# COMMISSION 22: METEORS AND INTERPLANETARY DUST
## (Météores et poussière interplanétaire)

ACTING PRESIDENT: I.P.Williams.
ORGANISING COMMITTEE: P.B.Babadzhanov, Z.Ceplecha, I.Hasegawa, J.Jones, C.S.L.Keay, C.Koeberl, R.K.Soberman, D.I.Steel, E.F.Tedesco, V.Porubčan (co-opted).

## I. INTRODUCTION

The organization of Commission 22 was disrupted by the untimely and much-lamented death of our President, Jan Štohl, in 1993 March. An appreciation of Jan appeared in the newsletter of the commission issued in 1993 April, and obituaries have been published in various other places. The Vice-President, Iwan Williams, assumed the duties of President thereafter, and with help from the OC has taken responsibility for the production of this report, and providing the formal sanction of the commission for various meetings associated with the 1994 General Assembly, and other conferences.

As is the usual practice, members of this commission with expertise in different areas have prepared contributions reviewing their own fields, and these have been consolidated by the Acting President and Secretary to form the report as it appears below.

Over the past triennium there have been a number of conferences concerned either solely with meteors and/or interplanetary dust, or including these subjects amongst the topics covered; in fact, too many to list here. In the papers referenced below, many are taken from the proceedings of those conferences, and such proceedings may contain other specific papers of interest to the reader. Specific conferences in which members of Commission 22 have played a major part were the following:

*Asteroids, Comets, Meteors 1991*: Flagstaff, Arizona, USA, 1991 June (proceedings now published: Harris & Bowell 1992);

*Meteoroids and their parent bodies*: Smolenice, Slovak Republic, 1992 July (proceedings now published: Štohl & Williams 1993);

*IAU Symposium 160, Asteroids, Comets, Meteors 1993*: Belgirate, Italy, 1993 June (Reviews to be published in one volume by Kluwer, Dordrecht; contributed papers to be published in a special issue of *Planetary & Space Science*).

Commission 22 currently has membership of two inter-commission Working Groups: Interplanetary Pollution (which is chaired by C.S.L.Keay of Comm. 22) and Near-Earth Objects (WGNEO, chaired by A.Carusi of Comm. 20, with I.P.Williams and D.I.Steel being Comm. 22 representatives, Williams having replaced J.Štohl). The WGNEO has had several meetings, at approximately six-monthly intervals, and has prepared a report to the XXII*nd* GA; input of Comm. 22 to that WG is of importance since clearly much may be learnt about the large bodies which strike the Earth infrequently by studying the smaller bodies (meteoroids and dust) which strike it more frequently. The Commission also has one Working Group of its own (Amateur-Professional Co-operation in Meteors, WGAPCM, chaired by V.Porubčan who is a co-opted member of the OC). The WGAPCM has held several meetings, notably at Smolenice in 1992 when the professional conference mentioned above was held in conjunction with the (mainly amateur) International Meteor Conference of the International Meteor Organization (IMO). Good progress has been made in bringing people interested in meteors together, from many backgrounds and many nations, as the body of this report shows. Porubčan has issued a regular newsletter of the WGAPCM.

## II. PHOTOGRAPHIC METEORS, FIREBALLS AND SPECTROSCOPY

Z.CEPLECHA

A survey of theoretical and observational aspects of meteor phenomena, with applications to photographic meteors and fireballs, was published by Ceplecha and Borovička (1992).

The European Photographic Fireball Network (EN) has continued systematic operations from 54 stations in the Czech Republic (Spurný, in press), Slovakia, Germany, Austria and Switzerland, and in the

J. Bergeron (ed.), Reports on Astronomy, Vol. XXIIA, 211–224.

Netherlands. Precise data on 117 fireballs were obtained between 1991 January and 1993 May. [Note: all papers listed in the body of this section as being 'in press' were presented at the *Asteroids, Comets, Meteors '93* conference, and have been submitted for publication in *Planetary and Space Science*]. Preliminary computations of the most significant fireballs photographed within the EN have been regularly published in the *GVN Bulletin* (Smithsonian Institution, Washington, D.C.). Photographic recording of the deepest-ever penetration by a meteoroid was obtained for the 'Benešov' fireball (Spurný *et al.* 1991): its very steep trajectory was photographed down to an altitude of 16 km, with spectral records of resolution from 67 to 22 Å/mm also being obtained. It was predicted from the observations that several meteorites with masses of some kilograms were produced by this event, but searches in the unfavourable countryside have so far brought no recoveries. Spurný (1993) published data on photographic Geminids. The German section of the EN is now closely linked to the amateur organization, Vereinigung der Sternfreunde (VdS), but the Max-Planck-Institut für Kernphysik in Heidelberg has provided the necessary funds to keep that part of the EN running. An independent part of the photographic fireball network in Europe is operated by J.Rendtel in Germany and the results published in *Mitteilungen des Arbeitkreises Meteore* together with visual sightings of fireballs (Rendtel & Heinlein 1991). Three new photographic fireball stations are being built in Sardinia, Italy (Quesada & Uras, 1993).

The analysis of the atmospheric trajectory and orbit of the Peekskill (New York) meteorite fall, partly based on video records, is being carried out (see section VI). An extremely bright fireball exploded over northern Italy (K.Korlevic, in press) and was also recorded at the Bologna radar station (G.Cevolani, in press). One of the potentially meteorite-dropping events photographed by the EN, the 'Valeč' fireball, was thoroughly studied by Bronshten (1991a) and by Stulov & Chernenko (1991).

Data on an Earth-grazing fireball photographed in 1990 October were published by Borovička and Ceplecha (1992). The U.S. daylight Earth-grazing fireball from 1972 is continuously referred to with much greater mass than the observations indicate (Z.Ceplecha 1993, submitted to *Astron. Astrophys.*). M.Connors (private communication to Z.Ceplecha) carried out computations regarding the possible return of the 1972 Earth-grazing fireball body to the Earth's vicinity in 1997 taking into account all planetary perturbations and came to the conclusion that the most probable time of the closest approach to Earth will be 1997 July 31, at a distance of 0.08 AU. It would be of about 24th magnitude at that time, so that in principal it could be recovered as a very faint asteroid. Computer simulations of Earth-grazing fireballs were published by Olson et al. (1991).

The amateur organizations in Europe and in Japan are very active in photographing meteors. Meteor and fireball trajectories and orbits are regularly published in *WGN* (the journal of the International Meteor Organization, IMO: see Gyssens *et al.* 1991). Multi-station photographic trajectories and orbits of fireballs and meteors have been determined by members of the Dutch Meteor Society, in particular many Perseids and Geminids (Betlem & de Lignie, 1990; Betlem *et al.* 1993). Several prolific groups of Japanese amateurs continued photographic studies of meteors and fireballs (Ohtsuka *et al.* 1991; Miyashita *et al.* 1993). The capacity of many amateur groups for observing and measuring meteor trails, and then computing trajectories and orbits of meteoroids, is notable.

The Global Network for collecting all fireball sightings (previously the *SEAN Bulletin*, now the *GVN Bulletin*) has ceased publishing these observations. The service was taken over by *FIDAC* (the Fireball Data Centre of the IMO, directed by A.Knöfel). Statistics of brightnesses of 16,000 visually-observed meteors and fireballs were published by Martynenko & Levina (1991). Miles (1991) published visual data from a bright fireball observed over Ireland in 1991 February.

