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The orbit, structure and evolution of the Lyrid meteoroid stream

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Summary. — The orbit and structure of the Lyrid meteor stream based on photographic orbits available in the IAU Meteor database are investigated. Seventeen Lyrids were found in the database and the radiant and orbit of the stream were derived. In the stream three very distinct groups of orbits—short-period, long-period and extreme (hyperbolic orbits), are separated. The mutual consistence of the groups is investigated by following the orbital evolution of individual meteors. The long-period group has the evolution almost identical with that of the parent comet C/1861 G1 Thatcher. The hyperbolic orbits are most probably the result of erroneous measurements.

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1. – Introduction

The Lyrids are a regular meteor shower, standardly of a weak activity, observed between April 14-26. The shower maximum appears on April 21-22 with a zenithal hourly rate of 5-10 meteors. However, occasionally an enhanced increase of the shower activity exceeding 100 meteors per hour is observed. The first note on a regular appearance of the stream was made by Arago in 1835 [1] and Newton in 1863 [2] in his work on the history of major meteor showers was able to trace the Lyrids for about 2500 years. The position of the present shower radiant is at a right ascension of 272° and a declination of 34°.

The Lyrids are produced by comet C/1861 G1 Thatcher discovered in April 1861. Its definitive orbit was determined by Oppolzer [3] and the association with the Lyrids was first indicated by Weiss [4]. The mean orbit of the stream based on photographic orbits [5] is very close to the orbit of the comet recalculated to the new equinox and epoch [6]. The comet and stream are moving in the orbits almost perpendicular to the ecliptic, with the period of revolution of 415 and about 330 years, respectively.

Higher activity of the stream was observed more times in the past. Lindblad and Porubčan [7] summarized the Lyrid activity outbursts observed in the last 200 years. All

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the peaks were of a short duration (two hours maximum) and at almost the same solar longitudes, approximately a quarter of a day before the main peak. These occasional activity enhancements suggest a filamentary structure and mass separation in the stream.

Emelyanenko [8] suggests that the activity outbursts in 1803, 1922 and 1982 are probably due to a libration motion of the orbit near a resonance with Jupiter.

The last higher activity maximum observed in 1982 with a half-maximum strength lasted for only 50 minutes and consisted predominantly of smaller particles [9]. Porubčan *et al.* [10] for this cloud of meteoroids in the orbit 120 years beyond the parent comet suggested that it could have originated by fragmentation of a larger boulder separated from the comet more revolutions ago.

Arter and Williams [11] looked for an explanation of the enhanced Lyrid maxima which from the older observations indicated a 12 year periodicity [12]. If the maxima appear in multiples of 12 years, it might suggest a resonance motion with Jupiter. Further, they studied [13] evolution of the stream by releasing 20000 model particles from comet Thatcher at its last four perihelion passages and followed occurrence of model particles at the descending node near the Earth. The integration results indicate the occurrence of higher density parts of the stream in a 12 year cycle.

2. – Structure of the Lyrid stream

The most precise information concerning the structure of the stream provides orbits obtained by photographic methods. Unfortunately, there are little photographic orbits of the Lyrids available up to now. Kresák and Porubčan [14] for an analysis of the shower had at disposal only 7 Lyrids. Lindblad and Porubčan [5] derived the mean orbit of the stream and motion of the radiant on the basis of 14 Lyrids.

The latest version of the IAU Meteor Data Center photographic catalogue contains 4581 meteor orbits [15] and in the present analysis the stream members were searched for by a search procedure utilizing the Southworth-Hawkins D-criterion [16]. For a limiting

TABLE I. – *Orbital and geophysical parameters of the photographic Lyrid meteors (eq.* 2000.0*).*

