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Dust in the Earth's Atmosphere Before and After the Passage of Halley's Comet (1984–1987)

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Everybody knows that with the exception of those who study the Sun, members of the astronomical profession must work at night to be able to record the faint light from the objects of their interest. It is true that CCD flat fields are often made at twilight, but otherwise it is necessary to wait until the Sun is far below the horizon and there is no more straylight in the atmosphere, before the "real" astronomical observations can start.

It is therefore always a surprise, especially to visiting colleagues, to meet astronomers/physicists, who are busy observing during twilight and dawn, when the sky is still very bright. And it seems even more strange that when it finally gets dark, then these observers close their telescopes and return to their offices and homes!

At the Abastumani Astrophysical Observatory in the Republic of Georgia, located near the border with Turkey in the southern part of the Caucasus mountains, you will meet observers of all three types. While some of them study the Sun with imaging and spectroscopic telescopes, others like ourselves observe the emissions from the Earth's atmosphere in the daytime, during twilight and dawn, and also during the night, when still other colleagues are busy unlocking the secrets of distant stars and galaxies.

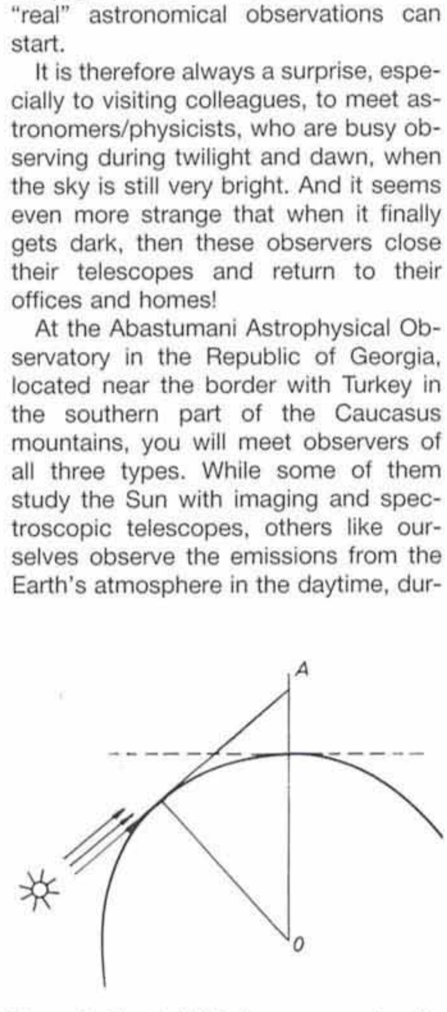

Figure 1: *The twilight phenomenon. An observer on the Earth's surface who looks up towards the zenith, only receives scattered light from those layers which are illuminated by the Sun's rays.*

We know that most astronomers have little experience with our kind of research and would therefore like to illustrate it by some examples. It is of course normally considered to be more of "geophysical" than of "astronomical" nature, but, as we shall see below, it may however also have some implications which are of interest to solar system astronomers.

The Twilight Sounding Method

Among the many interesting questions which concern the meteor showers associated with comet P/Halley, i.e. the *Orionids* with a maximum around October 21 and the *Eta Aquarids* (around May 4), is whether or not a particular activity was connected with the latest approach of this famous comet to the terrestrial orbit in 1985–1987.

Meteoric aerosol which enters into the Earth's atmosphere can be detected by the method of *twilight sounding*; this has been done many times in the past, see e.g. Fehrenbach et al. (1972); Divari and Mateshvili (1973), Mateshvili (1974), Link (1975) and Mateshvili and Mateshvili (1989).

The twilight phenomenon is explained by the fact that when the Sun sets below the horizon, its rays continue to illuminate the higher layers of the atmosphere. To begin with, these rays reach all layers, but as the Sun sinks, progressively higher layers come into the Earth's shadow and cease to be in the sunlight. The scattered light from the sky comes increasingly from the highest layers, but since the scattering efficiency falls off with the altitude (i.e. with the density) rather rapidly, we receive at any time mostly the scattered light from a rather narrow, sunlit atmospheric layer. A simplified scheme of the twilight phenomenon is shown in Figure 1.

