The spectacular airburst over Lugo (Italy) on January 19, 1993

G. Cevolani[1], M. Hajduková[2], L. Foschini[1] and G. Trivellone[1]

[1] *FISBAT-CNR, Via Gobetti 101, 40129 Bologna, Italy*

[2] *Dept. of Astronomy and Astrophysics, Comenius University, Mlynská Dolina, 842 15 Bratislava, The Slovak Republic*

Received: April 15, 1994

Abstract. The paper deals with the spectacular fireball observed on January 19, 1993 and ending with an explosion approximately over the town Lugo (44°25'N, 11°54.6'E).It is shown that the phenomenon was caused by a low density meteoroid entering the Earth's atmosphere at a hypersonic velocity. The shock waves recorded at six seismic stations are shown to be of infrasonic type generated after the blast at the height of about 30 km. The accurate determination of the epicentre by a computer program facilited the search of vaporized and recondensed microremnants of the cosmic body.

Key words: meteors – bolide

1. Introduction

On January 19, 1993, at about 0^h:33^m (UT) an extremely brilliant fireball of the apparent visual magnitude $M_V = (-22 \div -25)$ crossed Northern Italy from South-East to North-West and ended with an explosion approximately over the town Lugo. Observational data and theory of interaction of meteoroids with the atmosphere enable us to characterize this phenomenon in terms of disruption of a low density cosmic body, probably a carbonaceous chondrite or a cometary nucleus. Rabinowitz et al. (1993) suggest that the Earth-crossing small bodies, recently discovered by the Spacewatch telescope (Chyba, 1993), are transported from the main asteroid belt to the Earth approaching orbits by resonant interaction with Jupiter or alternatively they might be debris of extinct short-period comets. The same authors do not exclude that new sources as lunar ejecta or an undetected population of asteroids may be required. The scarcity of the available dynamic and photometric data have not permitted so far to determine the radiant and orbital parameters to be possibly connected with these Spacewatch objects, or with other parent bodies. This paper highlights the importance to determine accurately the explosion height of a cosmic body, as indirect means enabling to reveal its intrinsic composition or nature.

Contrib. Astron. Obs. Skalnaté Pleso **24**, (1994), 117– 124.

2. Description of the event

In the night of January 19, 1993, the CNR forward-scatter meteor radar recorded an exceptional fireball at $0^h33^m29^s$. The radar operates at the peak power of 100 W and is bistatic, with the transmitter in Budrio, near Bologna, and the receiving system in Lecce, in Southern Italy. The system utilizes a 42.7 MHz carrier frequency modulated at 1 kHz and was constructed in order to study the upper atmosphere and meteor physics (Cevolani and Hajduk, 1993; Cevolani et al., 1993a). During the flight of the fireball in the atmosphere, the automatic receiving system in Lecce recorded a saturation echo several minutes long (more than 12 minutes). The strong electromagnetic field associated to the meteor plasma produced a temporary black-out of many households and scientific electric devices. From the magnitude-linear electron density equation for sporadic meteors (McKinley, 1961) it is possible to derive a hypotetical value of the linear electron density close to $q = 10^{24}$ el/m.

The airburst of the Lugo bolide is thought to take place because of its relatively low mechanical strength and with most of energy dissipation occurring in a fraction of the scale height. Attempts to determine accurate values of the dynamic and photometric parameters of the body have shown to be not reliable as the eyewitnesses reports were very often contradictory. Nevertheless, crude estimates of the inclination angle are in the range $8 - 20°$, with an average value of $14 - 15°$. Another important parameter describing the exceptional event, is the apparent visual magnitude M_v which in the first part of trajectory was quite similar to the brightness of the Full Moon and according to estimates reported by some researchers of the Astronomical Institute in Bologna at the peak, the magnitude appeared be -22, or even higher. This terminal value of the bolide brightness is essential in defining the approximate dimensions of the meteoroid (with radius $r \approx 1.5 - 3$ m) according to the mass/luminosity relation (Cevolani et al., 1993b).

