# *V.M. Slipher: Master of the Spectrograph*

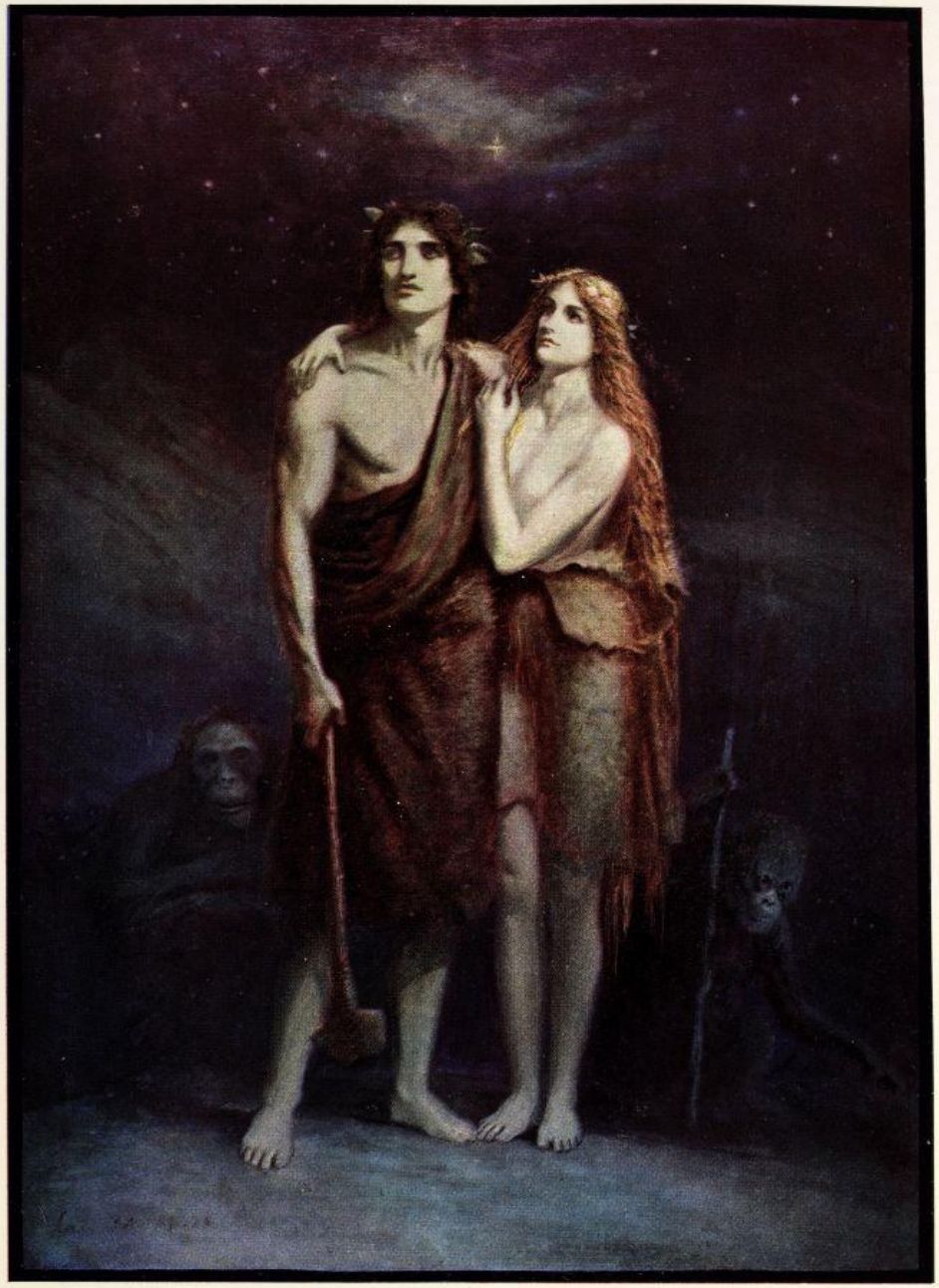
Robert Smith (University of Alberta)

