

environment. Among several nebular origin models like lightning, bipolar out flows from young Sun (X-wind), shock waves and collisions between smaller objects, Among these, nebular shock wave model is widely accepted by the cosmochemists. According to this model a shock wave of hot, high-speed gas abruptly heat and compress nebula of gas and dust. The sudden overrun by shock wave accelerate the dust particles present in nebula at several kilometers per second. Friction and/or drag from collisions of gas molecules heat the particles. In addition particles can also be heated radiatively and conductively by the hot post-shock gas until cooling begins. For example, micrometer-sized particles attain the speed of shock wave after few hundred meters of the dragging, whereas millimeter-sized particles drag for hundreds of kilometers before matching the speed of shock wave. This size dependent dragging results in variety of heating duration as well as peak temperatures for these nebular particles as required to explain variety of textures and sizes for chondrules. However, it is not certain that how the nebular shock waves were generated. Although there are some possible events like nearby supernova explosion, gravitational instabilities in protoplanetary disk, planetesimals moving supersonically relative to nebula. Detailed theoretical calculations are being provided to satisfy various major constraints.

Further reading:

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Physics and application of scintillation phenomenon

The awareness of phenomenon of scintillation is there to human since very early days. Ancient man looked at the sky and wondered about its variation and beauty in the form of twinkling of stars. *Scintillation or twinkling of a celestial object is generic term for rapid variations in apparent brightness or color of a distant luminous object viewed through the atmosphere. If the object lies outside the Earth's atmosphere, as in the case of stars, the phenomenon is termed astronomical scintillation; if the luminous source lies within the atmosphere, the phenomenon is termed terrestrial scintillation.*

The scintillation in the form of twinkling of stars is best described in a very popular English Rhyme for young children which reads as

Twinkle twinkle little star

How I wonder what you are

This means that we all know quite well that stars in the night sky twinkle. Though poet probably did not intend to say that only little ones twinkle, but today we know that only tiny stars twinkle and the celestial objects having apparent size large like planets mostly do not twinkle. Fig. 1 shows a typical scene of sky in a dark night.

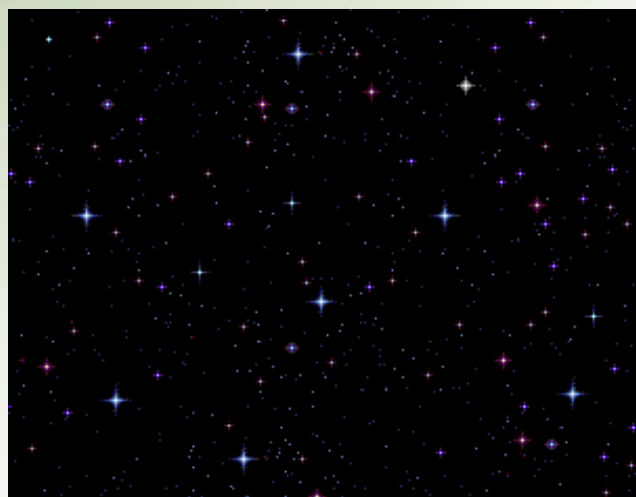


Figure 1: Typical night sky at a remote site, many of the stars twinkle.

The twinkling of stars or atmospheric scintillation is defined as variations in their luminance. This is also termed as atmospheric seeing in the literature. It is

clearly established that twinkling and all other scintillation effects are caused by anomalous refraction caused by small-scale fluctuation in air density usually related to temperature gradients and irregular densities in the propagating medium. Normal wind motion transporting such fluctuations across the observer's line of sight produces the irregular changes in intensity characteristic of scintillation. The primary cause of such small scale fluctuations is turbulent mixing of air with different temperatures. Scintillation effects are always much more pronounced near the horizon than near the zenith (straight up). Parcels of air in the centimeters to decimeters range are believed to produce most of the scintillatory irregularities in the atmosphere. Atmospheric scintillation is measured quantitatively using a scintillometer. Scintillation effects are reduced by using a larger receiver aperture. This effect is known as aperture averaging. In the upper atmosphere: there are little pockets of air that have different density, temperature, humidity etc. than the surrounding air. The density contrast causes refraction, and as different cells move in and out of your line of sight, the image of the star (which is point-like) is seen to move around from one site to the next. This movement is seen as twinkling by the eyes; if you take a photograph over several minutes, as astronomers often do, then the image becomes blurred. The seeing (this blurring) can be as good as ~ 0.5 second of arc (1 second of arc is $1/3600$ th of a degree) at the best astronomical sites on Earth, while the worst ever seen at a professional observatory is reported about 8 seconds of arc (under such atmospheric conditions astronomers give up observing that night; more typically, 2 seconds of arc would be considered bad by today's professional astronomers). Here, an attempt is made to describe basic principle and the effect of source size for the scintillation phenomenon. The phenomenon occurs at several locations and conditions in nature. The salient features of these are also summarized in the following sections.

