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LORENZO RESPIGHI AND STAR SCINTILLATION

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Lorenzo Respighi (1824 - 1889), one of the precursors of astrophysics, died one hundred years ago. I would like to remember briefly his contribution to the rise of astronomical spectroscopy during the second half of the 19th Century.

He began his career in Bologna where he carried out studies on hydrodynamics and aberration. In 1864 he was appointed director of the Capitoline Astronomical Observatory in Rome, a position he held until his death in 1889. Respighi's most important works are the daily measuring of the solar diameter; the realisation of objective-prism; and a catalogue of stars of the Northern hemisphere to the sixth magnitude.

During this meeting I shall present an interesting study of Respighi's on stellar scintillation that evidences his authority on and knowledge of spectroscopic applications.

Scintillation of the stars was known in antiquity. Aristotle, following the current opinion of his contemporaries that vision is due to rays emanating from the eyes towards objects, attributed star scintillation to the inability of the rays to reach them.

The stars, according to Tycho Brahe, have the shape of geometric solids in rapid rotation. Scintillation is due to different reflection of the light from an edge or a face and the difference from star to star depends on the difference in their rotation.

Simon Marius was the first to observe scintillation with a lens. Focussing his eye with a lens he observed the stars as circles in rapid changes of colour. Kepler accepted Brahe's idea in part. In " De stella nova" he expressed the opinion that scintillation is due to internal paroxysm of the stars,but even he thought that scintillation must be ascribed to atmospheric phenomena and real changes in the intensity and colour of the stars.

According to Galileo, however,this phenomenon is due to internal vibration of the heavenly bodies.

Hooke, in his "Micrographia" , attributes scintillation for the first time to the existence in the atmosphere of layers having different temperatures which act as lenses having different power of refraction.

In Newton's "Principia"we read that the scintillation phenomenon is due to trembling air and to vaporous upward flowing currents which deviate the luminous rays from the small diameter of the pupil. For this reason Newton, in the "Optics",attributed the lack of scintillation through the telescope to the large aperture of the objective.

We can see from these different opinions that studies on scintillation were not based on scientific enquiries also because these phenomena were not easily explained.

At the beginning of the 19th Century studies on this subject entered a new phase. William Nicholson, in the "Journal of Natural Philosophy" of 1813, announces that by tapping on the eyepiece of the telescope with the hand the star can be seen as a luminous line changing in colour and intensity and that by putting the eyepiece out of focus the star becomes a disc changing in colour continuously. Nicholson, observing scintillation of the star Sirius, calculates 30 changes in colour per second. He attributes the phenomenon to temporary absence of one or more rays of basic light colours.

We owe the first systematic work to Arago.He describes different scintillometers.One of them consists of a telescope in which the eyepiece is put out of focus, as described by Nicholson. By changing the position of the eyepiece he notices that the center of the star image is dark in certain positions. By moving the eyepiece constantly up and down,the dark spot grows and the star image is tranformed into a ring and again becomes a disc with a dark spot in the center only, and so on. When a star scintillates the center of the disc sometimes flashes; by counting the number of flasches Arago is able to measure the scintillation of a star.

A second scintillometer consists of a small mirror placed on the optical axis of the telescope at a 45° angle: the star image is transmitted to a lateral eyepiece. By rapid rotation of the mirror Arago obtains separation of the colours. A new measure is obtained by counting the number of variations.

Arago concludes that scintillation is an interference phenomenon due to refraction of the atmospheric layers. He demonstrates that it is not due to internal paroxysm of the stars because by observing a star with an eliometer, the two images will produce two different luminous ribbons when the eyepiece is vibrated.

G.Battista Donati was the first to observe scintillation through a spectroscope in 1855. He notes that in the spectroscope the stars near the horizon display enlargements or contractions of the bands of colour and in some stars the intensity of spectral colours is reduced

Donati carried out an experiment suggested by G. Battista Amici. He observed a solar ray reflected from a silvering sphere with a telescope and a solar ray reflected from the sphere but passing through a crystal prism placed near the sphere. According to Donati, two images will be generated: the first white and the second changing in colour. Thus we have the demonstration that scintillation is due more to dispersion than to interference.

C. Dufour prefers to observe scintillation with the naked eye.

He trains his eye so that it can appreciate star scintillation from 0 to 100. He divides his observations on the basis of their altitude and he traces a curve with the zenithal distance in abscissa and the scintillation intensity in ordinate. Dufour, after having submitted his work to Argelander, concludes that red stars scintillate less than white ones (fig. 1).

Dufour is in agreement with Arago's theory that the red wave, being teh greater of the luminous waves, needs greater deviation to reach an interference that cancels its colour. He pursues his obser= vations and speculations and discovers that the average curve of scintillation is similar to that obtained by result of astronomical refraction of a star at a fixed altitude multiplied by the height of the atmosphere crossed by luminous rays of the star at that alti= tude (fig. 2). Dufour thus finds that the coefficient to multiply scintillation to obtain the result is: n= 5.433 and that calculating the intensity of average scintillation to be equal to 100 gives scintillation value for the most important stars such as: Procion = 11 ; Vega = 110 ; Aldebaran = 99 ; Orionis = 90 and so on.

