REPORT ON THE DISCOVERY OF INTERSTELLAR DUST FILAMENTS

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ABSTRACT

Observational evidence described reveals the presence of previously unrecognized interstellar dust filaments against luminous backgrounds provided by: Milky Way starfields, globular clusters, galaxies, supernova remnants, galactic clusters, HII regions, reflection nebulae, and planetary nebulae.

KEY WORDS: Dust, Gas and Interstellar Medium

INTRODUCTION:

Interstellar dust filaments have been observed in projection against luminous backgrounds provided by Milky Way starfields, globular clusters, galaxies, supernova remnants, galactic clusters, HII regions, reflection nebulae, and planetary nebulae. Absorption within the dust filaments creates long thin streaks, dark bands, parallel striations, and mottling of the obscured backgrounds.

The most astonishing aspect of the interstellar dust filaments is their extreme length. In wide field photographs, dust filaments up to thirty degrees long have been observed. Their

appearance resembles the vapor trails of jet aircraft -- suggesting they are extremely long and narrow cylinders of gas and dust. They were almost always found to be members of a system of closely spaced parallel dust filaments, which gives a streaked and striated appearance to obscured starfields. Frequently two or more systems of parallel dust filaments oriented in different directions are superposed on a starfield, imparting a mottled or chaotic appearance to it. Such starfields give the impression of having many tiny irregular dust clouds dispersed throughout the region.

The reader should carefully study the photographs cited herein before rendering a judgment on the reality of the dust filaments. The filaments are barely perceptible against their backgrounds and occur in regions where many filaments crisscross in a haphazard fashion. If the dust filaments were obvious or easily seen, they would have been recognized many years ago when evidence of their existence was first reported (Minkowski 1955, Roberts 1960, and Sandage 1961).

DUST FILAMENTS IN MILKY WAY STARFIELDS

Systems of parallel dust filaments, which give a streaked and striated appearance to obscured starfields, have been recognized by the author in almost all photographs of starfields examined for their presence. They were recognized by carefully examining positive photographs for long, thin dark

filaments. The photographs were rotated until a thin dark filament was recognized. Then the photograph was examined for filaments parallel to the first filament.

Once a system of parallel filaments was recognized, the photograph was rotated and examined for the presence of additional systems of parallel dust filaments. Frequently two or more systems of dust filaments were found to overlie a starfield creating a complex dust pattern or filigree. These dust filigrees were found to be responsible for the mottled appearance of many starfields.

The rich star cloud in Scutum is an excellent example of a starfield having a streaked and striated appearance caused by foreground interstellar dust filaments. The streaked and striated appearance can be recognized in photographs published by the Yerkes Observatory (catalog numbers MW17, MW23, and MW106), and in The Milky Way (Bok and Bok, 1974, page 12). The most easily recognized system of dust filaments is oriented east to west, at an angle of approximately sixty degrees to the galactic equator. This system is prominent immediately south of M11, but can be seen to cover the entire starfield. A second system of parallel dust filaments oriented north to south, at an angle of thirty degrees to the galactic equator, can be recognized west of M11 after rotating the photographs by ninety degrees. A third system of dust filaments oriented northeast to northwest, parallel to the galactic equator, is also present.

Cygnus is another region exhibiting parallel dust filaments. Wide field photographs reveal at least four systems of dust filaments. Photographs published by Yerkes Observatory (catalog numbers MW68, MW69, MW72, MW85) show the region is obscured by dust filaments oriented east to west, north to south, southeast to northwest, and northeast to southwest, at angles of sixty, thirty, ninety and zero degrees to the galactic equator. The existence of dust filaments in Cygnus is confirmed by R. Minkowski, who described them in 1953 (Minkowski, 1955), but did not recognize their significance.

Four systems of parallel dust filaments--three distinct and a fourth barely evident--have been recognized in Cassiopeia (Astronomy 1978a). The most prominent system of parallel dust filaments is oriented parallel to the galactic equator in the east-to-west direction. A second system of dust filaments is oriented southeast to northwest at an angle of approximately thirty degrees to the equator. This system is most easily seen near the Cepheus border, but it covers the entire Constellation. The third system is oriented north to south, while a fourth system which is barely evident is oriented northeast to southwest.

