COMMISSION 22: METEORS AND INTERPLANETARY DUST (METEORES ET LA POUSSIERE INTERPLANETAIRE)

PRESIDENT: C.S.L. Keay
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ORGANISING COMMITTEE: P.B. Babadzhanov, W.J. Baggaley, O.I. Belkovich, Z. Ceplecha, E. Gruen, I. Hasegawa, J. Jones, C. Koeberl, D. ReVelle, I.P. Williams.

I. INTRODUCTION

As usual, a number of members of the Commission have contributed reviews of their own field. These have been edited in order to reduce overlaps and keep the whole report within the size limitation. Reference numbers from "Astronomy and Astrophysics Abstracts" have been used when available, and those references not (or not yet) included in the "Abstracts" have been gathered into a list at the end of the report. As editor, the President takes responsibility for any shortcomings in the report.

The following Proceedings of major meetings and significant books were published during the last triennium:

"Evolution of Small Bodies of the Solar System", Proc. of the International School of Physics "Enrico Fermi" Course 98, held at Varenna (Italy), 5-10 August 1985. Eds: M. Fulchignoni, L. Kresak, North Holland Publ., Amsterdam 1987 (44.012.041).

"Bibliographic Catalog of Meteors", P. Roggemans, 1987.

"Meteors, Meteorites, Meteoroids", V.A. Bronshten, Academy of Science of the USSR, Moscow 1987.

"Meteorites and the Early Solar System", eds. J.F. Kerridge, M.S. Matthews, University of Arizona Press, Tucson AZ, 1988.

"Meteors and a Meteoric Substance", Yu.I. Voloshchuk, B.L. Kashcheev, V.G. Kruchinenko, Academy of Science of the Ukraine SSR, Kiev 1989.

"Asteroids, Comets, Meteors III", Proc. of a Meeting held at Uppsala (Sweden), 12-16 June 1989. Eds: C.-I. Lagerkvist, H. Rickman, B.A. Lindblad, M. Lindgren, 1990 (49.012.064).

It is with deep sorrow that we record the deaths of the following members of Commission 22: E.L. Fireman, R.H. Giese, B.J. Levin.

II. PHOTOGRAPHIC AND TV METEORS Z. Ceplecha

The European Photographic Fireball Network (EN) continued in systematic operation at 52 stations in Czechoslovakia (Z. Ceplecha, V. Porubcan), Germany (H. Fechtig, D. Heinlein), and the Netherlands (H. Betlem); it yielded precise data on 124 fireballs from Jan 1988 to May 1990. Preliminary computations by Ceplecha and Spurny of the 11 most significant fireballs were published regularly in SEAN (and GVN) Bulletin (Smithsonian Institution, Washington); 3 meteorite falls were recognized and their probable impact area predicted: no meteorites were recovered so far. The German part of the Network changed positions of many stations and is now closely linked to the amateur organization, "Vereinigung der Sternfreunde (VdS)", but the Max-Planck-Institut fuer Kernphysik, Heidelberg, subsidizes the necessary funds to keep the project running. An independent part of the photographic fireball network in Europe is operated by J. Rendtel in East Germany. The amateur efforts in Australia with two fish-eye

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cameras yielded limited results (no time-marks) on the exceptionally bright and electrophonic fireball of Apr 30, 1989 (R. McNaught).

The Prairie Network and the Canadian Camera Network (MORP) have collected immense and valuable observational material on fireballs in the past. This material is still used and new data and results produced. Halliday, Blackwell and Griffin published detailed data on each of all predicted meteorite falls, which may have happened during the activity of the Canadian Camera Network (MORP) from 1971 to 1985 (49.105.040).

Wetherill (Carnegie Institution, Washington) initiated studies of photographic Geminid fireballs. Halliday (46.104.052) published data on 12 Geminid fireballs from the Canadian MORP Network. He found the average bulk density of Geminid meteoroids to be 1.0 $g.cm^{-3}$ and average ablation coefficient to be 0.008 s^2km^{-2}, (but he warned against using ablation coefficients determined deep in the atmosphere for smaller velocities). Geminid fireballs do not penetrate the atmosphere as deeply as meteorite-dropping fireballs. According to Halliday, Geminid meteoroids have too low a density to be associated with meteorites or normal asteroids.

R. E. McCrosky and C.-Y. Shao measured and computed data on 130 Geminid fireballs photographed during the activity of the Prairie Network (Smithsonian Astrophysical Observatory, Cambridge, U.S.A.). Ceplecha and McCrosky computed ablation coefficients of them using only dynamical data and a new theoretical approach relating the distance along the trajectory to time; the most probable value of ablation coefficient for Geminids confirmed that of Halliday, q.v. All higher values in these computations were recognized as being caused by fragmentation. Models of ablation taking into account gross fragmentation at several points are now under consideration: the first results point to bigger dynamic masses when compared to computations without gross fragmentation effects; bulk densities are also bigger, if compared to values obtained from simple models.

A new photographic fireball network may soon start a systematic program in Tadjikistan in the U.S.S.R. (P.B. Babadzhanov). Fish-eye cameras, f = 30 mm, with focal-plane rotating shutter will be used, in analogy to the European Network fish-eye cameras.

The amateur organizations in Europe and in Japan are quite active in photographing meteors. Betlem and deLignie (49.104.062) published data on trajectories and orbits of 70 meteors photographed in the Netherlands within a multistation program of Dutch Meteor Society. Orbits and trajectories of more than 300 meteors photographed by small cameras in Japan from 1964 to 1989 were published by Koseki (49.013.095). Amateur activities in photographing meteors no longer consist of only taking pictures, but now, thanks to PCs, several groups have the full capacity to measure meteor trails and to compute the trajectories and orbits of meteors.

Reduction methods for computing fireball trajectories from fish-eye camera records were supplemented by a new successful approach of straight combining of directions to the trajectory instead intersecting planes (Borovicka, 1990). Pecina (Ondrejov Observatory) has prepared a new procedure for computing fireball trajectory from multistation photographic records and takes into account the combined gravity-ablation curvature of the trajectory. Spurny (Ondrejov Observatory) has presented a new method of computing azimuths from fish-eye camera records (10th European Regional Meeting of the IAU, Proc. Vol. 2, 225). Pecina published an approximate analytical solution of computing theoretical distances along meteor trajectory as function of time with gravity term included in the drag equation. This method was successfully applied to several significant

EN fireballs with the result that the orbit differs by several standard deviations, if compared to classical computations of zenith attraction and only in case of the biggest fireballs on photographic records now (49.104.069).

