Distributions of Orbital Elements for Meteoroids on Near-Parabolic Orbits According to Radar Observational Data

S. V. Kolomiyets

Abstract Some results of the International Heliophysical Year (IHY) Coordinated Investigation Program (CIP) number 65 "Meteors in the Earth Atmosphere and Meteoroids in the Solar System" are presented. The problem of hyperbolic and near-parabolic orbits is discussed. Some possibilities for the solution of this problem can be obtained from the radar observation of faint meteors. The limiting magnitude of the Kharkov, Ukraine, radar observation program in the 1970's was +12, resulting in a very large number of meteors being detected. 250,000 orbits down to even fainter limiting magnitude were determined in the 1972-78 period in Kharkov (out of them 7,000 are hyperbolic). The hypothesis of hyperbolic meteors was confirmed. In some radar meteor observations 1 − 10% of meteors are hyperbolic meteors. Though the Advanced Meteor Orbit Radar (AMOR, New Zealand) and Canadian Meteor Orbit Radar (CMOR, Canada) have accumulated millions of meteor orbits, there are difficulties in comparing the radar observational data obtained from these three sites (New Zealand, Canada, Kharkov). A new global program International Space Weather Initiative (ISWI) has begun in 2010 (http://www.iswi-secretariat.org). Today it is necessary to create the unified radar catalogue of near-parabolic and hyperbolic meteor orbits in the framework of the ISWI, or any other different way, in collaboration of Ukraine, Canada, New Zealand, the USA and, possibly, Japan. Involvement of the Virtual Meteor Observatory (Netherlands) and Meteor Data Centre (Slovakia) is desirable too. International unified radar catalogue of near-parabolic and hyperbolic meteor orbits will aid to a major advance in our understanding of the ecology of meteoroids within the Solar System and beyond.

Keywords meteors · meteoroids · meteor orbits · meteor radar · hyperbolic meteors

1 Introduction

In a series of publications (Kolomiyets and Kashcheyev 2005, Kolomiyets 2002, Andreyev et al. 1993) the authors have identified a set of meteor orbits, with $e \geq 1$, of meteor sporadic background based on the Kharkov radar observations, which they named "hyperbolic meteors" similar to previous publications (Vsekhsvyatskiy 1978; Shtol 1970) based on analogous data. The Kharkov radar orbital data from the 1970s has proven to be extremely promising for finding the real hyperbolic orbits, as they were statistically many in terms of volume and uniformity, there have been twenty-four-hour and round off the annual cycles of observations were weaker meteors between masses $10^6 - 10^9$ kg, which are important for the building of the Meteor engineering distribution models (Dikarev et al. 2001). In addition, these data were obtained as a result of carefully designed and carefully executed multi-year monitoring experiment (Kashcheyev and Tkachuk 1980), using the Meteor automated radar system (MARS) of the Kharkov National University of radio electronics (KhNURE), which was recognized at that time to be the best in the world (Fedynskiy et. al. 1976, Kashcheyev 1977, Kashcheyev et al. 1977,

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Voloshchuk et. al. 1984). Hyperbolic meteors were recorded and continue to be recorded by other meteor radar and optical observations (Kramer et. al. 1986), and in "in situ" experiments (Weidensehilling 1978, Grün et al. 2001). The information on hyperbolic orbits is currently available as the new 2003 version at the International Astronomical Union Meteor Data Center IAU (MDC), provided by scientists from Slovakia (Hajdukova 2008; Hajdukova and Paulech 2006). Nevertheless, data on hyperbolic orbits that are available to scientists in print is very heterogeneous and not always meaningful for the categorical conclusions. Part of it are the consequence of errors (Hajduk 2001). In addition to that the real hyperbolic meteor complex has a naturally compound structure. The theories of the origin of hyperbolic meteor orbits near the Earth orbit and in the Solar System are still ambiguous and contradictory (Meisel et al. 2002a,b; Janches et al. 2001; Grun and Landgraf 2000; Kramer et al. 1998; Belkovich and Potapov 1985; Kazantsev 1998; Vsekhsvyatskiy 1978). The majority of scientists do not contradict the reality of hyperbolic meteor orbits altogether, but at the same time it is becoming increasingly attractive to research the emergence of new information and new submissions on this issue. As a rule the number of meteor orbits with the eccentricities much greater than 1 is very small, both theoretically and experimentally (~ 1%). Thanks to scanty statistics the problem of hyperbolic identities meteors ($e \geq 1$)is actually a problem near-parabolic orbits meteoroids ($e \sim 1$). The set of near-parabolic orbits of meteoroids is the most dynamic part of meteor substance of the Solar System. This orbital series is statistically far richer than the set of hyperbolic meteor orbits only and its properties and characteristics are the keys to solving both problems of hyperbolic meteor orbits, and other problems of cosmology and cosmogony of the Solar System. (Lebedinets 1980, 1990; Rietmeijer 2008, Drolshagen et. al. 2008, Suggs et. al. 2008, Chapman 2008).

2 The Kharkov (Ukraine) Meteor Radar Data

The final test of the validity of a theory has always been an experiment. The 1972-1978 Kharkov meteor radar data mentioned above was the result of a carefully designed and performed at the highest level experiment. During the radar observations of faint meteors in Kharkov, special attention was paid to the regularity, continuity and stability of the sensitivity of the surveillance equipment. The scheduling of observations was designed such that the observing cycles were distributed more or less evenly throughout the year. For example, during 1975, 29 observing cycles, ranging five to eight days, took place and, as a result, over 54,000 orbits of meteoroids were determined. The monitoring, carried out in times when main meteor showers were absent, with few exceptions (for ex., Geminids and Quadrantids), allows observation of prevalently the sporadic meteor background. Therefore the derived distribution of meteors was hardly influenced by meteoroids of main showers and characterized mainly sporadic meteor complex. In the 1972-1978 MARS of the KHNURE (Kharkov) registered about 250 thousand radiants, velocities and orbits of small meteoroids. The limiting magnitude of the Kharkov radar observation program in the 1970s was +12m (faint meteors). Parameter distributions of small meteoroid orbits registered in Kharkov were constructed. Variations of those distributions with time, seasons, and factors of selectivity were taking into account. Thus, the empirical model of the meteor substances from radar data in Kharkov between masses $10^6 - 10^9$ kg with mass parameter $s = 2$ was formed. Some of the properties and characteristics of this model were published (Kashcheyev and Tkachuk 1979, Tkachuk 1979). As a guide to the Kharkov meteor orbital empirical model, based on monitoring data of the 1972-1978, the selective catalogue of 5,317 meteors of up to +12 magnitude (Kashcheyev and Tkachuk, 1980) can be used. It demonstrates in brief all the characteristics of the model, the parameters, the methodology and peculiarities of radar observations (Kashcheyev et al. 1967, Tkachuk 1974). It contains

5,317 orbits, registered in Kharkov during the 1975, out of total record of 54,000 orbits.

