

ASTROMETRY, MORPHOLOGY, AND POLARIMETRY OF COMET DONATI IN 1858

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Abstract: We present unpublished observations of Comet Donati 1858 VI recently recovered in an old storage facility at the University Observatory in Oslo. Carefully-made drawings reveal temporal changes in the appearance of this comet. Fine structures in the tail were noted, some of which were short-lived. Envelopes in the comet's head, apparently due to outgassing from the nucleus, were monitored over several days. Astrometric positions of the comet's head derived by various combinations of telescopes and micrometers reveal a standard deviation of $\pm 6''$. Visual polarimetry of the coma and tail revealed polarized light and determined that the polarization plane contained the comet and the Sun. Thus the polarized light from the comet was reflected sunlight. The observations are discussed in relation to contemporary publications.

Keywords: Comet Donati – astrometry – morphology – polarimetry

1 INTRODUCTION

The University Observatory in Oslo was inaugurated in 1833 when the city was named Christiania. It became the national center in Norway for a number of scientific disciplines, e.g. astronomy, geodesy, geomagnetism, meteorology and applied mathematics. During its 100 years of operation it was led by a succession of five professors. The first four were active in classical astronomy and published astrometric results for stars, planets, asteroids and comets. Some objects were subjected to orbital analyses. Major projects were contributions to the Astronomische Gesellschaft's Zone catalog, a complete re-observation two decades later, and subsequent studies of stellar proper motions. In geodesy there was participation in Struve's meridian arc and the European meridian arc to determine the size and shape of the Earth.

The Observatory was abandoned in 1934 when astronomy moved to the new university campus in Oslo and its present residence in the Institute of Theoretical Astrophysics. Eventually, the original observing pavilions and the instruments were dismantled, and the main building was used for other purposes until 2010. Since then it has been refurbished, and it now serves in a university program to inspire and recruit young people to the sciences. Some of the old instruments have been re-installed to provide an historic time-line in the pedagogical activities. As such, the Observatory is also a collection of historical instruments in many sciences and an element in a museum of university history.

The founder of the Observatory was Christopher Hansteen (1784–1873), Professor of Applied Mathematics from 1816, who conducted astronomical observations in a temporary observing hut between 1815 and 1828 (Pettersen, 2002). The University Observatory was built in

1830–1833 (Enebakk and Pettersen, 2009). Hansteen was the only scientist at the Observatory during its first decade of operation.

2 THE COMET OBSERVERS

In 1844 Carl Fredrik Fearnley (1818–1890) graduated from the University of Oslo and was appointed Observer. He received a University stipend to study abroad during 1849–1852, and spent time with Argelander in Bonn and also visited Munich, Berlin, Königsberg and Pulkovo Observatory in St. Petersburg. Fearnley was appointed a Lecturer in Astronomy at the University of Oslo in 1857. Four years later he became Director of the Observatory (by this time Hansteen was 78 years old). In 1865, at the age of 47, Fearnley was promoted to Professor of Astronomy.

Henrik Mohn (1835–1916) graduated from the University of Oslo in 1858 at the age of 23. He was appointed a University Fellow two years later and Observer in 1861. In 1866 he founded the Institute of Meteorology and held its Professorship from 1866 to 1913.

Oluf Andreas Løwold Pihl (1833–1895) was trained as an engineer in Sweden and England. He moved to Oslo in 1850 as the Director of Oslo Gas Works, at the age of 28, and held this appointment until his death in 1895. Pihl's spacious residence just north of the University Observatory was equipped with a private observing tower which housed a small equatorial refractor.

When Donati's Comet developed into a bright object in the skies in mid-September 1858, Fearnley had been observing it for three weeks. He was a meticulous observer with an exceptional talent for drawing. The 40-yr old university lecturer enlisted the help of his 36-yr old friend Oluf Pihl to study morphological details in the tail and coma during the brightest phase, in

early October. And he worked with his talented 23-yr old student Henrik Mohn to conduct the first polarimetric studies of a night-sky object in Norway. Internal reports and drawings related to this observing program have recently been recovered from old storage locations, and they served as the sources for this paper, along with observing reports published in *Astronomische Nachrichten*.