# Aims

- Recover the contexts for V.M. Slipher's studies of the radial velocities of spiral nebulae, that is, to put the `strangeness' back in

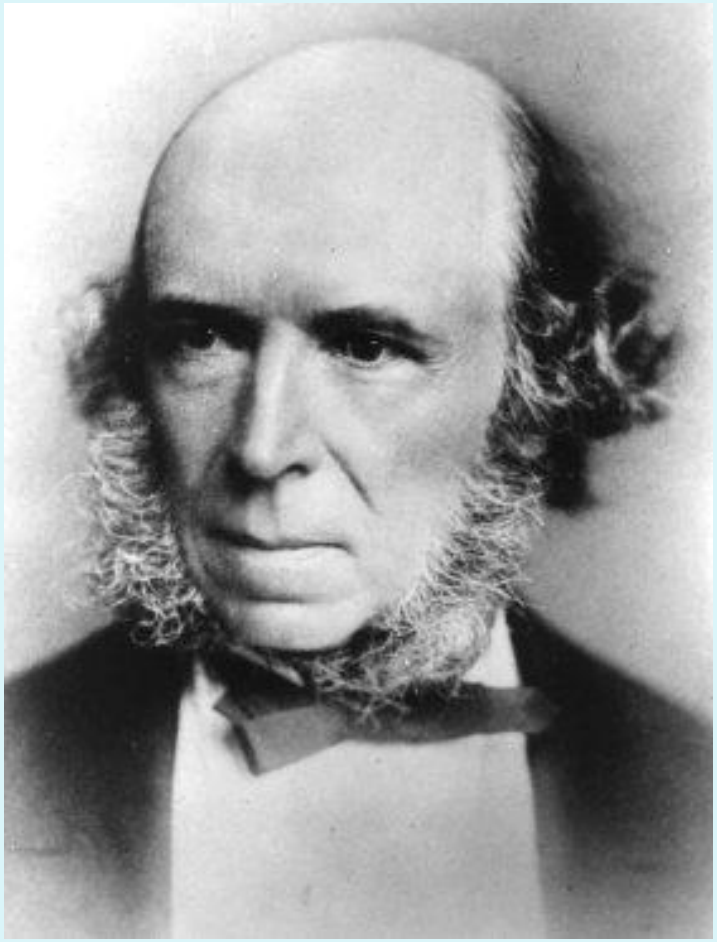
- Slipher's pursuit of credibility

- Address the question, Why successful in 1912?