Some characteristics of the Kharkov empirical model of orbital distributions of meteoroids using radar observations from 1975 in Kharkov are shown in Figure 1, where the dashed lines represent the set of elliptical orbits, available in the catalogue of Kashcheev and Tkachuk (1980), and the solid lines represent the set of hyperbolic orbits, selected by Kolomiyets (Kashcheyev et al. 1982). Meteoroid number distributions are plotted versus three orbit elements: perihelion distance, inclination and perihelion argument. The author listed nearly 1,000 meteor hyperbolic orbits with eccentricities close to 1, based on the 1975 data obtained in Kharkov. Their orbital distributions and some other facts support the existence of "hyperbolic meteors" (Kolomiyets 2001).

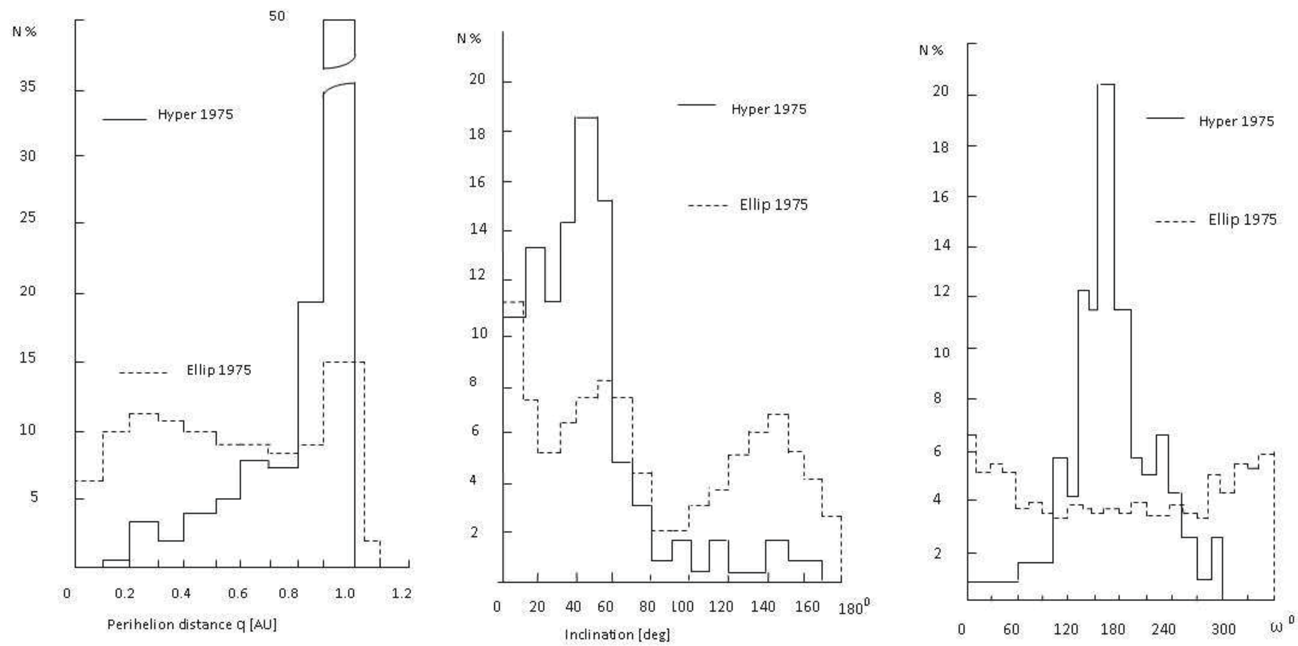

Figure 1. Left: Histograms of the number of orbits *N* (in %) depending on the perihelion distance *q* (in AU). Middle: inclination (in degrees) and right: argument of perihelion *ω* (in degrees) for two types of orbits with different values of the eccentricity: elliptical (dashed lines) and hyperbolic(solid lines).

In Table 1 we show an example of the data on hyperbolic and near-parabolic orbits of meteoroids registered on July 12-13, 1975 by radar method in Kharkov. During the 1990s, registered meteor data from 1972-1978, including the velocities, radiant coordinates and orbits, have been recalculated and put into electronic format. On the basis of this electronic database, the more sophisticated model of the meteor complex near the Earth's orbit for elliptical orbits of meteoroids (for stream and sporadic components) of faint meteors was constructed. A detailed description of the specified database and its thorough analysis for elliptic orbits is presented by Voloshchuk et al. (1995, 1996, 1997). In this analysis we did not include the hyperbolic orbits of meteoroids. Now the KhNURE scientists have the possibility to use the re-calculated meteor orbit database of the 1972-1978 dataset when they perform meteor research in the KhNURE. For the analysis of distributions of hyperbolic and near-parabolic orbits of meteoroids according to radar observations during the period 1972-1978, the author also used the recalculated KHNURE electronic database.

Table 1. Example of data on the hyperbolic and near-parabolic orbits of meteoroids from Kharkov (36.90E, 49.40 N) radar observations program 1975 (July 12-13). The columns are: (*H*:*M*) – hour and minute; V_g – geocentric velocity; V_h –heliocentric velocity; (β', λ') – radiant heliocentric coordinates; E_s' – radiant elongation from the Sun; e – eccentricity and σ_e – the standard deviation of eccentricity; q – perihelion distance; p – orbit parameter; i – inclination; ω – perihelion argument; Ω – longitude of ascending node; $\pi = \omega + \Omega$ – longitude of perihelion; ($R_{\Omega 1}$, $R_{\Omega 2}$) – nodes radius vectors.

