METEOR SHOWERS

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Meteoroid Stream Formation

Meteor showers which appear at about the same time each year have been observed for centuries. They occur when the Earth intersects the solar orbit of a tube-like structure of meteoroid trails, which are the remnants of a comet or asteroid. Depending on the intersected breadth of these particles, a meteor shower can last for hours or weeks. Figure 1 illustrates the process. The Earth's path V_g through the meteoroid stream is the vector sum of the Earth's and meteoroid stream's heliocentric velocities. "The measured duration of a meteor storm (W) is usually larger than the intrinsic width of the trail (W_t)" (Jenniskens, 2006: 42).

As an incoming meteoroid approaches the Earth, it encounters atmospheric atoms and molecules, some of which are absorbed and trapped in the meteoroid. The generated heat causes atoms to boil off and collide with those in the atmosphere. This produces ionized particles which surround the meteoroid with a glowing envelope leaving a column of plasma. The meteoroid is now seen as a meteor. If the meteor trail persists over a second, it's called a *train.* Trains may last for many minutes, and can be used to observe upper atmosphere movements. Very short meteor trails are called *wakes.*

Shower meteors travel in parallel paths as they encounter the Earth, so they all appear to originate from a small area of the sky, called the *radiant* or *group radiant*. A shower's radiant appears to move east about 1° daily due to Earth's orbital motion. Some meteor observers of the past believed in the existence of stationary radiants for some showers, but we now know this is impossible. The constellation in which the radiant appears usually gives the shower its name.

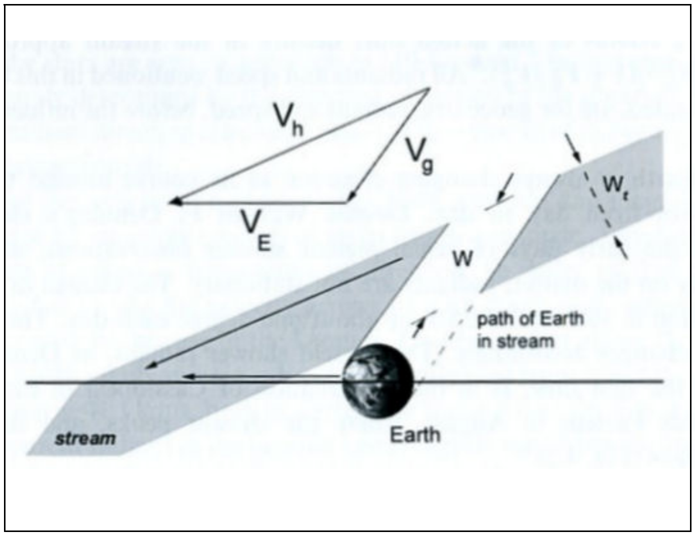

Figure 1. Earth's Path through a Meteoroid Stream (Jenniskens, 2006: 42)

A meteoroid in orbit around the Sun has a heliocentric velocity in the vicinity of Earth of about 42 km/s. So if a meteoroid has a heliocentric velocity greater than 42 km/s it will have an open orbit and is therefore not a part of the solar system. The geocentric velocity of a meteoroid is its velocity relative to the Earth, whose orbital velocity is about 30 km/s. Therefore, the maximum geocentric velocity of a meteoroid orbiting the Sun is about 72 km/s.

Less than one percent of observed meteors exceed a geocentric velocity of 72 km/s (Roggemans, 1989: 13-14). Recent radar results from AMOR (Advanced Meteor Orbit Radar) indicate significant meteoroid hyperbolic velocities exist, especially the faintest ones. Their source is unknown (Williams, 2004: 473).

Sporadic Meteors

A sporadic meteor is one that doesn't belong to an identifiable meteor shower. About 75% of all meteors are sporadic. They appear randomly at an average rate of about five per hour. The rate of sporadic meteors has a diurnal as well as seasonal dependency. Observers will see more sporadic meteors between midnight and sunrise, when the Earth's rotation positions them towards oncoming zodiacal dust particles. The seasonal variation is due to the Earth's inclination to the ecliptic. In the Northern Hemisphere the Earth's apex is optimally located near the autumnal equinox for maximum sporadic intersection.

Meteor Factors

In the middle of the twentieth century, studies were carried out on the meteoroid factors relating to the brightness of meteors:

> A commonly used relationship between the maximum brightness m_v, the meteoroid's initial speed *V*, its initial mass *m* and the zenith angle *z* was derived by Luigi Jacchia (Smithsonian Astrophysical Laboratory) and co-workers, who in the early 1950s conducted an extensive photographic study of meteor trails (Beech, 2006: 19).