3 THE OBSERVATIONS

Comet C/1858 L1 (Donati) was discovered by Giovanni Battista Donati (1826–1873) in Florence, Italy, on 2 June 1858. It was found to have an elliptical orbit ($e = 0.996$) with a period of revolution close to 2,000 years. Perihelion took place on 30 September 1858. The comet was closest to the Earth (0.54 AU) on 10 October 1858.

Comet Donati was observed with all available telescopes at the University Observatory in Oslo. In addition, Mohn used a homemade 2.5-cm refractor to initiate his experiments. Pihl's private observatory was equipped with an 8.1-cm refractor by optician H. Krog of Bergen, on an equatorial mounting manufactured by Lohmeyer of Hamburg (Pihl, 1869). Table 1 lists the telescopes at the University Observatory. Positions of the comet were determined relative to reference stars by Fearnley using ring micrometers on several refractors, which ranged in aperture from 10 cm to 19 cm. Filar micrometers with multiple threads were used on the Ertel meridian circle and on the Repsold equatorial refractor. The latter had graduated declination and right ascension circles (diameter 50 cm) for direct reading of celestial coordinates. Fearnley and Pihl also made drawings directly in star atlases in order to accurately determine the orientation and extent of the comet's tail. They did this without telescopic aid and with low power telescopes. At high magnifying power they recorded morphological details and temporal changes in the coma and tail of the comet. Fearnley repeatedly measured the extent of what he interpreted as the nucleus. He also monitored a succession of bright envelopes emanating from the nucleus. Some of the phenomena observed were reported and discussed by Fearnley (1858; 1860a; 1860b). The attempts to study the polarization properties of the light from the comet using his own small refractor, the comet finder and the 19-cm Merz refractor at

the University Observatory were described in an unpublished report by Mohn (1858).

3.1 Astrometry

Fearnley (1860b) determined the position of the nucleus of Comet Donati between 26 August and 13 October 1858. He used the Utzschneider alt-azimuth refractor (on 6 nights between 26 August and 5 September, and on 18 September) and the Repsold (on 2 October) and Merz (on 13 October) equatorial refractors equipped with ring micrometers to determine positions of the comet relative to reference stars with known celestial coordinates. He also used a filar micrometer on the Repsold instrument (on 17 nights between 4 September and 10 October) to determine celestial coordinate values with its large graduated circles. On five occasions he used the Ertel meridian circle for the same purpose. The results were published in *Astronomische Nachrichten* and were included in the database compiled by G.W. Hill (1867) for orbit determination. Hill found an elliptical orbit with a period of revolution of 1,950 years for Comet Donati. Coordinates computed from this orbit for the dates and times of Fearnley's individual position determinations were used to generate a list of deviations (observed – calculated) for declination and right ascension, respectively. The scatter of the observations may be expressed by the standard deviations, which are $\pm 5.5''$ in declination and $\pm 5.8''$ in right ascension.

3.2 Visual Observations of Comet Morphology

The first drawing was made by Fearnley from visual observations with the Utzschneider 10.7-cm refractor on 27 August, two hours after the full moon rose. The tail appeared 10'–15' long. On 1 September the tail had grown to 20'–25' (Figure 1). The comet was visible to the naked eye and was estimated to be magnitude 2–3. In unsteady weather on 5 September the tail appeared 5° long.

On 16 September the comet was drawn on two occasions, separated by 1.5 hours. The 11.7-cm Repsold equatorial was used. The Moon set between the two observations. The motion of the comet is noticeable in Figure 2. The tail is 4.5° long.

On 18 September several telescopes were used at the University Observatory. In the Utzschneider refractor with a ring micrometer the

Table 1: Technical Data for Telescopes at were the University Observatory in Oslo in 1858.