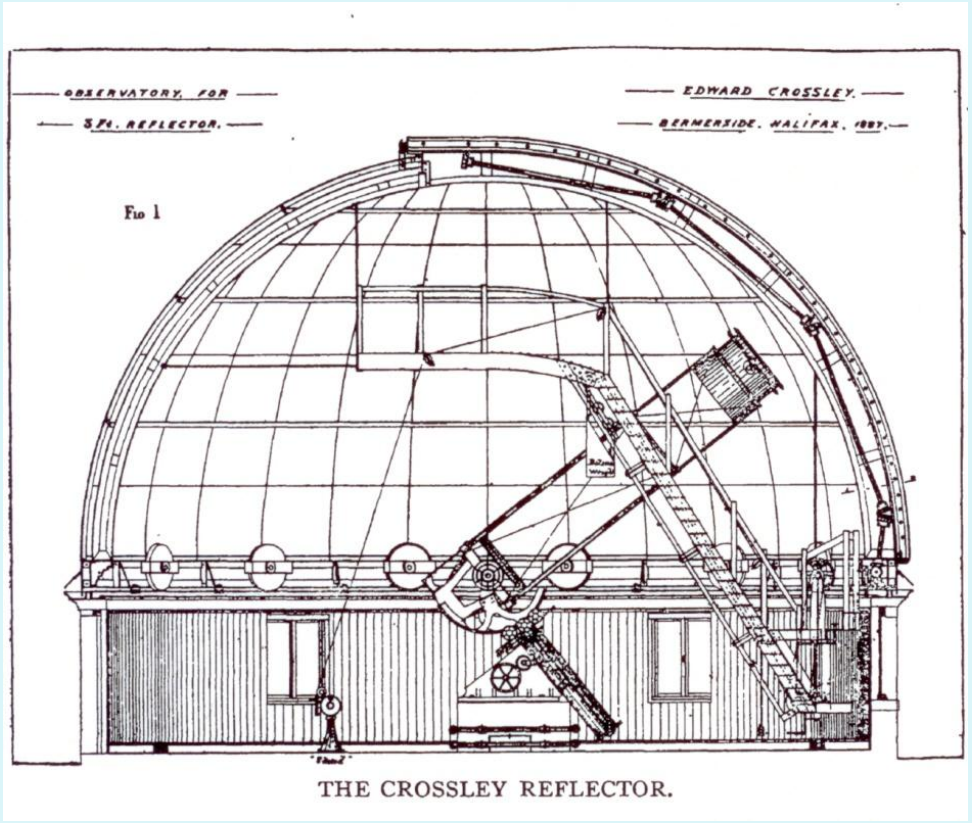


NEBULA TO MAN

# Lowell as Spencerian



# Keeler and Crossley Telescope




THE CROSSLEY REFLECTOR.

ASTRONOMISCHE NACHRICHTEN.

№ 3601.

Band 151. 1.

# On the Predominance of Spiral Forms among the Nebulae.

By *James E. Keeler.*

The spiral nebula has been regarded hitherto as a rara avis — a strange and unusual phenomenon among celestial objects, to be viewed by the observer with special interest, and marked in catalogues with exclamation points.

In beginning photographic work with the Crossley three-foot reflector, about a year ago, I placed on my observing list all those nebulae in which a spiral structure had been discovered, or suspected, by the Earl of Rosse. The spiral form of these nebulae was almost invariably confirmed; but so many other nebulae also proved to be spirals that the classification of Lord Rosse's nebulae in a special list soon lost its significance. As the work progressed, there was gradually brought about a complete reversal of the positions which the two classes of nebulae have always held with respect to frequency of occurrence, and I have now come to regard a small, compact nebula, which is not a spiral, as the object of greater interest.

A comparison of the forms of many different spirals shows that they are, in general, thin flat discs. Well-known examples of spirals whose planes are nearly perpendicular to the line of sight are Messier 57 in Canes Venatici, Messier 101 in Ursa Major, and Messier 74 in Pisces. The spiral H. IV. 76, (G. C. 4594), in Cepheus, is fairly typical of the fainter objects of this class. Of the spiral nebulae which are viewed obliquely, the Great Nebula in Andromeda is, of course, the most splendid example; but the same form occurs over and over again, on a smaller scale, among the fainter nebulae. To this class belong also, according to the observations I have made up to the present time, nearly all the greatly elongated or spindle-shaped nebulae of Herschel. In some of these, where the elongation is extreme, and the nebula becomes a mere ray, the spiral character is nearly or quite indiscernible.

Spirals which consist merely of two curved branches, like a letter S, are of not infrequent occurrence. One of the largest is H. I. 55, in Pegasus. Another example is N. G. C. 6951, (one of Swift's faint nebulae). In these and other cases, there are, however, traces of a more complicated structure, which would be clearly revealed by sufficient optical power.

The extended, diffuse nebulae, such as the Nebula in Orion, the Trifid nebula, and the great nebulous clouds spread through the Milky Way, are not considered in the present connection. They show little tendency to assume a spiral structure. This structure seems to require the action of a dominant central force.

