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CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
PASADENA, CALIFORNIA

RECEIVED 3/1/22
ANSWERED

February 23, 1922.

Dr. V. M. Slipher,
Lowell Observatory,

Dear Sir:

Your letter on the Nebulae report has just reached me. I have been considering a general nebular program for Mount Wilson and so am moved to inflict many words upon you. So many in fact that I shall try to keep to simple statements, leaving the arguments pro and con to your own most competent judgment. We begin flamboyantly.

The general problem of the nebulae is to determine their physical nature and the place they hold in the structure and evolution of that portion of the universe within the field of astronomical research. The problem in detail comprises a discussion of the following subjects:

Physical state of nebulosity
Mechanism of luminosity
Dynamics of nebular forms
Relation between nebulae and stars
Origin and evolution of nebulae.

Data are to be derived from investigations of

form and structure, Photog. spectrographic studies
distribution and motion " "
chemical constituents Combined studies
physical dimensions
nature and source of luminosity Combined spectrum etc.
relations to individual stars Photographic, spectrographic
relation to galaxy as a whole.

By physical dimensions are meant size, mass, density, degree of dissociation, luminosity, temperature, powers of reflecting, absorbing and scattering light.

CLASSIFICATION OF NEBULAE

First, I urge the general acceptance of a single system of nebular classification, and suggest the following:

I. Galactic Nebulae

1. Planetaries
2. Diffuse
   a. Luminous
   b. Dark

II. Non-Galactic Nebulae

1. Spirals
2. Spindles
3. Globular
4. Irregular.

No 2 might well be replaced by 2. Elongated
a. spindles (spiral affinities) H V 24.
b. ovate (variations from globular, such as M32, M59)

The distinction between galactic and non-galactic (not necessarily extra galactic) appears to be fundamental in structure, texture, spectrum and relation to stars as well as distribution in the sky. (In no case, save the Magellanic clouds and the allied object NGC 6822, is there any doubt as to the classification of any particular nebula.) ?

Galactic nebulae classify readily in a fashion that permits further subdivision by special investigators. Non-galactic nebulae are otherwise and the sub-divisions here suggested are very tentative. They are a middle course between Curtis' generalization and Wolf's specialization. (Curtis' argument for the truly spiral character of all non-galactic nebulae is wholly unwarranted by the observational data now on hand, and, I am confident, by such as we can hope to gather in the next generation at least.) Long and short exposures with the 100-inch under excellent observing conditions fail to show the slightest indication of spirality in the largest and brightest globular nebulae-- M 49, 60, 87, etc.--and of course the irregular objects such as NGC 2366 and 4449 are certainly not true spirals. Wolf's system is too detailed for general use, as it applies strictly to telescopes of a certain aperture and speed.

NGC numbers

For many years to come, the wholesale classification of non-galactic nebulae must rest on inspection of photographic images and the variety of telescopes employed will be a constant source of confusion. There is one method by which a certain degree of standardization can be determined for statistical purposes at least. This consists in photographing several rich fields of small nebulae with instruments of approximately equal speed but differing in apertures, using equivalent exposure times, and also in making series of exposures with one instrument but varying the exposure times. Separate classification of the nebulae on each exposure will give useful data on how numbers vary with exposure time and resolving power, on percentages of objects which switch classes, and consequently will give some basis for coordinating survey results from instruments of different dimensions. I have collected plates on five fields with apertures of 10, 24, 60, and 100-inches and graded exposures with the 100-inch. Study of the plates has not been completed but it is evident that spirals do not blossom as bountifully as Curtis would expect. Further work along this line is needed. Perhaps Mr. Lampland will cooperate with me to fill the gap between apertures of 24 and 60 inches.