Jacchia's formula for maximum visual magnitude m_v is:

$$m_v = 4.84 - 2.25\log_{10} m - 8.75\log_{10} V - 1.5\log_{10}(\cos z) \qquad (1)$$

The meteoroid mass *m* is in kg, initial geocentric velocity *V* is in km/s and zenith angle *z* is in degrees. Assume a 0.0001 kg (0.1 g) meteoroid has a velocity of 60 km/s with a zenith angle of 45°. The calculated maximum visual magnitude would be -1.5. If the meteoroid speed was 20 km/s, the maximum visual magnitude would be +2.7, a decrease in brightness of 4.2 magnitudes, or a 47x reduction in luminosity for a three-time reduction in velocity.

Very bright meteors are called *fireballs*. The definition of how bright a meteor must be to be designated a fireball varies. "If a meteor is so bright that its flash of light can be seen on buildings and landscapes at night, and is capable of producing shadows, it is called a fireball" (Whipple, 1955: 368). Olivier believed that, "Fireballs generally are considered to be at least as bright as Jupiter or Venus" (1925: 7). Lovell (1954: 142) defined a fireball simply as a "very bright meteor." Fireballs that explode are called *bolides.*

Several attributes are now commonly used to describe meteor showers. The *population index r* is the ratio of the number of meteors in subsequent magnitude classes of the magnitude function. For example, if r = 2.27 for a shower, there will be 2.27 more meteors seen of magnitude +2 than of magnitude +1. A shower's population index is an indicator of its age; small r's mean that the smaller meteoroids are no longer present, signifying an older shower. Sporadic meteors have an average population index of 3.4 (Hawkins, Upton, 1958: 727), while major annual meteor shower population indices range from 2.1 for the January Quadrantids to 2.9 for the April Lyrids. An important meteor shower concept is that of its zenith hourly rate. A *ZHR* or *zenith hourly rate* is the number of shower meteors that a single observer would see in one hour if the radiant were at the zenith, the limiting magnitude +6.5 and the sky cloudless. The concept of *limiting magnitude*, is “the magnitude of the first faint star just not visible to the naked eye” (Roggemans, 1989: 81-82). The ability to observe meteors under these exact conditions may be difficult or impossible. The following relationship can be used to determine the zenith hourly rate of a meteor shower in non-standard conditions:

$$ZHR = \frac{observed * r^{(6.5-lm)}}{\sin(ralt)} \tag{2}$$

Where: *ZHR* is the zenith hourly rate of the shower
observed is the number of observed meteors/hour
ralt is the altitude of the shower's radiant above the horizon in degrees
r is the shower's population index
lm is the sky limiting magnitude

The Role of Comets

Ever since Giovanni Schiaparelli (1835-1910) discovered in 1862 that the Perseids and Comet Swift-Tuttle had similar orbital elements, it has been known that comets produce meteoroid streams that are responsible for our annual meteor showers. An apparent exception is that of the Geminids, whose meteoroid source seems to be the short period asteroid 3200 Phaethon. Also, there is evidence that the Quadrantids’ parent may be asteroid 2003 EH1 (Porubčan, Kornoš, 2005: 5). Several other meteor showers listed in Table 1 may have asteroids for parents. The nucleus of a comet is made up of dust and gasses which reside in the form of ices. Water is the least volatile of the ices and the other ices are trapped in a matrix of water ice. The typical ice composition of cometary nuclei is “79% water (H_2O), 13% carbon monoxide (CO), 2.8% dry ice (CO_2), 3.0% formaldehyde (H_2CO), 1.0% methanol (H_2COOH), 1.2% ammonia (NH_3), and 0.08% hydrogen cyanide (HCN)” (Jenniskens, 2006: 22).