H:M	V_g	V_h	β'	λ'	E_s'	$e \pm \sigma_e$	q	p	i	ω	Ω	π	$R_{\Omega 1}$	$R_{\Omega 2}$
July, 12														
02:09	41±2.2	50±1.9	40	240	120	1.78±0.19	0.81	2.3	48	226	109	336	–	1.02
04:45	54±2.8	56±2.6	70	215	95	2.63±0.34	1.01	3.7	71	188	109	297	–	1.02
04:53	40±2.1	44±1.9	52	239	112	1.25±0.18	0.88	1.9	59	220	109	330	–	1.02
05:03	46±2.4	59±2.6	46	174	73	2.91±0.34	0.96	3.7	49	157	109	267	–	1.02
05:06	67±3.4	43±3.4	28	342	121	1.15±0.26	0.76	1.6	145	238	109	348	4.07	1.02
05:08	65±3.3	49±3.2	36	313	136	1.45±0.23	0.55	1.4	118	257	109	6	1.99	1.02
05:40	44±2.3	42±2.0	68	232	101	1.12±0.19	0.98	2.1	71	201	109	311	–	1.02
06:10	59±3.0	41±3.0	21	313	148	0.99±0.08	0.28	0.5	136	296	109	46	0.38	1.02
06:46	59±3.0	56±3.2	55	272	122	2.35±0.37	0.80	2.7	78	226	109	336	–	1.02
07:43	55±2.8	51±3.1	60	272	118	1.83±0.32	0.84	2.4	80	223	109	333	–	1.02
07:49	67±3.4	43±3.3	43	38	76	1.20±0.32	0.97	2.1	134	155	109	265	–	1.02
08:02	39±2.1	48±3.0	46	232	111	1.62±0.30	0.90	2.4	51	215	109	325	–	1.02
09:10	58±3.0	52±4.3	37	281	122	1.94±0.46	0.80	2.3	84	227	109	337	–	1.02
11:54	39±2.1	44±1.6	-0	138	28	1.06±0.05	0.26	0.5	0	243	289	173	1.02	0.35
July, 13														
02:05	42±2.1	44±1.0	21	264	113	1.09±0.07	0.33	0.7	42	287	110	37	0.53	1.02
03:40	41±2.2	41±1.7	63	236	111	0.97±0.15	0.95	1.9	68	210	110	321	11.93	1.02
05:26	59±3.1	67±3.2	57	229	105	4.15±0.49	0.97	5.0	60	199	110	310	–	1.02
05:31	62±3.2	43±3.1	16	318	147	1.04±0.10	0.31	0.6	147	290	110	41	0.46	1.02
08:37	67±3.4	49±3.6	43	328	125	1.57±0.32	0.74	1.9	123	236	110	347	14.32	1.02
15:29	35±1.9	46±1.6	9	152	42	1.25±0.10	0.52	1.2	14	96	110	207	1.33	1.02
15:57	31±1.7	41±1.4	28	158	53	0.98±0.09	0.65	1.3	36	106	110	217	1.78	1.02
16:08	50±2.6	71±2.5	15	168	59	4.22±0.35	0.8	4.4	17	142	110	253	–	1.02
16:23	34±1.9	54±1.7	18	170	61	2.14±0.18	0.84	2.6	21	138	110	249	–	1.02

2.1 Empirical Model of Orbital Distributions of Meteoroids with Near-parabolic Orbits According to the Kharkov Radar Data

Celestial bodies are moving around the Sun in curves of the second order, which are the conic sections with the Sun in one of the foci. The orbital elements are p, e, ω, Ω, i, τ, where p is the orbital parameter, e is the eccentricity, ω is the argument of perihelion, Ω is the longitude of ascending node, i is the inclination and τ is the time registration. These elements are called Kepler's elements and they determine the orbit of any type, elliptical $e < 1$, parabolic $e = 1$ or hyperbolic $e > 1$.

The author presents here the empirical model of orbital meteoroids complex for near parabolic orbits of faint meteors. This model is based on the observational data obtained by the MARS radar system in 1972-1978 in Kharkov. The model is presented in the form of distributions of numbers of orbits versus the orbital elements, perihelion distance q, inclination i and argument of the perihelion ω, for different types of orbits and different eccentricity values. As an important informative source, the distributions of the number of orbits versus geocentric and heliocentric velocities were also constructed. The model is constructed in such a way that one can compare a specific orbit-registered-size meteoroid samples that represent sets of orbits, which are close to the exact parabolic orbit, for both elliptical and hyperbolic orbits. That is, the selection of orbit was based on the approximation to the exact parabola in varying degrees. Depending on the degree of approximation the selections were called classic, close or average. These approximations had the following criteria. Classic selection for elliptical site of orbits (approaching the parabola from one side) was performed according to $0.9 < e < 1.0$, and hyperbolic test for site of orbits (approaching the parabola from the other side) by criterion $1.0 < e < 1.1$. Close approximation had $0.99 < e < 1.0$ for elliptical orbits, and $1.0 < e < 1.01$ for hyperbolic orbits. Average approximation criterion was $0.95 < e < 0.98$ for elliptical orbits, and $1.1 < e < 2.35$ for hyperbolic orbits. The set of the distributions (the empirical model) gives a clear representation of behavior of a meteoric orbital complex near a parabolic limit $e = 1$ (Figures 2-6).

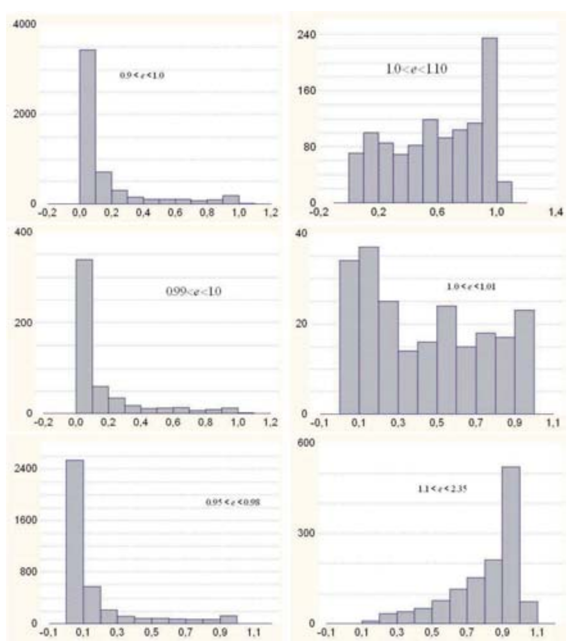

Figure 2. Histograms of the number of orbits N with different values of eccentricity e vs. perihelion distance q (in AU) for two types of near-parabolic orbits, elliptical (left column) and hyperbolic (right column).