Manufacturer	Mounting	Aperture	Focal length	Auxiliary instruments
Utzschneider refractor	Alt-azimuth	10.7 cm	175 cm	Ring micrometer
Ertel meridian circle	Meridian	10.8 cm	163 cm	Filar micrometer
Repsold refractor	Equatorial	11.8 cm	160 cm	Filar and ring micrometers
Merz comet finder	Equatorial	7.5 cm	70 cm	Polariscope
Merz refractor	Equatorial	18.8 cm	318 cm	Ring micrometer; polariscope

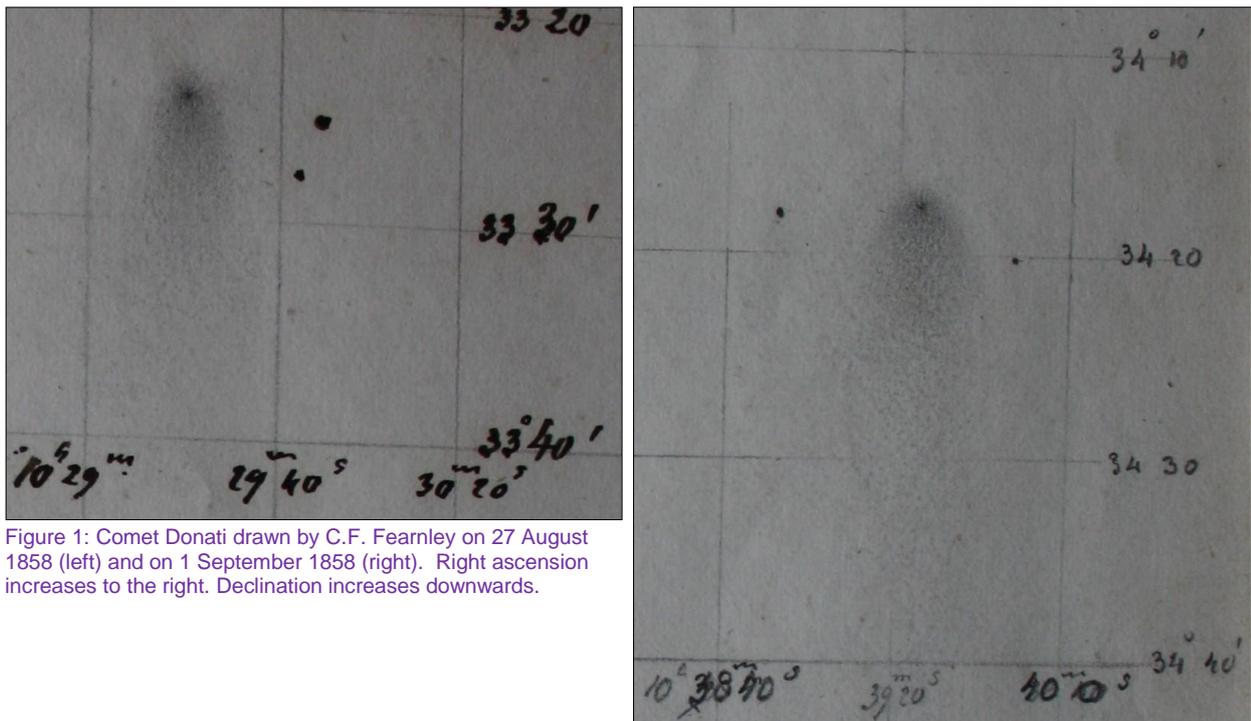


Figure 1: Comet Donati drawn by C.F. Fearnley on 27 August 1858 (left) and on 1 September 1858 (right). Right ascension increases to the right. Declination increases downwards.

nucleus of the comet had a diameter of 15"–16". At a higher magnification of 150 \times in the Repsold equatorial refractor equipped with a filar micrometer, the nucleus was 5"–6" in diameter. The comet finder was used to sketch the entire comet. There were indications of three bright rays extending from the nucleus into the tail. The last drawing focused on the head of the comet and the nearby tail (Figure 3).

The waxing Moon was high in the sky on 19, 20 and 21 September. The yellowish moonlight was accompanied on 20 September by a significant aurora in the region of the comet, which appeared much whiter and stood out despite the bright sky background. The comet finder was used to draw the entire comet, but the tail appeared longer with the naked eye (see Figure 4).

