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The "European Fireball Network": Current status and future prospects

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Abstract-Among the three large camera networks carrying out fireball observations through the seventies and eighties, the "European Fireball Network" is the last one still in operation. The network today consists of more than 34 all-sky and fish-eye cameras deployed with -100 km spacing and covering an area of -10^6 km^2, in the Czech and Slovak Republics, Germany, as well as parts of Belgium, Switzerland, and Austria. Network operation results in -10 000 image exposures per year, which represent on average 1200 h of clear sky observations-as imaging periods are restricted due to daylight, moonlight, and clouds. The cameras detect currently large meteors at a rate of -50 per year; this is in good agreement with the encounter rates determined in previous fireball studies. From sightings of "meteorite candidates" (fireballs that may have deposited meteorites) and meteorite recoveries in the network area, we estimate that 15% of the influx of meteoritic matter is currently observed by the cameras, whereas < 1% is recovered on the ground. Issues to be addressed by future fireball observations include the study of very large meteoroids (> 1000 kg) for which statistics are currently very poor and an examination of their relationship to NEOs (near-Earth objects) identified by current NEO search programs.

INTRODUCTION

Atmospheric entries of large meteoroids ("fireballs") are spectacular and rare celestial events. Their photographic recordings provide excellent means to examine physical properties, as well as the temporal and spatial distribution of extraterrestrial matter in near-Earth space. Naturally, there is a particular interest in those meteoroids that are suspected progenitors of meteorite falls. The photographic records can be used to determine the meteorite's preatmospheric orbit, which may bare important clues to the extraterrestrial origin of this sample. Furthermore, the data collected by the cameras can be used to determine the impact location of the meteorite and may result in the recovery of this extraterrestrial sample. Unfortunately, to obtain this type of photographic recordings, cameras covering very large target areas or long observation times are needed. With this goal in mind, three camera networks for fireball observations had been established in Europe (Ceplecha and Rajchl, 1965), the United States (McCrosky *et al.,* 1971) and Canada (Halliday *et al.,* 1978). Their data have provided a wealth of information on the population of large meteoroids. The efforts of the three networks were rewarded by the photographic recordings of entry trajectories and the successful recoveries of one meteorite each, Pribram (Ceplecha, 1961), Lost City (McCrosky *et al.,* 1971), and Innisfree (Halliday *et al.,* 1978).

What is the status of the fireball networks today? While the Canadian as well as the American network have shut down, the European Fireball Network (EN) is the only one that has remained in operation to monitor the meteoroid flux on a routine basis. This network has undergone changes in terms of geographical coverage, camera equipment, and management in the past years. In this paper, we therefore report on the current status of this last existing fireball network. In particular, we estimate the current areal and temporal coverage of the cameras, the expected detection rate of meteors and meteorite events, and compare this with the number of actual meteor sightings, large fireball events, meteorite candidates (fireballs that are believed to have supplied meteorites, for which a ground search, however, was not successful) and meteorite falls-and-finds in the network area (recoveries of meteorites whose atmospheric entries were not photographed). Finally, we discuss the role of camera networks in meteoritics today and raise science issues that could be addressed by future fireball observations.

HISTORY OF THE NETWORK

The first systematic photographic observations of meteors were performed on the present territory of the EN within the framework of the double-station small camera program (Ceplecha, 1957), which started at Ondrejov Observatory in 195 1. After the first eight years of operation of this program, a very bright fireball of -19 maximum absolute magnitude was photographed on 1959 April 7. Four meteorite fragments were found near Pribram in Czechoslovakia (now, the Czech Republic) at a location in agreement with predictions from the photographic data (Ceplecha, 1961). This first case of a recorded meteorite fall initiated a systematic observational program for photography of very bright meteors from multiple stations.

In 1963, a small network of cameras began regular monitoring of the night sky in former Czechoslovakia (Ceplecha and Rajchl, 1965). In 1968, this network was expanded to cover Germany, involving narrowly spaced camera stations located in the southern German states of Bavaria and Baden-Württemberg. Beginning in 1988, operation of the cameras in Germany was gradually transferred to amateur astronomers of the "Vereinigung der Sternfreunde, Fachgruppe Meteore." With the involvement of amateur astronomers, the network also expanded. Cameras were moved to more widely spaced new locations in northern Germany, Belgium, Switzerland, and Austria. Another areal expansion came with the reunification of East and West Germany in 1990. Today, the network comprises 12 camera stations in the Czech and Slovak Republics, and 22 camera stations in Germany, Belgium, Switzerland, and Austria (Fig. 1). In the following, these are briefly referred to as "Czech" and "German" cameras that were deployed in the "Czech" and the "German" section of the network, respectively.