Lindblad has published a new version of the catalogue of photographic and radar meteor orbits on magnetic tape (Lund University Observatory, IAU: Meteor Data Base: Center A). Detailed data (measurement for each time-mark) on many photographic meteors and fireballs from different observational projects are available at Meteor Data Base Center B (Ondrejov Observatory, Czechoslovakia).

Ceplecha (46.104.039) published values of the Earth's influx of different populations of sporadic meteors based on photographic and TV double- and multi-station data on 3624 sporadic meteors in the mass range of from $2x10^{-5}$ grams to $2x10^{7}$ grams: the total influx of all meteoroid populations in this mass interval of 12 orders resulted in $5x10^{9}$ grams per year for the entire Earth's surface. Most of this mass comes in the form of larger meteoroids. The paper contains also an updated survey of all meteoroid populations revealed so far.

III. RADAR METEORS

D.I.Olsson-Steel

This review describes research work on radar meteors published over the last triennium; radar observations of specific meteor showers are not reported here, but are reviewed in the next section. As has been the case for the past decade or two, much of this work has been carried out in the Soviet Union and Czechoslovakia, as described in the next two paragraphs, but it is notable that a re-awakening of interest has now occurred in the West, as will be seen from specific items which follow.

Investigations of various problems associated with radar observations of meteors have been carried out by Voloshchuk and Milyutchenko (43.104.062), Andrianov and co-workers (44.104.040, 46.104.042, Andrianov and Vasilchenko, 1988), Gajdaev (44.104.085), Kostromin (49.104.100) and Onofriev (1988), while Belkovich has reviewed the results obtained by the Kazan group (49.013.087). After a gap of some years, a meteor radar has again been operated in the Antarctic, this time at a Soviet base (49.104.038).

In Czechoslovakia, Pecina has investigated various radar phenomena including the effect of meteoroid deceleration in the atmosphere upon the determination of velocities and radiants (46.104.031, 038; Pecina, 1989), whilst Simek has discussed the determination of the mass distribution from underdense train observations (46.104.030) and has also used data from Perseid observations carried out since 1958 to derive information on the response function of the Ondrejov radar (43.104.002).

Joint Czechoslovak-Italian radar work has continued, with Hajduk and Cevolani investigating the relationship between meteor scatter and the physical properties of meteoroids (49.104.065). Cevolani (1988) has also studied the use of radar observations of long enduring meteor trains in determining turbulent wind parameters at 70-120 km altitudes.

In Australia Olsson-Steel and Elford have used data collected at 2, 6 and 54 MHz to show that VHF radars detect only a few percent, the lower altitude component, of the terrestrial influx of microgram-milligram meteoroids (43.104.048, 064; 46.104.029, 060), and Thomas et al (1988) have used their height distributions in conjunction with data collected with the Jindalee radar - which may be the most powerful detector of meteors ever used - to show that the total mass influx to the Earth for meteoroids of masses to one tonne

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is about 16,000 tonnes per year; other papers describing this work are Thomas (1989) and Elford et al (1989).

Near Christchurch, New Zealand, a 26 MHz narrow beam (approx. 1 deg) orbit radar has been operating since 1989 with routine recordings at 15-day intervals measuring heliocentric orbits for meteors to limiting magnitude +12. Velocity determination is achieved by both multiple echo timing from spaced stations and also by diffraction profiles. A dedicated PC having full graphics with back-up by VAX mainframe processing permits presentation of elements and parameters for 2000 orbits per day (40.036.144; 45.104.025). Current emphasis is on (i) orbital distribution of southern latitude dust; (ii) proportion of non-closed orbits; (iii) associations with apollo-type asteroids or outgassed comets.

A new radar allowing radiant mapping of the whole sky has been developed in South Africa by Poole and co-workers, and first results presented (49.104.003); other radar meteor work is also being carried out in that country (Melville et al, 1989).

Meteor Burst Communications have been revived over the past few years due to both military and civil interest, the latter being partially due to congestion of communications frequency bands (43.002.118; Scofido et al, 1988).

Pleasingly there has been a considerable increase in serious amateur work on radio meteors, largely in Europe, this having been aided by the formation of the International Meteor Organization; reports and guides have been published by the IMO and also in Great Britain (44.104.005, 011; 46.104.011; 49.104.023, 025, 026; 49.009.035; 49.036.128, 208; MacKenzie, 1988; White, 1989).

After remaining an enigma for several decades, a new attempt has been made to explain the head echo phenomenon by Jones and co-workers in Canada (45.104.040) (see section VI), whilst in Australia new observations of head echoes have been made by Thomas and Netherway (1989).

A new technique for monitoring meteors which may be mentioned here, and which apparently works on the basis of the change in electric potential at the ground produced by a meteor train "shorting" the ionosphere, has been described by Hopwood (1989) and Hopwood and Beech (1990); a simple electrometer is sufficient to detect this potential change so that the occurrence of meteors may be logged with a minimum of equipment. If proven to be viable this would be a cheap and easy method for monitoring the meteoric influx.

IV. METEOR SHOWERS

J. Stohl and V. Porubcan

General studies of the formation of meteor streams and their evolution under planetary perturbations have been presented by Andreev (43.104.028; 44.104.021, 038; 49.104.101), Babadzhanov and Obrubov (46.104.020; 49.104.004), Reznikov (46.104.050), Babadzhanov (49.104.061), Hajduk and Hajdukova (49.104.066), Williams (49.104.077), Kramer and Shestaka (49.104.36), Lebedinets et al. (1990) and Olsson-Steel (49.104.091). The dynamical evolution of meteor streams in resonance with Jupiter has been investigated by Scholl and Froeschle (45.104.029), Froeschle and Scholl (46.104.021), Emelyanenko (46,104.040; 49.104.042) and Belyaev and Emelyanenko (1990). The dispersal of meteor streams by radiative effects was studied by Olsson-Steel (46.104.022). Form, density, mass and internal structure of meteor streams have been studied by Babadzhanov and Obrubov (45.104.047), Koschack and Rendtel (46.104.012; 1990), Hughes and McBride (1989), Jenniskens (49.104.067), Grishchenyuk (49.104.097) and Andreev and Nasonova

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(49.104.099). Conditions for proper application of the meteor stream membership criteria have been delineated by Stohl and Porubcan (46.104.023). Discovery of several fireball streams has been announced by Terentjeva (49.104.076), identification of telescopic meteor showers has been presented by Znojil (1990).