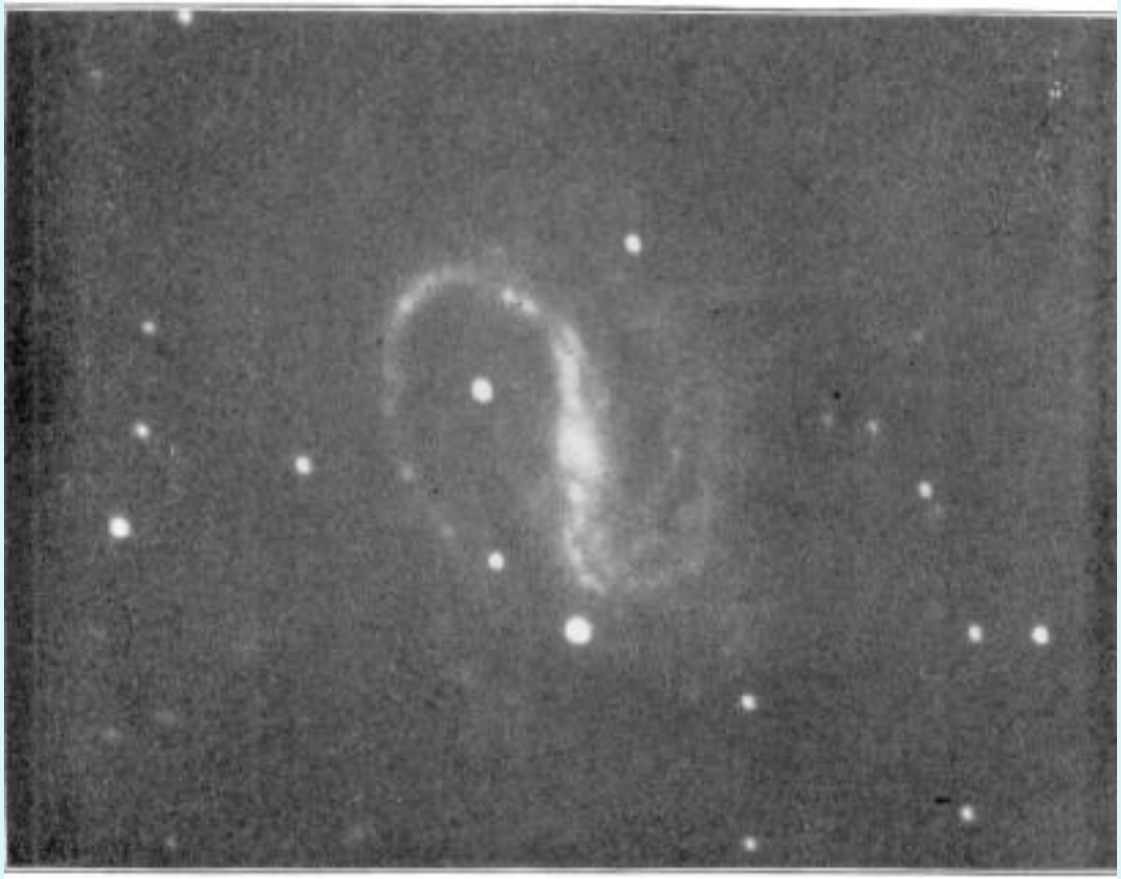
There are, of course, compact, isolated nebulae which are not spirals. The Ring Nebula in Lyra and the Dumbbell nebula in Vulpecula are conspicuous examples of such, and other interesting cases are afforded by the Crossley photographs. The nebula H I. 192 in Cepheus consists of a number of loops, completing the »falcated« curves described by Herschel, in which no spiral arrangement is apparent; and the nebula H. II. 240, in Pegasus, presents the appearance of two spindle-shaped parallel masses separated by a perfectly straight rift. Numerous cases of the same kind might be mentioned. There are also nebulae which, from their general resemblance to other forms, might be expected to have a spiral structure; yet none can be detected. Thus, the companion Messier 32 of the Great Nebula in Andromeda appears on my photographs as a round, cometary mass, which is very bright in the middle, and fades gradually outward, but which is otherwise structureless. H. I. 151, in Pisces, presents the same appearance on a smaller scale.

