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COMMISSION 22: METEORS AND INTERPLANETARY DUST

(METEORES ET POUSSIERE INTERPLANETAIRE)

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1. INTRODUCTION

The IAU Meteor Data Centre (MDC), maintained at Lund, Sweden, under the direction of Bertil Lindblad, remains a valuable resource for the meteor community. Commission 22 currently has representatives on two inter-commission Working Groups, The Prevention of Interplanetary Pollution (Chair C. S. L. Keay of Commission 22) and Near-Earth Objects (IAU C22 representative I.P. Williams). The Commission has one Working Group of its own, Amateur-Professional Co-operation in Meteors, consisting of P. Jenniskens (Chair), H. Betlem, N. Bone, P. Brown, T. Cooper, I. Hasegawa, R. Hawkes, G. Klar-Renner, V. Porubčan, J. Rendtel, J. Richardson, T. Yoshida. Meetings of the working group were held in Japan in Aug 1997 and in Ithaca, NY in Jul 1999, and circulated periodic electronic newsletters. The working group helped establish professional-amateur collaborations during the Leonid campaigns of November 1998 and 1999, facilitated amateur participation in NASA's Leonid Multi-Instrument Aircraft Campaign, and encouraged publication of amateur observations. The IAU Commission 22 www site has the following **new** location: http://www.mta.ca/ rhawkes/IAU22.

2. WORKSHOPS, COLLOQUIA AND CONFERENCES

Asteroids Comets Meteors 1996, Versailles, France, Jul 1996
Tunguska 1996, Bologna, Italy, Jul 1996
Formation and Evolution of Solids in Space, Erice, Sicily, Mar 1997
IAU JD 6 Interactions between Planets and Small Bodies, Kyoto, Japan, Aug 1997
IAU JD 23 The Leonid Meteor Stream, Kyoto, Japan, Aug 1997
Large Meteorite Impacts and Planetary Evolution, Sudbury, Canada, Sep 1997
Leonid Meteoroids Storm and Satellite Threat Conference, Los Angeles, USA, Apr 1998
Aerodynamics of Meteors: Theory and Observation, Latlengurg-Lindau, Germany, May 1998
Meteoroids 1998, Tatranská Lomnica, Slovakia, Aug 1998
IAU Col. 173 Evolution & Source Regions of Comets & Asteroids, Slovakia, Aug 1998
Leonid MAC Workshop, NASA Ames, CA, Apr 1999
Meteors and Meteor Swarms, EGS, Nice, Apr 1999
Leonid Meteoroids Storm and Satellite Threat Conference II, Los Angeles, USA, May 1999
Asteroids Comets Meteors 1999, Ithaca, USA, Jul 1999

In addition, each year the International Meteor Conference (IMC) is held, sponsored by the International Meteor Organization (IMO). Also, the regular meetings of the Division for Planetary Science (DPS), the Lunar and Planetary Institute, and the Meteoritical Society have many papers of interest to commission members.

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3. PHOTOGRAPHIC METEORS, FIREBALLS, SPECTROSCOPY (P. Spurný and J. Borovička)

The European Photographic Fireball Network (EN) continued systematic operations from 40 stations in the Czech Republic, Slovakia, Germany, and the Netherlands. The current status, detection efficiency and future prospects of the EN were described in Oberst et al. (1998) and Spurný (1997b). The EN010697 Karlštejn fireball (Spurný 1997b) is unique in decades-long records of the fireball networks in that it has a retrograde heliocentric orbit ($i = 138°$) typical of comets yet a behavior in the Earth's atmosphere typical of the hardest component of interplanetary matter. The summary of precise data for 32 prominent fireballs photographed within EN during the period 1993–1996 have been published by Spurný (1997a). Reports on individual EN fireballs are being continuously published in WGN, and more data can be obtained from P. Spurný.

The amateur organizations in Europe and Japan are very active in photographing meteors. Precise data from multistation Leonid observations in 1995 are presented in Betlem et al. (1997). Betlem et al. (1998) present 359 precisely reduced meteor orbits from the DMS photographic meteor survey for the period 1981–1993. Jenniskens et al. (1997) found on the basis of photographic observations that α–Monocerotids penetrate 5 km lower in the atmosphere than Perseid and Orionid meteors of the same brightness and at similar entry conditions. Japanese amateurs continued photographic studies of meteors and fireballs and published their results in Murayama et al. (1997), Shigeno et al. (1997) and Shiba et al. (1998).