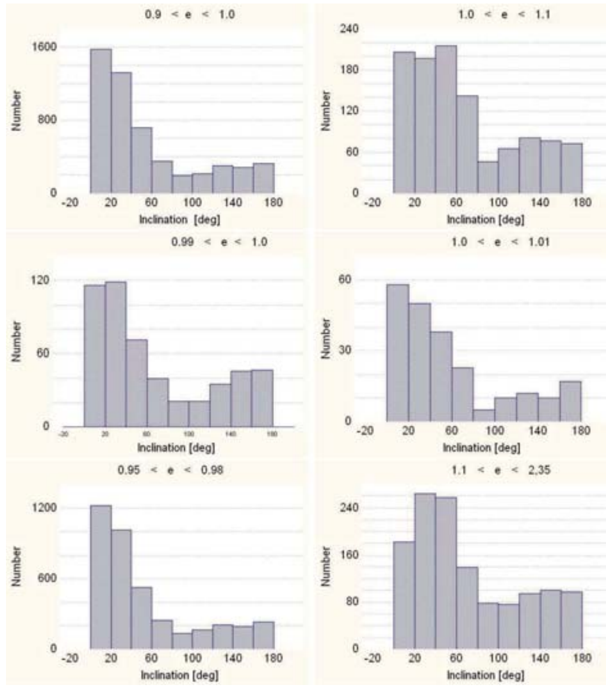

Figure 3. Number of orbits *N* with different values of eccentricity *e* vs. inclination *i* (in degrees) for elliptical (left column) and hyperbolic (right column) orbits.

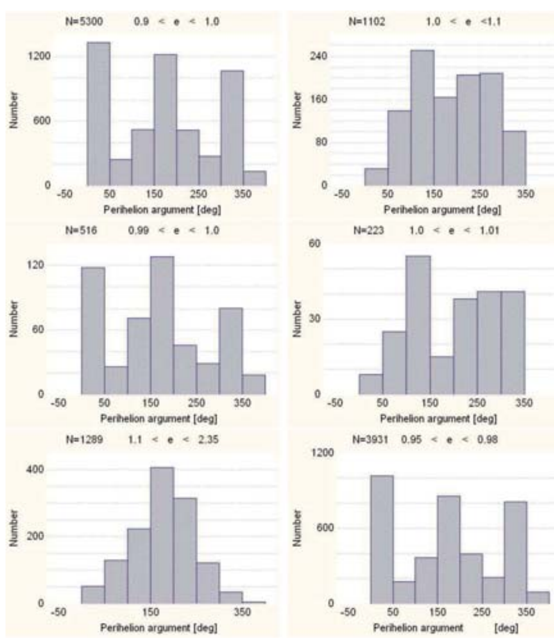

Figure 4. Number of orbits *N* with different values of eccentricity *e* vs. perihelion argument *ω* (in degrees) for elliptical (left column) and hyperbolic (right column) orbits.

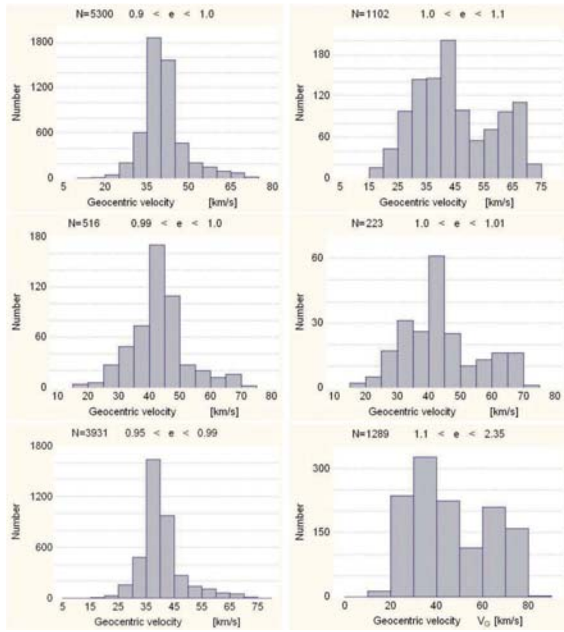

Figure 5. Histograms of the number of orbits *N* with different values of eccentricity *e* vs. geocentric velocity V_g for elliptical (left column) and hyperbolic (right column) orbits.

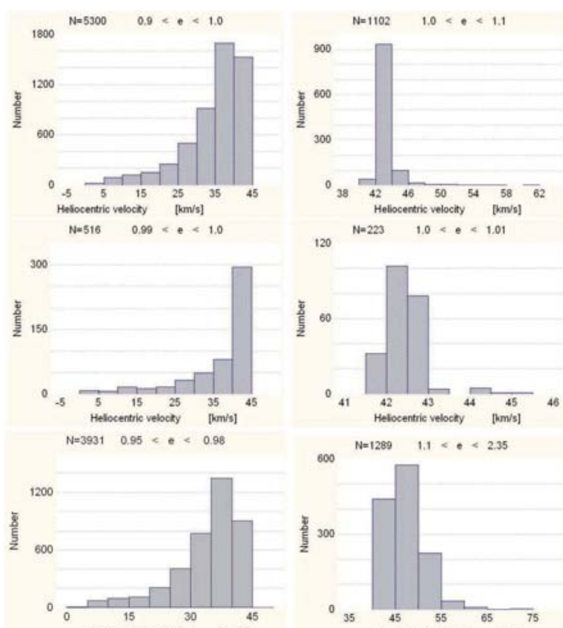

Figure 6. Histograms of the number of orbits *N* with different values of eccentricity *e* vs. heliocentric velocity V_h for elliptical (left column) and hyperbolic (right column) orbits.

3 Small-size Orbits of Meteoroids Near the Earth's Orbit

In the studies of hyperbolic meteors, the meteoroids on hyperbolic and near-parabolic orbits are mostly regarded as newcomers from distant regions of the Solar System and even from interstellar space (Baggaley 2005, Weryk and Brown 2005, Meisel et al. 2002a, b; Hawkes et. al. 1998). The fact that part of the hyperbolic and parabolic orbits complex can be formed and replenished by the component with small-size orbits in the nearby space between the Sun and the Earth's orbit is largely ignored. The recent sharp increase in interest in small bodies in the Solar System is undoubtedly due to the immediate opportunity to observe the Sun-grazing comets thanks to SOHO/LASCO and STEREO/SECCHI programs carried out over the past thirteen years. Spectacular images of comets, recorded on the disk of the Sun special satellites are available online (http://sungrazer.nrl.navy.mil/index.php) and are exciting to everyone. Comets grazing the Sun have been known for a very long time as the Kreutz comets. The working hypothesis of the origin of the Kreutz comets is the ongoing disintegration of one giant comet (Marsden 1967), and today there is some additional data to it (Guliyev 2010). These sungrazing comets are one of the specific parent sources of meteoroids with small-size orbits. The second specific parent source of meteoroids with small-size orbits is the Aten, Apollos and Amor streams that cross the Earth's orbit (AAA-asteroids).

