PARALLEL FILAMENTARY STRUCTURE
IN DIFFUSE NEBULAE*

Donald E. Osterbrock†
Mount Wilson and Palomar Observatories
Carnegie Institution of Washington
California Institute of Technology

The filamentary structure of the Pleiades nebulosity was discovered many years ago, and since that time several other similar but fainter objects have become known. They are reflection nebulae that show a network of long, fine filaments, apparently sensibly parallel at any point in the nebula, but curving gradually so that their direction changes continuously with position. Observations of the polarization of stars in the Pleiades, made by Hall¹ and by van den Bergh,² show that the long axes of the scattering particles are preferentially aligned perpendicular to the local direction of the filaments. This evidence strongly suggests that there is a magnetic field which, by preventing motions at right angles to its own direction, converts density fluctuations into long thin filaments. Parker has shown that the required magnetic field is of the order of $10^{-5}$ gauss,³ a field that may be present in many regions of interstellar space.

Parallel filaments of interstellar matter are also observed in absorption in several regions of the sky. Observations by Behr⁴ and by Tripp⁵ of stars in one of these areas, the region between the North America and the Pelican nebulae, again show a strong correlation between the planes of polarization and the directions of the filaments, which again can be explained on the basis of a magnetic field parallel to the filaments.

Both the reflection nebulae and the absorbing filaments represent effects of the solid particle or dust component of the interstellar matter, observed in neutral hydrogen regions. It is of some interest to inquire whether similar filamentary structures ever occur in H II regions. There are a few emission nebulae composed almost entirely of filaments, arranged in a more or less

† Now at the Washburn Observatory, University of Wisconsin.
tangential distribution about a center within the nebula. The Cygnus Loop and IC 443 are the brightest examples of this group of objects. They are not in any sense typical HII regions, and the absence of any known exciting stars in these nebulae, together with their great strength as radio sources, suggests that magnetic fields may play an important role in their structural and radiative properties. Likewise, the Crab Nebula is a peculiar object in which it appears that the filamentary structure is caused by the pinch effect in a magnetic field, and there are even indications of similar structure in some planetary nebulae.

However, among the ordinary diffuse nebulae, which are clouds of interstellar matter, ionized and caused to radiate by O stars, there is one type that does show parallel filamentary structure. The best known example of this type is IC 434, the Horsehead Nebula, which was very thoroughly described by Duncan over 35 years ago. The filaments, or striations, are approximately perpendicular to the boundary between the bright, ionized material and the dark, neutral and denser matter. The excitation is due to the O9.5 V star σ Orionis, which evidently lies to one side of a dense cloud, indicated by the relatively low star density. NGC 2023 and 2024 are two reflection nebulae that are apparently parts of this cloud, illuminated by stars within or near it. Radiation from the O star evidently ionizes the face of the cloud toward the star, and causes the ionized material to expand outwards away from the neutral cloud. The Horsehead is the largest of several “elephant trunks” or “comet tails,” structures that often occur at the boundary between an expanding HII region and a denser HI region. Though there is ionized material all around σ Orionis, its density is high only near the neutral cloud. The striations occur all along the front and are perpendicular to it; they appear to come out of the dark cloud, and in fact faint filaments occur in NGC 2024 that also seem to lead out from this same dark cloud (see Plate XII in Duncan’s paper). The longest filaments can be traced out to a projected distance of about 1.8 parsecs from the front; they are definitely not straight but curved.

*A 48-inch Schmidt plate of this nebula is reproduced in *Sky and Telescope*, 16, 531, 1957.
with a radius of curvature (of their projections on the plane of the sky) of about 12 parsecs. (A value of 500 parsecs was assumed for the distance of the I Orionis association.)\textsuperscript{11} The characteristic distance between filaments that can be easily recognized individually is of the order of 0.1 parsecs, though some filaments are as small as 0.02 parsecs in diameter.

Another somewhat similar object is the nebula NGC 1499 (see Plate I). Here the O7 star ξ Persei lies south of a large dark cloud;\textsuperscript{12} the bright material between appears to have resulted from the ionization of the face of this cloud by the radiation of the star. There are comet-tail structures, indicating expansion, and the density of ionized matter is low except between the star and the absorbing cloud. The filaments are roughly perpendicular to the ionization front, and may be traced out to a maximum length of 11 parsecs; the radii of curvature of their projections are about 50 parsecs. (For this nebula the assumed distance is 360 parsecs, since ξ Persei is a member of the II Persei association.)\textsuperscript{11}

A final example of this type of nebula is S 172,\textsuperscript{13} associated with the sixth-magnitude O6 star HR 2694 = HD 54662. Here again there is a dark cloud, ionized from one side by an O star. In this case the direction of the filaments deviates from the normal to the ionization front, and the deviation is in the direction toward the star.

It is not clear whether or not every nebula that is ionized from one side has this filamentary structure. The only other case of this type of geometry known to the writer is NGC 6188, excited by the sixth-magnitude multiple Oe5 star HR 6187 = HD 150135–6,\textsuperscript{14} the brightest member of which is an O star, and the second brightest an O6, according to Feast, Thackeray, and Wesselink.\textsuperscript{15} Neither a published reproduction,\textsuperscript{16} nor a Palomar 48-inch Schmidt plate taken by the writer shows parallel filamentary structure in this nebula, but the test is not decisive, because the Palomar plate is only a short exposure (on account of the far southern declination, $-48^\circ$) and does not show the faintest detail. Likewise the reproduction, which is from an ADH Schmidt plate that was not exposed to the faintest possible limit, probably does not show all the detail of the nebula.
NGC 1499

48-inch Schmidt photograph: 103a-E plate with red Plexiglas and Wratten No. 34A filters, λλ 6400–6700. Scale 1 mm = 155". The bright star is ξ Persei. The parallel filaments may be seen most easily to the east (left) of the star. A photograph showing the brighter parts of the nebula better is reproduced in the article by N. U. Mayall in these Publications, Vol. 65, p. 152, 1953.
All three of the filamentary nebulae are examples of ionized material, bounded on one side by denser neutral material, expanding in the other direction into a near vacuum. Round nebulae that have O stars within their boundaries never show parallel filamentary structure; apparently the expansion must occur into a very low density region for the striations to appear. The filaments probably represent regions of somewhat higher density than the mean, drawn out by the expansion into their characteristic long narrow shapes, and the main problem is to explain how the velocities can be so nearly the same in direction that the filaments preserve their identity.

One possible explanation is that the mechanism that generates turbulence in most diffuse nebulae is inoperative in these objects. In a crude way, one could say that turbulence occurs when macroscopic elements of gas moving in different directions collide with one another, but that in a situation in which material having a roughly plane boundary is ionized and expands into a vacuum, the velocities might be from the beginning so nearly parallel that chaotic motions could never be generated. An alternative explanation is that there is a magnetic field associated with the dark nebula, which prevents motions except those parallel to the local direction of the field. The magnetic field explanation has the advantage that the observed curvature of the striations is directly understood as a curvature of the field, while on the other picture it is hard to imagine that there is enough interaction with the surrounding gas to change the direction of motion of the matter in a filament, but not enough interaction to make the motion turbulent. However, the cirrus clouds in the earth's atmosphere demonstrate that filamentary structure is not always caused by a magnetic field.

The general conclusion is that parallel filamentary structure occurs in those diffuse nebulae that result from the ionization of the face of a dark cloud by a star outside the cloud. The mechanism of formation of the filaments is not definitely known, but may be associated with a magnetic field drawn out by the expansion.
PARALLEL FILAMENTS IN DIFFUSE NEBULAE