As it approaches the Sun, the temperature of a comet’s nucleus is about $T = 300/\sqrt{r}$, (r in AU) degrees Kelvin. At approximately 3 AU (175 K), water ice sublimates, releasing the other ices trapped in its matrix. The entrapped dust is released in greater quantities as the comet reaches perihelion forming its coma and may begin to show a tail (Jenniskens, 2006: 24-27). The coma of a comet (Figure 2) is formed from neutral gas molecules and large dust grains. The ion tail is made up of CO^+ molecules, created by solar radiation knocking an electron from carbon monoxide molecules. The Sun's magnetic field impacted by its solar wind forces the comet's ion tail away from the Sun. The dust tail is made up of small particles that are made visible by scattered sunlight and are affected by the Sun's radiation pressure. The heavier particles are less affected by radiation pressure, and "follow curved elliptical orbits in the same plane as the comet, forming a thin sheet" (Jenniskens, 2006: 33). The dust trail will grow in length as the comet repeats its orbital path, as illustrated in Figure 3.

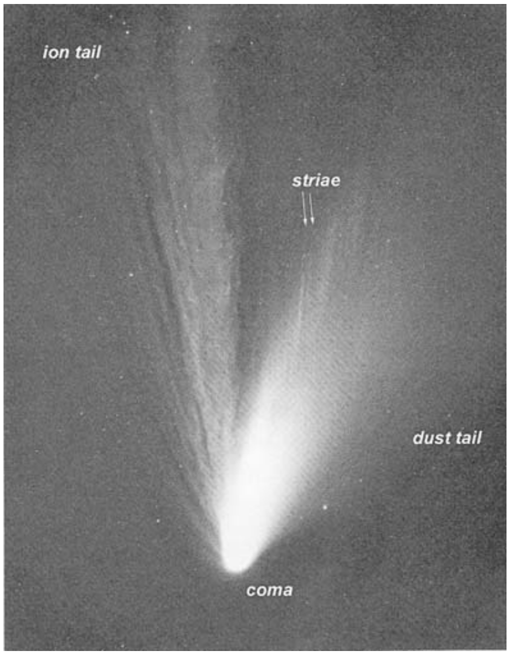

Figure 2. Comet C/Hale-Bopp Structure (Jenniskens, 2006: 32)

The determination of a shower's radiant, the area of the sky from which its meteors appear to originate, is not always a straightforward process. Radiants are areas in the star background whose size depends on the distribution of the meteoroid stream intersecting the Earth's orbital path. Visual observations and recording of meteor paths has to be done carefully to determine their intersection on gnomonic maps. Gnomonic map projections convert great circles to straight lines, permitting meteor paths to be recorded as straight lines. The presence of sporadic meteors can create false shower radiants. Some observers in the past, thinking that all meteors emerged from group radiants, mistakenly included sporadic meteors in their quest for discovering new low activity meteor showers. Sporadic meteor pollution can be overcome by employing multi-night observations, thereby minimizing the presence of random sporadics.

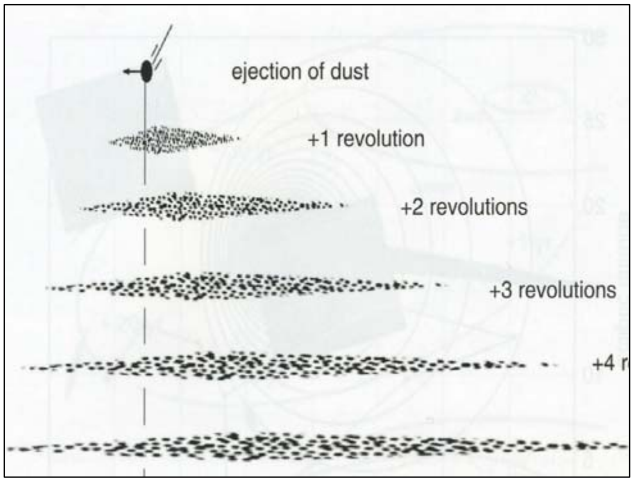

Figure 3. Dust Trail Growth (Jenniskens, 2006: 33)

A meteor shower occurs when the Earth's orbit intersects that of a meteoroid dust trail.

Radiant Corrections

The major correction to the observed meteor radiant is its zenith attraction (Lovell, 1954: 90-92). As a meteoroid approaches the Earth, its direction and velocity are altered by Earth's gravitational force. This increases the meteoroid's velocity and moves its original heliocentric orbital path towards the zenith. If V (km/s) is the speed of a meteoroid due to the vector sum of its and Earth's heliocentric velocities, and v (km/s) is the observed velocity,

$$v^2 = V^2 + 124.9 \tag{3}$$

If z is the apparent zenith angle of the radiant's location, the zenith attraction correction Δz is given by

$$\tan \tfrac{1}{2} \Delta z = \frac{v - V}{v + V} \tan \tfrac{1}{2} z \tag{4}$$

It's clear from Equations (3) and (4) that fast meteors near the zenith have minimal zenith attraction corrections. An observed Leonid meteor velocity of 71.8 km/s (v) would imply a geocentric velocity (V) of 70.9 km/s from Equation (3). If the apparent radiant was at 45°, the correction for zenith attraction would only be 0.3° from Equation (4). On the other hand, a Giacobinid V of 20.4 km/s implies an observed v of 23.3 km/s. This results in a zenith attraction of 3.1° when the Giacobinid radiant is at 45°.