A model of meteoroid ablation taking into account gross fragmentation was presented and applied to the most precise photographic data on the Prairie Network (PN) fireballs (Ceplecha 1993). Meteoroid strength, density, ablation coefficient and amount of fragmented mass was determined, and a two-dimensional classification of fireballs based on the dynamic pressure at the fragmentation point and on the ablation coefficient was proposed. The structure and composition of meteoroids from photographic observations were studied by Babadzhanov (in press) and densities typical of stony bodies found for most of them. Adolfsson and Gustafson (in press) pointed to the importance of rotation of meteoroids for the onset of their ablation.

ReVelle & Ceplecha (in press) proposed methods for recognizing iron meteoroids among the PN fireballs: they found 7 such objects and investigated their possible relation to the M-type Earth-crossing asteroids.

In the area of very large meteoroid impacts into the atmosphere, Chyba *et al.* (1993) and Hills & Goda (1993) published new theoretical models for the atmospheric ablation of small cometary or asteroidal bodies, and applied them to the 1908 Tunguska explosion, arguing for a stony composition of the Tunguska body; the latter authors also studied a whole range of possible interactions between small asteroids and the atmosphere. Z.Sekanina (1993, submitted to *Science*) has applied the Chyba *et al.* model to the expected 1994 July collision of P/Shoemaker-Levy 9 with Jupiter. Korobejnikov *et al.* (1991) developed an ablation-explosion model and applied it to Tunguska fireball. Steel and Snow (1992) suggested that the extensive forest devastation of the South Island of New Zealand was due to a large body detonation in the atmosphere some 800 years ago, similar to the Tunguska event.

Padevět (1991) studied meteors and fireballs produced in Mars' atmosphere, and comparing these with the better-known terrestrial phenomena. Partly based on fireball observations, Padevět & Jakeš (1993) proposed that chondrites come also from inside cometary nuclei, though they originated in larger bodies than comets are today.

Pecina (1991) published a new method for computing fireball orbits and applied it to several well observed EN fireballs deriving orbits quite different to those obtained by using the classical method, in particular for low velocities. A method for determining the pre-atmospheric velocities of meteoroids from photographic records was proposed by Zausaev & Pushkarev (1992). Kazantsev & Sherbaum (1990) came to the conclusion that hyperbolic orbits amongst photographic meteors are mostly due to observational errors.

B.A.Lindblad continues in charge of the IAU Meteor Data Center at the Lund Observatory, Sweden. A catalogue of photographic and radar meteor orbits is available from him upon request (see section IV). Data from many photographic meteors and fireballs observed in different observational projects are also available from the Ondřejov Observatory, Czech Republic (contact: P.Spurný). A new search for streams amongst fireball orbits resulted in a lower number than previously determined (Porubčan & Gavajova, in press).

Partially based on photographic observations of meteors, and also on Spacewatch Telescope discoveries of small asteroids down to sizes of ~10 m (Rabinowitz 1992) , Ceplecha (1992) computed influx to the Earth of meteoroids within the mass range from $10^{-21}$ to $10^{15}$ kg. He found a total annual mass influx of $1.7 \times 10^{8}$ kg. Rates of impacts by different types of the large bodies recorded as photographic fireballs (up to 7 m) were determined by Ceplecha (in press); there exist only 14 bodies on precise records with pre-atmospheric sizes over 1 m. In the mass range of fireball bodies most of the influx belongs to carbonaceous bodies both of asteroidal and cometary origin; the relative importance of stony material decreases for bodies with sizes larger than 0.3 m, while the softest cometary material becomes the most important for bodies larger than 2 m in size. Based solely on their orbits, Bronshten (1991b) came to the conclusion that the majority of fireball-producing bodies photographed within PN and EN were asteroidal.

TV observations of faint meteor spectra were reported by Mukhamednazarov & Mal'tseva (1990). In Japan, near-infrared spectra of Perseids and Geminids were obtained (Murayama 1990). One Perseid spectrum was described by Evans & Ridley (1993). Kokhirova (1993) analyzed Perseid spectra quantitatively. Theoretical considerations on the intensities of spectral lines in meteors were done by Smirnov (1992). Three photographic spectra of meteor trains are compared in Rajchl et al. (1993). Padevět began a TV meteor spectrum observation program at the Ondřejov Observatory.

The most extensive work on meteor spectra is that of Borovička (1993a,b). The spectrum of a bright EN fireball was studied from the physical point of view along the trajectory between heights of 57 and 35 km. A synthetic spectrum was computed and compared with the observed spectrum. Thermal equilibrium with temperatures varying in the range 3 500–4 700 K was found to be a good first approximation to the physical conditions. Moreover the high excitation spectrum ($T \simeq 10\ 000$ K) of the shock wave overlaid the main spectrum, showing that meteor spectra consist of two different components: low and high temperature. The refractory elements Ca, Al, Ti were underabundant in the radiating gas relative to chondritic values, pointing to incomplete evaporation. Melting was the favored ablation process. About 95% of the hot gas around the meteoroid was composed of atmospheric species.

## III. METEOR SHOWERS/METEOROID STREAMS

V.PORUBČAN

The formation and evolution of meteoroid streams in general was studied by several authors (Lebedinets *et al.* 1990; McIntosh 1991; Emel'yanenko 1992a,b; Williams 1992). According to Babadzhanov & Obrubov (1991a, 1992b), their investigation of the dynamics of the major meteoroid streams shows that up to eight related meteor showers may be produced by one stream. They have found five new complexes of small bodies. In a related study of 22 short-period meteoroid streams Babadzhanov & Obrubov (1991b) report that on the basis of theory these may produce 102 meteor showers, and of those 72 have been confirmed by photographic and radar observations. The mass distribution of comets and meteoroid streams and the shower/sporadic ratio in the incident visual meteoroid flux was studied by Hughes (1990).

Terenteva & Bayuk (1991) have studied the formation of short-period meteoroid streams and conclude that a transformation of cometary orbits into Geminid type orbits is possible. The association of 3200 Phaethon and the Geminids was discussed Kramer & Shestaka (1992) and Gorbanev *et al.* (1992). Since the discovery of Phaethon and its Geminid association the problem of meteoroid streams of asteroidal origin has become more intriguing. Several other associations with varying degrees of security have been identified (Hasegawa *et al.* 1992; Štohl & Porubčan 1993). Williams & Wu (1993) propose a new theoretical model for the Geminid stream which is based on the assumption that the parent of the Geminids is Phaethon, or at least a progenitor of that body.

The origin, dispersion mechanisms, evolution and structure of dense meteor storms are discussed by Kresák (1993), and predictions for future events of this kind are made. The formation of the Leonid meteoroid stream and its storms were studied by Wu & Williams (1992a) and by Brown & Jones (1993). Lindblad *et al.* (1993) determined the mean orbit and radiant motion of this stream.

Hasegawa (1992, 1993) has compiled a catalogue of historical records of meteor showers containing 331 good entries, and more than 100 uncertain records without the exact date of the shower being known. Hasegawa (1990) has also introduced a better method for the prediction of the meteor radiant associated with a parent body than that used previously.