Other observations of bright bolides are described in Molau and Gerhardt (1997), Miles (1997), Trigo (1997), Betlem & Spurný (1998), Irwin (1997) and Tatum (1998). Spurný & Borovička (1998) published data about first photographically recorded June Bootid meteor. A possible June Bootid was published by Tomita et al (1998). The atmospheric trajectory and orbit of the bright bolide over Spain in 1996 from combined video and visual observations is presented in Docobo and Ceplecha (1999). Two photographed satelite decays are described in Borovička & Spurný (1997).

Several papers were devoted to the observations and theory of the extremely bright fireballs, which are called ***superbolides***. Detailed study of the St-Robert fireball and subsequent multiple meteorite fall is presented in Brown et al. (1996) and Hildebrand et al. (1997). Reanalysis of the 1993 Lugo event including seismic data was done by Foschini (1998). The Juancheng and El Paso superbolides were reported by Wacker et al. (1998). Light curves from combined optical satellite and ground-based observations are analyzed in Ceplecha et al. (1997). ReVelle (1997) presented historical detections of large bolides using acoustic-gravity waves and derived influx rate of large bolides (source energy 0.1-1000 kt). Infrasound detections of individual bolides were described in ReVelle & Whitaker (1996), ReVelle et al. (1997,) and Bedard & Bloemker (1997) and ReVelle et al. (1998). Electrophonic sounds from large meteor fireballs are studied by Keay (1998).

Theoretical studies of large interplanetary bodies interacting with the Earth's atmosphere are described in several papers. Nemchinov & Popova (1997) analyzed the 1947 Sikhote-Alin event and compared it with the 1994 Marshall islands event. Ceplecha et al. (1996) found luminous efficiencies for the brightest PN bolides. Nemchinov et al. (1997a,b) analyzed optical and infrared satellite observations of large meteoroid impacts. Influx of large meteoroids onto Earth is studied by Ceplecha (1997). Loseva et al. (1998) determined analytical formulae for thermal ablation of large cosmic bodies. Borovička et al. (1998a) performed detailed analysis of one of the largest and well documented bolide - the Benešov bolide. Tunguska event is studied in the special issue of Planet. Space Sci. (Vol. 46, No. 2/3) and also in theoretical works of Svetsov (1996), Lyne et al. (1996), Foschini (1999) and Bronshten (1999). One peculiar high energy event is presented in Docobo et al. (1998).

Physical theory of meteors was described in papers of Ceplecha (1996a,b), Kalenichenko (1996 and 1997a), Ceplecha et al. (1998) and Stulov (1998). Fragmentation of meteoroids in the Earth's atmosphere was studied by Novikov et al. (1996), Korobejnikov et al. (1997) and

Novikov et al. (1998). Kalenichenko (1997b) modeled terminal flares of fireballs. Capture of meteoroids into Earth orbit by grazing atmospheric encounters is studied by Hills & Goda (1997)

Relatively few papers on meteor spectroscopy have been published in the covered period. A review is given in Ceplecha et al. (1998). Borovička & Betlem (1997) analyzed in detail the spectra of two bright Perseid meteors, finding that the hydrogen content in the meteoroids was not larger than in carbonaceous chondrites. The development of two spectral components and some spectral anomalies in meteor flares were also studied. Other Perseid spectra were described by Borovička & Majden (1998) and by Airey (1999). Majden (1998) suggested the use of inexpensive holographic gratings for meteor spectroscopy.

Advancement has been made in the theoretical prediction of meteor spectra. Golub' et al. (1996, 1997) presented predicted UV to IR spectra of bright deeply-penetrating fireballs based on a radiative-hydrodynamic model. Kosarev et al. (1996) published the meteor vapor opacities used in the model. The model shows an increasing role of continuous radiation with increasing size and decreasing height of the meteoroid. Borovička et al. (1998a,b) compared model predictions with real dynamics, light curve and optical spectrum of the bright Benešov fireball. The comparison showed the crucial role of meteoroid fragmentation and the fact that our understanding of the ablation processes is still limited.