It is possible, however, that such forms, of which a number have been photographed with the Crossley telescope, are really a special case of the ordinary spiral. The nebula H. II. 207 appears on a photograph of only moderately good definition as a round, cometary body, such as I have described above, surrounded by a faint ring about 50" in diameter; but a sufficiently good photograph, such as can be made on our finest nights, shows a delicate spiral structure, the spires being closely wound. It may be, therefore, that with sufficiently good definition a spiral structure would be found in the other nebulae I have mentioned; or that its absence, if it really does not exist, may be due to the more effective operation of the same cause which has determined the nearly complete absence of spirality in H. II. 207. The determining factor, in these cases, is perhaps simply the aggregate moment of rotation, resulting from motion inherent in the particles of the original contracting mass.

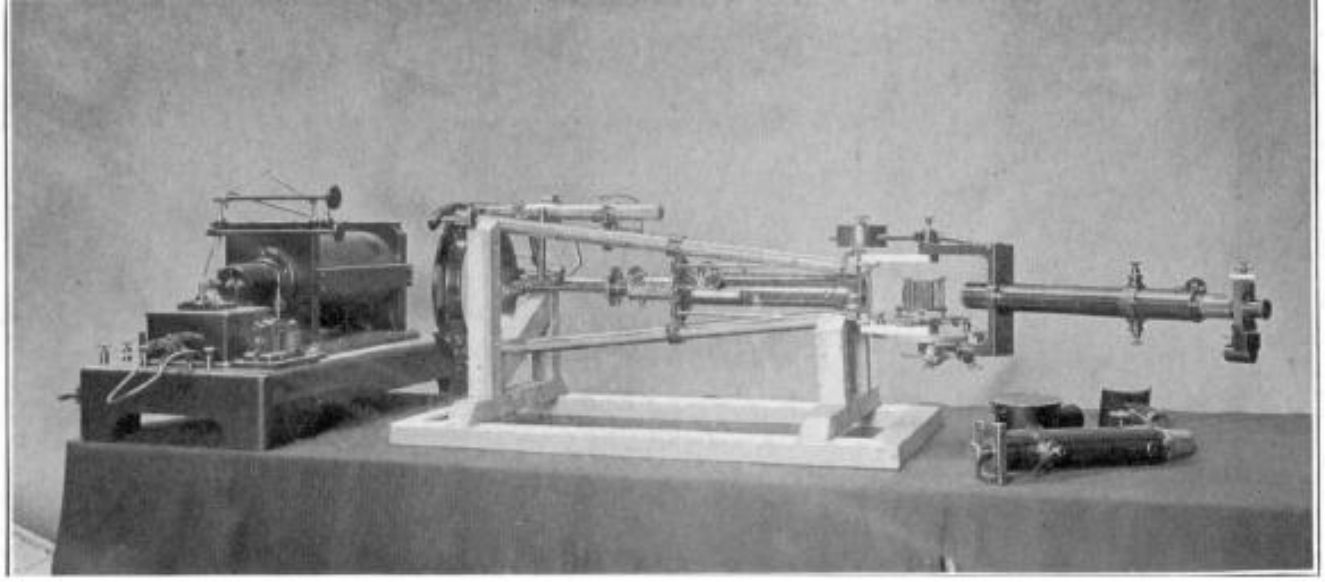
If, then, numerous exceptions prove that spirality in nebulae is not a universal law, it may perhaps be regarded as the usual or normal accompaniment of contraction in cosmical masses, and any departure from it may be explained as the result of special conditions, tending to suspend or weaken causes which are generally operative.

The number of spiral nebulae in the sky cannot be estimated from existing catalogues. Few photographs have been taken with the Crossley reflector which have not revealed the existence of new nebulae, in number from one or two to fifteen or sixteen. Many of these are spirals; while