Major Meteor Showers

Meteor showers change over time. New showers appear as the Earth encounters orbiting material from new comets. For example, in 1900 comet Giacobini-Zinner was discovered, with an orbital period of 6.52 years. Signs of low activity Giocobinid showers were first observed in 1915. Giocobinid storms of thousands of meteors per hour occurred in October 1933 and 1945. In 1998, Giocobonid rates reached 500 meteors/hour. However, other years had very low activity. Another example is the November Leonids, which were first noted in a storm in November 1833. Leonid storms were seen in 1866, 1867, 1966 and 2001. In other years the Leonids were a modest activity shower. The Leonid parent, discovered in 1865, is Comet Tempel-Tuttle with a period of 33.2 years. However, examination of historical comet sightings has revealed that the comet was also sighted in 1366 and 1699. Apparently Tempel-Tuttle's detritus hadn't created an observed major shower until 1833.

Table 1 contains a portion of IAU's working list of meteor showers as listed in Jenniskens' (2006) Table 7. Only showers with minimum ZHR's of 5 or more are included. As a result, the October Giacobinids aren't listed, since their activity has markedly subsided recently. Note also that there are significant daytime showers, detected via radar as radio waves are reflected from the ionized meteor trails.

NAME	PARENT	PEAK DATE	R.A.	DEC	ZHR	V_g km/s
Quadrantids	2003 EH1	01/04	231	+50	130 ± 24	41
α-Centaurids		02/08	212	-59	7.3 ± 1.5	58
γ-Normids		03/13	240	-53	5.8 ± 1.0	60
δ-Pavonids	C/1907 G_1 Grigg-Mellish	03/31	305	-66	5 ± 1	58
Lyrids	C/1861 G_1 Thatcher	04/22	272	+33	12.8±0.7	47
α-Virginids	1998 SH_2	04/18	196	+01	5	17
η-Aquariids	1P/Halley	05/06	338	-01	28 ± 4	65
S.Daytime ϖ-Cetids		05/07	30	+01	8	36
τ-Aquariids		06/29	340	-11	7.1 ± 1.6	64
N. ϖ-Scorpiids	1996 JG	06/01	244	-15	5	20
S. ϖ-Scorpiids		06/01	247	-26	5	23
Daytime Arietids	Marsden-group of Sun-skirters	06/07	44	+23	54 ± 12	37
Daytime ξ-Perseids	2P/ Encke	06/09	52	+23	20	28
Daytime β-Taurids	2004 TG_{10}	06/28	80	+21	10	10
July (ϒ-) Phoenicids		07/12	32	-48	4 ± 1.9	47 ± 3
β-Cassiopeids		07/30	336	+53	10	50
Southern δ-Aquariids	Related to Marsden Sungrazers	07/29	340	-16	18 ± 4	40
η-Eridanids	C/1852 K_1	08/10	45	-13	6	64
Perseids	109P/Swift-Tuttle	08/13	48	+58	84 ± 5	59
ϒ-Doradids		08/29	61	-50	4.8 ± 1.6	40
(α-) Aurigids	C/1911 N_1 (Kiess)	09/01	90	+39	4 ± 1	66
Daytime Sextantids	2005 UD	09/30	155	-01	20	31
Orionids	1P/Halley	10/22	95	+16	23 ± 4	66
Leonids	55P/Tempel-Tuttle	11/17	154	+22	13 ± 3	71
Northern Taurids	2004 TG_{10}	11/05	59	+22	7.3	28
Nov, ı-Aurigids		11/16	68	+30	8.2 ± 2.8	34
Ursids	8P/Tuttle	12/23	219	+75	12 ± 3	33
Puppids-Velids I		12/06	128	-45	4.5 ± 0.7	37
Geminids	3200 Phaethon	12/14	111	+33	120 ± 10	35

Table 1. Active IAU Listed Meteor Showers (Jenniskens, 2006: 691-746)

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