On the origin of ringing irregularities—A meteor hypothesis

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Abstract. Isolated ionospheric irregularities produce oscillating (ringing) diffraction patterns on the ground. Typical physical properties such as density, size, etc. of these irregularities have been estimated using the characteristics of these diffraction patterns. These physical properties agree well with those of meteor trail ionisation. In addition it has been found that most of the ringing irregularities occur on meteor shower days. Further, investigations of diurnal and seasonal patterns of ringing irregularities and meteor showers suggest that the meteor showers are the most likely cause of ringing irregularities. Hence it is hypothesised that the ringing irregularities are caused by meteor showers. It is to be noted that the current observations of isolated ionospheric irregularities are near the equator (around 9°N latitude) and they fill an observational gap in meteor showers which existed at equatorial latitudes. It has been observed that there is no marked difference in diurnal variation of meteor showers over the globe whereas there exists a strong latitudinal variation of the meteor showers.

Keywords. Ringing irregularity; ionospheric irregularity; meteor hypothesis.

1. Introduction

In recent years the study of radio star and satellite signal scintillations has brought to light a phenomenon that is referred to as quasi-periodic scintillation (Ireland and Preddy 1967; Elkins and Slack 1969; Heron 1976; Davies and Whitehead 1977). This form of scintillation is usually characterised by a broad minima in the received signal strength which is flanked on both sides by a damped oscillatory variation of the signal level (figure 1a). The phenomenon is generally attributed to the drifting of an orderly diffraction pattern generated by an isolated (ringing) irregularity across the radio line of sight (Titheridge 1971; Davies and Whitehead 1977; Elkins and Slack 1969). These irregularities hereafter will be referred to as Ringing Irregularities (RI).

Model calculations of these diffraction patterns have shown that in many cases the observed 'ringing' patterns may be explained by considering diffraction by symmetrical Gaussian irregularities of appropriate cross-sectional dimensions (d) and electron density enhancements (ΔN). In rare instances, however, more complex models such as asymmetric or perturbed Gaussian distributions of ΔN have also been proposed (Heron 1976; Trivedi *et al* 1978) to explain complex diffraction patterns.

Thus while there is a consensus of opinion about the cause of quasi-periodic scintillations, little is known so far about the origin of the isolated 'ringing' irregular-

Figure 1. Observed and theoretical diffraction patterns caused by an isolated irregularity.

ities responsible for such events. One possible mechanism for generation of these ringing irregularities may be meteoric ionisation, particularly in the case of irregularities located at *E* layer heights. The present paper examines this hypothesis.

The results are encouraging in that they show a fair correspondence between the statistics of meteor activity and the occurrence of ringing irregularities. The scale sizes and the strength of the irregularities seem to show agreement with those of meteor trails. In § 2 and 3 physical properties of these irregularities and those of meteor trails are discussed respectively. In § 4 comparison of experimental results of RI and meteor trails is given and § 5 gives conclusions.

2. Physical properties of irregularities

During September 1975 to August 1976 radio beacon signals were received at Ootacamund (Lat. 11.4° N, Long 76.7° E, dip 6° N) using the geostationary satellite ATS-6. Amplitude measurements of 40, 140 and 360 MHz carrier waves carried out to investigate characteristics of ionospheric irregularities. During this one-year period, many events of isolated (ringing) ionospheric irregularities were observed. The depths and widths of ringing irregularity signatures as seen on amplitudes of 40, 140 and 360 MHz radio beacon signals radiated from ATS-6 recorded at Ootacamund have been measured and processed to yield ranges of electron density enhancements and scale sizes of the irregularities. The basic approach for these computations is that used by Heron (1976) and Trivedi *et al* (1978). The graphical relationship between the depth of the recorded pattern and the irregularity scale size is, however, different from that given by Heron (1976); the latter having been computed for a 300 km irregularity height.

The results of the model calculations show that a considerable majority of the irregularities which were observed ($\approx 90\%$) have values of scale sizes d ranging from 50 m to 300 m and that of maximum possible electron density enhancements ΔN_0 ranging between 5×10^{11} el/m³ to 4×10^{12} el/m³.

3. Properties of meteor trails

Meteors are small bodies, most of them orbit around the sun. When a meteor enters earth's atmosphere it burns out due to the friction in the upper atmosphere and produces an intense column of ionisation and light. This effect has been observed and reported since 1920 (Skellett 1931). In general the effects noted are those associated with reflection of radio frequencies causing 'bursts' of received signals of a few minutes duration at the time when no reflection from *F* layer is observed and occasional short periods of strong absorptions (Pierce 1938). The maintenance of increased general level of ionisation at the altitude of the *E* layer during major meteor showers has also been attributed to meteors (Mitra *et al* 1934; Bahr 1937). The entry velocity of meteors lies between 11 and 72 km/sec. Typically a meteor travelling at a velocity ≥ 40 km/sec possesses sufficient energy to produce a column of ionisation 30 m to 1 km in diameter. The line ionisation density varies from 10^9 to 10^{18} el/m (Skellett 1935). Meteoric ionisation occurs mainly at altitudes between 80 km and 160 km, with a maximum around 115 km (Appleton and Piddington 1938). These observations further indicate the existence of marked ionisation clouds in the ionosphere which form and disappear through the day. Maximum ionisation occurs immediately after the trail has been formed, the trail then begins to expand due to diffusion and as a result electron density decreases with time. During the course of its expansion it also bodily moves due to winds in the upper atmosphere. Such clouds or trails of ionisation are capable of producing the diffraction patterns shown in figure 1. Theoretical calculations to evaluate physical properties of this diffraction pattern have been carried out using a slant height of 152 km and show (figure 1b) excellent agreement with observed patterns.

