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June 1988

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Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

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Quasi-periodic Comet Showers and Mass Extinctions by Supershell Passage

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Supershells [1-9] are expanding dense shells of gas surrounding OB star associations [1]. We propose that solar system passage through a supershell wall gravitationally produces comet showers, causing mass extinctions on earth. Mass extinctions may show a quasi-periodicity corresponding to the timing of the solar system's passage through supershell walls. The recent Late Pliocene mild mass extinction and the clustering of microspherule layers and crater ages at that time [10] may have been concurrent with passage through a wall of the local Loop I supershell.

In a young OB stellar association, the combined shell from the stellar winds and supernovae of the O stars quickly engulfs the other stars in that OB association [1]. Continued supershell expansion is produced by shell momentum and by thermal pressure from supernovae interior to the shell, and the substance of the shell wall is mainly the interstellar medium swept up by the expanding supershell [1]. A typical shell wall thickness is ~ 1 – 5 parsecs (M. MacLow – personal communication). The volume within a supershell is generally called a "superbubble" [2].

Equation (5) of McCray & Kafatos [1] describes supershell wall density, n_s, in molecules·cm^{-3}:

$$n_s = 32\ \mathrm{cm}^{-3}\left[N_* E_{51}\right]^{2/5} n_0^{3/5}\, a_s^{-2}\, t_7^{-4/5}\ , \tag{1}$$

where N_* = number of > 7 $M_\odot$ stars formed in the association, E_{51} = supernova energy divided by 10^{51} ergs, n_0 = ambient interstellar medium (ISM) density in cm^{-3}, a_s = magnetosonic speed in the shell in km·s^{-1}, and t_7 = time of shell evolution divided by 10^7 yrs. Typical values of shell molecular number density range from < 1 molecules·cm^{-3} to > 850 molecules·cm^{-3}, for typical values of N_* = 20 to 60, E_{51} = 1 to 2, n_0 = 0.1 to 2.0, a_s = 1 to 11.5, and t_7 = 0.3 to 5. With all other variables held constant, ambient densities, n_0, from 0.1 to 2.0 give shell densities that differ by a factor of six. Hence, when diffuse irregularities in the ISM are swept up by the supershell shock, there can be an increase in the local shell density. Regions of enchanced density undergo radiative cooling more quickly than the rest of the shell, amplifying density irregularities (knots) by a factor of two to three (M. MacLow – personal communication). Fragmentation of the shell by gravitational instabilities occurs on longer time scales [1].

Gravitational disruptions of the solar system's inner Oort Cloud of comets by passing objects can produce comet showers of 1 – 3 Myr duration [10, 11]; such perturbing objects may include the walls of expanding supershells as the solar system passes through or near them. Comet showers are produced by passing objects according to equation (11) of Hills [12],

$$F_c = \frac{27}{8}\left[\frac{M}{M_\odot}\right]^2 \left[\frac{a}{P_\odot}\right]^4 \left[\frac{G\, M_\odot}{q\, V^2}\right]\ , \tag{2}$$

where F_c = fraction of loss cone filled (the loss cone is the fraction of velocity space empty of long period comets due to perturbations by planets), M = perturbing object mass, $M_\odot$ = solar mass, a = pre-encounter semi-major axis of affected comets, $P_\odot$ = perturbing object's closest distance to the sun, G = gravitational constant, q = affected comets' new perihelion distance (taken to be 1 AU), and V = perturbing object velocity. A value for F_c approaching 1 or greater signifies a comet shower [12]. Comet showers are produced by passage near knots in supershell walls if the knots are

both sufficiently massive and numerous to make significant gravitational encounter probable. Table 1 lists the knot density required to produce comet showers as a function of knot radius and velocity. We note that an initial survey of a possible supershell (GS 090-28-17) shows density irregularities; however, these appear to be below the required levels [13].

We propose that if shell density knots have the devastating effects suggested here, that they be called Siva Knots, after the Siva of Hindu mythology, god of destruction (cf. [14]).

Gravitationally, the solar system's approach to a uniformly dense hollow sphere (shell) may be treated as though the entire shell mass were at the shell's center of mass, until passage through the shell, when the effective shell gravity then decreases rapidly and becomes zero. In cases where the supershell deviates significantly from sphericity and uniform density at a large scale, the effective summed gravitational force from the entire shell does not necessarily approach zero in the shell interior. Thus the effects of some shell passages may be better approximated by passage through or near a cloud rather than by passage through a uniform density wall of a hollow sphere. It is known that passage of the solar system near a molecular cloud may produce comet showers [12, 15]. Hence, it is possible that passage through an asymmetric and non-uniform density supershell could also produce comet showers; this may be particularly applicable for shells that have broken through to the galactic halo as they display extreme asymmetry [2].