An asteroid is considered a Near Earth Asteroid (NEA) when it comes to within 1.3 AU of Earth. A NEA is called a Potentially Hazardous Asteroid (PHA) when its orbit comes within 0.05 AU of the Earth's orbit and its absolute magnitude becomes $H < 22$ mag (i.e., its diameter is $D > 140$ m). The estimated total population of PHAs is ~ 25, 000 (http://neo.jpl.nasa.gov/ca). At the same time it is estimated that 32% of the total number of NEAs are Amors, 62% are Apollos and 0.6% are Atens.

The meteoroids-asteroids population discovered by A.K. Terent'yeva (Galibina and Terent'yeva 1981) is known as the Eccentrides. A table presenting the sample of orbital elements of some of the Eccentrides (Simonenko et al.1986) is shown in Table 2.

Table 2. Orbital elements of some of the Eccentrides. Columns N_2, N_3 are as in Simonenko et al. (1986). Other column names are as in Table 1.

N	N_2	N_3/name	*e*	*a*	*q*	*Q*	*Ω*	*ω*	*i*
1	4	6096	0.62	0.61	0.23	1.0	113	176	139
2	15	10573	0.87	0.54	0.07	1.0	191	177	135
3	19	11855	0.77	0.61	0.14	1.1	42	349	10
4	20	11941	0.79	0.62	0.13	1.1	44	13	47
5	38	231	0.75	0.57	0.14	1.0	260	354	34
6	39	11041	0.85	0.56	0.09	1.0	210	353	9
7	43	4473	0.94	0.53	0.03	1.0	177	3	17
8	51	1954XA	0.35	0.78	0.51	1.1	190	57	4
9	52	Hathor	0.45	0.84	0.46	1.2	211	40	6
10	53	Ra-Shalom	0.44	0.83	0.47	1.2	170	356	16

Eccentrides were defined as groups of small bodies in the Solar System with the smallest orbits ($a < 1$ AU) of medium or large eccentricity whose aphelion is near the Earth's orbit ($Q < 1.15$ AU). From existing meteors' and bolides' photographic data, Simonenko et al. (1986) has selected fifty Eccentrides. Three asteroids of the Atens team were also selected as Eccentrides (2340 Hathor, 2100 RA-Shalom and 1954 HA), although Hathor and RA-Shalom have an aphelion distance of $Q \sim 1.2$ AU.

Out of these objects, seven deserve special attention as a specific group having the most eccentric orbits (Simonenko et al. 1986). These orbits, projected on the ecliptic plane, are shown in Figure 7 (the orbital elements are presented in Table 2).

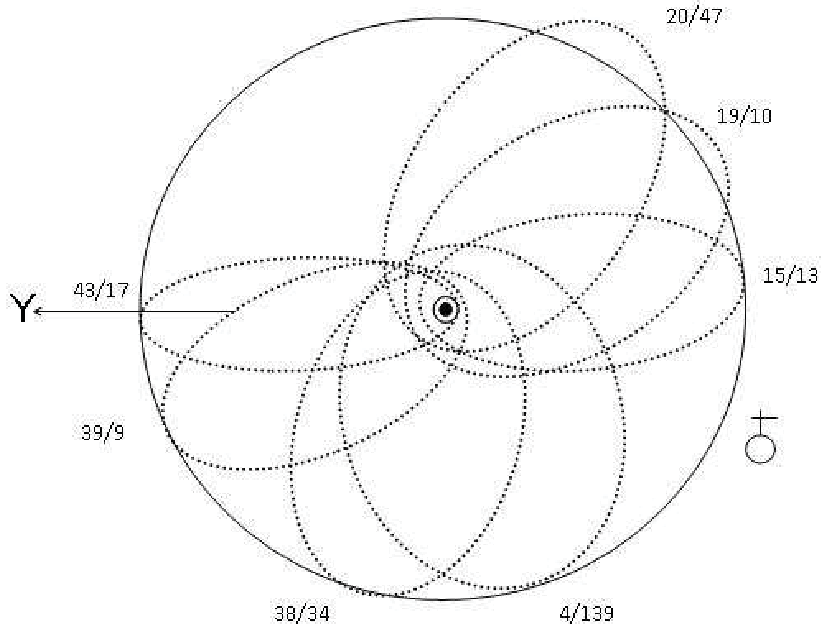

Figure 7. Seven Eccentrides with most eccentric orbits, projected on the ecliptic plane (orbital elements presented in Table 2). The numbers next to the aphelions are object numbers and their orbital inclinations, respectively (Simonenko et al. 1986).

According to Levin et al. (1981), at least 10% of the meteorites on Earth come from the population that has very small-size orbits, located entirely within the orbit of the Earth (such as, for example, Mauch, Murray, Old Peschanoe, Gorlovka and Vashugal). This class of meteorites has attracted the special attention of researchers, since they belong to the source of potentially dangerous objects for the Earth.

As the most dynamic component of the Solar System, meteoroids on near-parabolic orbits and orbits with very high eccentricities are a valuable source of information either about their progenitors, or about the place and mechanism of their formation. For example, from the Kharkov database of near-parabolic orbits it is possible to select a set of orbits with the aphelions that are characteristic for the Eccentrides. Figure 8 shows the distribution of near-parabolic orbits of sporadic meteoroids with the same aphelion distances Q as for Eccentrides. Using the streaming component (5160 orbits) of the Kharkov meteor electronic database (Voloshchuk et al. 1996, 1997, 1998), Voloshchuk et al. (2002), while calculating the probability of collision between the Earth and the parent bodies of meteor streams, has found that the most dangerous are the parent bodies whose corresponding meteor orbits have an aphelion distance of 1 AU. The authors selected 100 of the most potentially dangerous meteor streams, whose parent bodies may fall on Earth. Almost all of their orbits are the Eccentridestype. A table with examples from this list of the Eccentrides with $0.9 < e < 1$ (i.e. near-parabolic) is given in Table 3, where N_2 is a number in the list of meteoroids of the Kharkov Meteor database (ordered according to the likelihood of the stream falling on the Earth). This factor, identified above for the sporadic meteors of the Eccentrides-type, of the very low values of the perihelion distance q ("the Sungrazing orbits"), has also been identified in 12 meteor streams selected as the Eccentrides.