Despite the presence of the full moon a brightening was noticed in front of the nucleus using the Utschneider refractor on 23 September. The diameter of the nucleus was measured as 30" on 26 September, but was only 9" at a magnification of 150 \times in the Repsold equatorial. The nucleus was surrounded by a faint sphere of diameter 30" which had the appearance of a fan since a 90° sector was lacking at the rear (tail side) of the nucleus. A larger and even fainter structure was also noted. It continued around, into and along the tail. Outside of this was a very faint veil (the punctuated line in the drawing in Figure 5).

The tail grew markedly on 27, 28, 29 September and on 1 October (Figure 6), when it was longer than 20°. The diameter of the nucleus was measured on 27 September as 8.2"

with high magnification on the Repsold equatorial. The next day another envelope surrounding the nucleus was noted. It had expanded outwards by 1 October.

The remaining observations were made with the Moon below the horizon as new moon occurred on 6 October. On 3 October two circular envelopes were noted around the nucleus, both in the 12-cm Repsold equatorial and in the 19-cm Merz equatorial. One of these was noted also by Pihl, who determined its diameter to be 1' 28" with his 8-cm refractor.

On 5 October the envelopes in the inner halo took the shape of a spiral. Further details near the nucleus were noted on 6 and 9 October (Figure 7), using both the Repsold equatorial and the Merz equatorial. The diameter of the nucleus was less than 2". Pihl remarked in a letter to Fearnley dated 7 October 1858 that on 6 October the diameter of the nebulous circle surrounding the nucleus had increased by 15" relative to three nights earlier. He also noted a dark linear filament within the tail with weaker parallels on either side. They were inclined to the general direction of the tail and appeared to point towards the Sun.

On 10, 13 and 15 October further developments in the coma were noted (e.g. see Figure 8). By this time the comet was very low in the sky, and observations ended on 15 October.

3.3 Fine Structure in the Coma

Fearnley used the 12-cm Repsold equatorial to monitor changes in the head of the comet. He noted the development of concentric halos expanding out from the nucleus during the last