DUST FILAMENTS IN GLOBULAR CLUSTERS

Foreground interstellar dust filaments have been observed in all globular cluster photographs examined by the author. In addition, Helen Sawyer Hogg (1959) has observed, "...obvious

streaks of dark nebulosity..." in M13, M3 and M2. The existence of foreground dust filaments was recognized by the presence of radial or tangential streaks, parallel striations, and a mottled dusty appearance. Short exposure photographs revealed dark streaks and parallel striations crossing the central regions of globular clusters. Although longer exposure photographs over-expose the cluster central region, radially directed streaks and striations were observed in the outskirts of the clusters. When the streaks and striations were linearly extended to the opposite side of the cluster, using a card or ruler, radially directed counterpart streaks and striations were observed. These were thereby proven to be continuations of dust filaments which cannot be seen in the over-exposed cluster center. Tangentially oriented filaments, which are oriented perpendicular to the radial direction, were detected crossing the outskirts of clusters. In very long exposure photographs, dust filaments were observed to extend a considerable distance into the surrounding starfield. This observation was the most convincing demonstration of the foreground nature of the dust filaments seen against globular clusters.

All of the above phenomena have been observed in photographs of Omega Centauri (NGC5139). Short exposure photographs (Sky and Telescope 1963 and The Messenger 1979), show parallel dust filaments oriented east to west and north to south crossing the center of Omega Centauri. Photographs of longer exposure

revealed radial and tangential dust filaments in the cluster outskirts. Very long exposure photographs (Kitt Peak catalog number 01105; Yerkes catalog number SC355) (Shapley and Hodge 1972, p. 89 and Bok and Bok 1974, p. 17) show systems of parallel dust filaments oriented east to west and north to south, extending into the surrounding starfield.

Other globular clusters exhibiting evidence of foreground interstellar dust filaments are: 47 Tucanae (NGC104), (Kitt Peak catalog 01100); M3 (Hale catalog number 30, Lick catalog number D1, Kitt Peak catalog number 01102), M13 (Hale catalog number 34, Lick catalog number U7), M15 (Kitt Peak catalog, number 01103), and M92 (Lick catalog number D6 and Kitt Peak catalog number 01101). Dust filaments have also been observed crossing the very low mass, sparsely populated globular clusters NGC5897 (Hale catalog number 62), and NGC6791 (Lick catalog number D5) which resemble galactic clusters because of their low stellar density.

DUST FILAMENTS IN GALAXIES

Interstellar dust filaments have been observed in projection against galaxies ranging from dust-free elliptical to dust-rich irregular galaxies. Because elliptical galaxies contain little internal dust, the dust observed in photographs of these galaxies is likely to be foreground dust filaments seen in projection. Dust filaments have been observed in projection against all

types of elliptical galaxies from the giant ellipticals, which dominate galactic clusters, to local group dwarfs.

The similarity of the appearance of local group dwarf elliptical galaxies, such as NGC205, NGC185, and NGC147, to the appearance of globular clusters suggested the presence of foreground dust filaments. In photographs of these galaxies, the presence of foreground dust filaments was indicated by parallel striations, dark streaks, dust lanes, dust patches, and a mottled appearance. The appearance of NGC185 (Sandage 1961 and Shapley and Hodge 1972) resembles the appearance of a globular cluster overlain by systems of parallel dust filaments. The outer region has a mottled appearance due to systems of dust filaments oriented east to west, north to south, northeast to southwest, and southeast to northwest. Parallel striatic were also observed in photographs of NGC205 (Hale catalog number 2, and Sandage 1961) and NGC147 (Hale catalog number 1, and Sandage 1961).

Dust filaments have been observed in projection against the giant elliptical galaxies: M87 (NGC4486), M59 (NGC1621), M49 (NGC4472, and M85 (NGC4362). M87 is the best example. Dust filaments have been detected in both long- and short-exposure photographs. In short-exposure photographs (Sandage 1961, and Lick catalog number S4) of the M87 jet, parallel dust filaments were observed in the nuclear region, and crossing the jet at right angles. The dust filaments, which are oriented north to

south and east to west, impart a mottled appearance to the nuclear region causing it to resemble the appearance of globular clusters. In long exposure photographs of M87 (Sandage 1961, Evans 1968, Hale catalog number 24, Lick catalog number S5, and Kitt Peak catalog number 02120), dust filaments have been recognized in the faint outer envelope.

Late type irregular galaxies in which dust filaments were observed include the Magellanic Clouds, IC1613, and NGC6822. The Large and Small Magellanic Clouds are unique because they resemble detached portions of the Milky Way. The appearance of foreground dust filaments in projection against the Magellanic Clouds resembles their appearance against Milky Way starfields. Long dark streaks, parallel striations, and mottling have been observed. Photographs (Page and Page 1969; Sandage 1961; Alter, Cleminshaw and Phillips 1974; Hodge 1966; and Goldberg 1966) of the Central region of the Large Magellanic Cloud near 30-Doradus show two mutually perpendicular systems of parallel dust filaments oriented east to west and north to south. Systems of parallel dust filaments were also detected in the fainter outer regions (Dickson 1968). In long-exposure, wide-field photographs, wide filaments or bands were seen crossing the northwestern end of the bar of the Large Magellanic Cloud. Dust filaments were also recognized in photographs of the Small Magellanic Cloud (Dickson 1968; Menzel 1964, and

Goldberg 1966). Two prominent systems of parallel dust filaments oriented east to west and north to south were identified.