During its atmospheric flight, the meteoroid, moving at about 26 km/s, had a heavy ablation and fragmentation with conversion of kinetic energy into heat, light and ionization, exploding after few seconds approximately over the town Lugo. Explosion was the result of high pressure and temperature gradients along the cosmic body. Only an explosive burning can explain the high intensity flash observed for about 1-2 seconds, with plasma formation as consequence of direct transformation of solid matter into ionized gas. The air explosion produced infrasonic low frequency shock waves recorded by seismic stations situated close to the epicentral point.

3. Seismic data analysis

Data from six seismic stations located in the eastern part of Emilia-Romagna (Tab. 1) are available. Three stations monitor and control the environmental impact of geothermal activities and belong to an extended Microseismic Network of Ferrara. The stations are located in Pontisette, Cà Fornasina and Fiorile d'Albero, all near Ferrara (Fig. 1). Other stations (Fig. 2), located in Barisano, Santa Sofia and Poggio Sodo, all near Forlì, belong to the National Institute of Geophysics (ING).

Table 1. Geographic coordinates of sesmic stations.

Station	Latitude	Longitude	Code
Pontisette (FE)	44°52.45′ N	11°32.93′ E	PON
Cà Fornasina (FE)	44°52.90′ N	11°29.85′ E	FOR
Fiorile d'Albero (FE)	44°55.05′ N	11°32.42′ E	ALB
Barisano (FO)	44°16.98′ N	12°04.50′ E	BS9
Santa Sofia (FO)	43°54.24′ N	11°50.88′ E	SFI
Poggio Sodo (FO)	43°52.50′ N	11°43.26′ E	PGD

Geophons of the stations measure the vertical component of the seismic wave. Only the Pontisette station has three geophons able to measure vertical and two horizontal components. It is worthwhile noticing that the horizontal geophon named NS has 52° inclination angle from North, thus giving values of the real EW component. In the same way the EW geophon measures the real NS component. From the diagrams in Figs. 1b and 1c it can be seen that the real NS component (EW geophon) is stronger than the real EW component (NS geophon).

In order to determine the direction of the shock wave, trigonometric calculations were utilized taking the Pontisette station as reference point, because this station is the only one with the installed horizontal geophons. In our calculations we considered at first the three stations of Ferrara. By taking into account air-ground coupled waves, we used ground distances for sake of simplicity since the shock waves reach the three stations in the same sequence as in the air so on the ground. Azimut of 146.6° was obtained. The seismic plot of Barisano (Fig. 2a) shows a wave shape different from others, with a sudden display of the peak signal whereas the other plots show a gradual increase of amplitude. This enable us to point out that meteoroid was moving over or quite close to the station of Barisano thus giving us further information about the direction of shock waves (the azimuth of Pontisette-Barisano axis is 147.2°. From the analysis of the seismic data it is possible to determine accurately the time of appearance, maximum and disappearance of the phenomenon. Since the CNR meteor radar recorded the echo at $0^h33^m29^s$ UT, it is possible to evaluate the time employed by the shock waves to travel from the explosion point to the seismic stations (Tab. 2). In order to calculate the height of the explosion we considered three spheres centered alternatively on three stations and with the radius calculated from the shock wave mean velocity and the time interval measured from the ex-