N	YY	M	Day	q (AU)	a (AU)	e	i (°)	ω (°)	Ω (°)	π (°)	D	α (°)	δ (°)	Vg (km/s)
037B1	85	4	21.04	.916	8.980	.898	79.2	215.6	31.1	246.7	.090	271.5	33.0	46.07
001W1	50	4	21.35	.918	−6.000	1.153	81.5	213.1	31.4	244.4	.177	270.6	33.1	49.39
002W1	50	4	21.37	.911	12.653	.928	79.0	216.4	31.4	247.8	.070	270.8	33.0	46.25
007U1	79	4	21.67	.914	10.044	.909	79.7	215.9	31.3	247.1	.081	271.6	32.7	46.40
349B1	93	4	21.97	.935	6.585	.858	80.3	212.0	31.9	243.9	.127	274.6	33.2	46.15
048E2	96	4	22.07	.922	−25.611	1.036	77.1	213.1	32.3	245.4	.074	270.3	35.1	46.40
114J1	52	4	22.35	.918	9.766	.906	78.5	215.2	32.8	248.1	.081	272.3	33.5	45.83
004W1	50	4	22.37	.924	46.200	.980	80.2	213.3	32.4	245.7	.013	272.6	33.3	47.23
115J1	52	4	22.43	.913	27.667	.967	79.1	215.7	32.9	248.6	.039	271.6	33.2	46.67
174N2	82	4	22.79	.913	14.726	.938	78.9	215.9	32.6	248.5	.057	271.6	33.2	46.30
032E2	95	4	22.86	.921	−54.176	1.017	79.7	213.5	32.3	245.8	.038	271.8	33.6	47.37
079E1	79	4	22.91	.924	61.600	.985	80.5	213.2	32.5	245.7	.018	272.8	33.2	47.40
080E1	79	4	22.97	.930	−26.571	1.035	79.7	211.4	32.5	243.9	.070	272.6	34.2	47.50
048C1	57	4	23.02	.923	−184.600	1.005	80.6	213.2	33.2	246.4	.033	273.1	33.2	47.63
005W1	41	4	23.32	.927	309.000	.997	80.4	212.5	33.6	246.1	.034	273.6	33.5	47.43
029B1	84	4	23.92	.929	37.160	.975	80.9	212.4	34.1	246.5	.040	274.6	33.2	47.47
064K1	63	4	24.91	.925	−12.500	1.074	80.3	212.3	34.5	246.9	.103	273.3	33.8	48.10
Mean				.921	46.063	.980	79.7	213.8	32.5	246.3	-	272.3	33.4	47.03
s. d.				.007	12.658	.072	1.0	1.6	1.0	1.5	-	1.3	.6	.91

value of $D = 0.20$, 17 meteors from the period April 21-25 belonging to the Lyrid stream were found (table I). The mean values in table are represented by the arithmetic mean except for the semimajor axis which is given as the harmonic mean $a = 1/(\overline{1/a})$.

The orbits are compiled from a period of 55 years (1941-1996), which means that cover only about 13 percent of the orbital period of the parent comet and thus provide rather limited information on the distribution of meteoroids along the whole orbit of the stream. The Lyrid radiant daily motion and radiant ephemeris derived from 17 Lyrids is

$$\alpha = 272.3^\circ + 0.802^\circ(L_s - 32.5^\circ),$$
$$\delta = 33.4^\circ - 0.155^\circ(L_s - 32.5^\circ).$$

The daily motion in right ascension and declination was found by the least-squares solution and L_s is the solar longitude of the time of observation for equinox 2000.0 and 32.5° is the solar longitude of the maximum of activity.

To find the size and form of the stream radiant area, individual radiants were reduced to a common solar longitude of the maximum of activity by allowing for the derived daily motion of the radiant. The observed radiant area is slightly elongated of a size of approximately 5° × 2°, while the reduced radiant area is in the central part more concentrated to a size of about 2° × 1.5°.

According to the semimajor axis of 17 Lyrids (table I), three distinct groups of orbits can be separated: a short-period group (6-14 AU), a long-period group (27-61 AU) and a group with extremely long orbits (> 300 AU). The mean orbits of the groups together with the orbit of the parent comet Thatcher are listed in table II.