4. RADAR METEORS (W.G. Elford)

A detailed update of radar meteor techniques has been published as part of the general review of meteor science by Ceplecha et al. (1998). Observations of head echoes with large aperture radars have continued at Arecibo (430 and 47 MHz) and at the EISCAT facility (930 and 224 MHz). High speed meteoroids of mass about 1 μg from the North Apex sporadic source appear to move in retrograde orbits (Mathews, 1997). Scattering from Bragg structures within a trail has been suggested as the explanation of UHF echoes (Zhou & Kelley 1997). Simultaneous observations with co-located UHF and VHF radars have yielded very similar meteoroid fluxes down to magnitude +10, agreeing well with extrapolated values (Pellinen-Wanberg et al, 1998). The 54 MHz pencil beam radar at Adelaide has been used to determine speeds and decelerations of meteoroids to a very high precision from the measurements of range and phase of head echoes (Taylor et al. 1996a). Measurements of the amplitude of successive echoes along the trajectory of the meteoroid yield a trail profile that shows evidence of flares and fragmentation (Ceplecha et al. 1998, *p.* 418).

The distributions of the orbital elements of about 20,000 meteor orbits in the Harvard Radio Meteor Project, have been reanalysed to remove selection effects associated with trail production, radar detection, and probability of encounter with the Earth. The distributions of eccentricity, aphelion distance, and inclination are dramatically different from earlier analyses (Taylor 1997; Taylor & McBride 1997; Taylor & Elford 1998). The radiant distributions of sporadic sources have been determined by measuring angle of arrival of echoes (Bel'kovich et al. 1997)

A major outcome of *forward scatter* studies has been the determination of the mass distribution of meteoroid streams (Cevolani et al. 1998; Porubčan et al. 1997, 1998). Comprehensive studies of meteor activity over several years have been carried out in northern Europe (Yrjola & Jenniskens 1998) and in north America (Meisel & Richardson, 1998). A network of forward-scatter systems, Global-MS-Net, has been set up by amateur observers (Jenniskens 1998). The main factor determining the characteristics of the reflection region is the meteor velocity (Karpov et al. 1998)

Significant advances in the determination of meteor speed from transverse echoes have occurred. A refinement of the classical method of analysis of Fresnel patterns gives more reliable outcomes (Pecina 1996); the slope of the amplitude v.time profile near the t_0 point has been shown to be a reliable measure of meteoroid speeds (Baggaley et al. 1997); phase measurements prior to the t_0 point give precise speeds with high yields (Cervera et al.

1997). Distribution of meteor speeds from the Harvard Radio Meteor Project data have been reanalysed (Taylor & Elford 1998).

Precise measurements of meteoroid deceleration have been interpreted in terms of gross fragmentation (Elford et al. 1997), while it is claimed that the fragmentation of meteoroids responsible for meteors in the Verniani & Hawkins 1965 catalog is insignificant (Novikov & Zhdanov 1997). A filament of the Perseid stream contains meteoroids that exhibit a relatively high degree of fragmentation (Simek 1996).

Radar data collected during the Leonid shower over a 30 year period in the Czech Republic and the years 1964-1967 in Canada, have been corrected to reveal the long term activity of the shower (Brown et al. 1997). Radar meteor records from 35 Geminid campaigns undertaken in the Czech Republic have revealed mass dependent structure in the stream (Pecina & Simek 1999). A new meteor radar system in Ontario, Canada makes it possible to measure the angle of arrival of meteor echoes to discriminate meteors from different showers (Brown et al. 1998a). The activity and mass index of a new filament in the Perseid stream have been described by Simek & Pecina (1996, 1997).

Estimates of the ambipolar diffusion coefficients in meteor trails from decay of radar echoes show good agreement with values calculated from simultaneous measurements of density and temperature using a lidar (Chilson et al. 1996). Distributions of meteor echo durations from forward scatter observations have been used to estimate the change in ozone concentration at meteor heights (Cevolani et al. 1999). Down the beam echoes detected on two antennas with orthogonal polarization have been used to measure Faraday rotation caused by the ionosphere, thus making it possible to derive the electron density profile between 80 and 120 km (Elford & Taylor 1997).