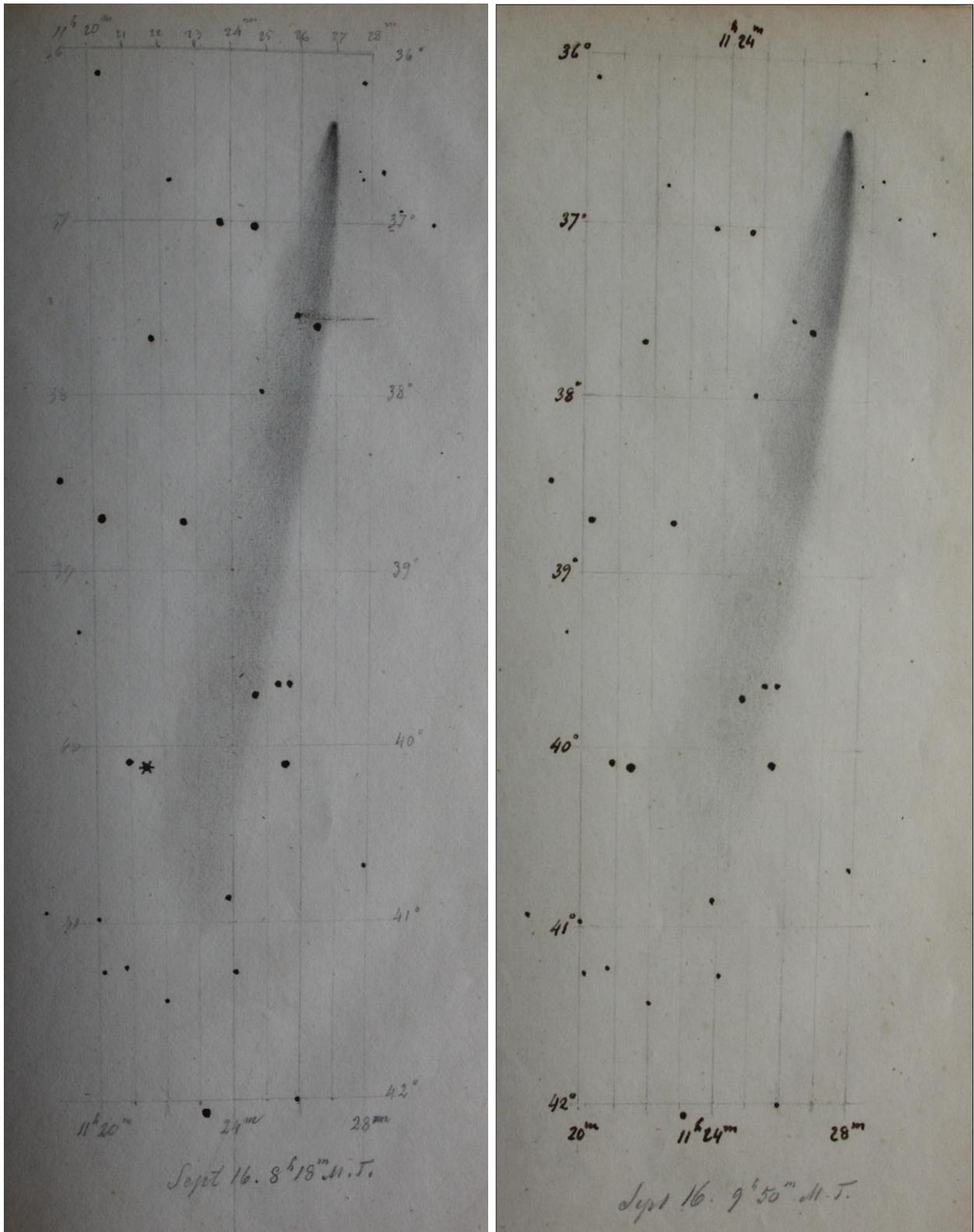


Figure 2: Comet Donati observed by C.F. Fearnley on 16 September 1858 with the Repsold equatorial refractor. East is right, north is down. Note the motion of the comet in the course of 1.5 hours.

half of September as the comet approached perihelion. On 3 October he used the 19 cm Merz refractor for a detailed visual study at high magnification. He could then determine that the two halos were not concentric circles around the nucleus. In fact, the centers of each halo lined up with the nucleus along a straight line oriented

along the radius vector from the comet to the Sun (Fearnley 1860a). By 7 October he had observed four halos expanding outwards from the nucleus. On 9 October there were three halos visible simultaneously. Fearnley also noted a dark spot comparable in size to the nucleus and located 7" away from it (i.e. between the

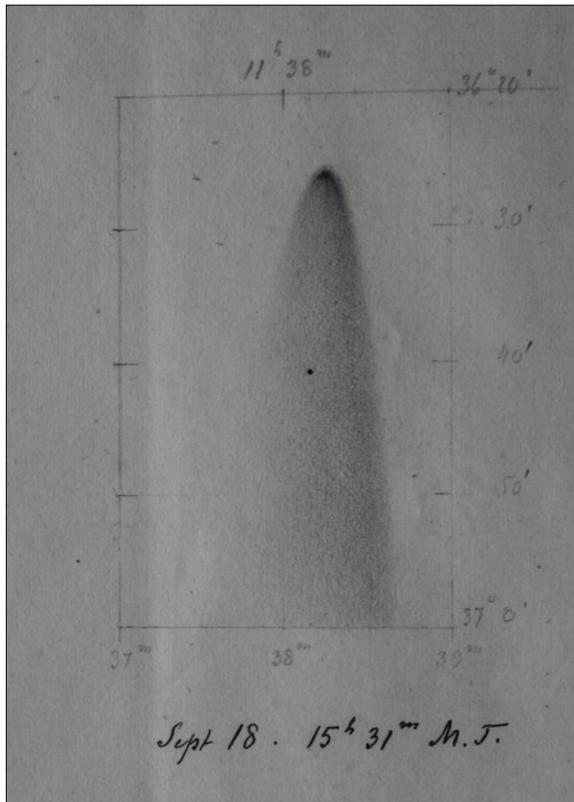


Figure 3: The head of comet Donati drawn by C.F. Fearnley on 18 September 1858 using the 7.5 cm Merz comet finder. The star in the tail is Lalande 22227. East is right, north is down.