E. GENERAL SURVEY

Cameras of the Franklin-Adams type and the Bruce 24-inch

Extension of Barnard's work in the southern hemisphere is very desirable and exposures from 6 to 10 hours should be encouraged. I would also suggest a survey of the southern sky with box cameras, Tessar I C lens, f 4.5, focus, 6 to 10 inches, exposures 4 or 5 hours, Seed 30 plates. The field is good over a circle 30° to 35° in diameter so alternate Kapteyn areas or better still an analogous system of galactic coordinates could serve as centers. This would complete a survey which I am making of the northern sky for general distribution of diffuse nebulosity, both luminous and dark. Diffuse nebulosity is found in Eradinus in as high as 37° galactic latitude; a double distribution is indicated. along the galactic plane and the inclined belt of bright helium stars; evidence

points toward absorbing clouds as explaining the branching of the Milky Way from Aquila to Centaurus. The importance of carefully checking these indications is obvious

Southern stations should study the Centaurus region with this absorption idea in mind, and further should make direct comparison of brightness between the southern and northern star clouds. Data of this latter subject is very unsatisfactory at present.

A Survey of non-galactic nebulae has not concerned me deeply as I feel it should be done with aperatures from 24 to 36 inches leaving the largest telescopes--40-inches and upward ~~and~~ free for special problems. A complete survey is out of the question at present. The proper type instrument is a 24-inch camera such as the Bruce at Arequipa.

A The most that can be done is to collect catalogues of nebulae photographed with f5 apertures 24-inches and upward from the various institutions, with prints, form, size and relative brightness, both nuclear and total. Such a central catalogue will reveal a large amount of duplicated work, of course, but will indicate the present state of the matter. The northern heavens could then be parceled out amongst Lick and Yerkes in America, Helwan, Heidelberg and England in Europe, so that those institutions would pay especial attention to the bright and large nebulae in certain zones. Shapley should be encouraged to have the Arequipa camera used on some of the brightest and most interesting southern objects, and every opportunity should be seized to urge a reflector for the southern latitudes which can be used for direct photography at the primary focus. This demands a central Bureau for card catalogues and catalogues of prints, ~~a small~~ to be revised yearly.

D MOTIONS a small observatory aided by grants from existing funds could do the work!

Parallax observers should be urged to place very large planetaries and planetaries with bright nuclei on their parallax program, and, on their proper motion programs, planetary nuclei, stars involved in diffuse nebulosity, and a list of non-galactic nebulae selected for size and approximately stellar nuclei. Van Maanen is already doing this.

Internal cross motions, rotations, and changes in nebulae are to be derived from comparisons of plates taken with the same instruments, preferably large reflectors. The Lick people should be urged to beg borrow a make a Blink machine and examine their splendid collection at once. Barnard should also be urged to have his material blinked.

B SPECTROGRAPHY

Slit Spectrography

I. Large Scale--Central stars in planetaries, especial emphasis on the absorption spectra.
Stars associated with diffuse nebulosity.
Spectroscopic binaries involved in nebulosity.
Diffuse nebulae with emission spectra for internal variations in velocity.
Extension of this work by Lick Obs

II. Medium Scale
(say 2 prisms and 6-inch camera)
Diffuse nebulosity with continuous spectra for comparison with spectra of associated stars. Ritchey, P Obs. 70 23
Emission nebulae for intensity and variation of whatever continuous spectra they may have. Comm. Wright
Non-galactic nebulae for rotation and study of absolute magnitude lines. Comm. Lowell work

F I avoid the subject of radial velocities of nebulae, leaving the consideration that entirely to you.

Internal variations in radial velocities of diffuse emission nebulae such as has been found in Orion are very useful in setting limits to mass and density from considerations of velocities of escape where no rotation or other steady state of motion are apparent.

Radial velocities of the nuclei seem to agree with those of the nebulosity in the case of planetaries, but little or no data on this subject is available in the case of stars associated with diffuse nebulae. The latter case is complicated by the very high percentage of binaries among such stars.

One view of diffuse nebulosity that has been steadily growing in my mind is that clouds of dust or molecules are temporarily illuminated by passing stars. The luminosity is emission or continuous depending on the spectral type (temperature ?) of the star and the state of dissociation of the nebulosity. Where no stars of sufficient brightness are present, the nebulosity will then be dark. Analogies are to be sought in the Corona, Aurora, Zodiacal Light and tails of comets. This idea calls for considerable spectroscopic and photometric data for thorough consideration. Some has already been collected here but much more is needed.

