one – phase φ_h repeated for the phase intervals 1–2, 2–3, etc. The dashed regression line corresponds to the true period P'' = 9597.924(9) s (Kotov, Haneychuk, 2020). (b) Same for years of the enhanced P_1 oscillation (the trial period is 9600.000 s, see text). The dashed regression line produces the precise value $P_0{}'$ = 9600.626(13) s.

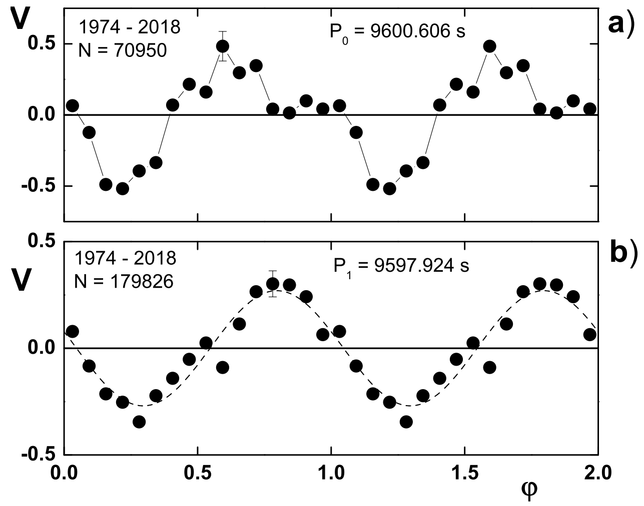

Fig. 5. (a) The mean curve plotted with the folding period P_0 = 9600.606 s for the datasets of 1974–1982, 1993–1995, 2001–2006, and 2016–2018 (N = 70 950). The horizontal axis denotes the phase φ, the vertical one – velocity V in m s^{-1}, and the vertical bar indicates a typical 1σ error for each of 16 blocks of data. (b) Same for the total data of 1974–2018 with the folding period 9597.924 s (N = 179 826). The dashed line is the best-fit sinusoid.

upper curve differs substantially from the sinusoid, while the second one is nearly harmonic; this likely indicates an essential difference between the corresponding excitation mechanisms.

6 Conclusion

According to Kotov, Lyuty (1990), Kotov et al. (1997b), the P_0 oscillation might have a cosmological significance: the same period was detected in luminosity fluctuations of some extragalactic objects and period distributions of variable stars (see points *(a)* – *(f)* in Section 3). As to the P_1 oscillation, it probably characterizes the dynamics of the Sun itself but with poorly understood origin.

Special interest is raised by the above amplifications of the P_1 oscillation during some years, and the fact that the characteristic timescale of these amplifications, 11–12 years, coincides with the Schwabe 11-year cycle. And the following enigma arises too: why does the beat period of these two oscillations, 397.7(2.6) days, coincide with the synodic period of Jupiter, 398.9 days? It is hard to think that this is a chance coincidence (for a discussion see Kotov, Haneychuk, 2020). Does the Sun behave like some “celestial chronometer”?

The present work gives strong arguments in favor of the solar origin of the P_0 period in the line-of-sight velocity of the solar photosphere. But because its origin is not yet known, and since the identical timescale (or period) was found in other variable objects, we hypothesize that the true nature of the P_0 phenomenon might be cosmic, being therefore of more general character than a simple normal vibration of the Sun (with unknown yet source of its excitation). The second vibration, P_1, might be treated as a by-product of the basic P_0 oscillation of the Sun, with the frequency shift likely caused by the gravitation perturbation of Jupiter. This is a hypothesis that needs a careful theoretical investigation.

To compare our results with the Doppler solar velocity observations made by other observers employing other techniques and different methods of observations, one should take into account that the CrAO observations were performed not over the total Earth’s orbit but on its “summer” part only (see Fig. 1). It also seems premature to make any speculations about a hypothetical association of the time variations of the pulsation amplitude with the global changes of the Earth’s climate, as interesting as that would be. Nevertheless, the present work likely gives a good stimulus for the future long-term Doppler observations of our star.

Acknowledgements. The authors are grateful to F.M. Sanchez (Paris) for many fruitful discussions on the Sun, Solar system and physical laws, as well as to the referee for useful comments.

References

Brookes J.R., Isaak G.R., van der Raay H.B., 1976. Nature, vol. 259, pp. 92–95.

Christensen-Dalsgaard J., Gough D.O., 1976. Nature, vol. 259, pp. 89–92.

Cox J.P., 1980. Theory of stellar pulsation. Princeton: Princeton Univ. Press.

Efremov V.I., Parfinenko L.D., Solov'ev A.A., 2018. Astrophys. Space Sci., vol. 363, p. 257, doi:10.1007/s10509-018-3477-9.

Fossat E., Boumier P., Corbard T., et al., 2017. Astron. Astrophys., vol. 604, A40, doi:10.1051/0004-6361/201730460.

Grec G., Fossat E., 1979. Astron. Astrophys., vol. 77, pp. 351–353.

Grec G., Fossat E., Pomerantz M., 1980. Nature, vol. 288, pp. 541–544.

Kotov V.A., 1985. Solar Phys., vol. 100, pp. 101–113.

Kotov V.A., 2008. Izv. Krymsk. Astrofiz. Observ., vol. 104, no. 1, pp. 169–184.

Kotov V.A., 2018. Earth Moon Planets, vol. 122, no. 1, pp. 43–52, doi:10.1007/s11038-018-9520-6.

Kotov V.A., 2019. Earth Moon Planets, vol. 123, no. 1–2, pp. 1–8, doi:10.1007/s11038-019-09526-3.

Kotov S.V., Kotov V.A., 1997. Astron. Nachr., vol. 318, no. 2, pp. 121–128.

Kotov V.A., Haneychuk V.I., 2020, Astron. Nachr., vol. 341, no. 6–7, pp. 595–599, doi:10.1002/asna.202013797.

Kotov V.A., Lyuty V.M., 1990. Compt. Rend. Acad. Sci. Paris, vol. 310, ser. II, pp. 743–748.

Kotov V.A., Lyuty V.M., Haneychuk V.I., Merkulova N.I., Metik L.P., Metlov V.G., 1997. Astrophys. J., vol. 488, pp. 195–201.

Kotov V.A., Sanchez F.M., Bizouard C., 2012. Izv. Krymsk. Astrofiz. Observ., vol. 108, no. 1, pp. 57–70.

Koutchmy S., Koutchmy O., Kotov V.A., 1980. Astron. Astrophys., vol. 90, pp. 372–376.

Leighton, R.B., Noyes R.W., Simon, G.W., 1962. Astrophys. J., vol. 135, pp. 474–499, doi:10.1086/147285.

Rosseland S., 1949. The pulsation theory of variable stars. Oxford: Clarendon Press.

Scherrer P.H., Wilcox J.M., 1983. Solar Phys., vol. 82, pp. 37–42.

Severny A.B., Kotov V.A., Tsap T.T., 1976. Nature, vol. 259, pp. 87–89.

Severny A.B., Kotov V.A., Tsap T.T., 1980. Astron. Astrophys., vol. 88, pp. 317–319.

Sevin É., 1946. Compt. Rend. Acad. Sci. Paris, vol. 222, pp. 220–221.