Comet-Meteor Stream Associations. Generic relationships between comets, asteroids and meteor streams have been investigated by Kresak and Stohl (1990). Conditions for the possibility of observing meteor streams connected with short-period comets were studied by Babadzhanov, et al. (43.104.069; 070). Associations between ancient comets and meteor showers were investigated by Kresakova (44.104.076). Meteor radiants associated with comets and asteroids were predicted by Olsson-Steel (45.104.045) and Hasegawa (49.104.093). Meteor streams as a criterion of the cometary dust ejection models are presented by Andreev (1990). Contribution of some comets to meteor streams is analysed and discussed by Stohl (43.104.009; 44.104.075). Associations of some comets (Biela, Grigg-Skjellerup, Honda-Mrkos-Pajdusakova, Lexell) with meteor streams were investigated by Ryabova and Sukhotin (43.104.026), Lindblad (44.104.074), Kulikova (44.104.079) and Olsson-Steel (45.104.028). The system of cometary meteor orbits of Halley's family was studied by Kramer and Shestaka (45.104.051). A causal link of interplanetary particles and the nuclei of comets was proposed by O'Dell (1989), suggesting asteroids as the main source of the particles. Apollo asteroids as parent bodies of several meteor streams was suggested by Olsson-Steel (44.098.084; 46.104.019, 037) and Kronk (49.104.004). The problem of hyperbolic meteors of asteroidal origin was studied by Kazantsev (46.104.084).

Sporadic Meteors. Inflow of sporadic meteors to the earth has been derived by Babadzhanov and Bibarsov (45.104.038). Seasonal variations of the density flux of sporadic meteor bodies have been studied by Svetashkova (49.104.098; 102). The mass distribution of sporadic meteors has been investigated by Stohl and Hajdukova (49.104.080). The distribution of orbital elements of sporadic meteors and their secular evolution has been analysed by Svetashkova and Sukhotin (49.104.104).

Quadrantids. Mean activity profiles of the stream based on visual observations have been presented by Roggemans (1990) and Veltman (44.104.051). The spatial density of the stream as a clue to the decay of its parent body is proposed by McBride and Hughes (1990). Evolution of the orbit of the Quadrantids in the time interval of 4000 years has been calculated by Zausayev and Pushkarev (1989).

Lyrids. Dushanbe radar observations 1982-1986 are presented by Chebotarev and Porubcan (46.104.048). Long-term activity profile derived from Ondrejov and Ottawa radar observation of 18 returns of the stream is delineated by Porubcan, et al. (1989). The mass distribution index is derived by Porubcan and Simek (45.104.041) from 1980-85 Ondrejov radar observations. Enhanced activity of the shower in 1982 was noticed by Porubcan and McIntosh (44.104.055) from Ottawa radar observations, with unusually high value of the mass index at the highest activity (Porubcan and Hajdukova 49.104.079). Very high activity of the shower is reported also in 1985 on the basis of visual observations (Gorshechnikov 45.104.042).

Eta-Aquarids and Orionids. These showers are ascribed to Halley's comet and much attention was paid to them during the International Halley Watch campaign. Main characteristics of the activity of both the showers have been deduced from Ondrejov and Budrio simultaneous radar observations by Hajdukova, et al. (44.104.070), Hajdukova

(46.104.025) and Cevolani and Hajduk (46.104.026); from Dushanbe and Ondrejov radar observations by Chembotarev, et al. (45.104.030); from Kharkov radar observations by Milyutchenko (1988) and from visual observations by Rendtel (1990). Results of the Japanese visual and radar observations of the Eta-Aquarids are presented by Koseki (45.104.033), while the analysis of Australian, European and American visual observations of this stream is given by Ticket (46.104.014). Lindblad (49.104.068) derives the mean orbit of the Eta-Aquarids from photographic and radar observations and confirms its agreement with the 989 A.D. Halley orbit. Activity of the Orionids in 1985 is derived from world wide visual observations by Spalding (44.104.083) and from telescopic observations by Znojil, et al. (44.104.100). Comparison of the Eta-Aquarids and Orionids observations with the Halley dust characteristics derived from the fly-by spacecraft is presented by Hughes (44.103.592). Evolution and formation of the Halley stream is investigated by Hajdukova (44.104.097), Babadzhanov, et al. (44.104.099), McIntosh and Jones (46.104.055) and Jones et al. (49.104.040).

Delta-Aquarids. Evolution of the orbit of the Delta-Aquarid meteor stream in the time interval of 4000 years has been studied by Zausaev (1988).

Perseids. Mean profiles of the Perseid stream activity from Ondrejov long-term radar observations for two groups of echo durations are derived by Simek (43.104.002), from Onsala 1953-1978 short-echo radar observations by Simek and Lindblad (49.104.073). Spatial structure of the Perseid stream from Dushanbe 1964-1981 radar observations is studied by Andreev, et al. (1988). Activity profile and/or mass distribution for the 1986 visual Perseids is presented by Brown (43.104.007), Roggemans (44.104.013; 45.104.009), Veltman (44.104.030) and Grishchenyuk et al. (45.104.010), for the 1988 Perseids by Rogggemans (49.104.005, 045, 057) and Martynenko et al. (49.104.058).

Taurid Meteor Complex. Structure of the Taurid complex including several minor showers associated with it has been studied by Stohl and Porubcan (49.104.074) on the basis of precise photographic orbits available from the Meteor Data Center in Lund. A global analysis of the Taurids activity from 1988 visual observations is presented by Roggemans (49.104.035). The mass of the Taurid complex is estimated by Kruchinenko (44.104.053). Several papers are devoted to the problem of the origin of the Taurid complex and its association with the comet Encke and possibly also with some other parent bodies: Babadzhanov, et al. (44.104.059; 1990), Porubcan and Stohl (44.104.096; 46.104.023), Olsson-Steel (44.098.029; 1990), Clube and Asher (49.102.033).