5. ELECTRO-OPTICAL OBSERVATIONS (R.L. Hawkes)

There are now more than 50 image intensified CCD systems in use for meteor work, with the majority being located in Japan, Canada, United States, Germany, and the Netherlands. The NASA Leonid Airborne mission (Jenniskens & Butow 1998) was instrumental in bringing new optical techniques into meteor observation. Hoffner et al. (1997, 1999) have used resonance lidar to measure Na, K, Ca and Fe in meteor trails. Grime et al. (1999) used a lidar to study meteor trail advection and dispersion. An exciting instrumental development is the use of image intensified high definition television (HDTV) for meteor studies (e.g. Watanabe et al. 1999). One of the most important advances in intensified video meteor work has been the development of two successful computer programs for automatic real–time detection (MeteorScan – Gural, 1997; MetRec – Molau, 1999). Detlef Koschny and collaborators have proposed a new FITS based standard for archival of intensified video observations of meteors: `http://www.so.estec.esa.nl/~dkoschny/vidas/`

Ueda et al. (1997) contributed more than 200 double station television meteors to the growing archive of precision multi-station video orbits. Quadrantid orbits were obtained by de Lignie and Jobse (1996) , while Shigeno & Shioi (1996) and Shigeno et al. (1997a, 1997b) obtained two station television meteor orbits for the period Nov–Jan. de Lignie & Betlem (1999) used double station television observations to study several showers in October. Suzuki et al. (1999) have studied the Giacobinid shower, while Brown et al. (1998) studied the 1996 Leonid shower with a combination of video, visual and radar techniques. Ueda & Fujiwara (1999) report on studies of the Leonids from 1991 and 1996, while Suzuki et al. (1999) provide television observations of the 1995–97 Leonids. de Lignie & Jobse (1997) investigated a number of minor and major showers in August and Shigeno et al. (1999) used 185 double station television observations from the southern hemisphere to search for shower activity and radiant structure in July. Shigeno et al. (1997c) studied the $\eta-Aquarid$ shower with two station video techniques. Molau & Arlt (1997) used single station television observations to study meteor shower radiant structure.

Campbell et al. (1999) developed a new procedure to fitting light curves from intensified video observations of faint meteors, and modelled the constituent grain size implied by the

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light curve shapes. Fujiwara et al. (1998) detected luminosity at 160 km altitude in two very bright Leonid meteors. Koseki et al. (1998) studied the Giacobinid shower with video techniques, confirming the fragile nature of these meteoroids. Kinoshita et al. (1999) report on observations of the 1997 Leonid shower with video techniques which indicated a very short duration outburst, possibly a single meteoroid which was fragmented in interplanetary space.

6. SATELLITE DETECTION OF SUPERBOLIDES (P. Brown and J. Jones)

Instruments on board U.S. Department of Defence satellites have been recording bright flashes associated with the impact of large meteoroids since 1972. The sensors detecting these events consist of both infrared and optical signatures and to date nearly 500 events have been documented. The optical sensors are operated by the U.S. Department of Energy and consist of broadband, unfiltered silicon detectors sensitive to radiation in the 0.4 - 1.0 micron band. These optical sensors are able to detect bolides with peak absolute brightnesses of approximately -17.5 and provide a detailed light curve for each detected event. The Infrared sensors operated by the Department of Defence are more sensitive by several magnitudes than the optical sensors, but only detect events for short periods of time, as they operate in a scanning mode associated with the spin of the satellite. Both sensors are able to detect these bright fireballs in either daytime or nighttime conditions. Further details can be found in Nemchinov et al. (1997a).

Detailed analysis of the most energetic event detected by these sensors, that of Feb 1, 1994 over Micronesia, has been summarized in McCord et al. (1995) and Tagliaferri et al. (1995). Other recent large events recorded by satellite sensors and studied in detail include the Oct 9, 1997 bolide over El Paso, Texas (Hildebrand et al. 1999) and the Juancheng meteorite fall in China (Wacker et al. 1998). The first meteorite producing fireball to be recorded by these satellite sensors resulting in a determination of the pre-atmospheric orbit was the St. Robert meteorite shower over Canada (Brown et al. 1995).