Unaided-eye observations

The twinkling of stars can be viewed very easily with unaided-eye. Dark nights at remote place, away from a large city or town would provide a very interesting observation possibility of this phenomenon. The observers can clearly compare the twinkling of stars as a function of elevation. The stars near the horizon twinkle more than those at higher elevation. One can monitor few

stars from East to West during the night; can easily learn that when the star is near horizon either in East or West, it twinkle more than when the same star is overhead. More careful observation can easily reveal the effect of source size. There are occasions when along with twinkling there is also dispersion of star light which changes the colour of the star. In such occasions one sees the star in different colours while twinkling, this is usually termed as colour scintillation.

One very interesting and exciting manifestation of this phenomenon is in the form of shadow bands. These form just before and immediately after the total solar eclipse (TSE). At these times, the Sun is visible as a tiny arc which is equivalent to series of tiny stars and each of them forms a scintillation pattern. These patterns will be placed on the ground one after the other; along the arc these will get smeared and while in the perpendicular direction there will be no smearing. Thus dots of the pattern seen in Fig. 3 will take the shape of bands. The motion of the wind and ever changing turbulence in the atmosphere make these bands drift across in various shapes and size. The resulting scene is very unique. So far the longest and the best shadow bands observations were recorded at Maitri, Indian Antarctic Observatory on 23 November 2003 during TSE. This total solar eclipse was of very low elevation $< 1^\circ$ and thus the light from the arc of the Sun before and after the totality had a very long path length through the turbulent atmosphere. The large path length through the turbulent atmosphere resulted into clearer and longer duration shadow bands. The shadow bands began 4 min. before the totality and lasted for 7 minutes after. The bands were clearer than all the previous recordings of this phenomenon.

Telescope observations

The twinkling phenomenon is of utmost interest to astronomers who view the skies from ground-based telescopes. The twinkling has an adverse effect on the observations. The best observatories are those where the twinkling phenomenon is minimized. Examples include the Mauna Kea Observatory in Hawaii, Indian Astronomical Observatory at Hanle and observatories in the foothills of the Andes Mountains in northern Chile. However, astronomers have developed the ways to largely get rid of this effect. It is done by monitoring the random deflections of the atmosphere and, within the telescope, to bend the deflected light back onto its original path. This optical technique is given the name

adaptive optics. The other alternative is to place a telescope in orbit above the atmosphere, as with the Hubble Space Telescope. While modulation variations are present, it is the deflection of light that causes the most serious problems. The entrance pupil of an optical telescope is often much larger than the characteristic size of atmospheric irregularities. The composite star image produced by a large telescope is a blurry circle that results when the randomly deflected light waves are added together in an extended time exposure. To diminish atmospheric effects, telescopes are built on high mountains, and are placed at least 30–45 m (100–150 ft) above the ground.

Radio observations of scintillation phenomenon

The radio observations of this phenomenon have three possibilities, namely, ionospheric scintillation, interplanetary scintillation and interstellar scintillation. There could be intergalactic scintillation, but this has not been observed so far. The salient features of the radio observations of the scintillation phenomenon are given below:

Ionospheric scintillation

There are plasma irregularities in all these regions in irregularly structured ionospheric regions can cause diffraction and scattering of trans-ionospheric radio signals. When received at an antenna, these signals present random temporal fluctuations in both amplitude and phase. This is known as ionospheric scintillation. This was first observed in 1948 by the radio observation of Cygnus A. Subsequent experimental and theoretical investigations established ionospheric scintillation can be observed by radio signals of stars (of angular diameter < 1 arc minute) and the radio beacons from the orbiting and geostationary satellites. It is now well known that the plasma irregularities in E and F region of the ionosphere are the main cause of ionospheric scintillation. Ionospheric scintillation may cause problems such as signal power fading, phase cycle slips, receiver loss of lock, etc., and degrade the quality of satellite navigation systems and radio communications. The ionospheric irregularities are one key component of the space weather.