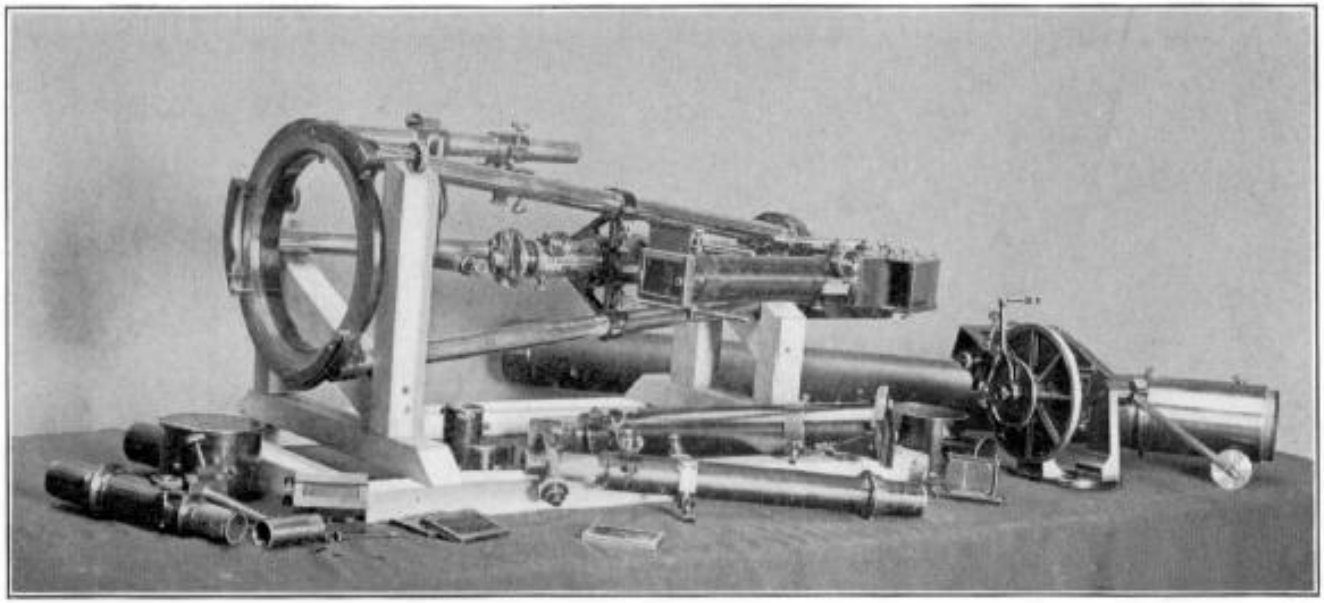
# PLATE II.