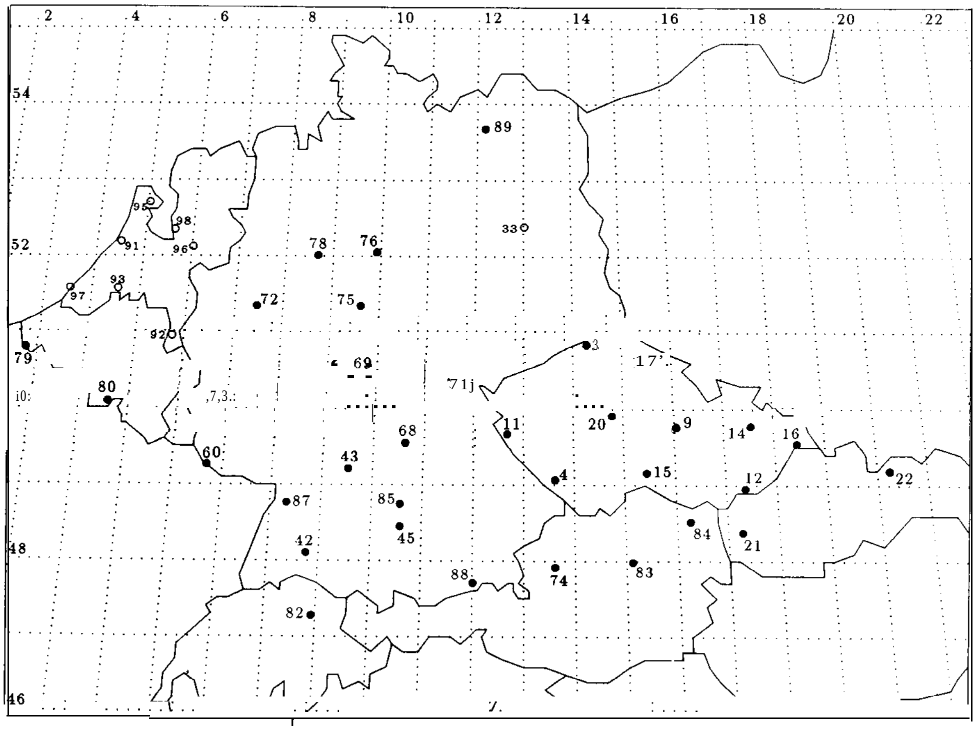


FIG. 1. Current coverage of the "European Fireball Network." The station tags correspond to station IDs listed in Table 1. Open circles designate associated observers currently not participating in regular EN operations.

CURRENT STATE

Cameras

The basic equipment of the 22 German network stations, regular 24 x 36 mm Leitz cameras with 50 mm Zeiss objectives, has not been modified since the beginning of operations. Imaging of the complete sky is achieved by obtaining photographs of an all-sky parabolic mirror of 36 cm in diameter (Fig. 2). In contrast, the Czech stations have been upgraded several times; the cameras today are equipped with Zeiss Distagon fish-eye lenses pointed to zenith. Fifteen such cameras at 12 different stations are in operation. Owing to this improved optical system and to larger film formats (9 x 12 cm), the data are geometrically more precise than those recorded by the all-sky mirror cameras. As a consequence, the fireball trajectories generally can be determined more accurately by a factor of 3-5. Also, the Czech fisheye cameras record more meteors, as their limiting magnitude is 2 or 3 magnitudes better.

German and Czech cameras operate with large exposure times. Timing information to open and close the aperture correctly is obtained from digital clocks. All cameras are equipped with rotating 12.5 Hz "shutters." Fast moving objects, thus, will result in interrupted trails on the film (Fig. 3, 4, right) from which the duration and the angular velocity of a meteor can be determined. If observations from several stations are available, the meteoroid's atmospheric trajectory can be determined. Knowledge of meteor event time is required in order to compute heliocentric orbits rather than geocentric trajectories alone. For the Czech camera stations, this is achieved by selected cameras being operated in the guided mode (Fig. 4, left). As the posi-

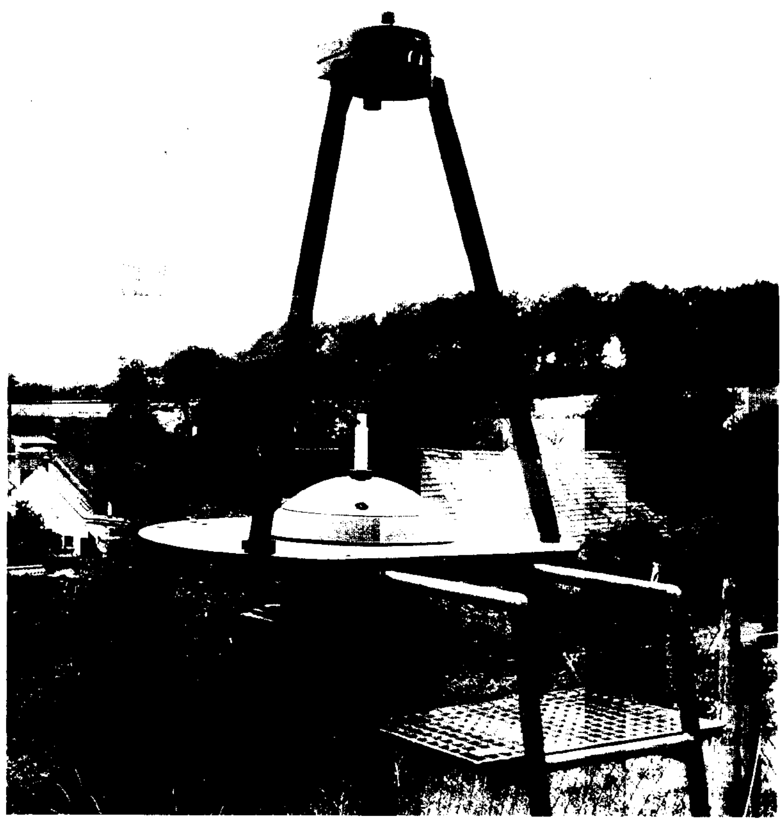
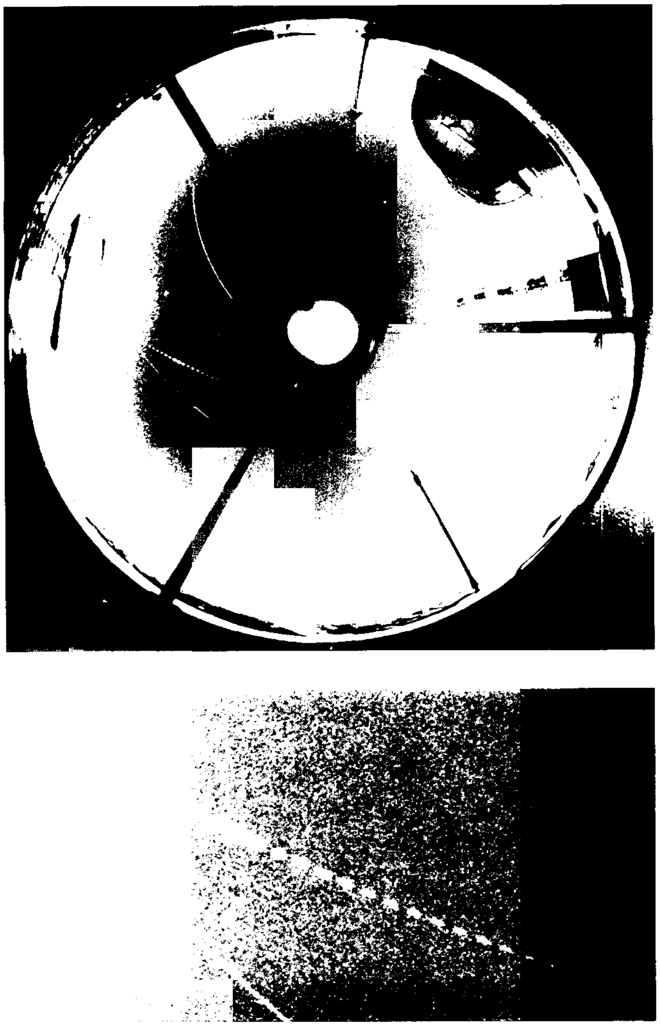