The cross-section of the Quadrantid meteoroid stream based on radar observations over a period of 30 years was studied by Šimek & McIntosh (1991). Babadzhanov & Obrubov (1992a,b, 1993) have simulated the evolution of the P/Machholz meteoroid stream that may produce eight meteor showers: among them the Quadrantids, Ursids, N and S $\delta$ Aquarids, Daytime Arietids and $\alpha$ Cetids. Wu & Williams (1992b) integrated 118 photographic orbits of Quadrantids back in time to 5000 B.C., five distinct subsets of orbits being distinguishable. Jones & Jones (1993) have shown by a computer simulation that if P/Machholz was captured by Jupiter about 2,200 yrs ago, there has been sufficient time to produce most of the presently observed features of the meteor shower complex mentioned above.

Emel'yanenko (1991) analysed the recent bursts in Lyrid activity and concluded that these had appeared near the centres of resonances with Jupiter. He (and Kresák 1993) suggest that the next outburst will occur in 1994. The radiant and orbit of the Lyrid meteoroid stream has been determined from precisely-reduced photographic meteors observed in 1941–1985 (Lindblad & Porubčan 1991).

The approach of the parent comet of the Perseids (P/Swift-Tuttle) was indicated by the meteors themselves, a secondary maximum being visually observed first in 1988, with enhanced Perseid activity since then. Spectacular outburts have been observed in the past three years.

The evolution of the orbit of P/Halley and its associated meteoroid streams was studied by several researchers (Babadzhanov *et al.* 1991; Wu & Williams 1993). Obrubov (1993) indicated the possibility that P/Halley may produce two other showers in addition to the well-known $\eta$ Aquarids and Orionids, and showed that the other two are indeed evidenced in radar meteor orbit data.

The structure and evolution of the Taurid complex has also been a topic of investigation (Steel *et al.* 1991; Štohl & Porubčan 1992; Asher *et al.* 1993). Steel *et al.* modelled the complex on the basis of the parent being a giant comet which entered the inner solar system some time 10,000–20,000 years ago.

## IV. METEOROID ORBITS D.I.STEEL

Since much of the necessary material on orbits has been covered in other sections of this report, particularly sections II and III, the present section will be relatively short.

As noted elsewhere, a catalogue of about 68 000 individual meteoroid orbits in machine-readable form is available from B.A.Lindblad at the IAU Meteor Data Center, Lund Observatory, Box 43, 22100 Lund, Sweden (Lindblad 1991a). This includes over 60 000 radar meteor orbits from various surveys in the U.S.S.R., the U.S.A. and Australia, photographic meteor orbits from the U.S.A. and the U.S.S.R., faint TV meteor orbits from Canada, and all the fireball orbits from the Prairie Network (U.S.A.) and Meteorite Orbits and Recovery Program (Canada). Some fireball orbits are also available from the European Network, although others are available from the Ondřejov Observatory in the Czech Republic (see section II). Examples of the sorts of data available have been given by Steel (1991).

Almost all of the orbits archived at the IAU MDC were collected pre-1976. In the years since then a number of groups of amateurs, in particular, have determined smaller (but significant) numbers of orbits using 35 mm cameras and similar, and such efforts have been concentrated on specific showers such as the Geminids and the Perseids (*e.g.* Koseki *et al.* 1990). Some mention of these has also been made in sections II and III; see also Lindblad (1991b) for an assessment of the orbits measured from Japan.

However, in terms of the pure bulk of data throughput, the new meteor orbit radar (AMOR) recently built in New Zealand by Baggaley and co-workers is the most significant development for over two decades. To the time of writing over 300 000 individual meteoroid orbits have been determined, to a limiting magnitude of +12–13 (limiting size about 100 $\mu$m). Full details of the system should be published soon (W.J.Baggaley *et al.*, QJRAS, submitted), with preliminary information having been given in various shorter papers (Baggaley *et al.* 1992a,b; Baggaley *et al.* 1993a). A preliminary analysis of the data indicates that about 1% of the measured orbits may be hyperbolic (Baggaley *et al.* 1993b).

An example of the usefulness of this new radar is as follows. During the 1980's the very great interest in the apparition of P/Halley led to several investigations of the orbital evolution of the meteoroid stream associated with that comet, which gives rise to the $\eta$ Aquarid and Orionid meteor showers. The best observed of these two is the $\eta$ Aquarid shower, but Lindblad (1990) showed that the orbital evolution studies had made use of a 'mean' orbit based upon just one meteor! Lindblad extended that list to a total of 16 orbits; Baggaley *et al.* (1992b) have now presented a mean orbit based upon 361 $\eta$ Aquarids, with over a thousand orbits from that shower now in hand from observation campaigns in 1990–93. In the context of the Halleyid stream, it should also be noted here that Obrubov (1993) has studied the orbital evolution of the comet, and finds two other theoretical showers (at quite different times of year, and different radiants), which apparently are evidenced in meteor surveys.

Other specific campaigns using the New Zealand radar have targetted the $\delta$ Aquarid showers and the times at which Apollo asteroid-related showers have been predicted; the data from these campaigns are now under analysis.

## V. RADAR METEORS J.JONES

One of the most exciting advances in meteor radars has been the development of the AMOR radar meteor orbit system in New Zealand (Baggaley *et al.* 1992a,b, 1993a). The geometry of the system enables meteor trajectories to be determined without measurements of the Fresnel oscillations making reduction of the data fast enough to measure the orbits of ~1 500 meteors brighter than +13 magnitude per day. Some mention of the results obtained with the AMOR system has been made in section IV.

There has been a significant increase in the use of radiant imaging radars which use measurements of the echo direction to determine radiant distributions. Watanabe *et al.* (1991) have used data from an MST radar to study the structure of the Geminid radiant, while Jones & Webster (1991) have adapted the technique for use with a short-hop forward-scatter system. Andreev *et al.* (1991) have extended the method so that it can be used to recover sporadic meteor radiant distributions.

The revival of interest in meteor-burst communication systems has stimulated Jones & Jones (1990a,b,

1991) to develop a detailed theoretical treatment of the oblique-scatter from underdense trains. Jones (1992) has shown how the WKB approximation may be applied usefully to the case of very overdense trains. Jones & Webster (1992), Cevolani & Hajduk (1993) and Cevolani *et al.* (1993) have developed short-hop forward-scatter systems with the aim of improving meteor-burst communication and to find ways of making forward-scatter systems into useful astronomical tools.

The persistent problem of the attenuation associated with both the finite velocity effect and the initial radius of the train has received renewed attention. Multi-frequency studies by Steel & Elford (1991) have indicated that the attenuation may be much more severe than previously recognised so that the rate of mass influx from small high altitude meteoroids may have been greatly underestimated. The formation of the initial radius has been modelled by Grusha (1991) who has considered the effects of fragmentation, while the diffusion of meteor trains has been studied by Shodiev (1992) and ambipolar diffusion of a multi-ion plasma has been investigated by Jones & Jones (1990c). Jones (1992) has had another look at the problem of the ambipolar diffusion of a meteor train in the presence of a magnetic field and shown that the cylindrical geometry allows a closed-form solution which indicates that the effect of the magnetic field is felt when the train is very closely aligned with the magnetic field lines. Novikov & Pecina (1990) have investigated the effect of fragmentation on the Fresnel oscillations.