The energy and flux of large meteoroids detected by satellite sensors has been examined in detail by Nemchinov et al. (1997b). Making use of numerical simulations of the passage of large meteoroids through the atmosphere, they compare the results to the satellite data and find that luminous efficiency of these large bodies is 5-10 % increasing with mass. The resulting number–energy curve for the observed satellite events sets a lower limit of 25 events per year in the energy range 10^{12}–10^{13} J over the entire Earth. Ceplecha et al. (1997) compared the light curves of satellite detected fireballs to those observed by ground-based instruments. They were able to show that the population of superbolides observed by satellites is dominated by cometary-type bodies. The flux value of large objects is given in Nemchinov et al. (1997b). Zolensky et al. (1997) have discussed the possible airborne collection of ablation particles associated with satellite detected bolides. Data concerning individual satellite fireballs released by the DoD can be found on the WWW at `http://phobos.astro.uwo.ca/~pbrown/usaf.html`.

7. METEOROID ORBITS (P.B. Babadzhanov and V. Porubčan)

The AMOR (Advanced Meteor Orbit Radar) meteor radar in New Zealand (Baggaley & Bennett 1996; Baggaley 1999a) remains the most efficient facility providing new meteoroid orbits. The radar limiting sensitivity corresponds to a visual magnitude of +14 (mass $\sim 10^{-7}$ g) and a routine operation yields between 300 and 1000 orbits daily. More than 300,000 meteor orbits have been obtained by AMOR since 1990. Though of lower accuracy than photographic orbits, the high data rates allow the statistics of many streams to be well determined (Galligan & Baggaley 1999).

Two larger photographic surveys have been added to the IAU Meteor Data Center in Lund in the last triennium. Babadzhanov et al. (1998) have determined orbits of 154 meteors photographed in Dushanbe (1975-1983). One third of the orbits are the Perseids and 66 are classified as sporadic. Betlem et al. (1998) have reduced a total of 359 meteoroid

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orbits obtained as the result of the Dutch Meteor Society photographic meteor program in 1981-1993. Lindblad (1999) analysed 1425 TV meteoroid orbits available from the IAU Meteor Data Center. The analysis revealed 86 streams, of which 21 streams were recognized in previous photographic searches.

The Arecibo 430 MHz radar is a powerful detector of micrometeors and observation near the apex (Mathews et al. 1997) have shown particles in heliocentric orbits with widely varying eccentricities at high inclinations including at least one observation with eccentricity e>1. Hawkes & Woodworth (1997) announced two positive video detections for meteoroids from interstellar space. Kramer & Markina (1997) suggested that a certain share (about 10-20%) of all hyperbolic orbits is related to the penetration of particles from interstellar space. This topic is further discussed Kramer et al. (1998) and Kramer & Smirnov (1999). The question of real detection of particles of interstellar origin is very important. Ongoing surveys carried out by the AMOR facility (Baggaley 1999a) enable to examine the characteristics of the population of non-bound particles in the inner solar system. Using a data set of ~40,000 orbits from 1996, ~3% of Earth-impacting particles was found to be hyperbolic. Hawkes et al. (1999) examine archived image intensified video data to study source regions for particles of interstellar origin, while Hawkes & Woodworth (1997a) have considered possible production mechanisms. Hawkes et al. (1999) conclude that no more than about 0.2% of photographic meteors have true hyperbolic orbits, while the limited sample of image intensified video orbits suggest that 1–2% are of interstellar origin.

Several analyses utilizing the orbits available at the IAU MDC have been published. Arter & Williams (1997a,b) derived the mean orbit of the April Lyrids and suggest an age of the order of 1.5×10^6 yr for the stream. Lindblad (1999) searched for the ξ-Orionids, Lindblad & Porubčan (1999) for the Orionids and Voloshchuk (1999) discussed the studies of derivation of the mean stream orbits. Jopek et al. (1997) have made a stream search among 502 TV orbits. Valsecchi et al. (1999) and Jopek et al. (1999a, 1999b) have suggested a new criterion for meteoroid stream identification based on variables directly linked to observations and applied it to a sample of 865 precisely reduced photographic meteors and to a set of 3725 radio meteors observed in Adelaide. Baggaley & Galligan (1997), Galligan & Baggaley (1999) and Volochchuk & Kashcheev (1996) discussed methods of cluster analysis of radar meteoroid orbits. From photographic orbits of the Qudrantids Jenniskens et al. (1997a) conclude that the main component of the stream is only about 500 yr old. IRAS has detected dust trails in the orbits of short-period comets, but not in the long-period comets and Jenniskens et al. (1997b) presented a study based on 10 orbits of the α–Monocerotids from 1995, that confirm that a dust trail is brought occasionally in collision with the Earth by planetary perturbations.