FIG. 2. Typical setup of the standard German all-sky camera showing the camera mounted on top of the 36 cm all-sky mirror



[illegible] all-sky photographic recording of the night sky from the Wendelstein observatory (station #88) showing the camera tripod, the horizon, stars, lunar stray light (right), and a fireball trail on the all-sky mirror. The fireball (interrupted by the rotating shutter) is shown in the magnified section of the image **at the bottom.** This magnitude M = -14 event was detected in the evening hours of 1995 November 9.

tions of stars in these images are fixed, they can be used to determine meteor radiants in equatorial coordinates. However, for the majority of the network, no information on the timing of meteors is available. This information must be obtained from "casual" observers of fireballs. Fortunately, the reporting of large and spectacular meteors is warranted through the high population density of Central Europe.

For more detailed studies of fireball properties, the standard fireball photography from the Czech part of the EN has been accompanied by six cameras for meteor spectroscopy placed at the Ondrejov Observatory from the very beginning of operation. Objectives (Tessar f/6.3 and f/3.5, f = 360 mm and 300 mm) with 3 Bausch & Lomb transparent objective gratings with 600 and 400 grooves/mm and 3 objective prisms have been used. Following a substantial modernization program, which was completed in 1996 March, all these cameras are now equipped with new objectives of identical type and identical new objective gratings of 600 grooves/mm. The analysis of such meteor spectra yields valuable information on compositional properties of the meteoroid, the ablation process and the atmosphere along the luminous trajectory (Borovicka, 1993, 1994; Borovicka and Spurny, 1996).

Temporal and Spatial Coverage

The network today covers the area of Germany, Austria, Switzerland, Belgium, and the Czech and Slovak Republics (Fig. 1, Table I) The cameras are deployed at -100 km spacing and cover a total area of $\sim 10^6$ km^2. There is one exposure of the sky each night from each of the German cameras regardless of weather. Hence, this area is continuously monitored during nighttime. In contrast, the apertures of Czech cameras are opened only when clear nights are expected. For the German and Czech section combined, this procedure results in -10 000 image exposures per year. Time information to open and close the aperture is computed individually for each camera depending on camera location, local time of sunrise and sunset, and lunar ephemeris. To prevent the overexposure of images, the exposure periods of the German cameras are cut short when the Moon is visible; whereas, the Czech stations operate in a special "Moon condition" imaging mode, characterized by multiple exposures and shorter exposure times. This observational schedule results in a total exposure time of 55 000 h for the German section of the network, which translates to 2500 h/year (6.8 h/day) for each of the 22 stations. However due to weather, clear sky observations are achieved for only 1100 h on average (3 h/day). The 12 camera stations in the Czech section achieve a mean clear sky coverage of 3.5 h/day. Hence, this efficiency is similar to that of the Canadian MORP (Halliday *et al.,* 1996) and the U.S. Prairie (McCrosky *et al.,* 1971) camera network. Sixty percent of the observational coverage is obtained during the winter season (October through March), because of longer nighttime viewing hours.

Operation

While camera operation in Germany, Austria, Switzerland and Belgium is coordinated by the DLR (German Aerospace Center) – Institute of Planetary Exploration, the operation of the Czech cameras (including the two cameras in the Slovak Republic) are coordinated by the Ondrejov Observatory. Camera imaging schedules are computed and mailed to the camera station representatives. The exposed films are returned to Ondrejov or to Berlin-Adlershof every month, processed, scanned for event-carrying images and archived. Currently, we maintain event records that include information on the day of the year and station ID of individual meteor observations, and the meteor's estimated magnitude. If large meteors are identified, images are sent to Ondrejov Observatory where they are geometrically and photometrically calibrated, and analyzed for fireball type, trajectory, and orbit. Due to lack of manpower and funding, the majority of the meteor recordings in the German section (>90%) cannot be subjected to this time-consuming procedure. In contrast, all large (>10 shutter breaks) fireballs recorded in the Czech section enjoy their full analysis. In the case of sightings of suspected meteorite candidates, films are returned for processing immediately to initiate a rapid ground search. While minor repairs are carried out by the camera station representatives themselves, all cameras are checked at least once a year. Recently, a pilot project has been carried out for digitization of fireball photographs and their semiautomated digital analysis (Molau, 1996). This efficient procedure, if applied on a regular basis, would greatly increase the availability of meteor orbit data from observations within the German part of the EN.