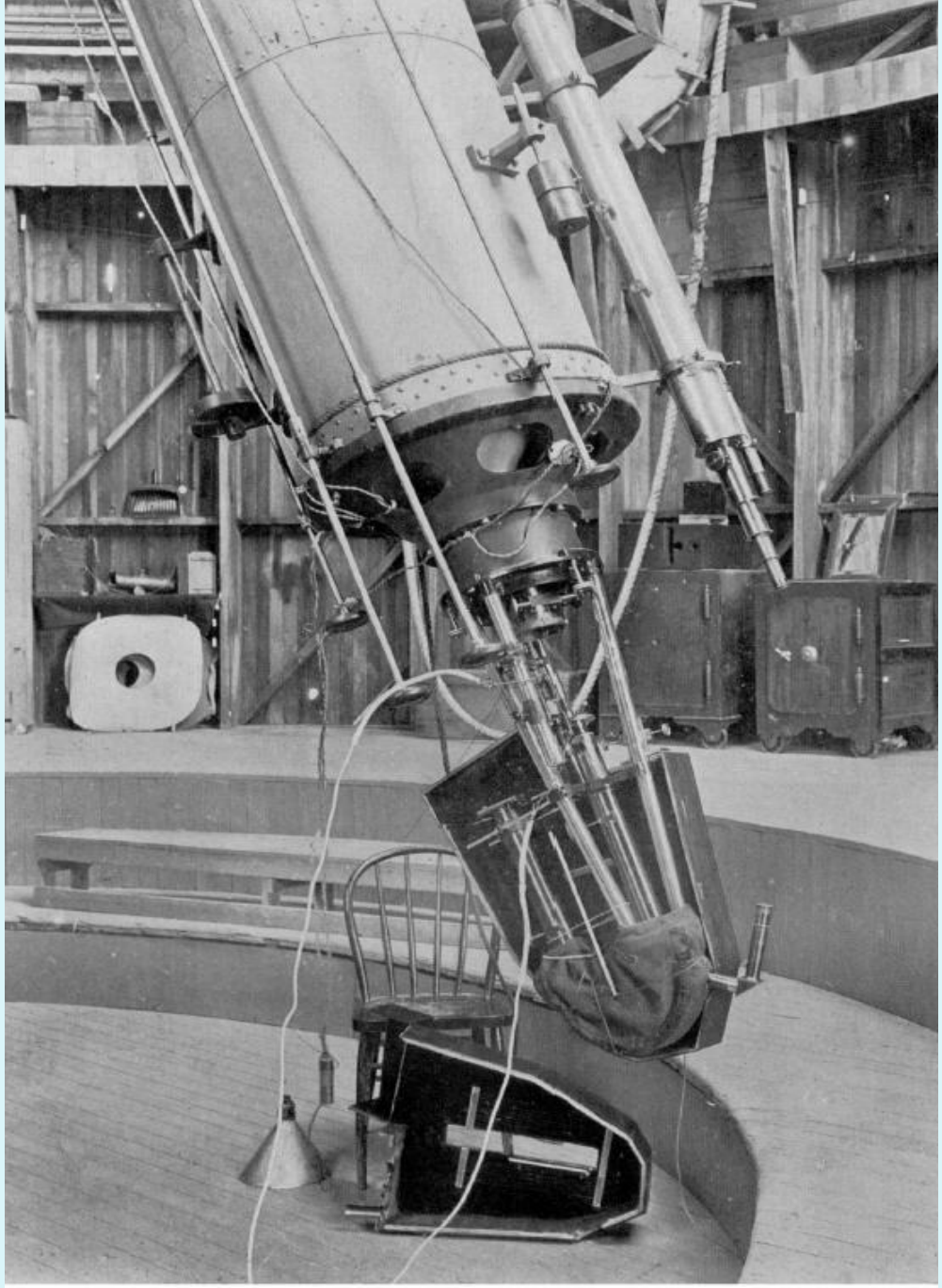
PHOTOGRAPH OF THE NEBULA *H I. 55 PEGASI*
Made with the Crossley Reflector