Šimek & McIntosh (1991) have investigated the cross-section of the Quadrantid stream using radar data. Kostylev (1992) has deduced many physical characteristic of the Draconid meteor stream from radio-meteor observations made in 1985. Bibarsov *et al.* (1991) have addressed the problem of determination of meteoroid mass and density from single station radar observations. Babadzhanov & Bibarsov (1992) have determined the mass distribution of sporadic meteors from the observations of overdense radio-meteors. The head-echo phenomenon has been explored again by Ol'khovatov (1991) and also by Jones & Webster (1991), who have been able to determine from an analysis of simultaneous radar and visual observations of meteors how the probability of getting a head echo depends on range and visual magnitude for several showers.

## VI. TELEVISION METEORS R.L.HAWKES

Many researchers are now employing low light level television (LLLTV) methods for the detection of meteors, with active work underway in (at least) Canada, the Czech Republic, Japan, the Netherlands, Tajikistan, and the United States. The cost of such systems (and the microcomputer-based frame-grabbing cards needed for analysis) has fallen to the point where a number of amateur observers now use LLLTV equipment. For example, in Japan alone there are at least 13 different detection systems in operation for studies of the meteoroid mass distribution and flux, radiant points, trajectories and orbits, spectra and light curves (Fujiwara 1993). Indeed the distinction between 'amateur' and 'professional' now has little meaning in this field, with the the best amateur groups performing careful analyses of results and publishing in the scientific literature. Examples would be the two station work recently published by groups in the Netherlands (de Lignie *et al.* 1993; de Lignie 1993) and Japan (Ueda & Fujiwara 1993a; Suzuki *et al.* 1993). Specific advice regarding the selection and operation of LLLTV detection systems has been published (Hawkes 1990a,b).

While the number of active observing groups has grown significantly, and the number of partially processed and archived LLLTV meteors is probably in the tens of thousands, the number of precisely reduced LLLTV meteor atmospheric trajectories and orbits remain under one thousand, with little increase since the mid-1980's. As pointed out in a recent review (Hawkes 1993), the time required by current video-based analysis procedures is the main limiting factor. Hopefully, this roadblock will be overcome in the next few years through more automated and powerful processing software, and we will see an increasing number of TV meteor orbits archived in the IAU Meteor Data Center in Lund, Sweden. At the moment, it is important for those using LLLTV data to realize that only a small fraction of the year is represented in currently-published summaries, and some of the major showers are not represented at all. The Geminid shower has now been studied by two-station LLLTV (de Lignie *et al.* 1993) and additional observations of the Perseids have been published (Rozhilo *et al.* 1990). Television has not been extensively used for mass/magnitude distributions, and the recent study on the Geminid shower is significant (Ueda & Fujiwara 1993b). The 1993 Perseid shower was recorded by a variety of LLLTV equipment in Europe, North America and Asia, and the profile of this shower for faint magnitudes should soon be clarified. A D-criterion stream search has now been conducted (Jopek 1993) on the published television orbital data with 6 clear and 20 tentative associations, although the strong bias in the observational sample must be kept in mind. Techniques for the determination of meteor parameters from single station LLLTV measurements were independently developed in Canada and Tajikistan in the mid-1980's. Single station techniques have recently been applied to an analysis of 21 bright (to +2.4) video meteors (Malyshev 1992). Single station techniques offer a less time consuming way to obtain basic data on shower meteors with reasonable precision, and should be more widely used.

Recent published contributions in the area of television meteor spectra include a detailed study of three faint meteors (Mukhamednazarov & Mal'tseva 1990), the results suggesting a very similar chemical composition for all three. In addition, a sophisticated LLLTV spectrum system is now in routine operation in the Czech Republic. A search for wake in faint television meteors (Robertson & Hawkes 1992) has yielded the surprising result that very few LLLTV meteors exhibit wake within the limits of the equipment. This finding (which is supported by more recent unpublished work) has important implications for models of the structure and fragmentation of dustball meteors. Techniques for video photometry have been developed and applied to an analysis of light curves of faint, double station, sporadic meteors (Fleming *et al.* 1993). The light curves were, on average, symmetric about the point of maximum luminosity. There has been recent LLLTV detection of a meteor cluster with at least five almost-simultaneous meteors, and evidence of finer scale fragmentation (Piers & Hawkes 1993). It is probable that CCD astronomical cameras at slower than conventional video frame rates will increasingly be employed for meteor detection. Indeed, it was initially believed that a meteor outburst had been detected by the CCD camera on the Canada-France-Hawaii Telescope (Brown *et al.* 1992), although subsequently a non-meteoric explanation has been proposed (Jenniskens *et al.* 1993).

While there have, over the past several decades, been occasional simultaneous television-radar and television-visual meteor observations, LLLTV has not been as effectively employed as is possible for the calibration of different meteor observing methods. Recent excellent work has used LLLTV to estimate the errors in telescopic meteor observations (Pravec 1992; Pravec & Bocek 1992). A television zenithal hourly rate (TVZHR) standard has been defined (Hawkes 1990b).

The most spectacular video meteor records are, without a doubt, the 14 videotapes obtained from various locations in the eastern United States of the fireball associated with the Peekskill meteorite fall (1992 October 9). These are the first ever motion picture recordings of a fireball with an associated meteorite fall. There is a wealth of dynamic detail with a complex and rapidly changing fragmentation, the video records now being analysed. With the increasing availability of camcorders among the general public, serendipitous recording of bright, long lasting fireballs will become increasingly common, and will represent a new and valuable source of data on fireball atmospheric dynamics.

## VII. DUST CHARACTERISTICS

E.GRÜN

In the time period 1990 to 1993 new spacecraft data on interplanetary dust (IPD) have become available, both from interplanetary space and near-Earth. NASA's *Galileo* and *Ulysses* spacecraft made measurements of IPD from Venus to Jupiter. ESA's *Giotto* spaceprobe flew by its second comet: P/Grigg-Skjellerup. The Japanese *Hiten* spaceprobe explored the near-Earth and lunar environment. Analyses of the surfaces of NASA's Long Duration Exposure Facility (LDEF), which was retrieved in 1990 after six years in space, are still revealing new information on IPD (natural particles) and man-made space debris. In 1991 the proceedings of a conference on IPD were published (Levasseur-Regourd & Hasegawa 1991): this will be the reference book on IPD for some years to come.

IPD data from the *Galileo* and *Ulysses* spacecraft covering the heliocentric distance range 0.7–5.4 AU are described by Grün *et al.* (1992a): they show that zodiacal dust inside about 3 AU orbits the Sun in low eccentricity, low inclination orbits.

Results from the Jupiter flyby of *Ulysses* are reported by Grün *et al.* (1992b); the discovery of periodic dust streams originating within the jovian system and of interstellar dust are reported by Grün *et al.* (1993). Interstellar dust grains are identified by their retrograde trajectories and hyperbolic speeds at the position of *Ulysses*. First ideas about mechanisms for the generation of the *Ulysses* dust streams are discussed by Horanyi *et al.* (1993) and by Hamilton & Burns (1993).