Occurrences of large meteor events are reported to the Fireball Data Center (FIDAC) of the International Meteor Organization (IMO) which gathers data on meteor sightings from worldwide observers.

Often, meteor fireball event times, crucial for fireball orbit determination, come from this source. Every year, summary reports on meteor data and their analysis are submitted to scientific journals (e.g., Ceplecha, 1977; Ceplecha et al., 1983, 1987; Spurny, 1994, 1995, 1997).

Associated Activities

In addition to the regular operation of the EN, a number of independent observers contribute to the fireball patrol of the EN in Central Europe. Members of the German amateur group "Arbeitskreis Meteore" (AKM) run cameras with fish-eye lenses and either 6 x 6 cm film or film sheets that result in images of 8 cm diameter. These are operated only under clear or partly cloudy skies but also in moonlit nights using shorter exposure times or less sensitive film. Unfortunately, only very few of these stations are active. The typical number of surveyed nights of any of these cameras is -180 per year. As observations are carried out in moonlit nights as well, the time covered by the station #33 in Potsdam, Germany (Fig. 1, Table l), for example, can be as high as 1200 h/year.

Seven 3.5 mm cameras have been operated by members of the amateur "Dutch Meteor Society" (DMS), the Netherlands (Fig. 1, Table l), since 1978. The stations use 7 mm or 16 mm fish-eye lenses and are automated to acquire 4 to 12 exposures per night. Some camera systems are equipped with overcast sensors that prevent the cameras from taking images when reflected light from cloud covers is detected. In addition, the Dutch meteor stations are equipped with photomultiplier systems to register fireball event times. The cameras are operated during most of the year except for the period around the full Moon. Due to climate conditions near the sea, however, there are only several tens of clear nights per year for simultaneous operation of all cameras. Double station events are analyzed by the DMS or together with photographs obtained from other EN stations (e.g., Rendtel and Heinlein, 1991). Operation of these stations adjacent to the far northwestern comer of the EN significantly extends the effective meteor target area covered by the EN and provides large convergence angles for the mapping of meteor trajectories, for example, over Germany.

Currently, efforts are being made to firmly integrate the observations of individual groups into the European Fireball Network operation. This requires the establishment of minimum standards regarding observational schedules and the consistent reporting of the fireballs.

METEOR DETECTION RATES

We wish to compare our currently observed rate of meteor encounters with flux data from independent sources with the goal to verify our estimates of detector area and the meteor detection efficiency. Such an independent estimate of the flux was obtained by Ceplecha (1992) using EN fireball data collected during earlier years of network operation.

Comparison with Overall Meteoroid Flux Data

On average, the network currently detects meteors having magnitudes brighter than m = -6 at a rate of well over 50 per year (Fig. 5), more than 50% of which are normally observed by two stations or more. The individual meteor detection rate of a camera strongly varies with the annual season, weather, and with station location. The Wendelstein camera (#88), for example, recorded eight bright meteors in 1996 January alone. This remote high-elevation (1838 m) station was commissioned in 1995 and often has excellent clear-sky viewing conditions. Furthermore, during the peak of a major meteor shower, such as the Perseids, Taurids, and Geminids, the rate of fireballs may increase by a factor of 10 over the average.

We computed the theoretical detection rate of meteors in terms of their brightness based on previous studies of fireballs (McCrosky, 1968) taking into account today's coverage of the network (10^6 km^2 and 3 h/day) and compared this with the observed number and magnitudes of fireballs. There is a general agreement between these num-

