Table 2. FOUR METEORS FROM PUBLISHED CATALOGUES

Meteor No.	Date	Radiant R.A.	Radiant Dec.	Heliocentric velocity km s^{-1}	a	e	q	1950·0 i	1950·0 ω	1950·0 Ω	Reference
1	Dec. 9.2, 1952	111	+11	34·0	1·38	0·94	0·08	39	154	77	4
2	Dec. 12.4, 1953	109	+13	39·6	3·79	0·98	0·08	36	149	80	4
3	Dec. 12.4, 1952	110	+11	35·1	1·55	0·93	0·11	30	147	80	4
4	Dec. 14.8, 1958	113·4	+15·2	37·2	2·13	0·971	0·06	26·4	154·7	82	8
Mean		110·9 ±1·5	+12·6 ±1·5	36·5 ±1·9	1·90 ±0·75	0·955 ±0·021	0·078 ±0·014	32·9 ±4·7	151·2 ±3·2	80·2 ±1·5	

Table 3. ASSOCIATION WITH THE COMET

		Telescopic meteors Elliptical orbits Solution 1	Telescopic meteors Elliptical orbits Solution 2	Photographic meteors Elliptical orbit	Orbit of Comet Mellish 1917 I
1950·0	i	59 ± 19°	32·9° assumed	32·9 ± 4·7°	32·68°
	ω	160·7 ± 1·6°	157·9 ± 1·6°	151·2 ± 3·2°	121·31°
	Ω	78·476 ± 0·002°	78·476 ± 0·002°	80·2 ± 1·5°	87·98° (*81·9°)
	q	0·038 ± 0·011	0·069 ± 0·012	0·078 ± 0·014	0·1902
	a	1·90 assumed	1·17 ± 0·09	1·90 ± 0·75	27·9
	e	0·976 ± 0·022	0·940 ± 0·023	0·955 ± 0·021	0·993

* Longitude of closest approach.

that the photographic and telescopic orbits represent the same meteor stream, the photographic meteors confirming the existence of the stream observed visually.

The 11 Canis Minorid meteor stream is remarkable in being only the second case of a stream with $q < 0{\cdot}1$ AU, the other case being the δ Aquarids ($q = 0{\cdot}061$ AU) (ref. 10). Orbits of this type do not possess long term stability. Because of dispersive and erosive forces, this new stream has a future lifetime of at most 10^5 yr. A full discussion of these effects will appear elsewhere[11].

The catalogue of known cometary orbits[12] reveals one comet with an orbit similar to the 11 Canis Minorids—Comet Mellish 1917 I. This is one of the nineteen comets with elliptical orbits passing within 0·1 AU of the Earth's orbit[13]. The comet orbit is quoted in Table 3 with an ascending node $\Omega = 88{\cdot}0°$. This is near the meteor nodes $\Omega = 78{\cdot}5°$ and 80·2°, but the longitude of the comet's closest approach to the Earth's orbit, where one would expect to be able to detect meteor activity, is $\lambda = 81{\cdot}9°$, very close to the observed meteor orbit nodes. The separation of the orbits of the comet and the Earth at this closest approach is only 0·061 AU. The orbital inclinations of the comet and meteor orbits are almost identical, but the stream perihelion averages $q = 0{\cdot}074$ AU, less than half of the comet's $q = 0{\cdot}190$ AU, making the difference in ω as high as 36°. But a stream with such a small q has elements which are very sensitive to perturbations and dispersive and erosive forces. We believe the differences between the comet and meteor orbits may be explicable on these grounds and that the evidence is good for the 11 Canis Minorids being associated with Comet Mellish 1917 I. This suggested association is similar in many respects to those suggested for the Orionids with Halley's Comet[14–16] and the Ursids with Comet Tuttle 1939 X (refs. 17 and 18).

We request groups and individuals who record meteors using either photographic or radar methods to look for evidence of this shower.

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Quantization of Wheeler–Feynman Electrodynamics

IN a recent letter, Katz, Ornan and Schwartz[1] (KOS) have argued that our treatment of spontaneous emission[2] deviates from the classical Wheeler–Feynman (WF) prescription[3]. They base their argument on the form of the interaction term

$$e_b \int A^{(a)}_{\mathrm{ret}}[b(t)] \cdot \dot{b}(t)\mathrm{d}t \qquad (1)$$

where $A^{(a)}_{\mathrm{ret}}$ is the retarded potential arising from the motion of the source particle a, and $b(t)$ is the path of a typical absorber particle b. Written in this form (1) denotes the retarded effect of particle a on particle b. KOS, however, rewrite (1) in the form

$$\begin{aligned} e_b \int A^{(a)}_{\mathrm{ret}}[b(t)] \cdot \dot{b}(t)\mathrm{d}t &= 2e_a e_b \iint \delta(S^2_{AB})\dot{a}(t') \cdot \dot{b}(t)\mathrm{d}t\mathrm{d}t' \\ &= e_a \int A^{(b)}_{\mathrm{adv}}[a(t')] \cdot \dot{a}(t')\mathrm{d}t' \end{aligned} \qquad (2)$$

and argue that (2) represents the advanced effect of b on a.

This argument would have been correct if we were dealing with a two-particle system. This, however, is not the case. In (1), $A^{(a)}_{\mathrm{ret}}[b(t)]$ represents not just the direct retarded effect of a, but also the retarded effect produced by other particles, $c, d, \ldots$, in the future absorber which have been excited by the retarded potential of a. The use of the simple delta function in (2) is therefore not valid. The effect of other particles in the future absorber is to attenuate and change the phase of the original retarded disturbance emanating from a. All these effects cannot be included in an equality of the type (2).