Draconids (Giacobinids). The 1985 Draconids return is presented by Ganin, et al. (43.104.044) for Kazan radar observations, by Lindblad (44.104.073) for Onsala radar observations, by Chebotarev and Simek (44.104.098) for Dushanbe and Ondrejov radar observations and by Holan, et al. (44.104.029) for Czechoslovakian telescopic observations. Ondrejov radar observations have not confirmed Ferrin's prediction of the Draconids occurrence between October 8.8 and 9.4, 1986 (Simek 44.104.056). Probabilities of observing the Draconid stream in the years 1992-2025 are proposed by Reznikov (45.104.052; 46.104.041). Numerical simulation of the Draconid stream is presented by Kulikova (1989).

October Capricornids. Visual observations of the October Capricornid stream between 1971-1987 are analysed and possible association of the stream with comet P/Honda-Campos is examined by Wood (46.104.061).

Epsilon Geminids. From a comparison of orbital parameters and theoretical meteor radiant with observed characteristics of the Epsilon Geminid stream, Olsson-Steel (44.104.004; 033) has concluded that comet Nishikawa-Takamizawa-Tago is more likely to be the parent body than comet Ikeya proposed previously.

Orionids. Cf. Eta Aquarids and Orionids.

Leonids. Evolutiion of the Leonid stream orbit for the period 1660-1799 has been investigated by Kondratyeva (44.104.039).

Monocerotids. Lindblad (44.104.012) has analysed photographic orbital data and 1985 visual observations of the November Monocerotids, confirming their association with comet van Gent-Peltier-Daimaca. For the December Monocerotids, Ohtsuka (49.104.032) confirms associations with Comet Mellish.

Geminids. Activity of the Geminid stream for different classes of echo durations (sizes of particles) is derived by Simek and McIntosh (1989) from Ondrejov and Ottawa radar observations. Structure of the Geminid stream is derived from long term radar observations in Dushanbe by Andreev, et al. (43.104.020). Activity for the 1986 and 1988 visual Geminids is presented by Gorshechnikov (1989) and Roggemans (1989), resp. Bimodality of the Geminid shower is discussed by Ryabova (1989a), Geminid fireballs are studied by Halliday (46.104.052) in an attempt to derive properties of their parent asteroid 3200 Phaethon. The origin, parent body and evolution of the Geminid meteor stream has been investigated by Belkovich, et al. (43.104.006; 45.104.050), Belkovich and Ryabova (49.104.037), Ryabova (49.104.103) and Gustafson (49.104.064). The age of the Geminid stream of the order of 2000 years is estimated by Ryabova (1989b).

Ursids. An outburst of the Ursids activity in 1986, comparable to that in 1945, is reported by Roggemans (43.104.040) and Hillestad (43.104.043) from Norwegian visual observations and by Jenniskens (44.104.050) and Jenniskens and Hillestad (1988) from visual and radio observations. Mean activity profile of the 1982, 1984 and 1987 Ursid shower from visual observations is presented by Jenniskens (1988).

Southern Hemisphere streams. Wood (44.104.008) reports unusual activity from a radiant near the Kappa Pavonis stream on July 17, 1986; results of the 1986 visual observations of the Kappa Pavonids, Gamma Normids and Delta Pavonids are also presented.

V. METEOR ORBITS

P.B. Babadzhanov

Babadzhanov and co-workers have determined orbital elements (in press) of 154 meteors brighter than zero absolute magnitude photographed in Dushanbe during 1975-1983 years using small cameras (250 mm). 55 of these meteors were Perseids, 10 - Geminids, 5 - Alpha Capricornids, 5 - Delta Aquarids. 13 more meteors belonged to different weak showers and the remaining 66 were sporadic. The orbits of more than four hundred meteors have been derived from photographic observations carried out in Japan using 35 mm cameras with rotating shutter were published by Koseki (49.013.095) and Ochiai, Sekiguchi and Ohtsuka (49.104.095). 100 of the meteors were Perseids.

An analysis of radiants and orbital elements of the Eta Aquarids meteors photographed using Super Schmidt cameras in Harvard and using small cameras in Japan and recorded by Harvard radio meteor project is given by Lindblad (49.104.068). The mean photographic orbit derived by him agrees reasonably well with the orbit of comet Halley.

Ceplecha, et al. (44.104.001), published the geometric, dynamic, photometric and orbital data on 15 fireballs photographed within the European Network in the year 1978. On the basis of precise photographic observations Porubcan and Stohl (44.104.096) have evaluated the mean orbits of meteor streams associated with comet Encke, together with the dispersion of individual orbits and changes of the orbital elements across the streams. Porubcan and Stohl (46.104.024) have compared the orbital characteristics, radiants and duration of the post-perihelion showers with corresponding theoretical values derived from the observation of pre-perihelion Taurids. Some of the associated showers (the Northern and Southern Chi Orionids, Northern Piscids and Southern Arietids) are confirmed to be in fact parts of the Taurid shower itself.

Babadzhanov, Obrubov and Mahmudov have modelled the Encke meteoroid stream and show that the time needed for the formation of P/Encke meteor showers, namely the Northern and Southern Taurids, Beta Taurids and Zeta Perseids is about 4700 years, for the Chi Orionid and Piscid meteor showers having northern and southern branches and twins is from 8000 to 18000 years. The theoretical and observed shower radiants and orbits are in satisfactory agreement. The activity of the northern and southern branches of showers of P/Encke meteoroid complex results from the increase in the dispersion of meteoroids orbital elements and selectivity of observations.

On the basis of mean elements of the Geminid meteor shower Belkovich, et al. (43.104.006), investigated the possibility of the existence of a stream's parent comet. Evolution of the orbits and generic connection of comet Biela with the Andromedid meteor stream was investigated by Ryabova and Sukhotin (43.104.026). The influence of secular gravitational perturbations of orbits of Apollo-Amor-type interplanetary bodies on their collision probabilities with Mercury, Venus, Earth and Mars has been studied by Kramer and Shestaka (44.104.078).