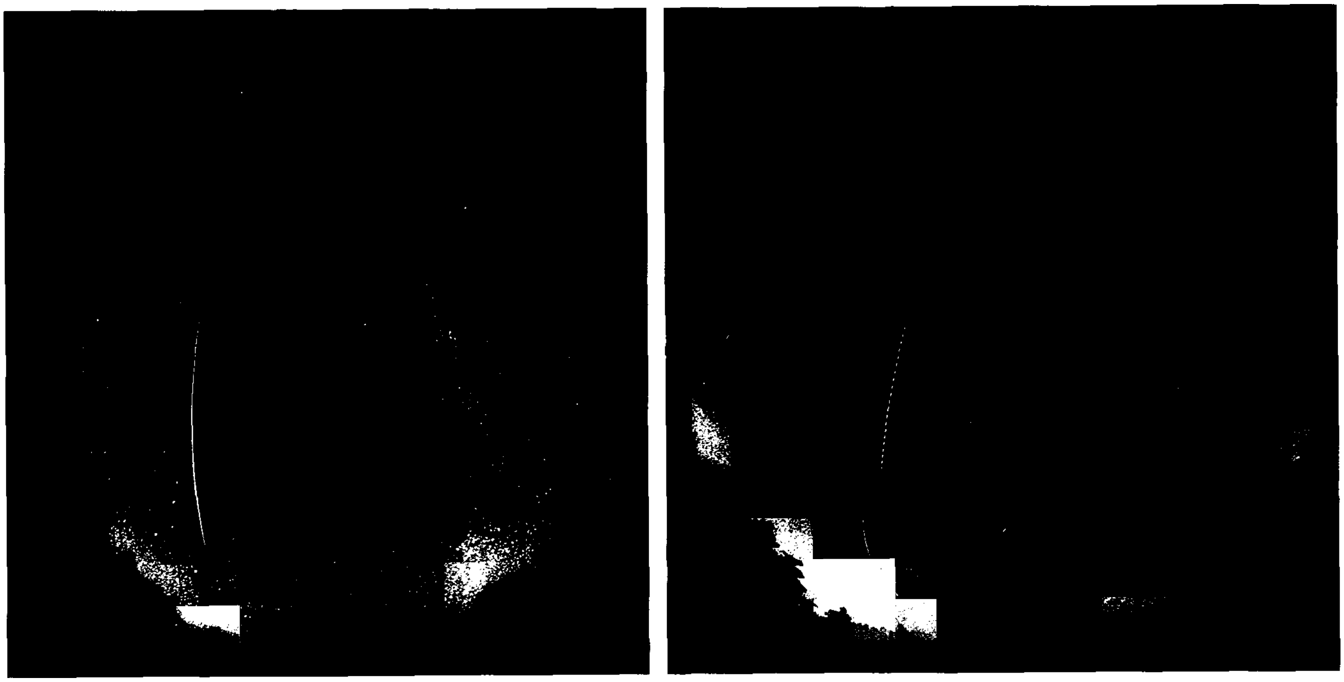


FIG. 4. Typical fixed fish-eye image with star trails and the 105" long path of the EN 220679 Melnik fireball (right) and corresponding guided fish-eye picture (left). Both records were taken at station #20 Ondrejov on 1979 June 6. The limiting magnitude for the stars is +5 (for the star trail image) and +10 (for the guided image). The maximum absolute magnitude of the fireball is -12.7.

TABLE 1. Locations of current European Fireball Network cameras and associated observers

EN#	Location	Longitude	Latitude	Elevation (m)	EN#	Location	Lonaitude	Latitude	Elevation (m)
3	Ruzova	14°17'17.9" E	50°50'05.7"	N 347	74	Gahberg	13"36'30.8" E	47"54'47.6" N	865
4	Churanov	13°37'00.5" E	49°04'08.5"	N 1119	75	Benterode	09"37'03.6" E	5 1'20'47.6" N	280
9	Svratouch	16°02'09.1" E	49°44'08.1"	N 744	76	Sibbesse	09Y4'39.0" E	52"03'13.0" N	196
11	Primda	12°40'47.2" E	49°40'10.9"	N 744	78	Leopoldshdhe	08"40'27.0" E	S2"OO'SO.O" N	106
12	Veseli nad Moravou	17°22'17.0" E	48°57'15.9"	N 173	79	Westouter	02°46'11.8" E	SO"47'18.7" N	98
14	Cervena hora	17°32'37.5" E	49°46'39.5"	N 750	80	Dourbes	04"35'01.4" E	SO"OS'29.4" N	195
15	Kostelni Myslova	15°26'25.4" E		N 577	82	Wald	08"55'19.1" E	47"16'33.0" N	669
16	Lysa Hora	18°26'58.6" E	49°32'47.0"	N 1323	83	Scheibbs	! S"O7'16.0" E	47"58'55.0" N	79s
17	Pet pod Snezkou	15°43'51.7" E	50°41'31.9"	N 810	84	Herzogbirbaum	16"15'23.0" E	48"3 1'00.0" N	270
20	Ondrejov	14°46'58.7" E	49°54'35.8"	N 529	85	Tuifstadt	lO"33'47.0" E	48"44'48.0" N	500
21	Modra	17°16'34.0" E	48°22'34.0"	N 533	87	Gernsbach	08"19'44.5" E	48"46'02.6" N	210
22	Skalnate Pleso	20°14'42.0" E	49°11'20.0"	N 1787	88	Wendelstein	12"00'49.4" E	47"42'15.8" N	1838
42	Klippeneck	08°45'23.0" E	48°06'24.0"	N 973	89	Reimershagen	12"10'41 .0" E	53"40'23.2" N	60
43	Ohringen	09°31'09.0" E	49°12'28.0"	N 280	33*	Potsdam	13"00'36.0" E	52"23'14.0" N	39
4s	Violau	10°34'28.5" E	48°27'13.5"	N 495	91*	Leiden	04"30'01 .0" E	52"11'02.0" N	0
60	Berus	06°41'24.5" E	49°15'54.0"	N 365	92*	Elsloo	05"46'02.0" E	SO"56'45.0" N	73
68	Losaurach	10°37'38.4" E	49°31'51.9"	N 382	93*	Bosschenhoofd	04"32'32.6" E	Sl"34'14.2"N	4
69	Magdlos	09°30'15.0" E	50°25'59.2"	N 420	95*	Benningbroek	OS"O1'30.9" E	52"42'08.1" N	0
71	Hof	11°54'57.0" E	50°18'07.8"	N 524	96*	Loenen	06"01'27.4" E	52"07'17.6" N	20
72	Hagen	07°27'26.0" E	51°20'49.5"	N 290	97*	Oostkapelle	03"32'16.0" E	Sl"34'21.7"N	0
73	Daun	06°50'55.0" E	50°09'48.6"	N 549	98*	Harderwijk	OS"36'5 1.2" E	52"20'3 I.0" N	IO

*Selected associated observers.

bers, which indicates that our estimated temporal and spatial network coverage is correct. The offset during the earlier years of network operation is explained by the fact that the network coverage at that time was smaller than today. The large number of meteor detections in 1991 and 1993 (Fig. 5) is due to enhanced fireball rates during the prominent displays of the Geminid and Perseid showers in these years, respectively.