The intensity of scattered light from point A is given by the relation:

$$I(\lambda) = I_0(\lambda)\,\omega_0\,P^m(\lambda)\,m\tau(\bar{H})$$

where $I_o(\lambda)$ is the extra-atmospheric solar brightness, ω_o is the size of the solar disk, m is the air mass, P is the vertical transmittance of the atmosphere, $\bar{H}(\lambda)$ is the instantaneous altitude of the Earth's shadow, τ is the optical thickness which is given by the expression:

$$r(\bar{H}) = \int_{\bar{H}}^{\infty} \sigma(\bar{H})\, d\bar{H}$$

where $\sigma(\bar{H})$ is the volumetric scattering coefficient (Rosenberg 1963). So, $I(\lambda)$ is therefore proportional to scattering coefficient $\sigma(\bar{H})$ and N_{aer}, the aerosol or particle content per unit of volume.

In Abastumani, we use for our twilight observations a photoelectric photometer with an interference filter that is centred at λ610 nm. During the evening twilight phase we then register the decreasing total intensity from a sky area

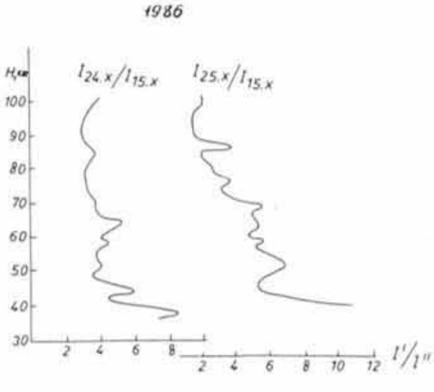

Figure 2: *Intensity ratios as a function of altitude, as observed on October 24 and 25, 1986, relative to October 15, 1986, i.e. before the Orionid period. The ratios are much larger than unity, and the scattering is therefore much larger at and after the maximum of the stream, than before. This shows the injection into the atmosphere of dust particles.*

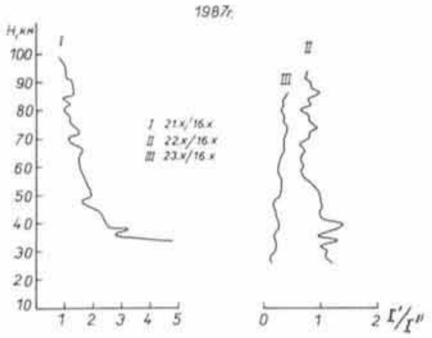

Figure 3: *As Figure 2, but for three dates in 1987. Now the intensity ratios are closer to unity than in 1986.*

defined by the optics of our instrument and in the morning twilight, we obtain a similar intensity curve in the reverse sense.

If there exists at a certain time in the atmosphere a layer with a higher scattering power and if it has a great horizontal extent, it will become apparent in our curve as an intensity excess at the same value of $\bar{H}$ in different sighting directions and therefore, at different values of ζ (the solar depression angle) and at different moments.

Our observations are usually carried out in two points of the sky on the solar vertical (the great circle through the Sun and the zenith); the zenith angles of these points are ±60°, that is, one point is in the general direction of the Sun and the other is in the opposite direction. The intensity is continuously recorded in each direction during one minute, then the system is switched to the other direction. A calibration standard is always recorded before and after the observations. This relative observing method to a large extent eliminates instrumental sensitivity drifts, etc.

Observations at the Time of Orionid Meteor Shower Activity

The observation dates in the Orionid periods of 1984, 1986 and 1987 are given in Table 1.

In Figure 2, we show the ratio of the sky intensity, as observed on October 24 and 25, 1986, respectively, to that on October 15, 1986, i.e. at a time when there should be no effect of the Orionid meteor shower. In comparison, the 1987 intensity ratios before and after the maximum of the stream (Fig. 3) are much closer to unity and reveal no significant increase. Thus, in 1986, after the maximum of the stream had been passed, the intensity of scattered light increased throughout the Earth's atmosphere. This implies that some matter was deposited into it, consisting of different fractions that moved downwards (precipitated) at different rates. When calculating the ratio of the intensities obtained in 1986 to those of 1984, i.e. before and after the passage of Comet Halley (Fig. 4), we find that the intensity of scattered light, depending on the altitude, increased from 4 to 14 times.