The structure of the Halley meteor stream and the orbital history of the comet was studied by Hajdukova (44.104.097) on the basis of Orionids and Eta Aquarids long base-line observations carried out in Czechoslovakia and simultaneously at other observatories.

Babadzhanov, et al. (44.104.099), have investigated the formation of meteor shower of comet Halley. Orbit of test particles, ejected from the nucleus of Halley's comet at its perihelion passage in 1910 with different velocities are studied for the next passages of the comet up to 2134. The calculations show that the return of the comet to its perihelion cannot produce an immediate influence on the activity of its meteor showers.

Olsson-Steel (45.104.028, 46.104.019) used a new technique for analysis of the 3759 radar meteor orbits determined from Adelaide in the 1960's. These meteor orbits have been compared to the orbits of all known Aten-Apollo-Amor asteroids. Evidence was found for streams associated with asteroids Icarus, Hermes, Adonis, Oljato, Hephaistos, 5025 P-L, 1954 TA and 1984 KB.

Froeschle and Scholl (46.104.021) have investigated the orbital evolution of known resonant meteor streams and of model streams and have found that the resonance intermittance causes the gravitational splitting of meteor streams.

Svetashkova and Sukhotin (49.104.075) have developed a method of constructing a distribution of meteor's orbital elements on the basis of the observed hourly rates of radar meteors.

The orbital elements of 78 fireball showers deduced from photographic data of 557 fireballs provided by networks in the USA and Canada during the years 1965-1984 have been published by Terentjeva (49.104.076).

The dependence of meteoroid density on the type of the orbit has been discussed by Lindblad (44.104.069), who notes that the mean density of stream meteoroids vary drastically with the size of the stream orbit.

VI. PHYSICAL THEORY OF METEORS AND FIREBALLS D.O. ReVelle

In this section both recent advances in physical modeling and related observations of effects produced by meteors and fireballs during atmospheric entry are considered.

Lebedinets' work (43.104.003, 025; 44.104.064, 080; 46.104.072) involves modeling the quasi-continuous fragmenation process during meteor entry into the atmosphere. One goal of the work is to allow a prediction of the meteoroid bulk density by comparing modeling results against observed meteor decelerations. Another goal is to evaluate both heat transfer and drag coefficients using the theory, a technique which the author subsequently used to study the behavior of iron meteoroids. After evaluating the behavior of 92 sporadic meteors, the author determined that his sample consisted of 62% carbonaceous chondrites, of 22% ordinary chondrites, of 3% "dustballs", etc. In a later paper the author used a similar analysis for 98 stream meteors from 17 different streams as well. Thus, it is important to model the meteor process as realistically as possible, since our conclusions about these pristine objects from the early solar system can depend significantly on our ability to predict their behavior during entry as realistically as possible. The papers by Babadzhanov and Novikov (43.104.008) and by Babadzhanov, Novikov, Lebedinets and Blokhin, (44.104.065, 066; 45.104.008, 044) all involve applications of their modeling of the meteor fragmentation process as being quasi-continous and comparing such model results against direct meteor observations. The paper by Novikov (49.104.096) deals with the manner in which the structure of the meteor coma region is affected by the meteor fragmenation process using the previously developed theory.

The papers by Kruchinenko (43.104.018), by Apshtejn (44.104.035) and by Novikov and Kayumov (46.104.085) are theoretical modeling efforts which calculate the heating and ablation characteristics, whereas those by Saidov (43.104.024; 46.104.081) and by Begkhanov (46.104.073) involve the calculation of the meteoric luminosity and emission and the remnant ionization or of the coagulation of material in the meteor trail behind the entering body as treated previously by Hunten, Turco and Toon (1980).

The paper by Linblad (44.104.069) is a review of the characteristics of meteor astronomy combined with the physics of the entry process for small bodies, with the overall theme being the understanding of the evolution of small bodies in the solar system. The meteor theory covered includes the conventional topics of linear momentum and thermal energy conservation, including the topics of luminosity and its relationship to the observed stellar magnitude, the luminous efficiency, the aerodynamic drag as a function of the shape factor and drag coefficient of the body and its bulk density, fragmentation processes, etc.

Further work related to the modeling of meteors has been carried out by Papaelias (43.104.023), by Ishmuratov and Karpov (43.104.059), by Hawkes, Hitchcock and Fyfe (44.104.068), by Benyukh (44.104.086), by Beech (45.104.001; 46.104.036), and by Olsson-Steel (49.104.091).

Work related to fireball modeling has been carried out by Padavet (43.104.066), by Apshtejn and Sakharov (44.104.042), by Kruchinenko (44.104.036), by Kalenichenko (44.104.037), by Getman

(46.104.033, 49.104.063) and by Pecina (46.104.027, 031, 038). These are theoretical modeling efforts related to either connecting the physics of fireball entry to the astronomical source of the bodies or to the physics of the entry process itself. More specifically, the papers by Padavet and by Kalenichenko are in the former category whereas the remaining papers relate to either modeling of radiation and heat transfer effects or to possible modes of thermal disruption of meteors, fireballs and of meteorites, to the separation of particles during meteor flares, to the deceleration characteristics of the entry and to the complete solution of the meteor entry problem (constant coefficients case).

Ceplecha (46.104.039) and Rajan and ReVelle (46.104.053) have attempted to evaluate the source regions of meteors and fireballs using a variety of data sources, but employing the concept of the end height as a diagnostic tool in the evaluation process. The results of Ceplecha (44.104.002) are an update of those developed over about the last decade, whereas the latter effort is an attempt to deduce the expected ablation characteristics of iron fireballs and to evaluate which fireballs within the U.S. Prairie network data are possibly iron in composition. The latter work was motivated by the recent discovery of Earth-crossing M Class asteroids by Tedesco and Gradie (43.098.023).