On the basis of these results Dufour enunciates three laws: 1)red stars scintillate less than yellow ones and yellow stars scin= tillate less than white ones; 2) the intensity of scintillation is proportional to the result of astronomical refraction of a star mul= tilplied by the height of the atmosphere crossed by the luminous rays of the star at that altitude; 3) the intensity of scintillation depends, besides colour, on internal differences of the stars.

C.Montigny constructed three scintillometers to make close stu= dies of the phenomenon.In the first he placed a rotating convex lens between the eyepiece and the eye. The optical axis of the lens was parallel to that of the telescope but slightly eccentric to avoid

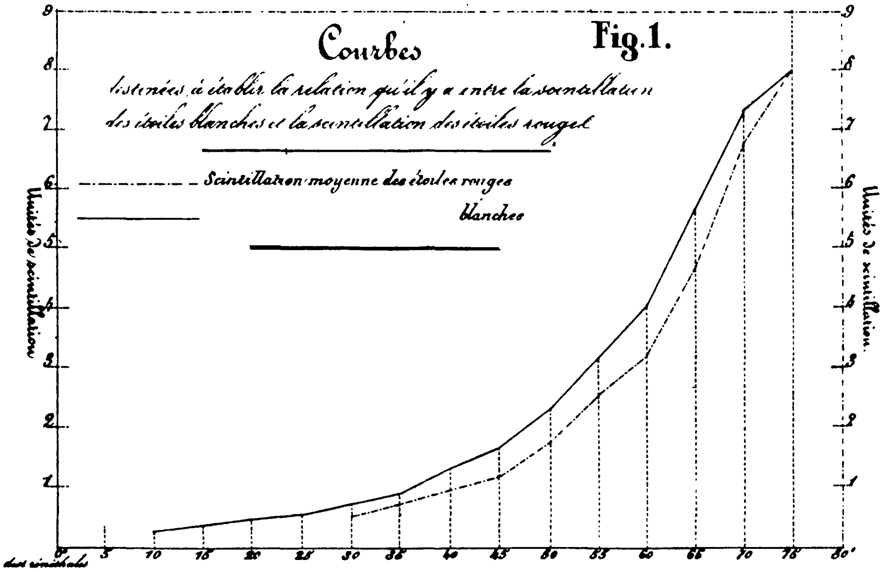

Fig. 1 - Function of the first law of Dufour.

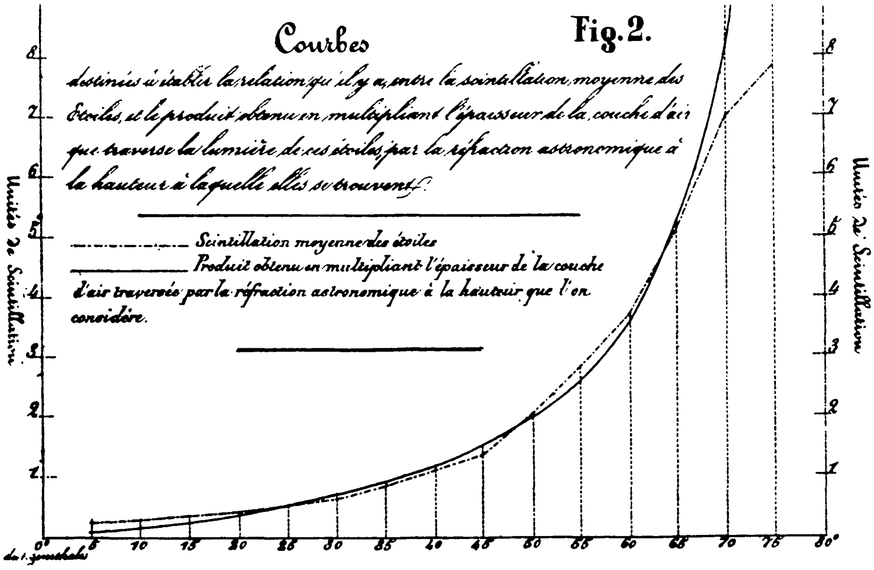

Fig. 2 - Function of the second law of Dufour.

the effects of prismatic colouring of the image due to the lens itself (fig. 3). He obtained a circle of light on which variously coloured arcs differed in continuity and on which red and yellow colours predominated. He calculated 70 variations per second in the star Sirius. Changing the velocity of rotation of the lens he observed a lesser number of coloured, but weaker arcs.

Another scintillometer conceived by Montigny consists of a glass plate turned on the optical axis at 45°. The ray of light is divided in the same way as the results obtained with an eliometer. A third scintillometer consists of a prism with 45° refraction angle placed in front of the objective of the telescope. Montigny is the first to observe that the spectrum is crossed by dark bands,that in the stars near the horizon the spectral colours are less distinctive and that blue and violet colours are often partially or totally extinguished. He ascribed the disappearences to lesser wavelength of these colours and to the fact that they encounter more air waves than the others. Montigny explains colour scintillation by atmospheric reflection and dispersion.