Observations at the Time of the Eta Aquarid Meteor Shower Activity

During the Eta Aquarid period in April/May 1987, we were only able to to compare the intensity $I(\lambda)$ with that obtained on the day preceding the onset of the activity of this meteor shower. The observations were carried out in the morning (9 times) and evening twilight (10 times), beginning on April 27 and ending on May 17, 1987.

The evening twilight observation on April 27 was chosen as the reference. When we plot the intensity ratios for the various series of observations, it is obvious that also during this period, the dust content in the upper atmospheric layers increased.

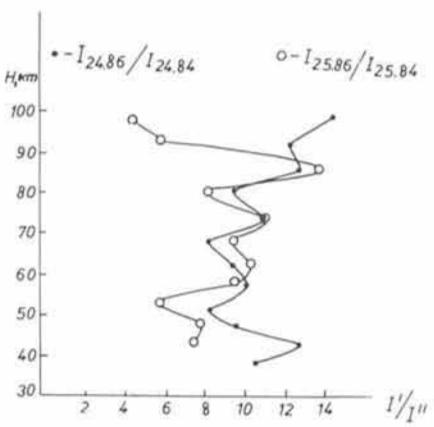

Figure 4: *A comparison of the dust content in the atmosphere on dates soon after the Orionid maxima in 1986 and 1987. The intensity ratios for the same dates in the two years are much larger than unity, i.e. there was much more dust in the atmosphere in 1986 than in 1987.*

How Big Are These Particles?

It would of course be very interesting to know the sizes of the particles which cause the increased scattering. We normally calculate this by three different methods:

1. The mean sizes are determined from the sedimentation velocities of the observed aerosol layers. The particle sedimentation velocity was determined using the Stokes-Cunningham law with the Cunningham correction

$$v_t = \frac{2r^2}{9\eta} g(\varrho - \varrho_a)\left(1 + \frac{Bl}{r}\right)$$

where η is the air viscosity, ϱ_a is the density of particles, ϱ is the air density for the appropriate altitude, l is the mean free path of a molecule, and B is a factor which for $l/\varrho \geq 10$ equals 1.65.