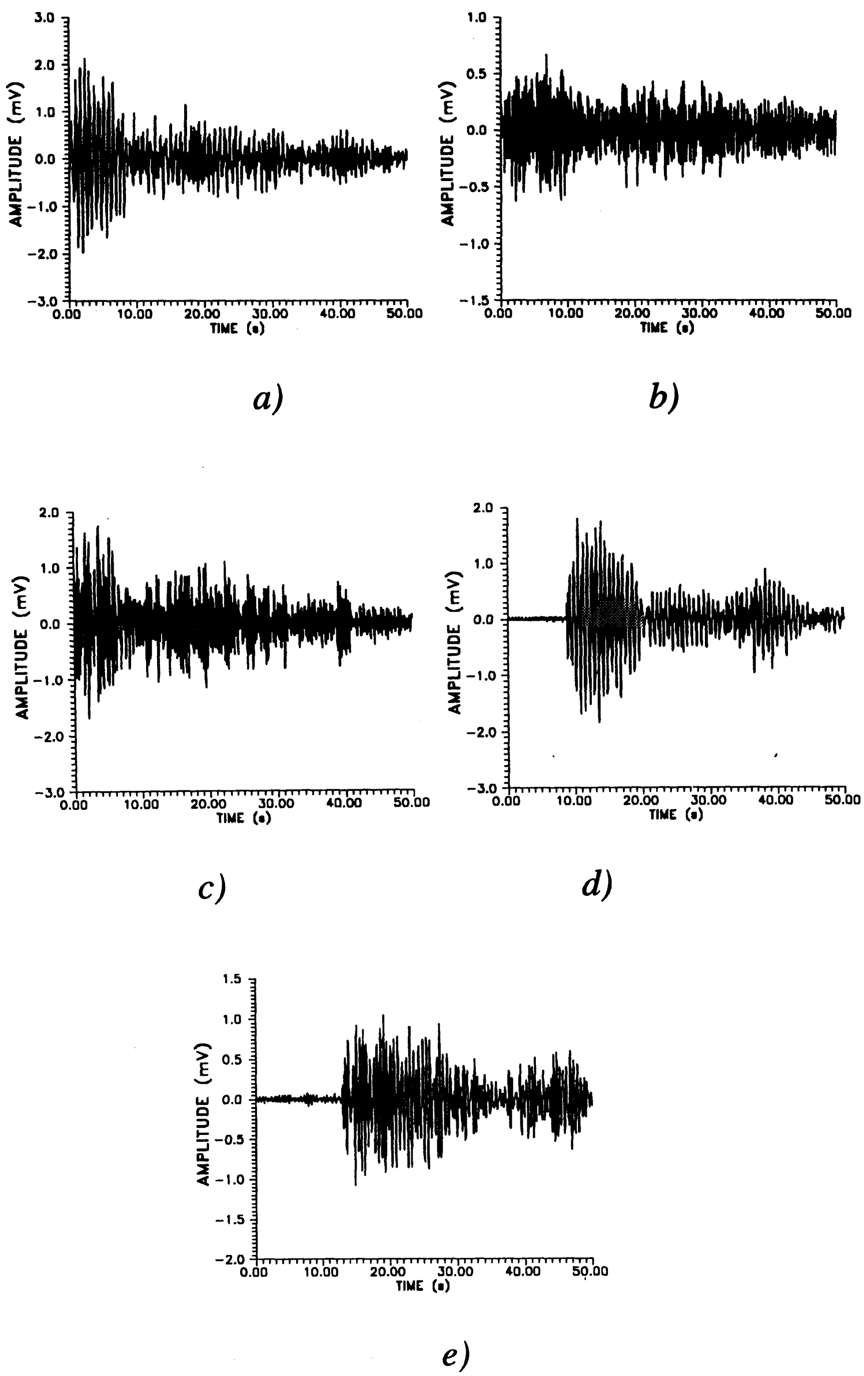

Figure 1. a) Pontisette station, vertical geophon; b) Pontisette station, NS horizontal geophon; c) Pontisette station, EW horizontal geophon; d) Cà Fornasina station, vertical geophon; e) Fiorile d'Albero, vertical geophon; start time 0:36:37.3 UT.