Figure 4: Comet Donati on 19, 20 and 21 September as drawn by C.F. Fearnley with the comet finder. East is right, north is down.

nucleus and the first halo). On 5 October it was noticeably larger. On 6 October it had split in two, and by 9 October it had disappeared. The sketches in Figures 9 and 10 illustrate this.

Similar events were reported from other observatories (e.g. see Schmidt, 1862). A subset of these data was analysed by Whipple (1978) on the assumption that the halos represented repetitive ejection of material from a single active area on the nucleus of the comet as it rotated into and out of direct sunlight. He determined a synodic rotation period of 4.6 hours. Whipple (1978) pointed out that such rapid rotation creates a centrifugal force that may cause ejection of material and even break-up of the nucleus. The observation of a secondary nucleus on 3 October, increasing in size by 5 October, and splitting in two by 6 October, may support this view.

3.4 Polarimetry

The majority of observations worldwide of Comet Donati were visual. Although this was the first comet to be photographed (Gasperini et al., 2009), the scientific measurements were all made by visual methods. Comet Donati appeared at the dawn of observational astrophysics which was eventually pioneered by astrophotography and spectroscopy. In Oslo, attempts were made to detect polarized light from the comet. Radiation from celestial objects is often unpolarized, meaning that the orientations of the electrical and magnetic vectors are randomly distributed. The dust and gas of a comet reflects sunlight, however, and the electrical vector is no longer randomly oriented but oscillates at a particular angle which depends on the angle of reflection. The purpose of the polarimetric observations in Oslo was to determine the orientation of the polarization plane.

Henrik Mohn constructed an experimental instrument consisting of an achromatic double-refracting prism with a polished 3.75-mm thick calcite crystal plate in front. This gave two images of the observed object. When polarized, the two images showed complementary colours. The polarization plane could be determined by rotating the polarizer to obtain the maximum intensity difference between the two images.

Mohn tested the instrument on his homemade 2.5-cm achromatic refractor on 5 October. By rotating the prism until the maximum intensity difference was obtained between a yellow and a violet image, the orientation of the polarization plane was found to be a great circle through the comet's head and Arcturus. He derived an angle of 33° between the polarization plane and the declination circle through the comet's head. The small objective lens limited the colour contrast, which contributed to an un-