Mass extinctions caused by supershell wall passage should show a quasi-periodicity, based on supershell evolution and fragmentation times, on the solar system's superbubble transit times, and on the filling factor of superbubbles at the sun's galactocentric radius. The mean period of this quasi-periodicity is as yet unknown. However, we estimate typical superbubble transit times to be ~ 10 – 60 Myr, using a model which incorporates a static lattice of supershells of 300 parsec radius and a relative speed of 10 $km \cdot sec^{-1}$ between the solar sytem and a supershell. We suggest the mean period of this quasi-periodicity may match proposed extinction periodicities, such as the 26 million year [16–18] or 30 ± 1 million year [15] mass extinction periodicity [19].

The age of the Loop I Bubble, the nearest supershell, is thought to be ~ 2 million years [20, 21]. Frisch [20] has suggested that the local Loop I Bubble may have expanded

asymmetrically, with rapid expansion into the low molecular density region the sun was traversing 2 million years ago. Hence, if Frisch is correct, the solar system recently passed through a supershell wall. A small scale mass extinction occurred at the end of the Pliocene, ~ 2 million years ago [10, 22]. Subsequent Pleistocene O^{18} data, after the Australasian tektite event, also are suggestive of the extreme values and rapid fluctuations [23] characteristic of mass extinction times [11, 24]. The cratering and microspherule layer records suggest impactor showers ~ 0.7 – 2 million years ago several times above background [10]. We propose that passage through the Loop I shell ~ 2 million years ago caused the recent, mild Late Pliocene mass extinction by producing a mild comet shower.

Kyte & Wasson have argued that insufficient iridium is found in the geologic record at mass extinction times, and that therefore comet showers are precluded as a cause of mass extinctions [25, 26]. In addition to objections [10, 27] that the sedimentation rate was too low to rule out comet showers of ~ 10 – 30 times above background comet influx in the sample used by Kyte & Wasson, we suggest that the constraint placed by Kyte & Wasson is lessened if the inner solar system is currently in the tail end of a Pliocene comet shower, which peaked perhaps ~ 1 – 2 million years ago [10]. A current comet and cometary dust influx above the true base level influx would throw off the base level terrestrial/extraterrestrial iridium ratios that are a cornerstone of Kyte & Wasson's argument. It has been estimated that as many as one half of earth-crossing asteroids are recently extinct comet nuclei [10, 28] (though recent estimates give a lesser percentage (E. Shoemaker – personal communication)). Earth-crossing asteroid numbers exceed time-integrated lunar cratering rates by a factor of two [10, 29]. Though this excess is near the factor of ~ 2 error in the cratering rate [29], we reiterate the suggestion [10] that the excess in earth-crossing asteroids may in fact be due to the tail end of a recent comet shower.

Limited space precludes thanking the > 25 people who contributed helpful conversations on related topics. However, in particular we thank E. Shoemaker, F. Asaro, D. Raup, M. McCray, M. MacLow, B–C. Koo, E. Kauffman, F. Kyte, G. Thomas, F. Paresce, D. Kline, C. Kitting, and R. Prinn. This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the US Department of Energy under contract DE-AC03-76SF00098 and the National Science Foundation under grant No. PHY-88-05101.

Necessary Knot Density as a Function of Knot Radius and Shell Velocity

Knot Radius $\times 10^{-4}$ (AU)	30 $km \cdot s^{-1}$	15 $km \cdot s^{-1}$	5 $km \cdot s^{-1}$
38	341	171	57
48	264	132	44
58	216	108	36
68	182	91	30
78	158	79	26
88	139	70	23
98	124	62	20

Table 1. Knot densities in H atoms$\cdot cm^{-3}$ necessary to gravitationally fill comet loss cone (to $F_c = 1$), as a function of knot radius and relative shell velocity. Radius of assumed uniform density spherical knot is given in first column. Distance from sun to center of mass of knot = knot radius + 2×10^4 AU. We do not consider cases where the gravitationally relevant knots overlap with the inner Oort Cloud (radius = 2×10^4 AU).

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