Meteorite Events

Based on our estimates of detection area and efficiency, we wish to evaluate the number of meteorite candidates and to predict the likelihood for photographic recording and the subsequent recovery of a meteorite. Table 2 shows the meteorite candidates that were recorded by the cameras since the beginning of network operation (*i.e.,* over the past four decades). These constitute meteors that were suspected to have deposited significant meteoritic mass on the ground, based on their observed rate of deceleration, atmospheric penetration depth, and estimates of their residual mass (Ceplecha and McCrosky, 1976; Wetherill and ReVelle, 1981 ; Halliday et al., 1989). Although most of these events initiated extensive ground searches, only one meteorite, Pribram, was recovered. Following the identification of the most recent meteorite candidate, Jindrichuv Hradec, a thorough-search was carried out over an estimated target area of 1 km^2 for about a week involving a crew of five. Conditions for a recovery seemed favorable, as the largest part of the area was within a housing district, but the meteorite was not found.

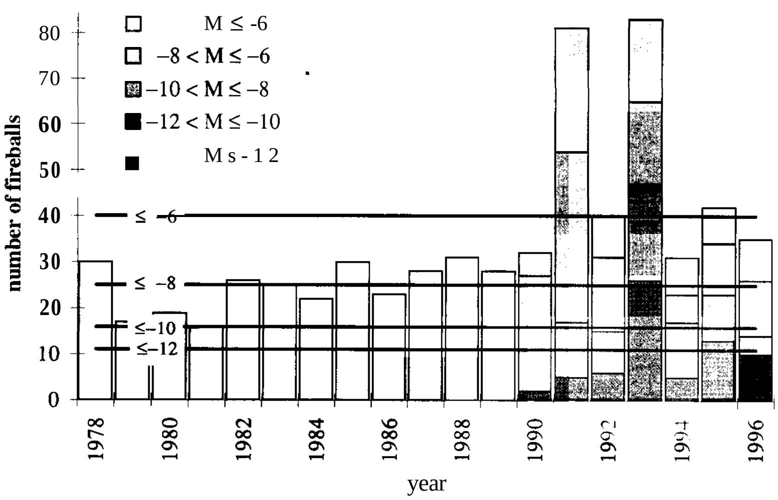


FIG. 5. Total number of fireball sightings within the German section of the network area; for meteor observations after 1990, numbers for given magnitude classes are shown. This is compared with the expected rate of meteors (marked by horizontal lines) (McCrosky, 1968) considering network area and temporal coverage. The peaks in 1991 and 1993 are due to enhanced fireball rates during the prominent meteor showers.

Likewise, we gathered all data on meteorite falls and finds in the network area for this corresponding period (Table 3). These represent meteorites that were witnessed to fall and that were subsequently recovered but, except Pribram and Salzwedel, not photographically recorded. The most recent meteorite fall occurred on 1990 April 7 at Glanerbrug near the Dutch-German border, about one hour before routine camera operation began. An approximate orbit was computed from 200 visual observations (Jenniskens et al., 1992a,b). The Salzwedel meteorite was photographed by only one of the German camera stations; a full analysis of the meteorite's trajectory and orbit was therefore not possible. Circumstances of meteorite recoveries and the lack of success during meteorite ground searches indicate that the recoverability of a meteorite, photographed or not, greatly depends on terrain type, local vegetation, population density, and the availability of eyewitnesses near the meteorite's impact location.

The cumulative mass distribution of the "meteorite candidates" and recovered meteorites is compared with the flux predicted from analysis of MORP data (Halliday and Griffin, 1982; Halliday et al., 1984) (Fig. 6). These data indicate that ~ 15% of the meteorite encounters taking place

TABLE 2. Presumed meteorite dropper fireballs photographed in the European Fireball Network area since 1959.

Date	Time (UT)		Name	Terminal Mass (computed) (kg)	Impact Point (computed) Longitude	Latitude
07.04.1959	19h30m s	±1s	Pribramt	50.0	l4"l l' E*	49"40'N*
15.10.1968	19h53m30s	± 30s	Cechticet	0.15	15"03' E	49"37' N
10.04.1969	2 h 44.5 m	f1.5 m	Otterskirchent	5.0	13"20' E	48"39' N
24.11.1970	01 h47m	± 1.0m	Mt. Riffler	0.9	lO"2l'E	47"OS'N
30.08.1974	01 h25 m	±5m	Leutkircht	9.6	09"54' E	47"5 l' N
02.05.1976	I9 h I2 m 00s	±20 s	Kamykt	0.07	14"19' E	49"39' N
01.06.1977	21 h46m	±2m	Freising	0.7	I I"39 E	48"28' N
12.06.1977	23 h 03 m	± 2m	The Alps	30.0	06"29' E	46"06' N
27.05.1979	20 h 38 m 50 s	±50 s	Zvolent	1.2	19"OS' E	48"34' N
09.10.1983	18 h 55 m 21 s	±43 s	Zdart	1.5	15"55'E	49"36'N
04.12.1983	17h09m48s	±5s	Neuberg I	4.0	15"32' E	47"43' N
03.08.1984	21 h05m53s	±12s	Valect	16.0	16"43' E	49"09' N
13.08.1985	23 h 32 m 00 s	±5 s	Valmezz	2.1	17"56' E	49"25' N
04.10.1987	02h57m	±1 m	Janovt	75.0	17"28' E	50'15'N
24.12.1987	02h25m23s	±56s	Freiberg	10.0	13"27' E	50"52' N
14.05.1988	23h15m50s	±5s	Brdy	1.0	14"06' E	49"47' N
07.05.1991	23 h 03 m 53 s	±3 s	Benesovt	3.0	14"37' E	49"47' N
22.09.1991	16h48m	±30 s	DobrisI,s	-100.0	14"15' E	49"43' N
09.05.1992	04h06mOOs	±30s	Neuberg III	10.0	15"36' E	47'39' N
22.02.1993	22hl2m45s	±2s	Meuse	2.7	04"48' E	49"25' N
07.08.1993	2 h 08 m15s	±15 s	Polna	0.2	15"55' E	49"32' N
25.10.1995	02 h 25 m53s	±1 s	Tizsa	2.6	20"47' E	47"48' N
23.11.1995	01 h29m	±1 m	Jindrichuv Hradecz	2.0	15"02' E	49"08' N