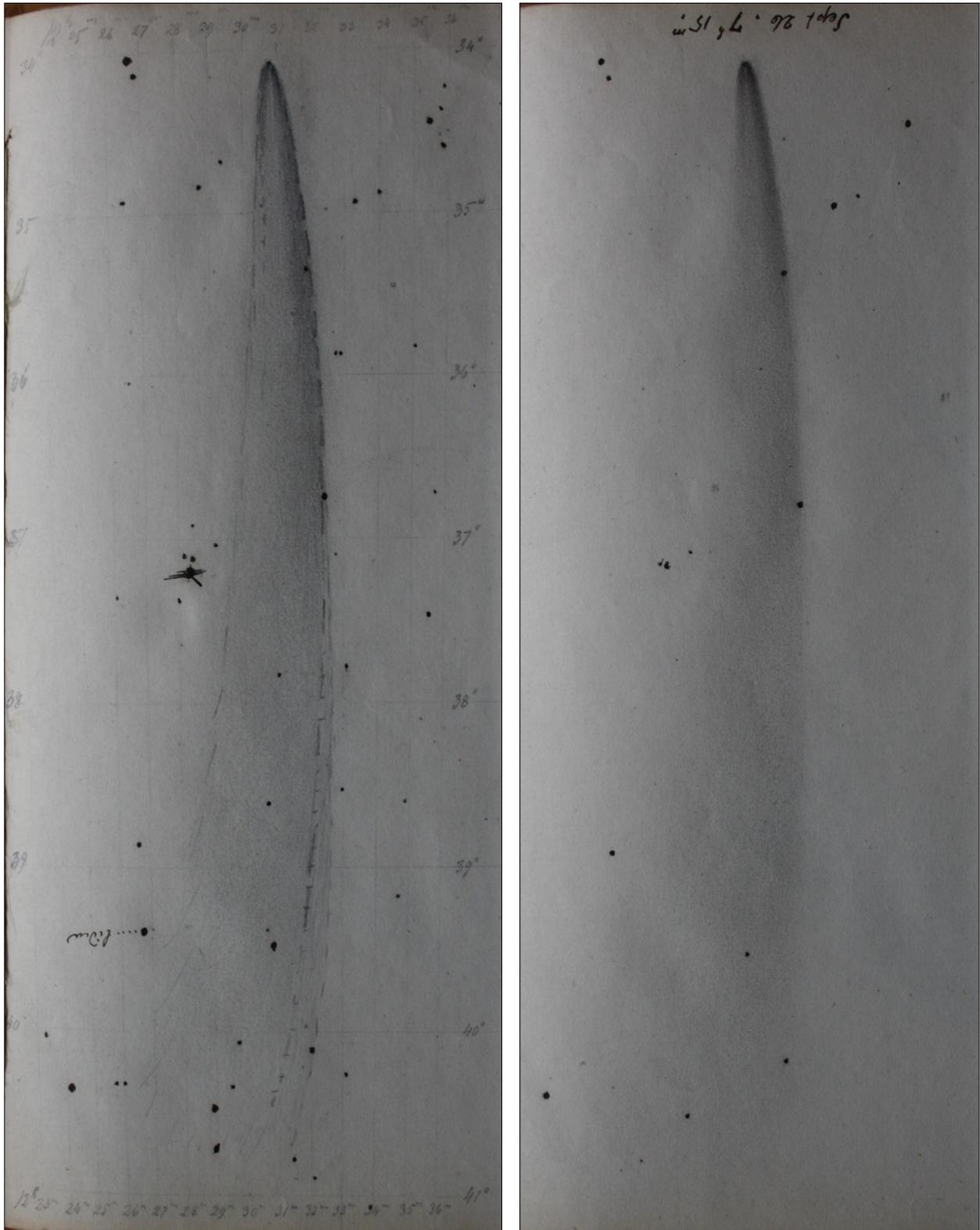


Figure 5: Two different drawings by C.F. Fearnley of Comet Donati on 26 September 1858. On the left is the original field sketch. East is to the right, and north is down.

certain result, which also was affected by coordinate and clock time errors.

During twilight on the next night, 6 October, Mohn mounted his instrument on the Merz 7.5-cm comet finder at the University Observatory. The complementary colours were distinctly noticeable and the light from the comet was strong-

ly polarized. The polarization plane was determined as a great circle through the comet's head and a point between α and β Corona Borealis at declination $28^{\circ} 36'$ and right ascension $231^{\circ} 15'$, which gives an angle of $48^{\circ} 46'$ relative to the declination circle through the comet's head.



Figure 6: Comet Donati on 26, 27, 29 September, and on 1 October 1858 as drawn by C.F. Fearnley. North is upwards, east is towards left. The brightest stars in the upper part belong to Ursa Major.



Figure 7 (left): Comet Donati on 5 and 9 October 1858 as drawn by C.F. Fearnley. North is approximately diagonally to the right and upwards. East is towards left and approximately diagonally upwards. The bright star near the comet head on 5 October is Arcturus.



Figure 8 (right): Comet Donati on 10 and 13 October 1858 as drawn by C.F. Fearnley. North is up.

Table 2: Observed and computed angles for the polarization plane.

Date 1858	Observed angle	Computed angle	Difference (O-C)	Angle of reflection
October 5	33.0°	41.7°	-8.7°	58.7°
October 6	48.8°	48.0°	0.8°	59.4°
October 9	75°–80° (clouds)	66.5°	8.5° – 13.5°	59.6°

The comet's appearance on 5 and 7 October is shown in Figure 7. Arcturus (α Bootes) is near the comet's head on October 5. Above it is ϵ Bootes and further up and to the left are α and β Corona Borealis. The orientation of the polarization plane is thus almost vertical in Figure 7. When twilight ended, Mohn repeated the observations with Savart's polariscope and obtained the same result. This instrument shows the presence of polarized light by interference patterns which change in intensity according to the relative position between the polariscope and the polarization plane. Fringes parallel to and orthogonal to the polarization plane were observed along the entire tail of the comet as far as ϵ Bootis (i.e. for about 10°). When the telescope was pointed away from the comet, the interference pattern disappeared.