Solar activity such as flares and coronal mass ejections often produce large variations in the particle and electromagnetic radiation incident upon the Earth. Such variations can, in turn, lead to disturbances of the "quiet-

time" magnetosphere and ionosphere. These disturbances, when affecting the ionosphere are known as ionospheric storms; tend to generate large disturbances in ionospheric density distribution, total electron content, and the ionospheric current system. Ionospheric storms have important terrestrial consequences such as disrupting satellite communications and interrupting the flow of electrical energy over power grids. They also provide the most challenging conditions under which accurate assessment of the vertical delay calibrations, to be used in the aircraft navigation system

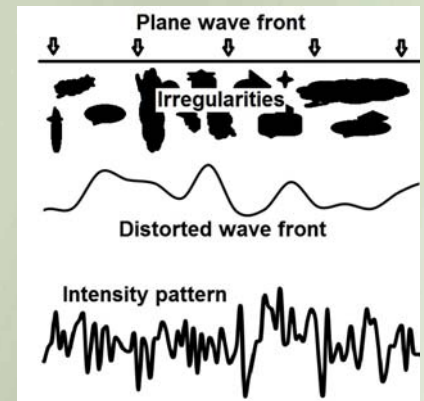


Figure 2: Schematic view of scintillation phenomenon

and must be maintained. Thus, it is important to monitor such storms, and, if possible, forecast their evolution. The ability to use the global GPS network to generate global maps of the ionosphere's total electron content (TEC) in near real-time presents us with a new and powerful tool for not only detecting ionospheric storms and monitoring their behavior, but also for pursuing scientific research that will lead to a more complete understanding of storm phenomena. Although ionospheric scintillation is highly random, however, observed statistical features of the phenomenon are as follows:

1. Daytime ionospheric scintillation is due to plasma irregularities present in the E and sporadic E layers of the ionosphere. More common occurrence of this is around 9 and 15 hours local time.
2. Night-time ionospheric scintillation is due to irregularities of spread F layer of the ionosphere. More common occurrence is post-mid night.
3. Night-time scintillation is usually more intense than daytime one.
4. Ionospheric scintillation is more intense during equinoctial months.
5. Ionospheric scintillation has two high occurrence regions around the globe; (1) Equatorial belt and (2) Polar regions. In mid latitude this activity is less.

The investigations of ionospheric scintillation have revealed several properties and formation process of the

plasma irregularities in the different regions of the ionosphere.

Interplanetary scintillation

The outer most terrestrial environment is magnetosphere and outside this is the interplanetary medium. This medium is filled with the plasma continuously flowing out from the solar corona in the form of 'solar wind'. This solar plasma is not uniform; it has irregularities as a function of both time and space. When signal from compact radio sources (angular diameter $< 1''$ arc) passes through this interplanetary medium, as explained earlier, the signal undergoes random phase variation and produces a diffraction pattern on the Earth. Since solar wind moves outward from the Sun with a velocity in the range of 250 -1250 km/sec, the intensity fluctuations seen by a stationary radio telescope are very rapid (fading rate faster than 1 per sec). These rapid fluctuations in the intensity of a compact radio source, caused by the solar plasma irregularities are called interplanetary scintillation. The interplanetary scintillation varies with the direction of the line of sight through the medium, being largest close to the Sun where plasma density is greatest. The investigations of interplanetary scintillation are useful for the estimation of following:

1. The density deviation and the scale size of the plasma irregularities in the medium.
2. The solar wind velocity by comparing the spatial fluctuations of the pattern as it drifts.
3. The angular structure of radio sources in the range of 0.01 -1 arcsec.

These are derived usually by comparing observations with the theoretical simulations. Most observations revealed that the interplanetary scintillation has two regimes of scattering e.g. weak and strong scintillation. A spherically symmetric model of the interplanetary medium is found to describe the experimental spectra well in most cases. It is known that observations at higher elongations exceeding 60 deg, where the effect of source size on the spectrum is relatively small, are more advantageous for studying the interplanetary plasma. The observations at smaller elongations say of the order of 30 deg or less makes it possible to estimate the sizes of scintillating sources.

Interstellar scintillation

The medium between the stars in our galaxy as well as in other galaxies is called interstellar medium. This medium

is known to have plasma which is usually not uniform. Thus, the radio waves from very compact sources while passing through such a medium undergoes fluctuations. These are termed as interstellar scintillation. Such sources are radio pulsars which exhibit interstellar scintillation. This effect is stronger at meter wavelength. It is found that the interstellar scintillation is larger in the inner parts of our galaxy and decreases away from the galactic center. The typical fading period, pattern scale and scattering distance are about 10 minutes, 10^6 km and 10^{15} km respectively. The studies of interstellar scintillation at radio wavelength have been used to estimate (1) medium velocity transverse to the line of sight and (2) the inclination of the orbit of binary pulsars.

The medium between the galaxies is called intergalactic medium. At present very little is known about this medium. This medium is extremely sparse by comparison with any other medium, however, the greater path length in the galactic medium adequately compensate for this. There should be scattering of electromagnetic waves within it, but it is yet to be convincingly detected. In this way it prudent to say that scintillation phenomenon prevails in nature at far and wide locations. The study of the phenomenon is very interesting and scientifically useful.