We now come to the connexion between the quantum and classical versions of the theory of direct interparticle action. Quantum theory is necessarily richer than the classical theory. The interference of probability amplitudes in the former leads to results that have no analogues in the latter theory. When $\hbar \to 0$, however, the quantum theory must lead to the classical theory. The following remarks show that this happens in the treatments given in refs. 2 and 3.

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The total field acting on particle a at time $t=0$ in the classical theory is given by

$$\tfrac{1}{2}\sum_{b\neq a}(F^{(b)}_{\rm ret}+F^{(b)}_{\rm adv})=\tfrac{1}{2}\sum_{\substack{b\neq a\\ t<0}}(F^{(b)}_{\rm ret}+F^{(b)}_{\rm adv})+R^{(a)} \qquad (3)$$

In (3) the left hand side denotes the field exerted by all particles $b\neq a$. Each particle acts on a via retarded and advanced fields. The first term on the right hand side denotes the part due to the past half of the universe ($t<0$), whereas $R^{(a)}$ denotes the part due to the future half ($t>0$). In a perfect future absorber $R^{(a)}$ is given by

$$R^{(a)}=\tfrac{1}{2}\sum_{\substack{b\\ t<0}}(F^{(b)}_{\rm ret}-F^{(b)}_{\rm adv}) \qquad (4)$$

$R^{(a)}$ is the classical response of the universe. The term $b=a$ in (4) leads to radiative damping. This is the classical WF theory.

In the quantum calculation of ref. 2, a path integral approach is followed. We can no longer calculate the unique path followed by a, we can only calculate probabilities for different paths. This necessarily leads to the squaring of the amplitude and hence to an influence functional $F[a,a']$ involving paths and conjugate paths (compare ref. 2). The quantum analogue of (4) expressed in terms of potentials is

$$R^{(a)}=\tfrac{1}{2}\sum_{\substack{b\\ t<0}}[A^{(b)}_{\rm ret+}-A^{(b)}_{\rm adv+}]+\tfrac{1}{2}\sum_{\substack{b\\ t<0}}[A'^{(b)}_{\rm ret-}-A'^{(b)}_{\rm adv-}] \qquad (5)$$

where $A^{(b)}_{\rm ret+}$ denotes the positive frequency part of $A^{(b)}_{\rm ret}$. The other quantities in (5) are similarly defined. The primed quantities arise from conjugate paths. The important point is that in a cold environment (provided by the expanding universe) paths contribute positive frequencies and conjugate paths negative frequencies. The appearance of paths and conjugate paths is an indication of the richness of quantum theory in comparison with the classical one, and is responsible for the variety of phenomena in quantum electrodynamics.

In the limit $\hbar\to 0$, paths and conjugate paths coincide and we arrive at (4). Thus the classical Wheeler–Feynman radiation reaction formula follows from the quantum calculation in the limit $\hbar\to 0$.

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Desert Stream Channels resembling Lunar Sinuous Rilles

Some of the sinuous rilles on the Moon seem to have been formed by fluid flow, but what the fluid was is unknown. Lava[1,2], ash[3], water[4,5], or combinations such as mud, or water under or over permafrost (refs. 6–8 and unpublished work of Hapke and Goldberg), have been suggested (Fig. 1).

Air photographs of the Mojave Desert geomorphic province of southern California show several stream channels that resemble certain lunar sinuous rilles. We have examined two of these in the Deadman Lake Quadrangle approximately 12 miles north of Twentynine Palms, to find how they are formed. The desert rilles are on alluvial slopes where windblown sand is present so that the intermittent streams emerging from canyons are forced to transport fine sand in addition to their normal burden of alluvium. The meandering channels are then

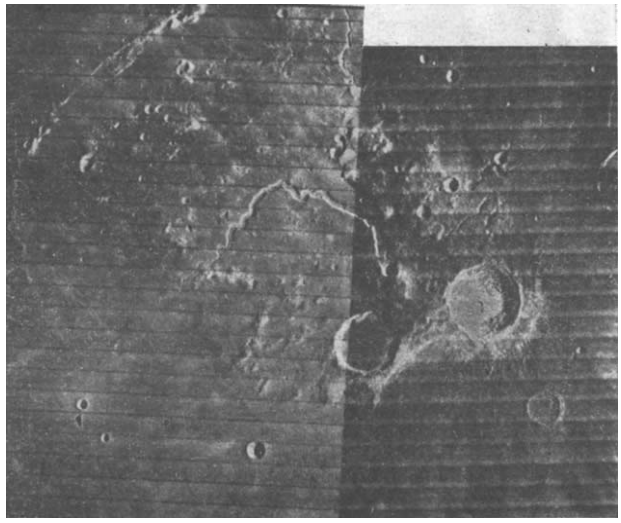

Fig. 1. Aristarchus region of Moon. Main channel of Schröter's Valley is 3 to 5 km wide. Lunar Orbiter IV, Frames H-150 and H-157.

partly covered by more windblown sand, much of it resting at the angle of repose typical for desert dunes. Thus all shapes are gently rounded and the channel banks are hidden except for occasional outcrops of loose or weakly consolidated sand, gravel and angular cobbles. These stream beds look quite unlike ordinary desert washes, but are strikingly similar to lunar rilles.

Fig. 2 shows the desert rilles, and Fig. 3 some examples of normal desert stream beds. The California rilles are about the same size as the smallest lunar rilles identifiable; they are 3–5 km long and up to 50 m deep at the upper end. Rilles on both the Earth and Moon differ from ordinary alluvial stream beds in that they lack tributaries, branches or braiding, and they taper away to nothing at the downstream end with no evidence of a delta. Some parts of the desert rilles (Fig. 4) have the same kind of channel banks as an ordinary wash or arroyo, including vertical walls where the alluvium is sufficiently con-



Fig. 2. Desert rilles. Rille at left is about 5 km long.

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