IC1613 is another Type I irregular galaxy, which is a member of the local group. Photographs (Sandage 1961 and Hubble 1936) show interstellar dust filaments crossing this galaxy from east to west, northeast to southwest, and southeast to northwest have also been observed in photographs of NGC6822 (Menzel 1964; Hodge and Shapley 1972).

The descriptions presented here serve as examples of galaxies having observable foreground dust filaments. The author has examined photographs of many other galaxies and observed foreground dust filaments in a large number of galaxies at both high and low galactic latitudes. This indicates that the dust filaments are not confined to the region of the galactic equator, but that they are widely distributed both above and below it. The existence of dust filaments in front of galaxies was confirmed by descriptions of galaxies in The Hubble Atlas (Sandage 1961), where a large number of instances of radial dust lanes and streaks which do not conform to the underlying galactic form are described.

PLANETARY NEBULAE AND REFLECTION NEBULAE

This section describes observations of interstellar dust filaments observed in projection against the luminous backgrounds provided by supernova remnants, HII regions, galactic clusters, planetary nebulae, and reflection nebulae. These observations expand the list of objects against which dust filaments have been observed; strengthening the evidence for the existence of interstellar dust filaments, and demonstrating their ubiquity.

Supernova Remnants

Dust filaments have been observed against the luminous backgrounds of supernova remnants in photographs of the Cygnus Loop (NGC6992-6995, 6990), IC443, Crab Nebula (M1), Vela Remnant, and Shajn 147. Although they require careful scrutiny to be seen, dust filaments have been observed crossing the network of luminous filaments comprising the Cygnus Loop (Hale catalog numbers 108, 109, 159 and S-20; Lick catalog numbers N3a, N3b, and N3c; and Kitt Peak catalog number 01010). Wide-field photographs (Dufay 1957 and Struve 1962) show the Cygnus Loop is overlain by a profusion of dust filaments criss-crossing the surrounding starfield and the luminous network of the remnant. In some short-exposure photographs, obvious gaps in the luminous arcs of the remnant were evident. Longer exposure photographs revealed that these gaps were regions darkened by foreground dust filaments. In very long-exposure photographs, dust filaments have been observed crossing NGC6992-6985 and followed to

where the same dust filament crosses NGC6990 on the opposite side of the remnant.

While dust filaments have been observed crossing the narrow luminous arcs of the Cygnus Loop, it is difficult to follow the dust filaments for any distance. IC443 provides a more uniform luminous background against which dust filaments have been identified in the Hale Observatory's photograph (catalog number 56). Both wide and narrow dust filaments were recognized. Their long filamentary nature is evident, since they can be followed for a distance across the luminous background. The mottled appearance of the Crab Nebula in continuum photographs (Hale Observatory's catalog numbers 102, 57 and S-22; Lick catalog number N5a) indicates the presence of foreground dust. Dark lanes, streaks and striations were detected criss-crossing this compact supernova remnant.

HII Regions

Although difficult to recognize, interstellar dust filaments have been observed in projection against the luminous backgrounds provided by the North American Nebulae (NGC7000), IC434 (surrounding Horsehead Nebula), Rosette Nebula (NGC2237), IC1396, IC2944 (surrounding Lambda Centauri) and the Eta Carina Nebula (NGC3372). Two factors contribute to the difficulty in observing dust filaments against HII regions. First, it is difficult to differentiate foreground dust from dust internal to the nebula, and, second, over-exposure obscures the weakly absorbing dust filaments.

The North American Nebula is the best example of an HII region, for which interstellar dust filaments have been observed in the surrounding starfield and against the background of the nebulae. Systems of parallel dust filaments have been recognized in photographs of NGC7000 (Hale catalog number S-19, Lick catalog number N11, Yerkes catalog number N21, Dufay 1957) which show dust filaments oriented east to west, north to south, northeast to southwest, and southeast to northwest.