C. Wolf carried out spectroscopic observations in 1868 by putting a cylindrical lens near the eyepiece to enlarge the spectral image. Like Montigny he observed dark bands moving rapidly from red to violet. Rotating the spectroscope around its axis, the dark bands incline in the spectrum direction and then rotate in elicoidal movement from red to violet; the stars at higher altitudes give less numerous bands. Wolf ascribed scintillation to interference phenomena on the basis of Fizeau's and Foucault's experiments but he was not able to deduce any laws from the observations.

Respighi's merit was the capacity to deduce important conclusions from the observation of dark bands crossing the spectrum with

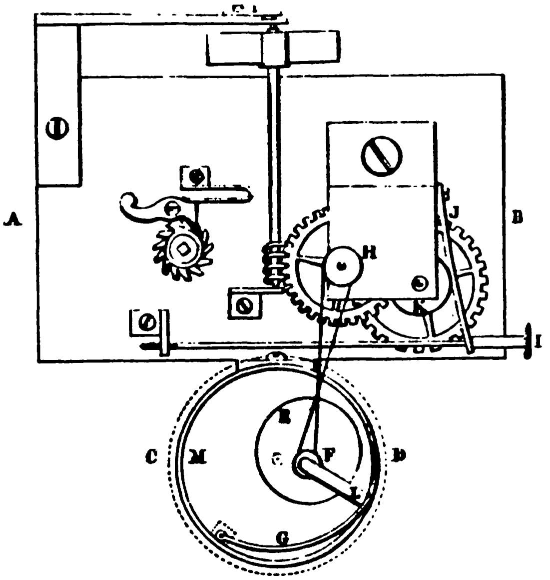

Fig. 3 - First scintillometer by Montigny.

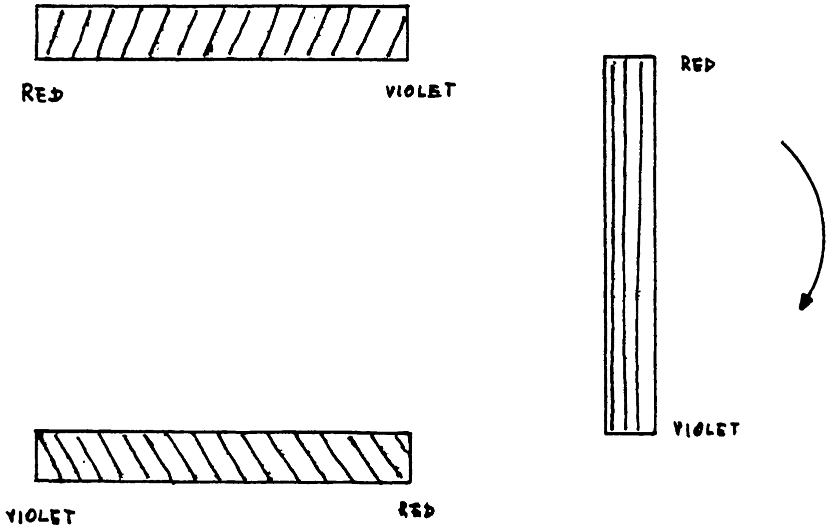

Fig. 4 - Variations of bands inclination relating to the rotation of the spectroscope by Respighi.

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variable inclination.

He studied scintillation of 1th, 2nd and 3th magnitude stars at altitudes from 0 to the Zenith and used a direct-vision Hoffmann spectroscope with cilindrical lens. In the stars near the horizon he observed transversal dark bands crossing the spectrum from red to violet, sometimes from violet to red; this phenomenon does not change withbad atmospheric conditions; putting the plane of dispersion in a horizontal position the inclination of dark bands grows with the altitude of the star; dark bands have no inclination near the horizon and they have maximum, that is 90°, at an altitude of 40°; at altitudes greater than 40° the bands become indefinite; rotating the prism the inclination of dark bands decreases and returns to a vertical position when the spectrum is vertical; turning the prism further, the bands assume symmetric positions; the distinctive spectral bands of the stars are motionless also during strong scintillation. From these observations Respighi concluded that scintillation is not due to interference, as conceived by Arago and Wolf, or to the reflection of the atmospheric waves as postuled by Montigny.

Respighi is of the opinion that the phenomenon is due to the extinction, that is temporary suppression of luminous rays owing to different refrangibility of these in the atmosphere. Respighi's first important conclusion was that scintillation occours in the tropopause; in fact, the lack of motion of spectral bands during strong scintillation proves that angular deviation of luminous rays is very little and takes place at a great height.

A second set of observations brings Respighi to another important conclusion. He observes that the movement of the dark bands goes from red to violet when stars are in the West and from violet to red when stars are in the East (fig. 4). The movement is oscillating or stationary when stars are in the North or in the South. Respighi deduced that scintillation is correlated with rotation of the Earth. In fact,the constant movement of the bands,relating to the meridian, demonstrates that the cause is not due to ascensional or descensional movements of air masses.

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