The possibility of the existence of meteoroid streams of asteroidal origin is still an area of active research. Obrubov (1999) has reviewed the formation of asteroidal meteoroid streams. Williams & Collander-Brown (1998) investigated the orbital evolution of the Quadrantids and suggest asteroid 5496 (1973 NA) as a possible parent or a fragment of the parent. Asher & Izumi (1998) discussed resonance effects within the Taurid meteoroid complex. Babadzhanov (1998, 1999a, 1999b) has suggested 11 asteroids (Adonis, Oljato, Hephaistos, Cuno, 1982 TA, Poseidon, Mithra, Heracles, Zeus, Jason and 1996 SK) as a part of the Taurid complex. Calculation of the orbital evolution of these asteroids show that they are quadruple-crossers of the Earth's orbit and therefore theoretically may produce four meteor showers each. The existence of meteor showers associated with Taurid Complex Asteroids confirms that these asteroids are probably extinct comets.

The overall sporadic radiant activity and structure of the helion (H) and antihelion (AH) sources at monthly intervals over a period of 103 months have been examined by Poole (1997). The activity in both regions rises to a maximum in mid-year after which the H source decreases significantly and the AH region dominates for the latter half of the year. Voloshschuk et al. (1997) have studied the contribution of asteroids and comets to the complex of stream and sporadic meteoroids. They conclude that for the masses greater than 10^{-5} g, 75% stream meteoroids and 37% sporadic meteoroids are products of

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asteroids. A large-scale longitudinal asymmetry in the distribution of sporadic meteoroids as well as the changes in the mass distribution index with orbital characteristics based on the long-term AMOR data were studied by Baggaley (1999b,c). There are indications that the interplanetary dust population around the Earth's orbit is ~30% greater near solar longitude 0^o than near 180^o. Moreover, there exist longitudinal changes in the mass distribution of the meteoroid population. Further, Sidorov et al. (1999) investigated the annual variation in the radiant distribution of meteors, based on the Kazan meteor radar data from 1987-88 and 1993-94. Andreev (1999) searched for the theoretical velocity and radiant distributions with respect to the densities of meteoroids and known population of asteroids and comets. Dynamical evolution of meteoroids via the Yarkovsky effect was studied by Bottke et al. (1998).

8. METEOR SHOWERS (P. Jenniskens)

Open issues in meteoroid stream evolution are discussed in Jenniskens (1998b). Attention has notably shifted from annual showers to meteor outbursts. The unusually fragile nature of outburst meteoroids has been confirmed for Perseids (Simek, 1996), Draconids (Koseki et al. 1998), June Bootids (Spurný & Borovička 1998) and Leonids. Kinoshita et al. (1999) observed a Leonid meteoroid that had disintegrated into hundreds of fragments prior to entry into Earth's atmosphere. Ofek's (1998) cluster analysis of 1998 Leonids show a small excess on 5 s. timescale.

Observations of the Perseid Filament outbursts (1989-1997) are summarized by Brown & Rendtel (1996), Simek & Pecina (1996, 1997), and Jenniskens et al. (1998a). There are numerous reports of individual Leonid returns. Observing conditions for the 1998 and 1999 return are discussed in Jenniskens et al. (1999b). Reports on what may be the Leonid Filament, a broad shower of bright meteors first seen in 1994, are given in Brown et al. (1997), Foschini et al. 1998, Brown & Arlt (1998), Arlt (1998a), Langbroek (1999) and Betlem & Van Mil (1999). These showers result from comet parent bodies of Halley-type.

Results from the 1998 June Bootids outburst are presented by Hashimoto & Osada (1998), Spurný & Borovička (1998) and Velkov (1999), while visual data are summarized in Rendtel et al. (1998) and Arlt (1999). The Draconid outburst of October 1998 is documented by amongst others (Koseki et al. (1998), Suzuki et al. (1999a), Ueda (1998), Suzuki (1998), Bus (1999), Maegawa et al. (1999), Arlt (1998b), and Watanabe et al. (1999). These pertain to Jupiter-type parents.