In the next step individual members of the Lyrid short-period and long-period group were numerically integrated backwards on a time scale of 5000 years. We have applied for the backward integration of the orbital evolution the DE multistep procedure of Adams-Bashforth-Moulton's type up to 12th order, with variable step-width, developed by Shampine and Gordon [17] and the positions of perturbing planets were obtained from the Planetary and Lunar Ephemerides DE406 prepared by the Jet Propulsion Laboratory [18]. In the integration, each mean orbit is represented by 18 modeled particles distributed equidistantly according to the mean anomaly by 20° along the mean orbit.

Orbital evolution of short-period and long-period group in the semimajor axis a, the excentricity e, the perihelion distance q, the inclination i is shown in fig. 1 and the evolution in the argument of perihelion ω, the longitude of the ascending node Ω, the longitude of perihelion π are in fig. 2, together with the orbital evolution of comet Thatcher. The last plots of fig. 2 show also the evolution in the heliocentric distance of the ascending R_a and descending R_d node. Curves in plots represent individual meteors marked in the upper plots (table I).

TABLE II. – *Orbital elements and radiants of the Lyrid filaments and orbit of comet C/1861 G1 Thatcher (eq.* 2000.0*).*

Object	Q (AU)	q (AU)	a (AU)	e	i (°)	ω (°)	Ω (°)	π (°)	α (°)	δ (°)	Vg (km/s)	n
short-period	20.0	.918	10.459	.908	78.8	215.5	31.8	247.3	272.1	33.1	46.17	6
long-period	85.4	.923	43.157	.977	80.2	213.6	33.0	246.6	272.9	33.2	47.19	4
hyperbolic	-	.924	−20.350	1.045	79.9	212.7	32.8	245.5	272.2	33.8	47.69	7
Thatcher	110.4	.9207	55.682	.9835	79.77	213.45	31.87	245.32	272.0	33.5	47.08	