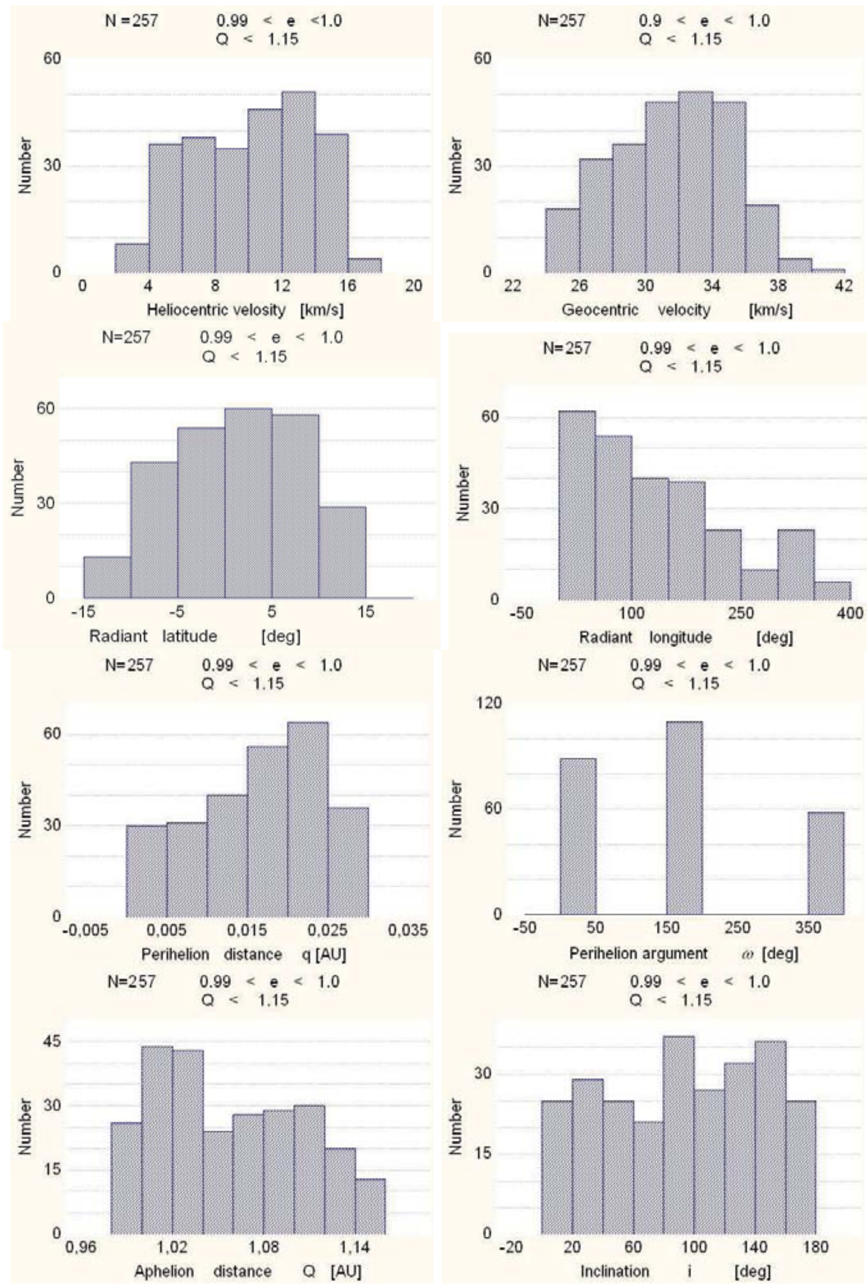

Figure 8. Distribution of the number of near-parabolic orbits of sporadic meteoroids with aphelion distance Q. The labeling of x and y-axes is the same as in Figs. 2-6 for Eccentrides. V_h is heliocentric velocity, V_g is geocentric velocity, (β, λ) are radiant latitude and longitude in ecliptic system, q and Q are perihelion and aphelion distance, ω is the argument of the perihelion, and i is the orbital inclination.

Table 3. Parameters of some streams according the KhNURE data (Eccentrides-type with $e > 0.9$) that have the highest probability of colliding with the Earth. N_2 is the number from the list of 100 dangerous streams, N_3 is the number in the KhNURE catalogue, Members - quantity, e is the eccentricity, i is the inclination, q is the perihelion distance and Q is the aphelion distance (Voloshchuk et al. 2002).

N	N_2	N_3	*Members*	e	i	q	Q
1	11	855	7	0.983	32.5	0.008	0.99
2	15	1167	10	0.98	172.9	0.001	1.02
3	16	3621	10	0.914	148.2	0.045	1.00
4	24	2807	13	0.958	163.3	0.022	1.02
5	31	313	13	0.943	41.4	0.029	1.00
6	36	4333	21	0.906	137.7	0.049	0.99
7	42	3175	18	0.923	160.2	0.041	1.03
8	45	3155	13	0.966	110.2	0.018	1.01
9	51	4123	8	0.943	159.1	0.030	1.03
10	62	3981	13	0.935	77.1	0.034	1.00
11	65	2596	7	0.996	155.2	0.002	1.04
12	98	3530	9	0.910	27.4	0.049	1.04

4 World Radar Data Resources of Hyperbolic Orbits

Main modern holders of world radar data resources of orbits of meteoroids are specified in Table 4. From Table 4 it can be seen that the r`esource-monitoring data on near-parabolic and hyperbolic orbits of meteoroids is quite impressive.

Table 4. World data resources of hyperbolic orbits: data, the methodology and the nominal parameters of meteoric automatic radar systems MARS, CMOR, and AMOR.

Country	Ukraine	Ukraine	Canada	New Zealand	Puerto Rico
Radar name	MARS	MARS	CMOR	AMOR	Arecibo meteor radar
Radar type	VHF	VHF	HF/VHF SKiYMET	HF/VHF SKiYMET	UHF, HPLA
Method	Impulse-diffraction,	Impulse-diffraction,	Impulse-diffraction,	Impulse-diffraction,	Not mirror
	mirror reflect	mirror reflect	mirror reflect	mirror reflect	reflection
Frequency	22.38 MHz	31.1 MHz	29.85 MHz	26.2 MHz	430 MHz
City	Kharkov	Kharkov	Tavistock, ON	Banks Peninsula	Arecibo
LAT	49.4 N	49.4 N	43.3 N	43.2 S	18.3 N
LON	36.9 E	36.9 E	80.8 W	172.5 E	66.8 W
Period	1967-1971	1972-1978	2002-2004	1995-1999	1997-1999, 2002
Enter data	ATC	ATC	ATC	ATC	Head echo
Record / Holding	Oscillograph / photofilm	Computer/paper tape/ Electronic (with 1996)	Computer / Electronic	Computer / Electronic	Computer / Electronic
Orbits	~90,000	~250,000	>1,000,000	~500,000	~50,000
Magnitude or size	+8m / +12m	+12m	+8m	+8m / +13m	< 20 – 100 μm
Hyperbola content	Didn't search	1-3%	1-10%	1-3%	~2%