The *Giotto* flyby of P/Grigg-Skjellerup in 1992 (McDonnell *et al.* 1993a; Levasseur-Regourd *et al.* 1993) showed that this comet is much less dusty than P/Halley.

The *Hiten* satellite was launched in 1990 and reached a maximum geocentric distance of 1.5 million km. After three years in orbit it crashed onto the Moon in 1993 April. The dust instrument on board monitored the dust environment near Earth and in interplanetary space (Iglseder *et al.* 1993).

An important question of the analyses of samples retrieved from LDEF is the separation of natural meteoroids from space debris. This is done both by studying the impact flux directions and by chemical analysis of residues in impact craters (*e.g.* McDonnell *et al.* 1993b). Both methods show that debris dominates the micron-sized particulates in low-Earth-orbit.

Progress has been made in the analysis and theory of IPD particles collected in the stratosphere. Significant enrichments in volatile elements compared to CI chondrites has been found (*e.g.* Gibson 1992). This observation may be interpreted as implying that these particles consist of very primitive solar system material that had never seen temperatures above 500°C. However, routine analyses of trace elements in nanogram particles (Jessberger *et al.*, 1992; Flynn & Sutton 1992) indicate that atmospheric effects may alter the volatile content of such particles.

Searches for the infrared signature of circumsolar dust during the 1991 solar eclipse failed to produce a positive result (Hodapp *et al.* 1992; Lamy *et al.* 1992). Such signatures were observed during the 1966 eclipse; these signatures may therefore be a time-dependent phenomenon.

Considerable progress has been made in determining the optical properties of fluffy porous dust aggregates (Kozasa *et al.* 1992; Mukai *et al.* 1992). Earlier approaches used simple spherical grains to model zodiacal light. However, studies of IPD particles and comet dust show that a significant fraction of dust grains is of more a complex nature and, therefore, the new results are more realistic.

## VIII. TEKTITES AND IMPACT GLASSES C.KOEBERL

Important progress has been made in the study of tektites and other glasses formed by meteorite impact. The study of tektites is closely linked with the investigation of impact craters and impact processes in general which are of great importance in planetary science. Impact craters are known for two of the four well-defined tektite strewn fields but no unequivocal association with a source crater has yet been possible for the Australasian and North American strewn fields. Hartung (1990) proposed Lake Tonle Sap in central Cambodia as a likely candidate for the Australasian tektite source crater. No direct evidence is yet available regarding the impact origin of Tonle Sap but this proposal is in agreement with a location derived from geographic variations in the abundance of microtektites (Glass 1993). Geochemical (Koeberl 1992a) and isotopic (Blum *et al.* 1992) analyses of Australasian tektites are also consistent with such a source location and favour a single large impact. Wasson (1991) proposed that the Australasian tektites originated in a multitude of small impacts; however, this proposal is difficult to reconcile with chemical and isotopic data. Schnetzler (1992) provided a detailed analysis of the distribution of some Australasian tektites and suggested that the source crater is situated in Laos.

Glass & Wu (1993) discovered shocked impact melts, quartz, and coesite and stishovite (high-pressure modifications of quartz) to be associated with microtektite-bearing layers at numerous deep-sea sites in the Australasian and North American tektite strewn fields, providing another direct link to impact processes. Schneider *et al.* (1992) and Glass *et al.* (1991) made a detailed study of the stratigraphy of microtektite-bearing layers in the Australasian and Ivory Coast strewn fields and concluded that the associated impact events were not related to the near-by geomagnetic polarity reversals. Regarding a source crater for the North American tektite strewn field, Poag *et al.* (1992) found a small structure on the continental shelf off the eastern coast of the U.S.A., but no definitive conclusions as to an impact origin of the structure are available so far. Using the distinctive characteristics of the rhenium-osmium isotope system, Koeberl & Shirey (1993) were, for the first time, able to provide unequivocal evidence for the presence of a small meteoritic component in tektites which otherwise have a composition indistinguishable from that of upper terrestrial crust. Glass & Wu (1992) and Fudali (1993) were able to show convincingly that there is no evidence for the occurrence of 'young' tektites (*i.e.* that are supposed to have fallen only recently, in contrast to their older radiometric age). These two important papers once again reiterate that the so-called 'age paradox' which is still occasionally advanced, is in fact a red herring.

Considerable progress was made regarding clarification of the nature of the famous Cretaceous-Tertiary (K-T) boundary event, 65 million years ago. It is now firmly established that a gigantic impact occurred at that time, and the 200–300 km diameter Chicxulub impact structure in Yucatan, Mexico, was identified as the source crater (Sharpton *et al.* 1992), making it the largest known impact crater on Earth. Glasses were discovered at a K-T boundary site in Haiti (Sigurdsson *et al.* 1991) and were confirmed to be of impact origin (Koeberl & Sigurdsson 1992; Koeberl 1992b). Isotope geochemistry confirmed that these impact glasses originated from the Chicxulub crater (Blum *et al.* 1993). As new impact craters and impact glasses are discovered (*e.g.* Claeys *et al.* 1992) it becomes clear how important impact processes have been in the evolution of the Earth.

## IX. METEORS AND AERONOMY W.J.BAGGALEY

The following is a summary of the work into the aeronomy of meteoric products and the fate of meteoric material subsequent to ablation. It is useful to consider the various topics in order of increasing distance from the immediate meteor trail invironment.

*Meteor coma:*

Work has continued on the phenomenon of the head echo: by collating visual and radar data Jones & Webster (1991) have shown how the plasma coma size depends on meteor parameters, while Ol'khovatov (1991) has developed a model for radar scattering as due to plasma turbulence resulting from the rapid injection of metals into the surrounding atmosphere. The probability of occurrence of visual trains as a function of shower type has been tabulated by Rubio (1992).

*Initial expansion and diffusion:*

Grusha (1991) considered fragmentation effects and micro-atmospheric density inhomogeneities to model the dependence of plasma initial expansion on meteor speed and height, and used two-wavelength data to test the model. The expansion of a meteoric plasma into the atmosphere depends on the ambient electric field, and the geomagnetic field (Jones 1992). Jones & Jones (1990c) gave solutions for the case of diffusion of a mixture of ions having different mobilities. Shodiev (1992) gave data on the dependence of the effective diffusion coefficient on both height and local time and the role of turbulent diffusion.

*Aeronomy of the meteor region:*

Since the ionic concentration of a meteoric plasma column is affected by reaction chemistry, it is possible, by studying enduring echo characteristics (and providing a correct understanding of the radar reflection process is available: Jones 1991), to realise a diagnostic for ozone profile determination (Jones *et al.* 1990).

*Deposited products:*

Kamijo (1991) modelled micrometeoroid ablation and subsequent re-condensation of vapour and coagulation. The general problem of the fate of ablation products and micrometeoritic material and of subsequent re-condensation and coagulation to form layers (Begkhanov *et al.* 1992) and aerosols (Lebedinets & Kurbanmuradov 1992) has received attention, as has the global balance of sulphate aerosols under the action of both cometary and volcanic sources (Lebedinets 1992). Thomas (1991) has provided a comprehensive review of mesospheric cloud aeronomy.