4. Comparison of RI and meteor showers

In this section ringing irregularity events have been investigated in conjunction with earlier meteor data. Figure 2a shows the days on which known meteor showers occur (Whipple and Hawkins 1959; Millman and McKinley 1963). These have been shown by rectangular blocks. The dots show the days on which RI are observed. It is shown that most of the RI occur on meteor shower days except during the months of January and February. It is to be noted that the rectangular blocks indicate only known meteor shower days as observed at high latitudes. It is quite likely that the RI during January and February might have been caused by the sporadic meteor showers since there are no known meteor showers in these months. One example of sporadic meteor shower is Dhajala meteorite which fell on 28 January 1976 in Gujarat (Lal and Trivedi 1977). It is interesting to note that from the middle of September to the middle of December there are many days with overlapping meteor showers. This period is associated with intense occurrence of RI.

It is known through earlier investigations (McKinley 1961; Vogan and Campbell 1957) of meteor by radar and optical techniques that meteor occurrence rate is maximum during morning hours. This is attributed to the fact that the earth is moving in its orbit at 30 km/sec and hence on forward side (sunrise side) of earth will encounter more meteors, than those in the evening hours.

The diurnal occurrence of hourly meteor rates for northern high latitudes is shown

Figure 2 a. Days on which meteor showers (rectangular blocks) and ringing irregularities (dots) occur (meteor shower data from Whipple and Hawkins 1959, Millman and Mckinley 1963). b. Diurnal variation of hourly meteor occurrence and ringing irregularities (meteor data from Mckinley 1951).

in figure 2b. The data for meteor trails were collected by backscatter radar observations of 100,000 echoes. This curve indicates maximum occurrence of meteors around 0730 hr local time and a broad minimum around 1800 hr (Mckinley 1951). Diurnal radio meteor rates were also estimated by VHF forward scatter technique (Srirama Rao *et al* 1978) between Dehra Dun and Waltair in India for the period December 1974 to November 1975. This link looks at the ionosphere around 25°N latitude. The diurnal variation trend was found to be maximum around 0600 hr local time and a minimum around 1800 hr local time. The observations also showed a sharp fall in the meteor rates in the post-sunrise hours with a minimum around 0800–0900 hr local time which was attributed to sharp rise in absorption of the VHF radio waves caused by rapid rise in O^+ ionisation in the *D*-region. The above results show a peak diurnal meteor rate between 0600 and 0730 hr local time.

Figure 2b also shows diurnal occurrence of RI. The RI observations were collected for one year beginning September 1975 and show a maximum at 1000 hr with a delay of $2\frac{1}{2}$ hr compared to that of the meteor curve. It is worthwhile to note that the peak time in meteor occurrence varies by about 3 hr depending on the technique (Mckinley 1951; Vogan and Campbell 1957). In addition the meteor echo observations and RI observations are taken during different epochs. Current observations on RI were made near the equator (10°N lat.) whereas meteor observations are available around 40°N, 25°N and 40°S latitudes. There is a reasonably good agreement between RI occurrence and hourly meteor rate.

In figure 3b the seasonal variation of meteor occurrence around 40°N latitude shows a maximum around July–August and a broad minimum around February. The observations were made by Keay (1963). In the southern hemisphere the meteor occurrence rate is opposite to that in the northern hemisphere though their magnitude is very small. Note that the ordinate for southern hemisphere data is multiplied by 12 (Keay 1963).

Using meteor forward scatter propagation link at 48.2 MHz between Dehra Dun and Waltair, Srirama Rao *et al* (1978) reported that the mean monthly meteor rate has a minimum in February and maximum in October with a secondary maximum in

Figure 3 a. Occurrence of ringing irregularities during different months. b. Occurrence of hourly meteor rate in northern and southern hemisphere. Note that the ordinate of southern hemisphere is to be divided by 12 (meteor data from Keay 1963).

June. Further, they reported that there is steady rise from February to October and a rapid fall after that. Our results shown in figure 3a seem to agree to a large extent with those of Srirama Rao *et al* (1978), but not with those of Keay (1963). There is a minor difference between our results and those of Srirama Rao *et al* (1978) in that the earlier one (RI) shows a double peak during October to December.

5. Conclusions

Based on diffraction patterns produced on the ground by isolated ionospheric irregularities (ringing irregularities—RI) the physical properties of these irregularities such as density, size etc. can be evaluated. These properties resemble with those of meteor ionization trails. In view of this a hypothesis on the origin of these RI has been proposed. It is suggested in this hypothesis that meteor ionisation trails are responsible for producing these RI. The diurnal and seasonal patterns of RI and those of meteor trails strongly support the above hypothesis. The diurnal meteor occurrence shows uniform behaviour over the globe with a maximum during early hours of the day; whereas there seems to be a strong latitudinal dependence of seasonal variation of meteor showers over the globe.

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