The November 1995 α-Monocerotid outburst is documented by Arter et al. (1997b), Jenniskens et al. (1997b) and Jenniskens & Docters van Leeuwen (1997). From multi-station video and photography, Jenniskens et al. (1997b) was able to demonstrate the hypothesis by Jenniskens (1997) that the outburst was caused by dust in long-period orbits, and the periodic disturbances of planetary perturbations on individual meteoroids cause a dust trail to periodically move in the path of the Earth. Other recent outbursts may be those of the μ-Perseids (Miskotte 1996) and June Lyrids (Langbroek 1996).

In an elaborate theoretical study, Brown & Jones (1998) showed that a similar mechanism may be responsible for the Perseid Filament outbursts. The returns of individual years are ascribed to ejecta from different but relatively recent epochs. Grishchenyuk (1996), too, argued that the filament was due to ejecta from the 1862 return. The issue is not settled, however. Based on significant dispersion of photographic orbits, Jenniskens et al. (1998a) argued for an older age and longer accumulation of dust in the Filament, but a selective depletion of dust away from the comet position due to close encounters with Jupiter and Saturn. Williams (1997) pointed out that planetary perturbations by Uranus can selectively deplete the Leonid shower from the comet position. Chambers (1997) gives the dynamic criterion between Halley-type and long-period cometary orbits, which can account for the mutually exclusive nature of *far-comet* and *near-comet* type outbursts. Asher et al. (1999a,b) studied the subset of meteoroids in orbital resonance, and concluded that the Leonid Filament may be the result of such orbital dynamics, specifically as a result of an ejection in 1333.

E.D. Reznikov correctly predicted the return of the Draconid shower at 13h UT, rather than earlier estimates around 17h UT (e.g. Langbroek 1998, Rao 1998). Asher (1999) and McNaught & Asher (1999) have subsequently used similar techniques to predict the times of occurrences of the Leonid shower.

Meteor outbursts are recognized now to be a significant influx anomaly and relevant to the satellite impact hazard (Beech et al. 1997, McDonnell et al. 1997, Jenniskens 1999). The effect of annual showers is explained by McBride (1997). The rich Leonid showers have lead to the deployment of new technologies and increased interest in meteors. Among annual showers, of particular interest remain the Quadrantids (Jenniskens et al. 1997) and Geminids (de Lignie 1998, Pecina & Simek 1999), both of which are young showers with unusual features.

9. DUST CHARACTERISTICS (I. Mann)

Previous in-situ measurements of interstellar dust particles onboard the Ulysses spacecraft have been continued and have been confirmed with dust measurements onboard the Earth orbiting Hiten satellite (Svedhem et al. 1996) and the Galileo spacecraft (Grün et al. 1997). The measurements allowed for detailed studies of the dust flux (Landgraf & Grün 1998) and of the electric grains charging of interstellar dust (Kimura & Mann 1998).

Dust particles in the Kuiper belt have been studied as a dust population that is comparable to dust in circumstellar debris shells. Yamamoto & Mukai (1998) have shown that the impact of interstellar dust onto the surface of Kuiper belt object has a significant contribution to the production of dust particles in the Kuiper belt. In a dynamical model for dust particles produced in the Kuiper belt, Liou & Zook (1999) have suggested that Neptune, by trapping dust particles in mean motion resonances, creates a ringlike structure along its orbit while Jupiter and Saturn are ejecting dust particles from the solar system. Recent analysis of data from the plasma wave experiments on Voyager 1 and 2 has shown a small number of signals that are consistent with impacts of dust particles, with masses beyond 1.2×10^{-14} kg. The fluctuation of the derived density with distance from the Sun measured out to 51 AU with Voyager 1 and 33 AU with Voyager 2 is beyond statistical uncertainties.