*Meteoric ion layers:*

Both rocket-borne mass spectrometers (Steinweg *et al.* 1992) and lidars (Kane *et al.* 1992; Kane & Gardner 1993), measuring positive ions and neutrals respectively, have yielded composition, abundances and vertical structure of metal layers while incoherent-scatter observations of have given high resolution profiles of ion layers (Bristow & Watkins 1993). With such detailed layer data and with improved chemical reaction schemes (*e.g.* Swider 1992) it is possible to model the formation and decay of the meteoric metal layers. Rocket-borne mass spectrometers have also permited detailed study of heavy negative ion clusters at the mesopause which have their source in meteoric smoke particles (Schulte & Arnold 1992). At lower altitudes, Krieger & Arnold (1992) have found aerosols at 40 km using a balloon-borne mass spectrometer and discussed the paths taken meteoric metallic species to reach this level.

*Ionospheric effects:*

Though it is known that there is little direct relation between meteoric influx and ionospheric $E_s$ in the short term (hours), Baggaley (1990) presents evidence for close seasonal association. Some correlation was found between $E_s$ and fireball events (Rajaram & Chandra 1991).

*Atmospheric dust:*

The effect of dust created by the 1908 Tunguska event in producing large scale sky luminescence increases (Bronshten 1992a) and noctilucent cloud formation (Romejko 1991) has been considered. On a global scale, a source of water and oxygen from the terrestrial influx of small comets and dust was suggested by Lebedinets (1991); the climatic effects of cometary/asteroid impact dust was discussed by Covey & Thompson (1991).

*Electromagnetic effects:*

Investigation of electrophonic sounds from large meteor fireballs has continued (Keay 1992a, 1993) and Astapovich's empirical conclusion that only fireballs brighter than mag −9 produce sustained electrophonic sounds has been substantiated on the basis of Keay's model (1992b). Keay and Ostwald (1991) have conducted laboratory experiments revealing that mundane objects can transduce audio-frequency electromagnetic emissions into sound. Keay (1992c) has shown that the reporting rate of electrophonic fireballs has greatly increased since the effect was explained physically, and he has examined the substantial contributions of Chant concerning electrophonic sounds produced by aurorae (Keay 1990). Bronshten (1992b) reviewed the models of the electrical and electromagnetic processes in meteoric plasma, including a discussion of train currents and electrophonic fireballs.

## X. REFERENCES

Andreev V.V., Bel'kovich O.I., Filimonova T.K., Siderov V.V., 1991, in Harris & Bowell, 17–22.

Asher D.J., Clube S.V.M., Steel D.I., 1993, in Štohl & Williams, 93–96.

Babadzhanov P.B., Bibarsov R.Sh., 1992, Solar Sys. Res., 26, 103–108.

Babadzhanov P.B., Hajduk A., Obrubov Yu.V., Pushkarev A.N., 1991, Sol. Syst. Res., 25, 153–160.

Babadzhanov P.B., Obrubov Yu.V., 1991a, Astron. Vestn., 25, 387–407.

Babadzhanov P.B., Obrubov Yu.V., 1991b, Astron. Zh., 68, 1074–1085.

Babadzhanov P.B., Obrubov Yu.V., 1992a, in Harris & Bowell, 27–32.

Babadzhanov P.B., Obrubov Yu.V., 1992b, Celest. Mech. Dyn. Astron., 54, 111–127.

Babadzhanov P.B., Obrubov Yu.V., 1993, in in Štohl & Williams, 49–52.

Baggaley W.J., 1990, Planet. Space Sci., 38, 145–147.

Baggaley W.J., Steel D.I., Taylor A.D., 1992a, in Harris & Bowell, 37–40.

Baggaley W.J., Taylor A.D., Steel D.I., 1992b, *Periodic Comets*, eds. J.Fernández & H.Rickman, Universidad de la República, Montevideo, Uruguay, 115–124.

Baggaley W.J., Taylor A.D., Steel D.I., 1993a, in Štohl & Williams, 245–248.

Baggaley W.J., Taylor A.D., Steel D.I., 1993b, in Štohl & Williams, 53–56.

Begkhanov, M., Kurbanmuradov O., Lebedinets V.N., 1992, Sol. Syst. Res., 26, 212–220.

Betlem H., de Lignie H., 1990, in Lagerkvist *et al.*, 509–512.

Betlem H., ter Kuile C., de Lignie H., 1993, in Štohl & Williams, 161–164.

Bibarsov R.Sh., Narziev M., Chebotarev R.P, 1991, Solar Sys. Res., 24, 212–216.

Blum J.D., Chamberlain C.P., Hingston M.P., Koeberl C., Marin L.E., Schuraytz B.C., Sharpton, V.L., 1993, Nature, 363, 325–327.

Blum J.D., Papanastassiou D.A., Koeberl C., Wasserburg G., 1992, Geochim. Cosmochim. Acta, 56, 483–492.

Borovička J., 1993a, in Štohl & Williams, 303–306.

Borovička J., 1993b, Astron. Astrophys., in press.

Borovička J., Ceplecha Z., 1992, Astron. Astrophys., 257, 323–328.

Bristow W.A., Watkins, B.J., 1993, J. Atmos. Terr. Phys., 55, 873–894.

Bronshten V.A., 1991a, Sol. Syst. Res., 24, 102–110.

Bronshten V.A., 1991b, Sol. Syst. Res., 24, 206–211.

Bronshten V.A., 1992a, Sol. Syst. Res., 25, 93–104.

Bronshten V.A., 1992b, Sol. Syst. Res., 25, 369–381.

Brown P., Asher D., Steel D., 1992, WGN, 20, 28–31.

Brown P., Jones J., 1993, in Štohl & Williams, 57–60.

Ceplecha Z., 1992, Astron. Astrophys., 263, 361–366.

Ceplecha Z., 1993, Astron. Astrophys., in press.

Ceplecha Z., Borovička J., 1992, in *Interrelations between physics and dynamics for minor bodies in the solar system*, eds. D.Benest & C.Froeschlé, Editions Frontières, Gif-sur-Yvette, France, 309–368.

Cevolani G., Hajduk A., 1993, in Štohl & Williams, 253–256.

Cevolani G., Hajduk A., Kingsley S.P., 1993, in Štohl & Williams, 257–260.

Chyba C.F., Thomas P.J., Zahnle K.J., 1993, Nature, 361, 40–44.

Claeys P., Casier J.G., Margolis S.V., 1992, Science, 257, 1102–1104.

Covey C., Thompson S.L., 1991, Bull. Am. Astron. Soc., 23, 1150–1151.

de Lignie M., 1993, Radiant, 15, 44–46.

de Lignie M., Jobse K., Schievink R., 1993, in Proc. Int. Meteor Conf. 1992, eds. D.Očenáš & P.Zimnikoval, Observatory Banská Bystrica, Slovak Republic, 59–62.

Emel'yanenko V.V., 1991. Sol. Syst. Res., 24, 199–202.

Emel'yanenko V.V., 1992a, Astron. Vestn., 26, 58–66.

Emel'yanenko V.V., 1992b, Celest. Mech. Dyn. Astron., 54, 91–110.

Evans S.J., Ridley H.B., 1993, J. Brit. Astron. Assoc., 103, 27–29.

Fleming D.E.B., Hawkes R.L., Jones J., 1993, in Štohl & Williams, 261–265.