PHOTOMETRY

Accurate catalogues of planetary nuclei and stars associated with diffuse nebulosity giving photographic magnitudes and color indices, surface brightness and color of diffuse nebulosity at various distance from associated stars, colors and light curves along various axes of figure for non-galactic nebulae, and sizes and forms of various monochromatic images of emission nebulae, are very desirable.

Small instruments can be used to determine total brightness and effective wave-lengths, though care should be taken that stars and nebulosity are not mixed in the case of diffuse nebulosity.

VARIABLE STARS

Light curves, colors and spectral types should be determined whereever possible for the variable stars in nebulosity. Orion, M8, M20, and NGC 7023 furnish cases in point. Special attention should be paid to the star-37°13024 in NGC 6727. This appears to be an Algol in dense nebulosity. A good light curve of such an object is a matter of first importance. The star is B9 or Ao but very red. Visual observations would give the general curve, but the minima should be observed photographically.

VARIABLE NEBULAE

NGC 1555, 2261 and 6729 should be closely followed by direct photography and motion of variations, mainly movements of waves of obscuration over backgrounds of permanent details, and local brightening near the nuclei, should be measured. Colors and spectra should be carefully compared to those of the variable stars forming the nuclei, and light curves should be determined for these stars, so that possible changes in spectra at various stages of their light curves can be investigated.

Non-galactic nebulae suspected of variability from visual observations are, in all cases photographed, spirals with faint stars close to the nuclei. The entire list however should be photographed for future comparison. 3666, 5195

NOVAE

Half a dozen of the largest spirals in addition to Andromeda should be followed carefully for novae. They might be divided between various telescopes. Light curves, colors and spectral types should be determined where possible.

Galactic Novae and bright line stars in general should be investigated for envelopes, using slitless focal plane spectrographs of considerable scale and dispersion. Photg of non-nebulous area

DARK NEBULOSITY

Star counts in large areas of obscuration should be continued and along with this, the distribution of colors and color excesses among stars in and neighboring the obscured areas.

A long list of subjects for investigation could be added. Such for instance as temperatures of early B stars and the relation between color index and temperature (some planetary nuclei seem to have color indices impossible on a strict temperature explanation). Evidences of repulsion as well as attraction forces in nebulosity, and the explanation of chaotic nebular forms on these grounds, mathematical formulae expressing forms of arms in a number of spirals, tendency of small non-galactic nebulae to cluster, the old and very questionable idea that such nebulae cluster around large spirals, the spectra of faint diffuse nebulosity around late type stars such as +31°597, -19°4357, +28°645 and the late K dwarf in Barnard's nebula at $\alpha = 4^h\ 14^m$, $\delta = +28°\ 5'$ (1920), the power of dust clouds in our own atmosphere to reflect, absorb and scatter light, the possibility of stellar radiation exciting continuous luminosity over and above that reflected in a cloud of nebulosity, the sifting effect of radiation pressure on non-homogeneous clouds of dust, etc.

Visual observations of nebulae appear to me to have no place in modern research except possibly the micrometric measures of individual nebulae with stellar nuclei for proper motion. Even there the work can be done better photographically. The only use for the existing visual data is for setting an upper limit to proper motions. Lundmark is now making the necessary discussion. Bigourdan's five volumes, for instance, do not add materially to our knowledge of nebulae.

Even Barnard's observation on the variability of the nucleus in NGC 7662 are almost certainly not real. Photographs both with and without filters have shown no indications whatsoever of variability.

I hope these hurried notes may be of some service. If time permitted I would put them in better shape, and it may be that I will write you further before you leave for the Rome meeting. I take a great interest in the whole problem and am concerned to get the work systemitized and coordinated so that the collection of essential data can be carried rapidly to the point where discussion will have some meaning.

Sincerely,

Edwin Hubble

EPH/MW