Chapter 1: Introduction

Frontispiece:

"*From the beginning of time, shooting stars have caught the attention of man and have been recorded sometimes with vivid expressions of admiration. It might then seem astonishing that this phenomenon has only recently occupied scientists' attention*."

- translated from Chapter IV: Des Etoiles Filantes in Sur La Physique Du Globe by L.A.J. Quetelet (1861)

1.1 Periodic Meteor Streams

The study of meteors as an established scientific discipline originated with the great Leonid meteor storm of 1833. It was the sudden and unexpected appearance of the storm over North America, which prompted scholars of the time to begin studying meteors as an astronomical (as opposed to upper atmospheric) phenomenon.

That the Leonids were so obviously visible in 1833 and yet much weaker in 1834 reflects a fundamental characteristic of the stream; namely that it can be a storm (very strong meteor shower) in one year and a weak shower the next. That the Leonid storms come in cycles of 33 years reflects the strongly periodic nature of the activity associated with them and hence leads to their classification as a periodic stream.

Of the dozen or so meteor showers which occur throughout the year, the majority show consistent levels of activity from year to year at nearly the same location along the Earth's orbit. The showers which show no noticeable changes in activity from one year to the next are referred to as annual showers, while those with a periodic component in their levels of activity are referred to as periodic streams. Table 1.1 lists the most recognized showers visible throughout the year and their classification as periodic or annual.

Table 1.1. List of showers visible throughout the year (after Rendtel et al., 1995 and Hawkes, 1997). ZHR refers to the Zenithal Hourly Rate and gives an approximate measure of the number of meteors visible to a ground-based observer under good conditions at the maximum of the shower. A = Annual Stream, P = Periodic Stream, R = Visible for Radar observations only. V in ZHR column refers to variable.

Name	Date of Max	Velocity (km/s)	ZHR	Type of Shower
Quadrantids	Jan 3	41	120	A
Lyrids	Apr 22	49	15(V)	P
π Puppids	Apr 24	18	5(V)	P
η Aquarids	May 6	66	60	A
Arietids	Jun 7	39	60	A,R
ζ Perseids	Jun 9	29	40	A,R
β Taurids	Jun 30	30	25	A,R
Phoenicids	Jul 14	47	(V)	P
S. δ Aquarids	Jul 28	41	20	A
α Capricornids	Jul 30	23	4	A
N. δ Aquarids	Aug 9	41	4	A
Perseids	Aug 12	60	80 (V)	P
κ Cygnids	Aug 18	25	3	A
α Aurigids	Sep 1	60	10(V)	P
Orionids	Oct 21	66	20	A
S. Taurids	Nov 6	27	5	A
N. Taurids	Nov 13	29	5	A
Leonids	Nov 17	71	10(V)	P
α Monocerotids	Nov 20	60	5(V)	P
Geminids	Dec 13	35	110	A
Ursids	Dec 22	33	10(V)	P

Periodic meteor showers occur when the Earth intersects an uneven distribution of meteoroids from one year to the next. As a result, the levels of activity change dramatically when the Earth encounters this “clump” of material. This sometimes happens when the parent comet is near its time of perihelion and close to the Earth’s orbit or it may be due to cyclical planetary perturbations moving parts of the stream into intersection with the Earth. As these “clumps” tend to disperse under the action of differential perturbations and differing orbital periods of the constituent particles, they are generally young in terms of orbital periods of the parent comet relative to the other components in the stream. It is the young age of the material associated with periodic streams that make the associated meteoroids of great scientific value. All other meteoroids associated with annual meteor streams are produced through a long process of decay of the parent comet; hence the age of any one meteoroid observed in the stream can only be guessed at in a broad statistical manner. As a result, the study of an annual stream and its evolution is complicated by the unknown age of the material making up the stream and thus features associated with the shower (such as its duration and dispersion) cannot be uniquely ascribed to initial ejection conditions from the comet or subsequent evolutionary effects.

Periodic streams allow us to separate to some degree the effects of perturbations (which affect the stream over time) from the initial conditions of ejection from the comet. In this sense the data concerning periodic streams can be interpreted as a direct probe of the comet-meteoroid birthing process. By comparing observations of periodic meteor showers with theoretical models of the formation and evolution of the associated meteoroid streams, we can formulate a more complete understanding of the factors which affect their evolution and set them on an Earth-crossing path, as well as how and when meteoroids from a given year’s shower on Earth are released from their parent comets. It is a study of these matters that is the primary objective of this thesis.

1.2 Case Studies : The Perseids and Leonids.

A complete understanding of all aspects of periodic streams is possible only through exhaustive investigation of the major periodic streams listed in Table 1.1. Such investigation is beyond the scope of the current work. Instead, we will attempt to define some of the probable central mechanisms at work in the formation and evolution of periodic streams through studying two of the best documented periodic streams: the Perseids of August and the Leonids of November. In particular, it is our aim to develop a generic numerical model of the formation and subsequent evolution of these streams and to compare the resulting stream behaviour with observations. In this regard, we concentrate on those model outputs, which can be compared to observations, whether existing or future.

The Leonids is the archetype of the periodic streams as well as the first shower clearly documented to recur on an annual basis (Olmsted, 1834). The Perseids have long been categorized as an annual stream (cf. Lovell, 1954), but detailed observations over the last decade have revealed a periodic component as well (Brown and Rendtel, 1996). It is the wealth of recent observations of these two periodic streams, which has led to our adopting them as case studies.

Since the early 19th century, studies of meteor streams have proceeded along two principal lines: observational and theoretical. The former have included visual observations and more recently photographic, video and radar observations of meteor showers (cf. Steel, 1994 for a review) while the latter has only recently been developed in detail through the use of computer simulation of the formation and evolution of meteoroid streams (cf. Williams, 1992).

In this thesis we will examine the present observational summaries of the activity of the Leonids and the Perseids. To interpret these data in a theoretical framework, a numerical model for the formation and subsequent evolution of both streams will be developed and its “reality” measured via comparisons with the available observations. As well, we make predictions of the future times and magnitudes of activity based on these modelling results.

1.3 Thesis Outline and Focus

We will begin with a description of the basic physical and kinematic processes of meteoroid stream formation and the forces affecting its subsequent evolution in Chapter 2. In Chapter 3, a detailed summary of recent observations of the Perseids will be presented. In Chapter 4, a numerical model for the formation of the Perseid stream is developed and the evolution of the stream is compared to the observational results from Chapter 3. Similarly, Chapter 5 presents and summarizes our available observational information concerning the Leonid stream while in Chapter 6 the model is applied to the Leonid stream and compared to the observations enumerated in Chapter 5. Finally, Chapter 6 compares and contrasts the two streams, provides a brief synopsis of the major conclusions resulting from this study and suggests avenues for further work.

We wish to focus on some basic questions pertaining to these two streams, among them:

- What are the probable ages of the “young” periodic portions of these streams, as well as the older “annual” components?
- What are the model-inferred ejection velocities from the parent comets based on observations of the associated meteor showers?
- What is the root cause of the periodic component in each stream? Is material moved to Earth intersection primarily by planetary perturbations, radiation pressure, or other effects? Does the Earth intersect a dense cometary “trail” or are we simply skirting the outside of a much broader distribution of meteoroids?
- Why are the periodic components unstable in position from year to year and also in some cases from cometary passage to cometary passage?
- How does the stream “diffuse” over time, both in terms of removal of meteoroids (sinks) as well as quantitative changes in density within the stream? What does this imply about the variations in activity from year-to-year?

References

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