Korobejnikov, Chushkin and Shurshalov (44.104.034, 077, 084) have continued their earlier work that began with the theoretical modelling of the expected explosion wave from the entry of the Tunguska event of 1908. They consider very large bodies entering at a relatively low angle with respect to the horizon and model the atmospheric flight, but also consider the interaction with the surface as well. Rajan and ReVelle (1988) considered the cratering effects of iron impactors at the earth's surface due to entries over a large range of angles and velocities. They considered seven, single impact craters from a list of iron impact craters from Shoemaker (1983) and determined the pre-atmospheric mass, velocity, shape factor-drag coefficient and ablation parameter combination, along with realistic error bar estimates on each parameter, that was consistent with the parameters of the entry, i.e., terminal mass, crater size (or terminal kinetic energy) and angle of impact. This work was possible due to the recent work on the ablation of iron meteoroids that was discussed earlier regarding the possible sources of iron fireballs in the atmosphere. The paper by Shurshalov is also a continuation of earlier work related to the model of an explosion of a large meteor and possible wave effects produced by the explosion.

Jones, Mitchell and McIntosh (45.104.040) have sought to finally understand the enigma of the meteor head-echo phenomenon. It has been long interpreted as the result of the meteor acting as a moving ball target for the radar beam for objects traveling at hypersonic speeds in the continuum or near-continuum flow regime. The authors conclude that ionized trains which contain a large abundance of water cluster ions (since they have a very large recombination rate) are potential producers of the head echo return. This may have implications for the concept of the Hygropause in the atmosphere and the vertical distribution of water vapor which is currently attracting much attention.

Babadzhanov, Novikov, Konovalova and Blokhin (44.104.041) consider the light production by bright meteors and present their interpretation in the presence of fragmentation, as was discussed earlier above for fainter meteors.

Babadzhanov and Konovalova (46.104.028) deal with the interpretation of bright Geminids through the use of light curve data. Halliday (44.104.067, 46.104.052) has also done a very complete study of the Geminid fireballs and has related this meteor stream to its proposed source, the peculiar asteroid 3200 Phaethon. Halliday, Blackwell and Griffin (49.104.084) have attempted to categorize a typical meteorite fall from the records of 44 deep penetrating bright fireballs from the Meteorite Observation and Recovery Project (MORP) photographed between 1971-1984. Typical pre-atmospheric velocity, duration, end height, end height velocity, peak stellar magnitude, etc. were determined. Finally, Babadzhanov and Ceplecha (46.104.034) applied the "exact" theory of meteor entry of Pecina and Ceplecha (1984) to one of the most precisely recorded double station meteors observed in Dushanbe in 1962.

Pho and Marin (43.104.001) have given an account of the detection of the blast wave from a fireball by a seismic station in the Alps. These records were used to determine the altitude of the source to be 32 km and further to locate the probable location of meteorite fragments on the ground. Papers by Olsson-Steel and Elford (43.104.048, 43.104.064) have examined the possibility that meteor radars have missed a significant fraction of small meteors to altitudes approaching 140 km, with revised fluxes computed to be 10 to 20 times larger than those that were previously estimated. Two papers by Olsson-Steel (44.104.033, 46.104.037) deal with relating meteors to their source, i.e. comets or asteroids. After searching the records of 3759 meteors from the Adelaide radar returns of the 1960's, associations are found between the meteor stream members and the Apollo asteroids, with no associations with the orbits of the Amor or Aten asteroids. Halliday (43.105.199) has also analyzed the orbital characteristics of a second MORP fireball and found that to an extremely high precision, it is identical to that of the Innisfree meteorite. Galibina and Terentjeva (1987) have also found similar associations from the predicted dynamical behavior of the orbit of Innisfree during the past 500,000 years.

Bronshten, Grebennikov and Rabunskij (46.104.087) have produced a catalogue (in Russian) of the electrophonic sounds from very bright fireballs. According to earlier work by Keay (1980), there are two reasons for the infrequent incidence of these "sounds". There is a threshold effect with only very deep penetrating or exploding fireballs being capable of generating the ELF/VLF radio frequencies which are transduced into sound, and there must be suitable transducing objects close to an observer. Watanabe, Okada and Suzuki (1988) have obtained a detailed record of radio signals matching the photometry of a simultaneously photographed fireball. This is the first direct evidence of such signals and verifies Keay's explanation of the phenomenon.

Halliday, Blackwell and Griffin (1989) have summarized a number of detailed records of fireballs observed by the Canadian Prairie Network (MORP) for which meteorites are likely to have fallen to earth and which deserve further search efforts. Finally, the paper by Oberst and Nakamura is a reexamination of the flux of meteoroids on the earth's moon based on recent modeling and analysis of additional data using short period seismomometer records that began in the Apollo era. The very significant earlier discrepancies between the flux determined by terrestrial fireball networks and the detection of "airwave" objects (Shoemaker, 1983) as compared with those recorded by the lunar seismic network have now been largely resolved.

Other papers either directly or indirectly related to physical modeling of meteors and of fireballs include those by Nagasawa and

Miura (46.104.056), by Terentjeva (49.104.076), by Ovchinnikov and Pasechnik (49.104.002), by Zotkin and Chigorin (49.104.001), by Ovchinnikov and Pasechnik (49.104.002), and by Oberst and Nakamura (1989).

VII. METEORS AND AERONOMY

W. J. Baggaley

Trails and Ablation. Models have been given of the interaction of large meteoric bodies with the atmosphere for explosive conditions (44.104.077), of the radiative heat exchange processes influencing ablation (45.104.008) and the effect on meteor observations of fragmentation processes considering separately the parent meteoroid and fragments (Pilyugin and Chernova, 1987). The mechanisms leading to the production of trails which are geometrically non-linear (curved or sinusoidal) have been recently discussed by Beech (46.104.036 and 1989).

Diffusion. The influence of multiple ions on train diffusion and a corresponding prediction of how the expected diffusion coefficient will depend on height has been discussed by Jones and Jones (1990). The problems of anisotropic train diffusion in the geomagnetic field has again received recent attention by Lyatskaya and Klimov (1988 and 49.104.083), while the effects of any anisotropic molecular processes in the expanding plasma train have been considered by Delov (1987). The fate of meteoric species during diffusion and mechanisms of coagulation have been modelled (46.104.073). Observational work at 2 MHz has been reported (43.104.064) on the effects of diffusion in producing the height ceiling effect that is responsible for the distortion of meteor-echo height distributions when radars operating at HF are employed.