Galactic Clusters

Galactic clusters resemble the globular star clusters because they are regions of increased star density. However, they contain fewer stars, are less dense, and less massive. Because of the low star density, it is difficult to observe foreground dust filaments projected onto galactic clusters. The galactic cluster M11 is an example of a relatively rich, compact cluster against which interstellar dust filaments have been observed. M11 is located within the Scutum star cloud which was previously shown to be obscured by dust filaments. Dark lanes, filaments, and striations similar to those observed in globular clusters have been observed in photographs of M11 (Mallas and Kreimer 1978). In some photographs, dust filaments crossing M11 can be seen extending into the surrounding star-field. The dark lanes and filaments seen in M11 photographs can also be observed through small telescopes. The author has seen these features using an eight-inch telescope.

The Messier Album (Mallas and Kreimer 1978) presents photographs of all galactic clusters in Messier's catalog. These photographs were studied for evidence of foreground dust filaments. Interstellar dust filaments were detected in photographs of: NGC6603 (part of M24), M26, M35 and its companion NGC2158, M37, M46, M50 and M93.

Planetary Nebula

It is difficult to identify, with certainty, dust filaments projected onto planetary nebulae. However, photographs show they frequently have a mottled dusty appearance characteristic of the presence of dust filaments. Dust filaments have been observed against the Dumbell Nebula (M27), NGC6781 in Aquarius, the Helix Nebula (NGC7293), and the Ring Nebula (M57).

The Dumbell Nebula is the best example of a planetary nebula having a mottled appearance due to dust filaments. The mottled dusty appearance is easily recognizable in the Hale (catalog numbers 106 and S-26) and Lick (catalog numbers N40 and X16) photographs. In these photographs, the face of M27 has a blotched appearance. Closer examination shows the blotched or mottled appearance is due to dust lanes, thin filaments, and dark patches on the face of M27. Prominent dust lanes are obvious at the northwestern and southwestern ends of the luminous hourglass.

A second planetary nebula having a mottled appearance due to the presence of foreground dust filaments is NGC6781. Thin streaks and striations oriented east to west have been observed

in the Hale Observatory's photograph (catalog number S-39). Photographs of the Helix Nebula (Hale catalog number 48) show thin parallel dust filaments crossing the luminous rings, which have a mottled appearance and exhibit evidence of dust, on the inside of the rings. L. H. Aller (1970) confirmed this in a description of the Helix Nebula as follows: "The highly complex structure of this large, nearby planetary is also shown by the mottlings and striations of the ring." Finally, Hale Observatory photographs (catalog number 66) of the Ring Nebula suggest the presence of parallel dust filaments aligned parallel to the major axis of M57. The luminous ring also has a mottled dusty appearance in a Lick Observatory color photograph (catalog number X14).

Reflection Nebulae

The presence of foreground dust filaments in photographs of reflection nebulae is indicated by long thin streaks, bands, and striations seen in projection against reflection nebulae. The pleiades (M15) is the best example of a reflection nebula obscured by foreground dust filaments. Careful examination of Pleiades photographs (Hale catalog number 112, 128 and S-30; Lick catalog number D4, Kitt Peak catalog numbers 01106 and 01107; and Yerkes catalog numbers N71 and N72) revealed dark streaks, bands, and striations superposed onto the nebulae. An interesting feature of the Pleiades reflection nebula is the presence of long thin and straight luminous filaments. These luminous filaments may

be caused by interstellar dust filaments in the vicinity of the Pleiades cluster, which are illuminated by the bright stars of the cluster. Evidence of foreground dust filaments has also been observed in photographs of Rho Ophiuchi (Yerkes catalog number MW

SUMMARY, CONCLUSIONS AND QUESTIONS

This paper has demonstrated that long, thin and straight dust filaments populate the interstellar medium. They are characterize by low absorption, narrow width, straightness, and extreme length. They are found to be lined up in systems of closely spaced dust filaments which impart a striated and mottled appearance to obscured backgrounds. Frequently, two or more systems of parallel dust filaments are superposed along the line of sight.

The existence of previously unrecognized dust filaments will require revision of theories for the structure and dynamics of the interstellar medium. Their existence adds a new dimension to studies of the intersteller medium and provides the opportunity to use observations of dust filaments as probes of the physics of interstellar space. The presence of foreground dust filaments in projection against globular clusters, galaxies, HII regions, reflection nebulae, and planetary nebulae will require revision of how the appearance of these objects is interpreted, because much of the dust apparently within these objects must be foreground dust filaments.

The existence of interstellar dust filaments has significant implications for theories of star formation because infinitely long cylinders of gas cannot become unstable to gravitational collapse (Kaplan and Pikelner 1970). If this is correct, then stars cannot form out of interstellar dust filaments. This leaves us with the questions: How were the dust filaments created? Do they play a role in star formation? What role do they play in the structure and dynamics of the interstellar medium?

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