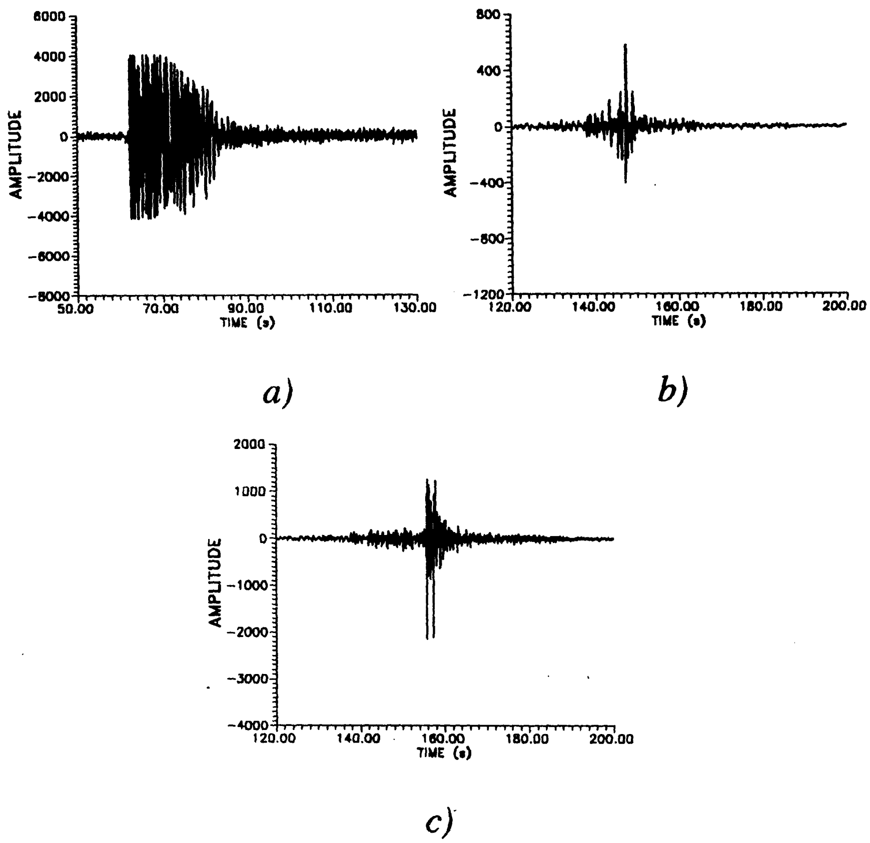

Figure 2. a) Barisano station, vertical geophon; start time 0:34:25.24 UT; b) Santa Sofia station, vertical geophon; start time 0:34:45.72 UT; c) Poggio Sodo station, verticale geophon, start time 0:34:50.84 UT;

explosion point to the station: the intersection has given two points, with a positive and negative height. We considered only the point having a positive height. Since the available data were not sufficient to calculate the precise coordinates of the intersection points, an iterative computer program was performed, taking into account an initial value of the shock wave mean velocity. The program calculated the coordinates of the explosion, the azimut and the times of the shock waves to go to other stations. Data obtained were compared with the available data and if errors were higher than a defined value, the program increased the mean velocity value and started calculations again. Velocities and heightse obtained from 10 different three stations configurations are shown in Tab. 3. The mean velocity and mean height values of about 320 ms^{-1} and 30 km, respectively, were obtained. Maximum error is about 9% and is due to the overfilling signal at the Barisano station, so that it isn't possible to know accurately the peak time. The mean velocity value is in a good agreement with experimental data from US Standard Atmosphere (1966). Using this program we also found the explosion place some kilometers north of Lugo.

Table 2. Lugo fireball: time of appearance and maximum. ΔT indicates the time interval (related to the time of begining and maximum) employed by the shock wave to travel from the explosion point to the seismic stations.

Station	Start $T_i(UT)$	Max $T_{max}(UT)$	$\Delta T_i(s)$	$\Delta T_{max}(s)$
Pontisette (FE)	$0^h36^m37^s$	$0^h36^m40^s$	188	191
Cà Fornasina (FE)	$0^h36^m46^s$	$0^h36^m48^s$	197	199
Fiorile d'Albero (FE)	$0^h36^m50^s$	$0^h36^m52^s$	201	203
Barisano (FO)	$0^h35^m27^s$	$0^h35^m28^s$	118	119
Santa Sofia (FO)	$0^h37^m03^s$	$0^h37^m13^s$	214	224
Poggio Sodo (FO)	$0^h37^m09^s$	$0^h37^m27^s$	220	238

Table 3. Results obtained from computer analysis getting the shock wave 0velocity and the height of explosion of Lugo fireball.