Ionospheric effects. More observational work is available on the effects of meteoric material on the earth's ionosphere and upon propagation conditions. The changes in VLF reflection height, reflection coefficient, group retardation and phase deviations have been reported (42.083.023) during Geminid and Alpha-Scorpid activity while changes in ionospheric total electron content have been attributed to deposition by showers (Lokanadham, et al, 1988). The simultaneous observation of meteoroid impacts on the moon by lunar-surface seismographs and changes in ionospheric VLF paths has permitted (Kaufman, et al, 1989) an estimation of meteor induced ion production rates in the D and E regions. An inter-hemisphere comparison of meteoric influx rates and ionospheric sporadic-E activity at the equinoxes has permitted Baggaley (1990) to place constraints on the time-scale of Es production after meteoric deposition.

Remote sensing of ablated meteor species. Measurements of the MgI resonance line in the UV nightglow (Sharpe and Siskind, 1990) have been made of magnesium atoms present in the 110-112 km height interval during Orionid shower activity while height changes of calcium deduced from Ca+ emission under sunlit conditions during the epoch of the Leonid shower have been discussed (Torr, et al, 1990). Further Lidar observations on meteoric sodium layers have been carried out; studies of their dynamics and relation to Es and tidal action (Kwon, et al, 1988) while short-lived events have been associated with expanding meteor trains in the field of view (Beatty, et al, 1988). Lidar observations have also been reported of Fe neutrals (Bills and Gardner, 1990) and their association with tidal and gravity wave characteristics.

Effects of meteoric debris. The role of meteoric spheres in enhancing ozone depletion in the Antarctic stratosphere has received

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attention. One suggestion (Prather and Rodriguez, 1988) is that magnesium and iron oxides accumulated in the antarctic stratosphere in spring as a result of atmospheric circulation, are instrumental in removing nitric acid, allowing an increased catalytic action of free chlorine atoms Cl, to proceed. An alternative proposal considers (Aitken and McPeters, 1987) the accumulation of metal hydroxides followed by a subsequent reaction with hydrochloric acid to form metal chlorides whose spring-time photo-dissociation release free Cl. An investigation (42.104.021) of the association between Northern Hemisphere Noctilucent Cloud (NLC) occurrence and the incidence of bright fireballs as recorded by the European Fireball Network indicated little apparent causal relation. In a related study (44.082.001), attention has been given to the role of meteoric ions and meteoric dust, as redistributed by global circulation, in the production of enhanced nightglow emissions and NLC. Attention has been revived into the possible role of meteors in influencing rainfall: the mechanisms involved in cloud production resulting from nucleation by small (1-10 micro-m) micrometeorites has been examined by Cevolani and Bonelli (1987).

VIII. METEOR SPECTROSCOPY — I. Halliday

There is very little activity upon which to report. In the Soviet Union, S. Mukhamednazarov and R.I. Shafiev (46.104.049) have obtained television and electron-optical spectra of faint meteors, and K.Kh. Saidov and A.N. Kadyrov (46.104.080) have studied sodium emission in meteor spectra.

I. Halliday has studied the spectra of bright Orionid meteors in the spectral range from 3100 A to 8700 A (43.104.013) and from 3440 A to 8700 A (44.104.071), providing clear evidence that particles of a few grams mass survive to encounter the Earth. Comparison with Perseid spectra suggest that there is only marginal difference in the composition of their parent comets.

IX. TEKTITES — C. Koeberl

Tektite research remained vigorous in the period covered by this report. Studies on tektites and other meteorite impact glasses were mainly done by members of the meteorite and planetary science community. In the past few years the increasing importance of interdisciplinary work (involving planetary scientists, astronomers, geo- and cosmochemists, petrologists, geologists, etc.) became even clearer than before. A majority of workers in the above fields now accept that tektites and impact glasses have been produced during a hypervelocity impact of an asteroidal or cometary body on the earth. During this process, the enormous energy released is used to vaporize the bolide, and vaporize and melt huge amounts of terrestrial target rocks which are quenched to produce tektites and impact glasses. By studying these materials we can learn important facts about the physical and chemical processes occurring during a large-scale impact. This gains importance in view of the vigorous and ongoing debate about the Cretaceous/Tertiary extinction event, now widely believed to be caused by a giant impact. A conference on the question of large-scale impacts and extinction events was held in 1988. Due to the growing literature on this subject, interested readers have to be referred to the proceedings of this conference, which give an up-to-date summary of the current knowledge (Sharpton and Ward, 1990).

In 1987, the 2nd International Conference on Natural Glasses was held in Prague, and the proceedings (Konta, 1988) contain a large number of specialized and general papers on tektites and impact glasses. Important developments have also been published in the Proceedings of a conference held in 1987 in South Africa (Nicolaysen and Reimold, 1990). Reviews by Koeberl (1988, 1990) and Glass (1990) describe the current state of tektite research. A recent monograph by Melosh (49.003.022) provides important information on impact cratering with references to the production of impact glasses and tektites.

Regarding individual tektite strewn fields, the North American field has received increased attention. This was due to the discovery of a tektite-bearing layer at the Eocene-Oligocene boundary in a drill core from DSDP Site 612 off the coast of New Jersey on the continental slope (Thein, 1987). Stratigraphic, age, isotopic, and geochemical analyses of the tektites and microtektites found at DSDP Site 612 and on Barbados demonstrated that they belong to the North American strewn field, but have a distinct chemical and isotopic composition (Koeberl and Glass, 1988; Stecher et al., 49.105.127). The discovery of the first submarine impact crater (named "Montagnais") on the continental shelf off Nova Scotia by Jansa and Pe-Piper (43.081.067) led to the initial hypothesis that it may be the source crater of the North American tektites (Glass, 1988), which was later refuted due to an older age of 51.5 Ma for the Montagnais crater (Bottomley and York, 1988). It was shown by Glass and co-workers (e.g., Glass and Burns, 1988) that the North American tektite strewn field is confined to the eastern part of the North American continent, while the so-called cpx-strewn field, which extends into the Pacific Ocean and was earlier thought to be part of the North American strewn field, was in fact caused by a separate event, although closely related in time. This, together with a reevaluation of the Cuban tektite (46.105.017), prompted Koeberl (49.081.038) to provide new estimates for the geographical extension and the mass of the North American tektite strewn field and to derive a (possible) crater location on the eastern continental shelf of the North American continent. DSDP Site 612 is also of importance because there tektites, microtektites, and impact debris (shocked minerals) are found within one layer, showing not only the connection between tektites and impacts, but also between microtektites and tektites, thus eliminating the so-called age paradox (some workers maintained that tektites are not related to microtektites because they are sometimes found in younger sediments, which is mostly interpreted as being due to reworking). Regarding the source materials, Love and Woronow (1988) suggested a minimum of two different sediments.