There are radars in New Zealand and Canada providing extensive observation results (reported by Baggaley et al. 2001, Weryk and Brown 2005). The Advanced Meteor Orbit Radar (AMOR) is located near Banks Peninsula on the South Island in New Zealand (172.6E, 43.6S). The Canadian Meteor Orbit Radar (CMOR) is located near Tavistock, Canada (80.8W, 43.3N). The CMOR has accumulated over one million meteor orbits. These meteor radars (AMOR and CMOR) are based on the commercially available SKiYMET system. The Kharkov meteor radar of 1970s (MARS) had some distinctions.

Difficulties exist in comparing the radar observation data obtained from these three sites (Banks Peninsula, New Zealand; Tavistock, Canada; Kharkov, Ukraine). Moreover, comparison of data collected by the above mentioned three stations with the classical meteor radar and the Arecibo radar data requires an even more complex approach (Pellinen-Wannberg 2001). This data is not published in full and is not accessible for the general use, neither it is transferred to the IAU MCD.

A new global program "International Space Weather Initiative" (ISWI) started in 2010 (http://www.iswisecretariat.org). Today it is necessary to create the general unified meteor radar orbit catalogue (with hyperbolic and near-parabolic orbits) in the framework of this new international program ISWI (or in any other way) with the collaboration of Ukraine, the USA, Canada, New Zealand, possibly Japan, and other countries. Both the IAU MDC (Slovakia) and the Virtual Meteor Observatory (the Netherlands) shall be used for creating this International Radar Catalogue.

5 Links to International Projects

5.1 International Heliophysical Year

This work was undertaken in the framework of the international project 2007-2009 International Heliophysical Year (Harrison et. al.2007, Davila et. al.2004). Meteor research was officially included as an IHY program under the title "Meteors, Meteoroids and Interplanetary Dust" only in 2007 (Kolomiyets and Slipchenko 2008). The principal mechanism for coordinating scientific activities for the IHY was the Coordinated Investigation Programs (CIPs). Information on research works in the scientific discipline "Meteors, Meteoroids, Dust" (Coordinator Svitlana Kolomiyets, Ukraine) of the IHY project is shown in Table 5.

Table 5. The meteor IHY 2007/9 Activities of the NIS (the Discipline: Meteor/Meteoroids/Dust). It has 7 Coordinated Investigation Programs: CIP 60, CIP 65, CIPs 72-76.

CIP	Program Title	Lead Proposer	Affiliation, *city*, country
CIP 60	Influence of Space Weather on Micrometeoroid Flux	Dr. Thomas Djamaluddin, Senior Researcher, Head of Center for Application of Atmospheric Science and Climate	National Institute of Aeronautics and Space (LAPAN), *Bandung*, Indonesia
CIP 65	Meteors in the Earth Atmosphere and Meteoroids in the Solar System	Dr. Svitlana Kolomiyets, Researcher, Meteor Radar Centre	Kharkov National University of Radioelectronics (KhNURE), *Kharkov*, Ukraine
CIP 72/65	Meteors in the Earth Atmosphere and Meteoroids in the Solar System	Prof. Oleg Belkovich	Kazan State University, Zelenodolsk branch, *Kazan*, Tatarstan, Russia
CIP 73/65	Meteors in the Earth Atmosphere	Prof. Nelly Kulikova	Obninsk State Technical University, *Obninsk*, Russia
CIP 74	Meteoroid-Atmosphere Interactions	Dr. Olga Popova, Senior Researcher (SR)	Institute for Dynamics of Geospheres of the Russian Academy of Sciences, *Moscow*, Russia
CIP 75	Meteoroid Streams: Origin, Formation, Observations	Prof. Galina Ryabova	Tomsk State University, *Tomsk*, Russia
CIP 76	Physical Properties of Meteoroids and Bolide-Meteorite-Asteroid Associations	Dr. Natalia Konovalova, Senior Researcher	Institute of Astrophysics, Tajik Academy of Sciences, *Dushanbe*, Tajikistan

The IHY, an international program of scientific collaboration in order to understand the external drivers of planetary environments, has come to the end. Many aspects of the IHY are continuing through the program International Cosmic Weather Initiative. As it was presented and discussed on February 18, 2009 at the meeting of the UN's COPUOS (United Nation Committee on the Peaceful Uses of Outer Space) Science and Technical Subcommittee (STSC), the ISWI is a 3-year plan (2010-2013). The study of the energetic events in the Solar System will pave the way for safe human space travel to the Moon and planets in the future, and may serve as an inspiration for the next generation of space physicists. To complement the ground-based data, a huge amount of data from space-based missions on the Earth and heliospheric phenomena is available. Support of local governments and institutions is needed for local scientists to participate in the analysis and interpretation of this data.

5.2 The Meteor Heritage of the Twentieth Century

One of the objectives of the IHY project and the coordinated research IHY CIP65 Meteors in Earth's atmosphere and meteoroids in the Solar System is to reflect the important role in the development of meteor studies during the previous similar worldwide program The International Geophysical Year 1957 (IGY). At the same time the CIP 65 draws the attention of the scientific community in a large reserve not only unpublished observation data and knowledge gained during the Soviet period in the meteor centers of the USSR, but also to the significant scientific publications of the meteor heritage of the former USSR, which continue to be available only in Russian. The huge amount of data and knowledge about meteors of scientific value was accumulated in the former USSR thanks to the rapid development of meteor science during the second half of the twentieth century, from realization of the IGY project in 1957-1959 (Lebedev and Sologub 1960). The linguistic barrier, along with other reasons, limits access of world meteor science to the sources of meteor information of the former Soviet Union. The meteor heritage of the NIS is also not available to every modern researcher of meteors. Without the knowledge and the experience of meteor centers of the former USSR, the modern researchers of meteors sometimes have to 'invent a bicycle all over again'. This, of course, impoverishes modern meteor science and, perhaps, slows the pace of its development. In Fig. 12 the table displays the main supervision centers of meteor studies in the former USSR that participated in the international IGY program, and where the powerful meteor scientific schools were subsequently developed. These centers keep the meteor heritage of the twentieth century of the former Soviet Union.