Stations	Velocity (ms^{-1})	Height (km)
1. PON-FOR-ALB	323.5	31.2
2. PON-FOR-BS9	329.0	31.4
3. PON-FOR-SFI	323.0	32.9
4. PON-FOR-PSD	322.0	32.9
5. PON-ALB-BS9	324.0	30.2
6. PON-ALB-SFI	319.4	31.5
7. PON-ALB-PSD	318.9	31.6
8. PON-BS9-SFI	310.0	27.0
9. PON-BS9-PSD	310.0	27.0
10. PON-SFI-PSD	311.0	27.6
Mean value	319.1	30.3

4. Analysis of microremnants

The calculated height is in agreement with actual models of interaction of meteoroids in the atmosphere (Hill and Goda, 1993; Chyba et al., 1993) and with the size of microremnants found in the explosion area. The search of spherules after the explosion was conducted taking into account the time of fall of different size particles from various heights and their abundances. For particles of $100 - 200$ μm it takes $3 - 4$ hours to fall down whereas $1 - 2$ μm size particles have times of fall of about 1 week or more. Spherules generally with the sizes of about $2 - 200$ μm were spread in the explosion area under the influence of weak zonal winds blowing in the direction of the Adriatic sea at a velocity of $20 - 25$ $km\ h^{-1}$. The anticyclone regime active over the Northern Italy during and after the time of explosion facilitated the deposition of larger particles after a short time without spreading them in a larger area. Samples of particles were picked up from flat roofs, tree-resins and small meteorological stations in the Lugo area. A Philips Scanning Electron Microscope SEM XL30 equipped with an EDAX