* Coordinates of the greatest found meteorite fragment "Luhy"; 5.6 kg recovered.
TSystematic ground search activities in the predicted impact area, typically involving a crew of IO searching an area of I square km within three weeks.
IOnly nonsystematic attempt to recover the meteorite: people in the area were informed by radio, local newspapers and-postings.
GDaylight fireball, all data from -200 visual observations.

in the network area are photographically recorded. This is in agreement with our estimates that the fireball network enjoys clear and dark sky conditions of only 3 h/day, on average. Furthermore, the data (Fig. 6) show that 1% or less of all meteoritical material deposited on the ground in the considered mass range is actually recovered. From this, we make a conservative estimate that the probability of capturing photographic records of a meteorite fall ***and*** recovering the meteorite of a given event is 0.0015 *(i.e.,* a meteorite of mass 100 g or 1 kg, given the flux rate from MORP data, would be recorded *and* recovered in the European Fireball Network area within 20, or 100 years, respectively). This, of course, does not take into account the possibility that the fireball observations actually make the recovery of the meteorite feasible. However, the circumstances of the Pribram fall, for example, suggest that some of the meteorite fragments would have been recovered, even if camera observations had not been available. Eyewitnesses were in the neighborhood of the impact point to immediately recover the sample.

VERY LARGE FIREBALLS

In the long history of the network, the cameras have recorded a number of spectacular fireballs. We briefly discuss the largest of these (Table 4). From our fireball records (e.g., Ceplecha, 1977; Ceplecha *et al.*, 1983, 1987; Spurny, 1994), we selected meteors that either had preatmospheric masses > 1000 kg or brightness >M = -15. Thus, 13 events met these criteria, among them the brightest fireball ever recorded by photographic means, EN 041274 Sumava, which had an initial mass of -3000 kg and an absolute brightness of M = -21 (Borovicka and Spurny, 1996).

These objects are of scientific interest for a number of reasons. First, they do not represent routinely photographed occurrences but extremely rare events, about which limited photographic data and, thus, poor statistics are available. While six or less of them appear to be asteroidal (type I), the rest appear to be of the more fragile types II and IIIb according to a classification by Ceplecha (1988, 1992). Only seven of them represent meteorite candidates from Table 2. Thus, it appears that about half of all large meteoroids include objects that are not represented in our meteorite collections and about which, therefore, little is known.

With densities ranging from 0.1-3.0 g/cm^3, the sizes of these objects in space, assumed to be spheres, can be estimated to range from 0.1-5 m. Hence, some of these objects would be well within the size range of objects observed by the spacewatch NEO (near-Earth object) search program (Rabinowitz, 1993; Rabinowitz et *al.*, 1994). These objects therefore are an important link to comparative studies of meteoroids using complementary observational means.

DISCUSSION AND FUTURE PROSPECTS

The successful operation of the fireball networks in the past decades has resulted in a wealth of information on the population of meteoroids in near-Earth space. However, following these early studies, the field of meteoroid sciences has evolved considerably. Previously, fireball networks provided the only means of observing large meteoroids. A large gap in mass range existed between "meteoroids" observed by fireball cameras and "asteroids" studied by telescopes. Today, owing to advances in NEO search strategies and techniques, this gap has effectively vanished. Also, alternative methods for observations of these objects now exist. Satellite infrared sensors detect large meteoroid explosions in the atmosphere anywhere on Earth (Tagliaferri et *al.*, 1994). Lunar crater statistics (Neukum, 1983; Neukum and Ivanov, 1994) and seismic recordings of large lunar impacts (Oberst and Nakamura 1989, 1991) provide further means to study today's overall meteoroid flux and its temporal variations.

What is the role of the fireball network today? Still, observations by a network of cameras is the only way of detecting atmospheric entries of meteorites and to possibly recover them after impact. This was indeed the primary goal of fireball networks when they were put into commission. However, considering the disappointingly low me-

TABLE 3. Meteorite falls in the European Fireball Network area since 1959.

Date	Time (UT)	Location	Longitude	Latitude	Mass (kg)
07.04.1959	I9 h 30 m	Pribram*	14"02' E	49"40' N	5.6
26.04.1962	11 h 45 m	Kiel	1 0"09' E	54"24' N	0.738
12.06.1963	12 h 58 m	Usti nad Orlici	16"23' E	49"59' N	1.26
16.09.1969	07 h I5 m	PolicenadMetuji	16"Ol'E	50"3l'N	0.84
14.11.1985	I8 h I7 m	Salzwedelt	I l"l2' E	52O48'N	0.043
01.03.1988	I2 h 30 m	Trebbin	13"lO' E	53"13'N	I .25
07.04.1990	I8 h 33 m	Glanerbrug	06"57'E	52"13'N	0.855

*First photographed meteorite fall in the history of meteoritic research.
TPhotographed by one German EN-station.