The instrument was then mounted on the Merz 19-cm refractor at the University Observatory. The complementary colours were easily distinguished. The magnification allowed only parts of the comet to be seen in the telescope field of view but the size of the objective lens ensured enough light for Savart's polariscope. The interference patterns appeared at approximately equal intensity across the field of view. Thus every point on the comet referred to the same polarization plane.

Attempts with Savart's polariscope on the Merz 19-cm refractor were made also on 9 October, but drifting clouds corrupted the results. An uncertain determination of the polarization plane resulted (75° – 80° relative to the declination circle through the comet's head).

Mohn's observations proved that the light from the comet was strongly polarized in a plane directed towards the Sun. Reflected sunlight is polarized. A great circle through the comet and the Sun represents the polarization plane. Its position angle was computed from the celestial coordinates of the two objects and may be compared to the observations. The angle of reflection is derived from half the angle (Snell's Law) between the Sun and the Earth as seen from the comet's head. The results are shown in Table 2.

4 SUMMARY AND CONCLUSIONS

Comet C/1858 L1 (Donati) was observed on 30 nights at the University Observatory in Oslo between 26 August and 15 October 1858. Astrometric observations with a precision level of $\pm 6''$ were made on 26 nights with various in-

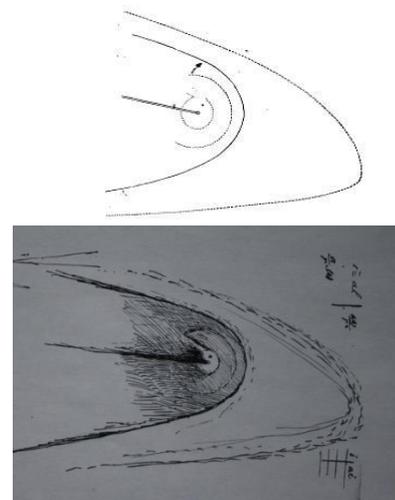


Figure 9: Sketches of the coma on 3 October showing the nucleus, halos, a dark spot, the dark ray in the middle of the tail, and a dark ray above the nucleus that bridges the two inner halos. The upper figure is from *Astronomischen Nachrichten* (Fearnley 1860a), and the lower one is a recently-recovered sketch by Fearnley.

struments, which resulted in 37 individual positional measurements. Morphological studies of the comet's head and tail were carried out on 20 nights. This time series revealed the development of the tail and episodic events in the coma. The latter was probably repeated outgassing from the comet that manifested itself as expanding envelopes. A possible breakup of the nucleus was observed during one week in October. Polarimetry determined that the light from the comet was reflected sunlight.

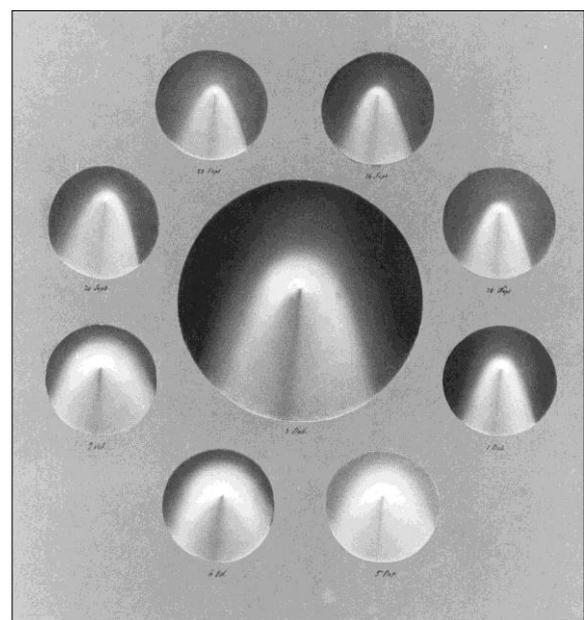


Figure 10: A time series of changes in the coma between 20 September and 7 October, as drawn by C.F. Fearnley.

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