Flynn G.J., Sutton S.R., 1992, Proc. Lunar Planet. Sci. Conf., 22, 171–184.

Fudali R.F., 1993, Meteoritics, 28, 114–119.

Fujiwara Y., 1993, in Štohl & Williams, 265–268.

Gibson E.K., 1992, J. Geophys. Res., 97, 3865–3875.

Glass B.P., 1993, Meteoritics, 28, 354.

Glass B.P., Kent D.V., Schneider D.A., Tauxe L., 1991, Earth & Planet. Sci. Lett., 107, 182–196.

Glass B.P., Wu J., 1992, Meteoritics, 27, 605–608.

Glass B.P., Wu J., 1993, Geology, 21, 435–438.

Gorbanev Yu.M., Kramer E.N., Skoblikova L.Ya., Shestaka I.S., 1992, Astron. Vestn., 26, 113–120.

Grün E., *et al.*, 1992, Geophys. Res. Lett., 19, 1311–1314.

Grün E., *et al.*, 1992, Science, 257, 1550–1552.

Grün E., *et al.*, 1993, Nature, 362, 428–430.

Grusha G.V., 1991, Sol. Syst. Res., 25, 58–62.

Gyssens M., Knöfel A., Rendtel J., Roggemans P., 1991, in Levasseur-Regourd & Hasegawa, 335–338.

Hamilton D.P., Burns J.A., 1993, Nature, 364, 695–699.

Harris A.W., Bowell E.L.G., eds., 1992, *Asteroids, Comets, Meteors 1991*, Lunar and Planetary Institute, Houston, Texas, USA.

Hartung J.B., 1990, Meteoritics, 25, 369–370.

Hasegawa I., 1990, Publ. Astron. Soc. Japan, 42, 175–186; 42, 601.

Hasegawa I., 1992, Celest. Mech. Dyn. Astron., 54, 129–142.

Hasegawa I., 1993, in Štohl & Williams, 209–223.

Hasegawa I., Ueyama Y., Ohtsuka K., 1992, Publ. Astron. Soc. Japan, 44, 45–54.

Hawkes R.L., 1990a, WGN, 18, 145–151.

Hawkes R.L., 1990b, WGN, 18, 152–158.

Hawkes R.L., 1993, in Štohl & Williams, 227–234.

Hills J.G., Goda, M.P., 1993, Astron. J., 105, 1114–1144.

Hodapp K.W., MacQueen R.M., Hall D.N.B., 1992, Nature, 355, 707–710.

Horanyi M., Morfill G., Grün E., 1993, Nature, 363, 144–146.

Hughes D.W., 1990, Mon. Not. Roy. Astron. Soc., 245, 198–203.

Iglseder H., Grün, E., Münzenmayer R., Svedhem, H., 1993, in Štohl & Williams, 377–380.

Jenniskens P., Cailloux M., de Lignie M., Kuiper J., 1993, WGN, 21, 32–36.

Jessberger, E., *et al.*, 1992, Earth & Planet. Sci. Lett., 112, 91–99.

Jones J., Jones W., 1990a, Planet. Space Sci., 38, 55–66.

Jones J., Jones W., 1990b, Planet. Space Sci., 38, 925–932.

Jones J., Jones W., 1991, Planet. Space Sci., 39, 1289–1296.

Jones J., Jones W., 1993, Mon. Not. Roy. Astron. Soc., 261, 605–611.

Jones J., McIntosh B.A., Šimek, M., 1990, J. Atmos. Terr. Phys., 52, 253–258.

Jones J., Webster A.R., 1991, Planet. Space Sci., 39, 873–878.

Jones J., Webster A.R., 1992, in Harris & Bowell, 273–276.

Jones W., 1991, Planet. Space Sci., 39, 1283–1288.

Jones W., 1992, Planet. Space Sci., 40, 1487–1497.

Jones W., Jones, J., 1990c, J. Atmos. Terr. Phys., 52, 185–191.

Jopek T.J., 1993, in Štohl & Williams, 269–272.

Kamijo F., 1991, in Levasseur-Regourd & Hasegawa, 303–306.

Kane T.J., Gardner C.S., 1993, Science, 259, 1297–1300.

Kane T.J., Mui P.H., Gardner C.S., 1992, Geophys. Res. Lett., 19, 405–408.

Kazantsev A.M., Sherbaum L.M., 1990, Sol. Syst. Res., 24, 47–51.

Keay C.S.L., 1990, J. Roy. Astron. Soc. Canada, 84, 373–382.

Keay C.S.L., 1992a, in Harris & Bowell, 297–300.

Keay C.S.L., 1992b, Meteoritics, 27, 144–148.

Keay C.S.L., 1992c, Scientometrics, 23, 355–359.

Keay C.S.L., 1993, in Štohl & Williams, 315–318.

Keay C.S.L., Ostwald P., 1991, J. Acoust. Soc. Am., 89, 1823–1824.

Koeberl C., 1992a, Geochim. Cosmochim. Acta, 56, 1033–1064.

Koeberl C., 1992b, Geochim. Cosmochim. Acta, 56, 4329–4332.

Koeberl C., Shirey S.B., 1993, Science, 261, 595–598.

Koeberl C., Sigurdsson H., 1992, Geochim. Cosmochim. Acta, 56, 2113–2129.

Kokhirova G.I., 1993, Astron. Vestn., 27, 100–112.

Korobejnikov V.P., Chushkin P.I., Shurshalov L.V., 1991, Sol. Sys. Res., 25, 242–255.

Koseki M., Sekiguchi T., Ohtsuka K., 1990, in Lagerkvist *et al.*, 547–550.

Kostylev K.K., 1992, Astron. Vestn., 26, 112–115..

Kozasa T., Blum J., Mukai T., 1992, Astron. Astrophys., 263, 423–432.

Kramer E.N., Shestaka I.S., 1992, Astron. Vestn., 26, 85–90.

Kresák L., 1993, in Štohl & Williams, 147–156.

Krieger A., Arnold F., 1992, Geophys. Res. Lett., 19, 2301–2304.

Lagerkvist C.-I., Rickman H., Lindblad B.A., Lindgren M., eds., 1990, *Asteroids, Comets, Meteors III*, University of Uppsala, Sweden.

Lamy, P.L. *et al.*, 1992, Science, 257, 1377–1380.

Lebedinets V.N., 1991, Sol. Syst. Res., 25, 261–272.

Lebedinets V.N., 1992, Sol. Syst. Res., 26, 280–286.

Lebedinets V.N., Kulikova N.V., Pivnenko E.A., 1990, Sol Syst. Res., 24, 1–11.

Lebedinets V.N., Kurbanmuradov O., 1992, Sol. Syst. Res., 26, 61–69.