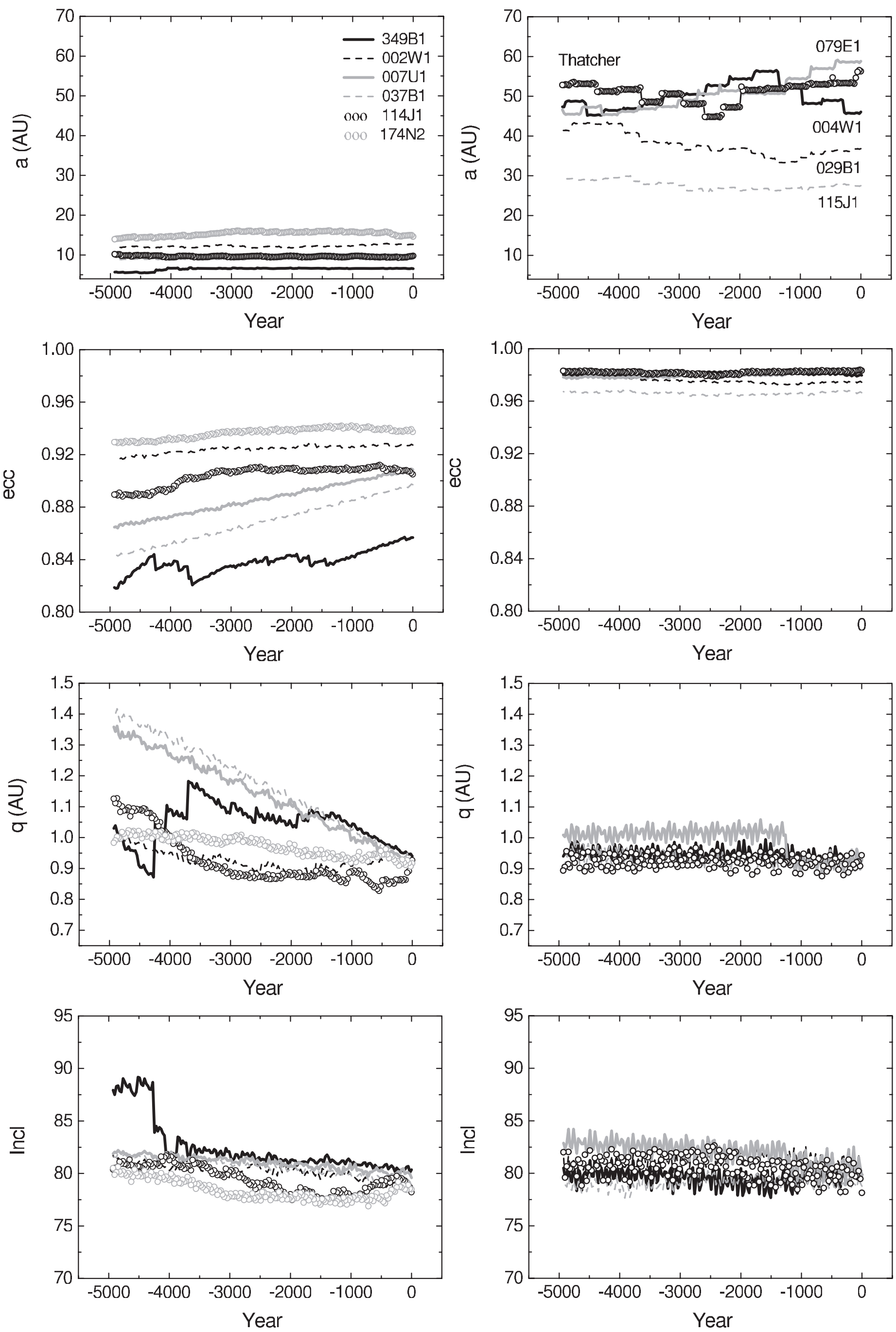

Fig. 1. – Orbital evolution of the Lyrid short-period orbits (left plots), long-period orbits and comet Thatcher (right plots) in a, e, q, i over 5000 years.