2. The size of the particles can also be calculated from the relation

$$r = \left(\frac{9LkTV}{8\pi\varrho_a g}\right)^{1/5}$$

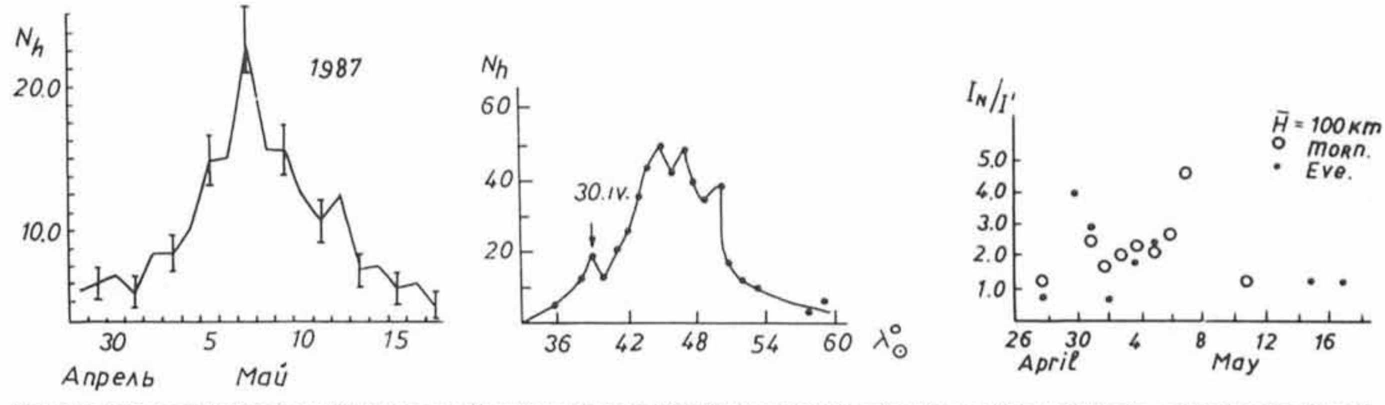

Figure 5: *Activity of the Eta Aquarid shower as a function of date in 1987. (a) Mean hourly echo rate over 8-hour intervals, centred on the time of radiant transit on that date (from Poole 1988); (b) the visual rate as a function of solar longitude (after Hajduk and Buhagiar 1982); (c) the intensity of twilight scattering at altitude 100 km in 1987 as measured in the morning and evening twilight from Abastumani (normalized to the level outside the shower period).*

Table 1. *Observation dates at the time of the Orionid shower (M: Morning (dawn) observations; E: Evening (twilight) observations)*

October	15	16	17	18	19	20	21	22	23	24	25	26	27
1984	–	–	–	–	–	–	–	E	E	E	E	E	M
1986	M	–	–	–	–	–	–	–	–	E	E	–	E
1987	–	E	–	–	–	E	E	M	–	–	–	–	–

where L is the thickness of the aerosol layer, k is the Boltzmann constant, T is the absolute temperature, g is acceleration due to gravity and $v=2.2\cdot10^{-10}\sigma(\bar{H})km^{-1}$, an empirical relation, where $\sigma(\bar{H})$ is the volumetric scattering coefficient.

3. Finally, the size of the particles may also be obtained by comparison of experimental sedimentation velocities with theoretical ones, calculated for different particle size and density (Ivlev 1982).

For the Orionids in 1984, the mean particle sedimentation velocity on October 22–27 and at altitudes 70–80 km, was 5.747 cm sec^{-1}. The estimated particle radii were ~0.08 μm. In 1986, the mean particle radius was about the same, ~ 0.065 μm. A great amount of cosmic matter consisting of particles with a wide range of sizes was injected into the atmosphere during the 1987 Eta Aquarid activity period. Very small particles with radii of the order of 0.0005 to 0.005 μm accumulated at an altitude of 100 to 120 km and those with r=0.5 mm at $\bar{H}=60$ to $\bar{H}=80$ km. Moreover, the background aerosol content increased at all altitudes.

Time variations of the intensities at different altitudes reflect the intrusion of the particles ($\bar{H}>70$ km) and their subsequent rearrangement in the atmosphere ($\bar{H}<70$ km). The time variation of I_N/I' coincide with those of meteor hourly rates from the radar (Poole 1988) and visual (Hajduk and Buhagiar 1982) observations (Fig. 5).

Conclusions

Thus, it is clear that twilight observations of the type described here may be used to reveal structures of meteor showers. We plan to continue this work and hope eventually to accumulate enough material to be able to make more explicit statements about this.

The apparent increase in the aerosol content of the upper atmosphere when the Earth passed through the two meteor streams associated with P/Halley for the first time after the recent passage of this comet, is indeed very intriguing. We can offer no easy explanation to this at this moment.

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Visiting Astronomers

(April 1 – October 1, 1993)

Observing time has now been allocated for Period 51 (April 1 – October 1, 1993). The demand for telescope time was again much greater than the time actually available.

The following list gives the names of the visiting astronomers, by telescope and in chronological order. The complete list, with dates, equipment and programme titles, is available from ESO-Garching.