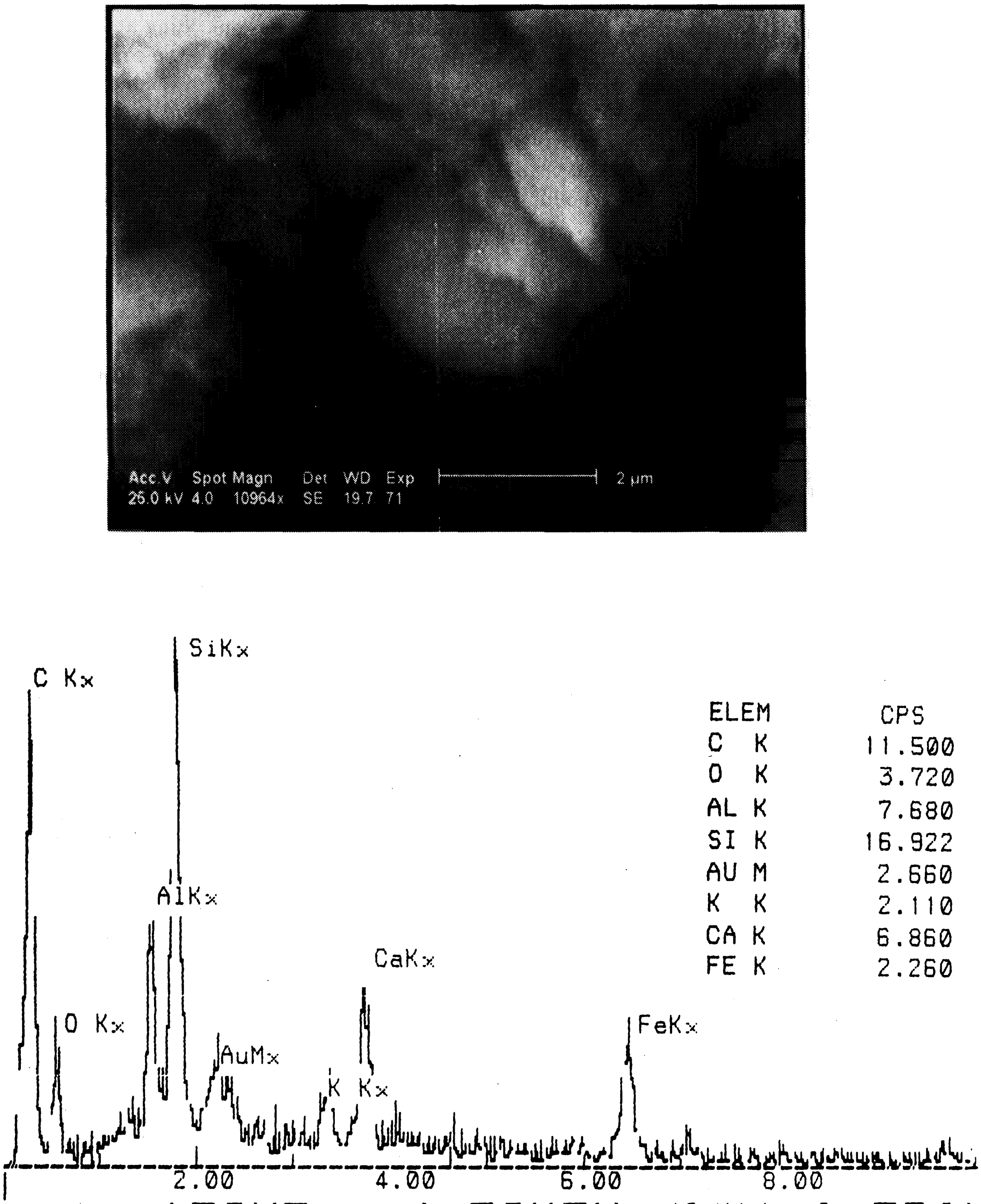

Figure 3. Spherule of Lugo fireball collected close to the explosion area.

windowed X-ray spectrometer has been used to investigate morphology, dimensions and chemical composition of the microremnants. The SEM was operating at 25 – 30 kV and a computerized electron detector has been used for determining the concentration of components with atomic number higher than 5. Fig. 3 shows one of the large amount of spherules (2 – 20 μm size) collected in the explosion zone. The quantitative analysis of the spherules reveals the relative importance of light chemical elements as Ca, Al and Si including the presence of C and O. The presence of C is extremely important for a possible association of the bolide to low density bodies as carbonaceous chondrites or cometary meteoroids.

5. Conclusions

A report on spaceborn observations declassified and recently released by the U.S. Departement of Defense, reveals that a total of 136 airbursts of probable meteoric nature (each with an energy of roughly 1 kton or more) have been recorded since 1975 to 1992 by infrared scanners on military satellites (Beatty, 1994). The exceptional meteor phenomenon observed on January 1993 over high-density population area mainly in Northern Italy belongs to this series of air impacts and was particularly impressive for the involved catastrophic fragmentation with the final pyrotechnic flash. The seismic plots from many stations have decisively enables to determine the location of the explosion over high-density population area at about 30 km in the stratosphere. The evidence of an explosion terminal height at about 30 km, underlines the existence of very weak structures (carbonaceous chondrites or cometary material?) as for many examples of bolides in the past. Ceplecha (1993) demonstrates the large relative deficiency of stony material in the 1 – 10 m size bodies, the majority being carbonaceous and even cometary bodies of weaker structure. The microanalysis of recovered material nearby the epicentre in the form of spherules of vaporized and recondensed material, reveals the relative importance of light chemical elements including C and O in 2 – 20μm size particles. These studies are only preliminary and are intensely in progress.

References

Beatty, J.K.: 1994, *Sky Telesc.* **87**, No 2, 26

Ceplecha, Z.: 1993, *Asteroids, Comets, Meteors abstracts*, Lunar Planet. Inst., Belgirate, 55

Cevolani, G., Foschini, L. and Trivellone, G.: 1993, *Il Nuovo Cimento* **16C**, 463

Cevolani, G., Hajduk, A.: 1993, in *Meteoroids and Their Parent Bodies*, ed.: J. Štohl and I.P. Williams, Astron. Inst. SAS, Smolenice, 253

Cevolani, G., Hajduk, A. and Kingsley S.P.: 1993, in *Meteoroids and Their Parent Bodies*, ed.: J. Štohl and I.P. Williams, Astron. Inst. SAS, Smolenice, 257

Chyba, C.F., Thomas, P.J. and Zahnle, K.J.: 1993, *Nature* **361**, 40

Chyba, C.F.: 1993, *Nature* **363**, 701

Hills, J.K. and Goda, M.P.: 1993, *Astron. J.* **105**, 1114

McKinley, D.W.R.: 1961, *Meteor Science and Engineering*, McGraw-Hill,

Rabinowitz, D.L., Gehrels, T., Scotti, J.V., McMillan, R.S., Perry, M.L., Wisniewski, W., Larson, S.M., Howell, E.S. and Mueller, B.E.A.: 1993, *Nature* **363**, 704