5.2.1 Historical Note

The IGY program played an important role in the development of science, and the meteor science, inter alia. The IGY was the largest and most extensive international scientific program of the 20th century on the world-scale with 69 countries participanting, whose most significant result was the launch of the first artificial satellite of the Earth (Sputnik). The IGY has established the institutions for international scientific collaboration, which continues to play an important role in modern scientific cooperation. One such structure is the International Data Centers (IDC) that were created to store the obtained information. The first data centers were established in the USA (Boulder, IDC A), the Soviet Union (Moscow, IDCB), the UK (Slough) and Japan. The IDCs collected the observational reports from participants in all sections of geophysics, including meteor data (activity numbers, etc.). The preparations for the IGY started in 1950, but the meteor program was introduced only after 1954. The founders of the IGY Meteor Program were Prof. D. Link, Prof. V. Guth and Prof. B. Lovell. The IGY meteor studies were supervised by the 22 Commission of thr International Astronomical Union (IAU) with Prof. Guth in charge. At the same time, the Special Committee for the IGY was established in the USSR and Prof. V. V. Fedynskiy was appointed as the head of the Soviet meteor program adapted to local conditions.

The main objective of the IGY was the research of solar-terrestrial connections, with the emphasis on understanding the ionosphere and near-Earth space. Rocket technology and radar techniques were the cornerstones of the IGY. These areas are directly connected to the studies of meteors in the Earth's atmosphere and of meteoroids in the Solar System. Meteors as a research area were included in section V "Ionosphere" of the IGY program under the title "Ionosphere. Meteors". The main reason for the progress in IGY meteor studies was the implementation of the radar method. This is reflected in the table in Table 6.

Table 6. Participants of the IGY-1957 meteor program (section V Ionosphere. Meteors) in the USSR. Meteor observations: *R* radar, *Ph* photographic, *V* visual (Fedynskiy 1962).

№	City, number	*φ*	*λ*	*H* *m*	Scientific institute/Republic of the USSR/Head	Program IGY number
1	Ashkhabad (C126)	37° 56'	58° 24'	200	Astrophysical Laboratory of the Institute of Physics and Geophysics AS / Turkmen SSR / Sadykov, Ya.F., Astapovich, S.I.	R, Ph, V N696
2	Kazan	55° 47'	49° 07'	80	Astronomical observatory named Engelgart of the Kazan University / Tatarstan / Russian SFSR / Kostylyov, K.V.	R N233
3	*Kiev*	50° 27'	30° 30'	185	Astronomical observatory of the Kiev University named Shevchenko / Ukrain. SSR / Bogorodskikh, A.F.	R, Ph N320
4	*Odessa*	46° 29'	30° 46'	50	Astronomical observatory of the Odessa University / Ukrain. SSR / Tsesevich, V.P.	R, Ph, V N680
5	Stalinabad (Dushanbe) (C115)	38° 34'	68° 46'	820	Institute of Astrophysics AS Tajik SSR / Tajik SSR / Babadzhanov, P.B.	R, Ph, V N680
6	Tomsk	56° 29'	84° 59'	120	Tomsk Polytechnical Institute / Russian SFSR / Fialko, Ye.F.	R N224
7	*Kharkov* (B141)	50° 90'	36° 14'	140	Kharkov Polytechnical Institute / Faculty of Radioengineering / Ukrain. SSR / Kashcheyev, B.L.	R N358

All meteor centers of the Soviet Union that performed the IGY observation program had to carry out radar observations. In the former USSR a great importance has been given to the fulfillment of the IGY meteor program with allocation of public funds (the main initiative and the general management was performed by Prof. V.V. Fedynskiy). During the existence of the USSR, the research on meteors, both in specified centers (see Table 6) and some other establishments, has been actively sponsored at the highest level (as is a rule for large international projects). In the second half of the twentieth century, the experimental meteor radar-tracking supervisions, lead by Kharkov, were considered as one of the best in the world.

With the purpose of preservation and the development of meteoric knowledge in view of a meteor heritage of the former Soviet Union, it is necessary to establish a sponsored program for the accumulation of Soviet meteor study results of the NIS. The first implementation of such a program can be the establishment in Kharkov, Ukraine, of the first piloted center of preservation and development of meteor knowledge of the former Soviet Union on the basis of the KhNURE. KhNURE possesses access to the basic part of the meteor scientific heritage of the former USSR due to the fact that it is one of the oldest meteor radar centers of the former USSR.

Other countries also face problems in the preservation of the meteor scientific potential of the 20th century, especially for NIS. In the 20th century, the amount of data was so great that the researchers were unable to cope with its handling, especially since the existing computer facilities were inadequate. In the 21st century, new levels of information processing may allow processing of data from previous years with modern methods. This also applies to the meteor data that were preserved in WDCs (Boulder, USA; Moscow, Russia; Slow, UK, and Japan). Finding, extracting and translating meteor observation data of the past to modern media could fill up the Slovakia international meteor data centre. This also applies to the meteor data recorded in the sixties on 35-mm film everywhere in the world.

6 Conclusions

- This work was undertaken in the framework of international projects 2007-2009 International Heliophysical Year.
- Received in the KhNURE, distributions of parameters of a class of near-parabolic and hyperbolic meteoric orbits on the Kharkov data of radar-tracking supervision of 1972-1978 represent an empirical model of an observable sporadic complex of meteor orbits of this class.
- Separate attention is deserved with an observable complex of meteoric orbits of the small sizes (e.g. the Eccentrides, the Sungrazing group).
- The problem of near parabolic/hyperbolic orbits is not solved yet.
- There are facts supporting the reality of “hyperbolic meteors”. Scientists haven’t enough published uniform hyperbolic orbital data.
- There are difficulties in comparing the radar observation data obtained from 4 sites (Banks Peninsula, New Zealand; Tavistock, Canada; Kharkov, Ukraine; Arecibo, Puerto Rico).
- Today it is necessary to create the common unified radar catalogue, maybe, in the frame of the international program ISWI, maybe other ways, with collaboration of the Ukraine, the USA, New Zealand, Canada, Slovakia (IAU MDC), the Netherlands (Virtual meteor radar observatory), Japan, etc. in addition to the major advances in our understanding of the ecology of meteoroids within the Solar System and beyond it.
- There is dormant meteor data in the Meteor Centers of the IGY and WDCs.
- It is necessary to create international meteor centers of the NIS for preserving meteor heritage, outreach and to promote meteor research, for example, with a pilot center located in Kharkov.

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