3.6-m Telescope

April 1993: De Graauw et al. (9-003-49K), Danziger/Bouchet/Gouiffes/Lucy/Fransson/Mazzali/Della Valle, Böhringer et al. (1-023-49K), Shaver/Wall/Kellermann, Jablonka/Bica/Alloin, Turatto et al. (4-004-45K), Danziger/Bouchet/Gouiffes/Lucy/Fransson/Mazzali/Della Valle, De Graauw et al. (9-003-49K),

May 1993: De Graauw et al. (9-003-49K), van der Hucht/Williams/Yudiawati Anggraeni/Bouchet, Habing et al. (7-008-51K), Danziger/Bouchet/Gouiffes/Lucy/Fransson/Mazzali/Della Valle, Kudritzki/Pakull/Méndez/Conti/Gabler/Motch, Danziger/Bouchet/Gouiffes/Lucy/Fransson/Mazzali/Della Valle, Magazzù/Martín/Rebolo, Macchetto/Sparks, Danziger/Bouchet/Gouiffes/Lucy/Fransson/Mazzali/Della Valle, Amram/Balkowski/Boulesteix/Le Coarer/Marcelin/Cayatte/Sullivan, Lagage/Cabrit/André/Pantin/Olofsson/Nordh.

June 1993: Lagage/Cabrit/André/Pantin/Olofsson/Nord, Lagage/Pantin, Nissen/Lambert/Smith, Lemoine/Ferlet/Vidal-Madjar/Emerich, Baade/Kjeldsen, Leone/Pasquini, Mermilliod/Raboud/Levato, Barbuy/Renzini/Ortolani/Bica, Lagrange-Henri/Corporon/Bouvier.

July 1993: Rouan/Hofmann/Normand/Alloin/Cuby/Tacconi-Garman/Gallais, Beuzit/Lagrange-Henri/Tessier/Vidal-Madjar/Ferlet/Beust/Hubin, Dougados/Rouan/Lopez/Coudé du Foresto/Forveille, Ménard/Léna/Malbet/Dougados/Monin/Schuster, Rigaut/Léna/Gehring/Hofmann/Cuby, Della Valle/Bianchini/Duerbeck/Ögelman/Orio, Borkowski/Tsvetanov/Harrington, Danziger/Gilmozzi/Zimmermann/Hasinger/Macgillivray, Tadhunter/Morganti/Fosbury/Danziger/Shaw, Tinney/Mould/Reid, Molaro/Pasquini/Castelli/Bonifacio.

August 1993: Molaro/Pasquini/Castelli/Bonifacio, Zaggia/Capaccioli/Piotto/Stiavelli, Bedding/Beckers/von der Lühe/Weigelt/Urban/Beckman/Grieger/Kohl/van Elst, Danziger/Bouchet/Gouiffes/Lucy/Fransson/Mazzali/Della Valle, Barbon/Notni/Radovich/Rafanelli/Schulz, Véron, P./Hawkins, Seitter/Spiekermann/Schücker/Böhringer/Hartner/Crudacce, Fosbury/Villar/Binette, Danziger/Bouchet/Gouiffes/Lucy/Fransson/Mazzali/Della Valle, Schulz/Mücke, Molaro/Primas/Castelli/Bonifacio.

September 1993: Saint-Pé/Combes, M./Rigaut/Tiphène/Demailly/Tacconi-Garman, Combes, M./Saint-Pé/Tomasko/Demailly/Fauchèrre, Vettolani et al. (1-019-47K), Mazure/Rhee et al. (1-014/005-43K), Hainaut/West R.M., Møller/Warren, Kneer/Bender/Krautter, Danziger/Bouchet/Gouiffes/Lucy/Fransson/Mazzali/Della Valle, Habing et al. (7-008-51K).

3.5-m NTT

April 1993: Moorwood/Oliva/Origlia/Kotilainen, Oliva/Marconi/Salvati/Moorwood, Miley/van Ojik/Röttgering/Moorwood, Oliva/Marconi/Salvati/Moorwood, Miley et al. (2-001-43K), Turatto et al. (4-004-45K), Tammann et al. (1-022-47K), Thomsen/Sodemann, Held/Renzini/Cappi.

May 1993: Gredel/Zinnecker, Gry/Baluteau/Cox/Armand/Emery, Lutz/Genzel/Drapatz/Cameron/Harris/Najarro/Hillier/Kudritzki, Bertola/Amico/Zeilinger, Motch/Pakull/Pietsch, Danziger/Méndez/Kudritzki/Mazzali/Lucy/Ciardullo/Jacoby/Roth, Tammann et al. (1-022-47K), West/Hainaut/Mars-