For the evolution of dust in the inner solar system Liou & Zook (1998) have shown that we can not always expect dust particles from comets and dust particles from asteroids to have different orbital eccentricities near the Earth orbit. Ishimoto & Mann (1999) have shown that the collisional evolution of dust particles that drift towards the sun under Poynting–Robertson drag most probably changes the size distribution of dust inside the Earth orbit. In an analysis of Ulysses dust measurements, Wehry & Mann (1999) have shown that only a small amount of the dust particles that were detected in unbound orbits are really produced in the near solar region and can be classified as beta meteoroids. The flux rates of beta meteoroids, however, are comparable to previous results.

It is still an open question whether observed features in the infrared brightness of the solar F - corona are associated with the formation of dust rings (Kimura & Mann 1998) and whether they show a variation with the solar cycle. Studies of near solar dust have shown that the formation of dust rings depends critically on the composition of grains (Kimura et al. 1997). While the orbits of very small grains change with the solar cycle variation of the magnetic field (Krivov et al. 1998), the effect is assumed to be too small to have a significant effect on the observed brightness.

10. METEORS AND AERONOMY (W.J. Baggaley)

The fate of meteoric species subsequent to ablation has been studied by modelling the evolution of metals including effects of transport, chemistry, dynamics, electric field interaction, and tides (Helmer et al. 1998, Carter & Forbes 1999). Laboratory measurement of one of the critical charge exchange processes, that with sodium, has been carried out (Levandier et al. 1997). Rocket ion measurements analysed in terms of the role of differing condensation temperatures have been given by Kopp 1997. A novel potassium lidar has been operated during shower times (Hoffner et al. 1999) while Kelley et al. (1998) provided evidence for particle coagulation from derived retardation of diffusion coefficients. Murphy et al. (1998) reported in-situ measurements of meteoric material in aerosols at 5-19 km.

The last few years have seen the recording of meteoric species in the tenuous lunar atmosphere with sodium detection (Levandier et al. 1997) and enhancement during showers (Verani et al. 1998). All sky camera imaging of a Leonid meteoroid impact produced sodium glow opposite the new moon (Smith et al. 1999) was complemented by modeling the generation of a tail of excited atoms in terms of solar radiation pressure (Wilson et al. 1999).

Meteor plasma studies can be used for the sensing of minor atmospheric species: a knowledge of the relevant chemistry enables estimates to be made of the ozone density in the 80-100 km region (Hajduk et al. 1999, Baggaley 1999) as well as indications of possible long-term trends (Cevolani et al. 1999).

In studies into dispersal processes in meteor trains, ambipolar diffusion coefficients derived from meteor plasma have been related to parameters infered from a UV Rayleigh lidar (Chilson et al. 1996). Hocking et al. (1997) related meteor derived diffusion to standard atmospheric models (pressure and temperature). In a twin sodium resonance lidar arrangement (Grime et al. 1999) measures of neutral diffusion have been made.

The role of the general meteoric influx in modifying the Earth's atmosphere is still not clearly understood. Incoherent scatter radar surveys over eight years (Zhou et al. 1999) indicated a night-time E-region enhancement in the post-midnight period attributed to sporadic inflow but any signature from individual showers was unclear. Multiple rocket flight sampling of meteoroic ion layers together with a compilation of available rocket data of ion height-profiles have been completed (Grebowsky et al. 1998) to better establish a picture of ion pathways.

A comprehensive study of the impact ionisation (and luminous) coefficient has been carried out by Jones (1997): the velocity dependence of the coefficient is poorly understood for low speeds where a threshold behaviour is expected. Meteoric ablation products are thought to play a role in the formation of nucleation centres for noctilucent clouds: however in a survey of cloud activity over Europe Gadsden (1998) noted the lack of a correlation with meteor shower activity. Other meteor-related work has been the study of electrophonics (Beech & Foschini 1999); meteor-aided measurements of height changes of the hydroxyl and atomic oxygen airglow layers (Plagmann et al. 1998); small scale shears measured by height changes of radar meteors during the echo life (Baggaley 1999); and the influence on radio-meteors of the rotation of the plane of polarisation by underlying ambient ionisation (Elford & Taylor 1997).

W.J. Baggaley
President of the Commission

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Note: Any articles with more than 3 authors have been reduced to *et al.* due to space limitations. Also note that references to *Meteoroids 1998 ed. W.J. Baggaley & V. Porubčan (Tatranska Lomnica: Astron. Inst. Slovak Acad. Sci.)* have been reduced to Meteoroids 1998.

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