The basic cause of these fluctuations:

It is easy to assume that light from a distant star reaches our atmosphere almost in the form of plane wave front as shown in Fig. 2. The atmosphere has irregularities and these can be represented by the random patchiness in the medium. The irregularities will have refractive index slightly different than the ambient medium. If the absorption of the waves in the medium is neglected (which is usually applicable in most situations), the phase of the plane wave front after passing through such a medium will get distorted.

The different portions of this phase distorted wave front will act as individual sources. The waves from these will interfere with each other. The interference can be of two type; (1) constructive interference; wherein the signals from most waves get added. The amplitude and/or intensity will enhance. The star will appear brighter. (2) Destructive interference; wherein the signals mostly will cancel each other. Thus amplitude and/or intensity will diminish, could become zero (no signal). The star will be invisible in this situation. A typical pattern as a function

of space and time can be represented as shown in the Fig. 2.

The effect of source size:

The effect of source size for scintillation can be visualized by looking a tiny star and broad source e. g. Moon, planets, bigger stars. An example is shown in the Fig. 3 below. There are sky views of two objects at night. The atmospheric turbulence makes scintillation pattern of a tiny star in the observer's plane and the pattern of broad source gets smeared to produce simple image of the source as shown in figure below:

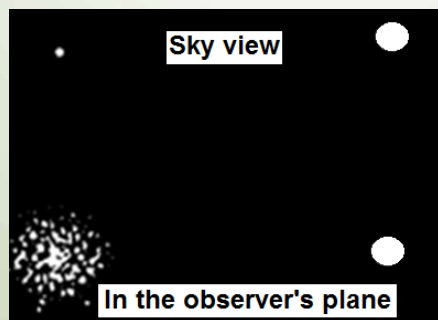


Figure 3: (left) Pattern of a scintillation of tiny star and (right) a broad source

The source size effect could also be explained on the basis of the principle of superposition of coherent waves. The waves from broad source are incoherent and hence do not form

sustained interference pattern. As the turbulence in the air moves due to wind the scintillation pattern of the star is not stationary. It moves and causes flicker of a star in our eyes. Thus flicker depends on three factors:

1. Size of the source
2. Amount of turbulence in the medium and
3. Wind velocity

Thus scintillation is a very interesting and universal phenomenon. The readers may refer to the following articles and references therein for more information and details of this phenomenon:

Further Reading:

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Search of another Gaia

One of the founding fathers of Rocketry and space exploration, Hermann Oberth defined the goal of space science as “To make available for life every place where life is possible. To make inhabitable all worlds as yet uninhabitable and all life purposeful.”

Quest for life beyond Earth has motivated mankind to explore the infinite universe for a long time. A region around a star where a planet could sustain life is known as ‘habitable zone’. Discovery of a planetary system around star Gliese 581, the potentially habitable exoplanet system has invoked excitement in the scientific community. But this is not it, for NASA’s Kepler mission specially designed to discover ‘Earth like planets’ has found 1235 planetary candidates, revolving around 997 host stars in which 68 planets are earth like in size and 54 lie in the habitable zone(NASA/Kepler News release). This statistic is mind boggling since this single mission has found more than twice the number of possible exoplanets than known before, unraveling so many possibilities!

A habitable Zone planet is neither too close to its host star to be so hot that it vaporizes all its water and not too far to freeze it all together. But this criterion of ‘not too hot and not too cold but just warm enough’ isn’t enough to describe this habitable zone (also called as the Goldilocks Zone). Then what makes a planet habitable?

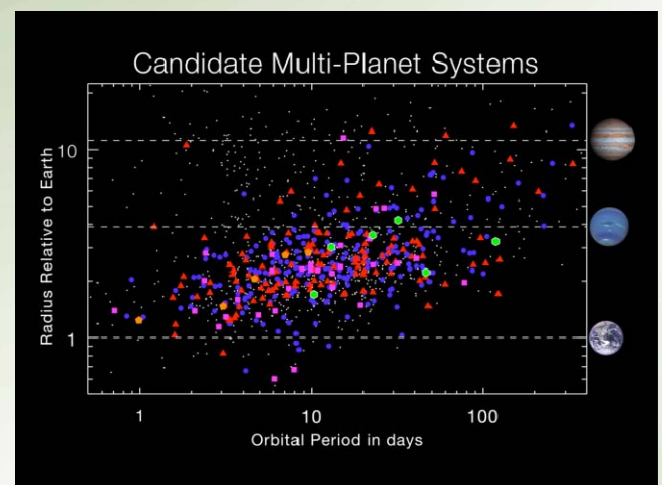


Figure 1: Exoplanets discovered by NASA’s Kepler Mission. (Source: NASA)