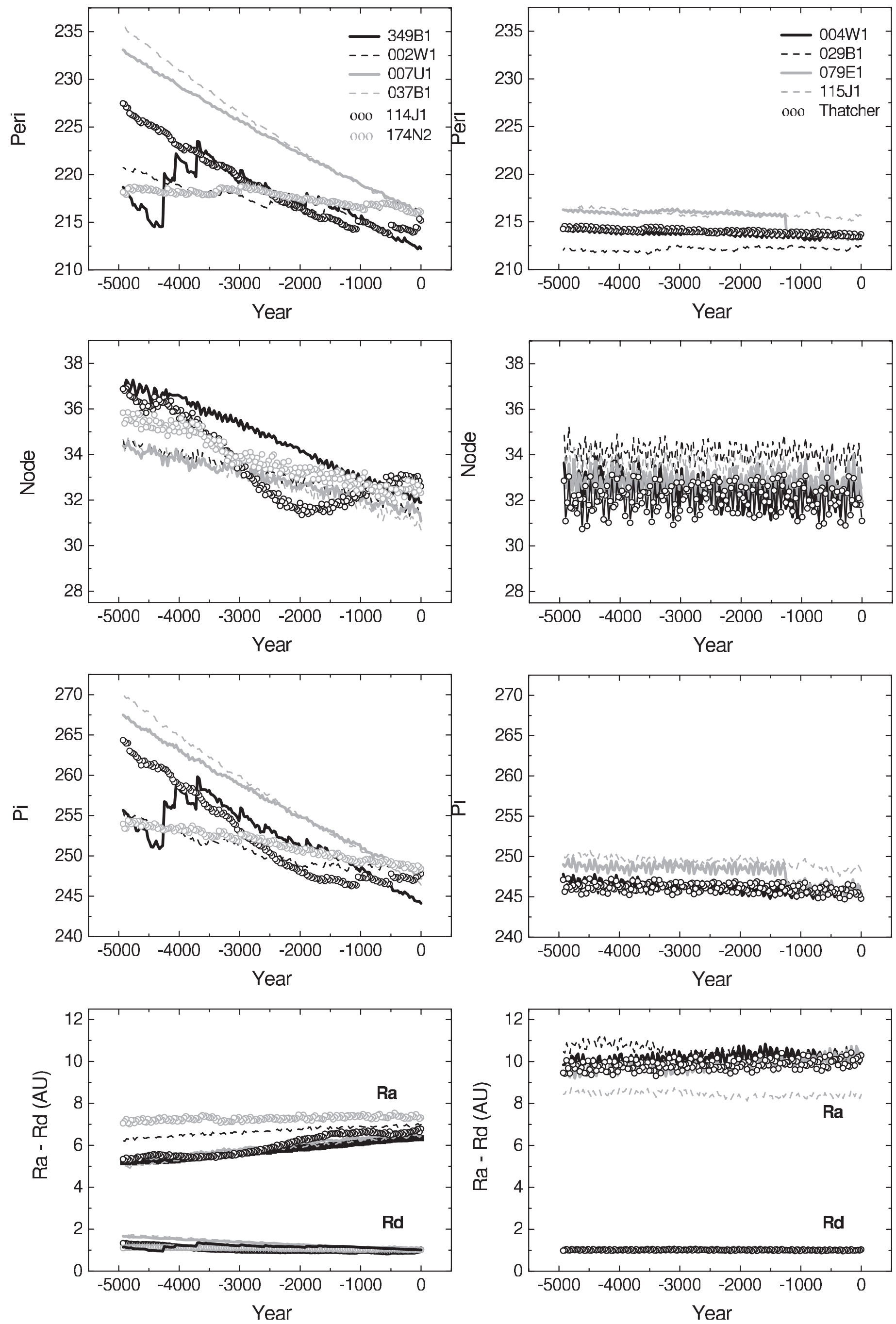

Fig. 2. – Orbital evolution of the Lyrid short-period orbits (left plots), long-period orbits and comet Thatcher (right plots) in ω, Ω, π and evolution of the heliocentric distance of the ascending (Ra) and descending node (Rd) over 5000 years.

3. – Discussion and conclusions

The orbital evolution of the Lyrid parent comet C/1861 G1 Thatcher from a long-term point of view was investigated by Porubčan and Wu [19]. They have pointed out the possibility of a capture of the comet into the inner Solar System approximately 300000 years ago. It means that practically since that time a stream of meteoroids could be associated with the comet. In the present study the stream and comet are analysed from a short-term point of view and it can be seen that the orbits of the stream and comet are relatively stable (figs. 1 and 2).

The orbits in the plots divided into two groups can be designated as a "short-period filament" and a "long-period filament". Integration of Lyrids on extreme orbits of which six are hyperbolic has indicated that these are most probably the result of measurement errors. No one of these meteoroids before the collision with the Earth had a closer approach to a larger perturbing body which would accelerate it to a hyperbolic orbit.

Individual meteors in figs. 1 and 2 are depicted by different curves and labeled using their designation in the IAU Meteor Database catalogue. Also the evolution of the orbit of comet Thatcher is indicated in the plots of long-period filament. It is evident that meteors pertinent to this filament are moving in the orbits very close to the comet during the whole period of integration.

Summarizing, based on photographic observations, two very distinct groups of orbits, short-period and long-period, can be recognized in the Lyrid meteor stream. The groups were probably formed under the gravitational influences of planets on the stream. Integration of orbits of short-period group indicates that this branch of the stream is affected predominantly by Jupiter. Long-period set of orbits is modified also by Saturn. The ascending nodes of orbits of short-period group lay between Jupiter and Saturn. The evolution of long-period Lyrid group is more stable and its members have similar evolution as the parent comet Thatcher. The ascending nodes are close to the orbit of Saturn. The descending nodes of all orbits are stable and close to the Earth. The hyperbolic Lyrid orbits are most probable due to not enough precise measurements.

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