Levasseur-Regourd A.C., Hasegawa H., eds., 1991, *IAU Colloq. 126, Origin and Evolution of Interplanetary Dust*, Kluwer, Dordrecht, Holland.
Levasseur-Regourd A.C., *et al.*, 1993, Planet. Space Sci., 41, 167–169.
Lindblad B.A., 1990, in Lagerkvist *et al.*, 551–553.
Lindblad B.A., 1991a, in Levasseur-Regourd & Hasegawa, 311–314.
Lindblad B.A., 1991b, in Levasseur-Regourd & Hasegawa, 299–302.
Lindblad B.A., Porubčan V., 1991, Bull. Astron. Inst. Czechosl., 42, 354–359.
Lindblad B.A., Porubčan V., Štohl, J., 1993, in Štohl & Williams, 177–180.
Malyshev I.F., 1992, Astron. Vestn., 26, 112–114.
Martynenko V.V., Levina A.S., 1991, WGN, 19, 132–136.
McDonnell J.A.M., *et al.*, 1993a, Nature, 362, 732–734.
McDonnell J.A.M., *et al.*, 1993b, Adv. Space Res., 13(8), 87–101.
McIntosh B.A., 1991, in *Comets in the Post-Halley Era*, eds. R.L. Newburn, Jr., M. Neugebauer & J. Rahe, Kluwer, Dordrecht, 557–591.
Miles H., 1991, J. Brit. Astron. Assoc., 101, 291–292.
Miyashita A., Tanaka K., Watanabe H., Watanabe J., 1993, in Štohl & Williams, 319–322.
Mukai T. *et al.*, 1992, Astron. Astrophys., 262, 315–320.
Mukhamednazarov S., Mal'tseva N.V., 1990, Solar Syst. Res., 23, 179–183.
Murayama H., 1990, Tokyo Meteor Network Report No. 9, 53–57.
Novikov G.G., Pecina P., 1990, Bull. Astron. Inst. Czechoslov., 41, 380–387.
Obrubov Yu.V., 1993, in Štohl & Williams, 69–72.
Ohtsuka K., Murayama H., Hidaka E., Shigeno Y., 1991, Tokyo Meteor Network Rep. No. 10, 59–63.
Ol'khovatov A.Yu., 1991, Geomag. Aeron., 31, 606–607.
Olson D.W., Doescher R.L., Watson K.M., 1991, WGN, 19, 130–131.
Padevět V., 1991, Bull. Astron. Inst. Czechosl., 42, 206–215.
Padevět V., Jakeš P., 1993, Astron. Astrophys., 274, 944–954.
Pecina P., 1991, Bull. Astron. Inst. Czechosl., 42, 307–316.
Pecina P., 1993, in Štohl & Williams, 331–334.
Piers P.A., Hawkes R.L., 1993, WGN, 21, 168–174.
Poag C.W., Powars D.S., Poppe L.J., Mixon R.B., Edwards L.E., Folger D.W., Bruce S., 1992, Geology, 20, 771–774.
Pravec P., 1992, WGN, 20, 46–49.
Pravec P., Bocek J., 1992, WGN, 20, 70–83.
Quesada V., Uras S., 1993, in Štohl & Williams, 335–338.
Rabinowitz D.L., 1992, in Harris & Bowell, 481–485.
Rajaram G., Chandra H., 1991, Proc. Indian Acad. Sci. Earth Planet. Sci., 100, 255–65.
Rajchl J., Očenáš D., Zimnikoval P., Peresty R., 1993, in Štohl & Williams, 339–342.
Rendtel J., Heinlein D., 1991, Sterne, 67, 289–294.
Robertson M.C., Hawkes, R.L., 1992, in Harris & E. Bowell, 517–520.
Romejko V.A., 1991, Sol. Syst. Res., 25, 362–368.
Rozhilo A.A., Eremin S.S., Taranukha Yu.G., Kazantsev A.M., 1990, Komet. Tsirk., 417, 12.
Rubio L.R.B., 1992, WGN, 20, 140–144.
Schneider D.A., Kent D.V., Mello G.A., 1992, Earth & Planet. Sci. Lett., 111, 395–405.
Schnetzler C.C., 1992, Meteoritics, 27, 154–165.
Schulte P., Arnold F., 1992, Geophys. Res. Lett., 19, 2297–2300.
Sharpton V.L., Dalrymple G.B., Marin L.E., Ryder G., Schuraytz B.C., Urrutia-Fucagauchi J., 1992, Nature, 359, 819-821.
Shodiev U., 1992, Sol. Syst. Res., 26, 228-232.
Sigurdsson H., D'Hondt S., Arthur M.A., Bralower T.J., Zachos J.C., van Fossen M., Channell E.T., 1991, Nature, 349, 482–487.
Šimek M., McIntosh B.A., 1991, Bull. Astron. Inst. Czechosl., 42, 124–132.
Smirnov V.A., 1992, Astron. Vestn., 26, 116–120.

Spurný P., 1993, in Štohl & Williams, 193–196.

Steel D., 1991, in Levasseur-Regourd & Hasegawa, 291–298.

Steel D.I., Asher D.J., Clube, S.V.M., 1991, Mon. Not. Roy. Astron. Soc., 251, 632–648.

Steel D.I, Elford W.G., 1991, J. Atmos. Terr. Phys., 53, 409–417.

Steel D., Snow P., 1992, in Harris & Bowell, 569–572.

Steinweg A., Krankowsky D., Lammerzahl P., Anweiler B., 1992, J. Atmos. Terr. Phys., 54, 703–714.

Štohl J., Porubčan V., 1992, in *IAU Symp. 152: Chaos, resonance and collective dynamical phenomena in the solar system*, ed. S. Ferraz-Mello, Kluwer, Dordrecht, 315–324.

Štohl J., Porubčan V., 1993, in Štohl & Williams, 41–47.

Štohl, J., Williams, I.P., eds., 1993, *Meteoroids and their parent bodies*, Slovak Academy of Sciences, Bratislava, Slovak Republic.

Stulov V.P., Chernenko T.V., 1991, Sol. Syst. Res. 24, 203–205.

Suzuki K., Akebo T., Suzuki S., Yoshida, T., Ohtsuka K., 1993, WGN, 21, 214–215.

Swider W., 1992, Planet. Space Sci., 40, 247–253.

Terenteva A.K., Bayuk O.A., 1991, Bull. Astron. Inst. Czechosl., 42, 377–378.

Thomas G.E., 1991, Rev. Geophys., 29, 553–575.

Ueda M., Fujiwara Y., 1993a, in Štohl & Williams, 281–284.

Ueda M., Fujiwara Y., 1993b, WGN, 21, 215–217.

Wasson J.T., 1991, Earth & Planet. Sci. Lett., 102, 95–109.

Watanabe J., Nakamura T., Tsuda T., Tsutsumi M., Miyashita A., Yoshikawa M., 1991, in Harris & Bowell, 625–627.

Williams I.P., 1992, in *IAU Symp. 152: Chaos, resonance and collective dynamical phenomena in the solar system*, ed. S. Ferraz-Mello, Kluwer, Dordrecht, 299–313.

Williams I.P., Wu Z., 1993, Mon. Not. Roy. Astron. Soc., 262, 231–248.

Wu Z., Williams I.P., 1992a, in Harris & Bowell, 661–665.

Wu Z., Williams I.P., 1992b, Mon. Not. Roy. Astron. Soc., 259, 617–628.

Wu Z., Williams I.P., 1993, in Štohl & Williams, 77–80.

Zausaev A.F., Pushkarev A.N., 1992, Sol. Syst. Res., 25, 456-459.

I.P.WILLIAMS
Acting President, Commission 22

D.I.STEEL
Secretary, Commission 22