Even though the moldavite and Ivory Coast tektites have been successfully linked with impact craters, the crater responsible for the largest strewn field, the Australasian field, is still at large. Wasson (1987) proposed that not one single impact, but thousands or millions of small impacts are responsible for the Australasian tektites, while most other researchers agree that one large impact is more likely. However, the location of this crater is still under discussion: Schnetzler et al. (1988) proposed a submarine location on the continental shelf southeast of Indochina. From the study of Muong Nong-type tektites, Glass and Koeberl (1989), Wasson (1989), and Murty et al. (1989) were able to derive further clues about the (sedimentary) source of the Australasian tektites.

In a detailed study of moldavites, v. Engelhardt et al. (1987) showed a relation between Middle Miocene sands from the Ries crater and moldavites, and invoked a plasma-like vapor phase during the origin of the moldavites. Koeberl et al. (46.105.224) reported on the discovery of moldavites in Austria. Muong Nong-type moldavites were described by Meisel et al. (1989) and Glass et al. (1990). An extensive new study of the geochemistry and age of Ivory Coast tektites was started (Koeberl et al., 1989) and confirmed the association with the Bosumtwi crater in Ghana. In a study of Australasian and Ivory Coast microtektites, Burns (1989) and Schneider and Kent (1990) were able to show that, in contrast to earlier theories, there is no connection between tektite events and geomagnetic reversals.

In a more general study, Glass et al. (1988) demonstrated that, by analogy with atomic bomb glass beads, tektite-like glasses can be produced in short-time high temperature events. Glass (1986), and Barkatt et al. (1986, 1989) investigated the solution behavior of tektite glasses and were able to show that seawater provides a natural buffer against the rapid dissolution of tektite glass, thus explaining why microtektites are more stable in the ocean than on land. In relation to tektite studies, the investigation of an ever growing number of impact craters shows the similarity between tektites and impact classes and gives important results on cratering processes and products.

X. DUST CHARACTERISTICS — E. Gruen

The time period from 1987 to 1990 is characterized by the development of new analytic techniques and the in depth study of interplanetary dust particles (IDPs) which are collected by high flying aircraft or balloons. Following the first time analyses of cometary dust by the Halley missions it is now possible to compare dust from various sources of the interplanetary complex. Recent recovery of dust collectors on board the US Long Duration Exposure Facility (LDEF) and the Soviet Mir station and the successful launches of NASAs interplanetary Galileo spaceprobe and the Japanese Muses/Hiten satellite in a high eccentric Earth orbit promise new results for the next future which may allow us to test theoretical predictions. Preliminary results from these missions have been reported at the COSPAR Conference in The Hague, The Netherlands.

The study of interplanetary dust particles (IDPs) gives insight into their relations to asteroids, comets and interstellar dust. IDPs are found to be heterogeneous down to almost atomic scale. Powerful new microanalytical techniques are developed over the last years which allow the analysis of individual fragments on different size scales. Isotopic measurements with the ion microprobe can be made on individual fragments of a few micrometer in size. D/H measurements show that many IDPs have large isotpic excesses that differ greatly between different fragments of a given dust particle. In one particular example a D enrichment of more than a factor 10 was found by McKeegan et al. (1987) and Stadermann et al. (1990). Other examples of isotopic measurements in IDPs that revealed large anomalies are those of N and O. Similar enrichments have been found in refractory phases of primitive meteorites by Fahey and co-workers (44.105.059). The large isotopic anomalies in IDPs are believed to be of presolar (interstellar cloud) origin even if the particles as a whole may have younger ages.

Bradley, Sandford and Walker obtained mineralogical information at nanometer spatial resolution by application of an ultramicrotome in order to obtain electron-transparent thin sections for subsequent analysis by an analytical electron microscope (49.106.038). Schramm, Brownlee and Wheelock have shown that the bulk composition of chondritic IDPs generally agrees with that of the primitive carbonaceous chondrites (49.105.128). Olivine, pyroxene and layer silicates are the major components of these IDPs. Analysis of layer silicate IDPs by Bradley show that they were derived from parent bodies in which aqueous alteration has occurred (45.106.041). Pyroxene dominated IDPs are highly porous objects which contain only anhydrous mineral assemblages of less than 0.1 micrometer in size. The crystal chemistry of these IDPs shows that they are the most primitive, least equilibrated IDPs (Kloeck et al., 1990) and match closely the composition of Halley dust by Kissel and Krueger (43.103.647) and by Jessberger, Christoferidis and Kissel (45.103.453).

On the theoretical side, a better understanding of the orbital evolution of interplanetary dust is obtained by numerical analysis. Gustafson, Misconi and Rusk (44.106.036) and Jackson and Zook (49.106.042) demonstrated that the combined influence of the Poynting Robertson effect and planetary perturbations lead to significantly different results than the individual effects alone. Dust rings near the positions of the planets may be expected for 100 micron sized particles. Mukai, Fechtig, Gruen and Giese (1989) showed that a plentiful release of icy particles from comets can only be expected at distances larger than 7 AU from the sun where sublimation can be neglected. In October 1989 the Galileo spaceprobe was successfully launched on its 6 year interplanetary trajectory towards Jupiter involving multiple swing-bys of the Earth and Venus. The dust detector onboard will take measurements of the interplanetary dust flux and its orbital characteristics between 0.7 to 5.2 AU from the sun. A similar dust detector was deployed in January 1990 on board the Muses/Hiten satellite. It will take measurements in the Earth-Moon system and during several close lunar fly-bys. Five and a half years after launch the Long Duration Exposure Facility (LDEF) was retrieved in January 1990. Examination of surfaces from detectors with unique attitude stabilisation offers scope for examining the sources of space particulates. Similar collectors were exposed on and retrieved from the Soviet Mir station early this year.

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C.S.L. Keay

President of the Commission.