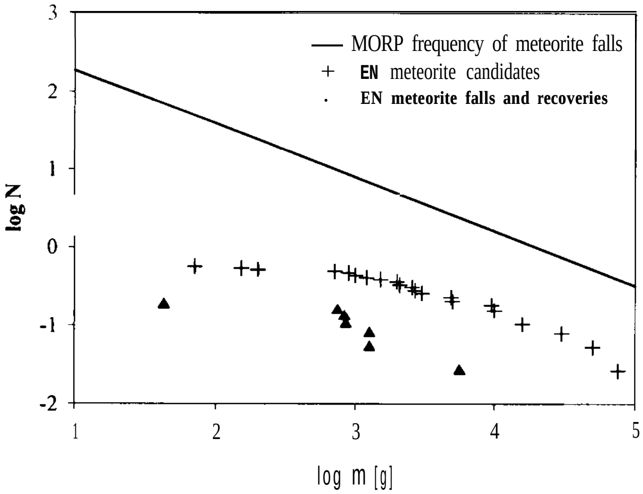


FIG. 6. Theoretical encounter rate of meteorites determined from MORP data (Halliday et al., 1984) scaled to 106 km2 and an observational period of one year. This is compared to the detection rate of "meteorite candidates" and witnessed meteorite falls in the European Fireball Network area over the past 38 years. The left axis refers to residual meteoroid mass for "meteorite candidates" and meteoritic mass recovered on the ground.

teorite recovery rate, more emphasis was then placed on the study of physical properties of "meteorite candidates" based on their interaction with the atmosphere (Wetherill and ReVelle, 1981; Halliday et al., 1996). Although meteoritic samples are not available for laboratory studies, information on their precise orbits and properties constitute important data for our understanding of the origin of meteorites. Clearly, more observations are needed to obtain statistically reliable data on these "candidates" to resolve open issues, such as the relative abundance of meteorites and orbital classes, possible clustering of meteorite falls (Halliday, 1987; Halliday et al., 1990), and the association of meteorite orbits with those of NEOs (Halliday et al., 1990; Drummond, 1982).

The population of meteoroids, regardless of whether they deliver meteorites or not, certainly deserves further studies. It is apparent that the objects comprise a wide range of physical and orbital properties (Table 4) and include fragile objects that do not survive their atmospheric descent and are therefore not available for laboratory studies. Clearly, more data are needed, as., due to their scarcity, statistics on these objects are very poor. For example, the observed variation of the orbital distribution of meteroids with meteoroid type and meteoroid masses needs to be addressed further, as this may reveal important information on the origin and evolution of the meteoroid population. While this type of study has been carried out for smaller-mass meteors (Ceplecha, 1988; Halliday et al., 1996), no such study has been done involving the scarce very large meteoroids.

For a more meaningful analysis, it is suggested that different observational data sets, spacewatch, fireball, crater, and lunar seismic data, should be combined. Although spacewatch camera observations provide information on surface spectral and orbital properties of these objects, the meteoroids' atmospheric entries are the only way to determine their masses, densities, and strengths-not to mention that meteorite candidates among them could possibly be recovered on the ground. Unfortunately, no such combined analyses have ever been done. Fireball, spacewatch, satellite, and lunar seismic data appear to be strongly biased in terms of temporal/spatial coverage and detection efficiency for certain meteoroid or asteroid types (e.g., Oberst, 1989; Oberst and Nakamura, 1989; Halliday et al., 1996). The proposed synthesis might help in the identification of such observational bias.

While two of the former three large fireball networks have shut down, the European Fireball Network is still in full operation. The continuing work of the cameras demonstrates that with the involvement of amateur astronomers, in the German section of the network, operation can be maintained and important scientific data can be obtained at relatively low costs. In addition to scientific merits of fireball observations, the involvement of amateurs has great potential to create public interest in meteor research and planetary sciences.

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TABLE 4. Large fireballs observed in the Eurooean Fireball Network area.

Event ID	Date	Name	M pan (mag)	Preatm. Mass (kg)	Fireball Type	Meteorite Candidate	a(AU)	e	i (°)
19241	07.04.1959	Pribram	-19.2	21500	I	yes/found	2.401	0.671	10.48
EN 151068	15.10.1968	Cechtice	-5.5	1600	II	no	1.713	0.419	25.72
EN 100469	10.04.1969	Otterskirchen	-15.4	5000	II	no	2.32	0.598	6.77
EN 241170	24.11.1970	Mt. Riffler	-15.1	3000	I	yes	1.199	0.252	31.0
EN 170171	17.01.1971	Würzburg	-17	3200	IIIb/II	no	2.35	0.594	2.71
EN 041274	04.12.1974	Sumava	-21.5	3000	IIIb	no	1.98	0.76	2.3
EN 010677	01.06.1977	Freising	-16.9	5200	II	yes	1.82	0.750	1.5
EN 140977A	14.09.1977	Bmo	-16.2	1500	II	no	2.277	0.835	2.42
EN 070591	07.05.1991	Benesov	-19.5	13000	I or II	yes	2.427	0.619	23.70
EN 220293	22.02.1993	Meuse	-17.3	3000	I	yes	1.50	0.567	32.6
EN 221095	22.10.1995	Visla	-7.1	900	IIIb	no	2.39	0.908	7.3
EN 251095A	25.10.1995	Tisza	-16.1	890	I	yes	1.077	0.807	6.2
EN 231195	23.11.1995	Hradec	-16.9	3600	I	yes	13.39	0.779	11.99

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