A. The Spectrograph as Spectrometer.



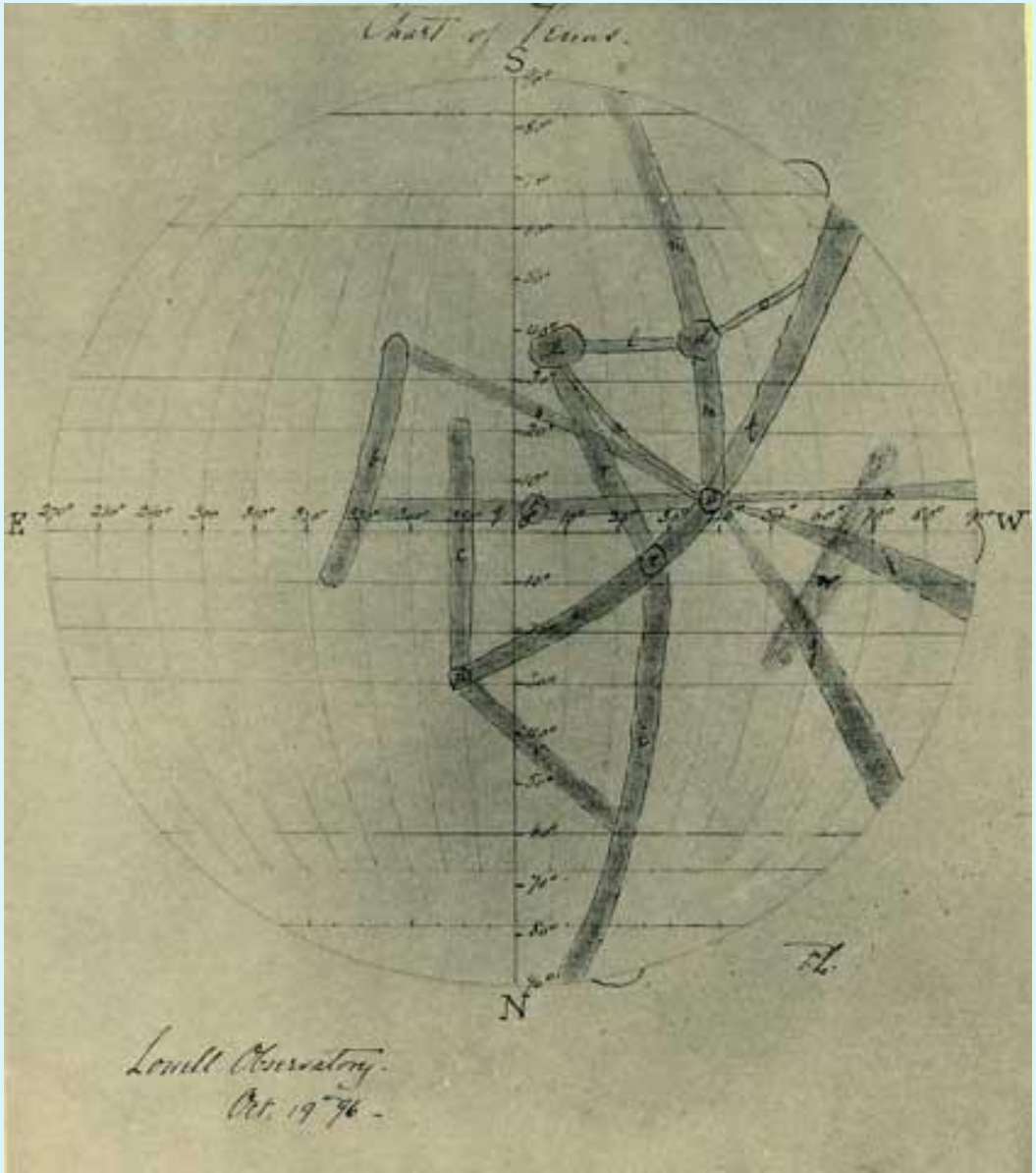
B. The Spectrograph and Auxiliary Equipment.



THE LOWELL SPECTROGRAPH ATTACHED TO THE TWENTY-FOUR INCH REFRACTOR.

# Campbell and Mills Spectrograph

# Chart of Venus by Lowell, 1896



# OBSERVATIONS OF STANDARD VELOCITY STARS WITH THE LOWELL SPECTROGRAPH (1905)

By V. M. SLIPHER

In the present paper are given the results of my observations of the list of "Standard Velocity Stars,"[1] made with the Lowell Spectrograph during the summer and autumn of the present year. Owing to the circumstance that the time that the spectrograph is available for stellar radial velocity work is limited, I have not been able to follow closely the recommendation[1] that the three observations of each star be made at the beginning, middle, and end of the two months symmetrical about the date of the star's opposition with the Sun. Inasmuch as *α Crateris*, the faintest star of the regular list, has been, and will be for some time yet, too near the Sun for observation, I have substituted for it *γ Cephei*, the faintest star of the supplementary list, in order to bring these observations to an early conclusion. The ten stars that I have observed are, then, the following:

| | |
|---|---|
| α *Arietis* | β *Ophiuchi* |
| α *Persei* | γ *Aquilae* |
| β *Leporis* | ε *Pegasi* |
| β *Geminorum* | γ *Piscium* |
| α *Boötis* | γ *Cephei* |

I have secured, as was suggested, extra spectrograms of *α Persei* and *α Boötis;* and, in order to check the performance of the spectrograph, I have measured at frequent intervals the spectrographic velocities of *Venus, Mars*, and the Moon.

The spectrograph,[2] as employed in these observations, consists essentially of a collimator of 30 mm aperture and 490 mm focus, a train of three 63° dense flint prisms and a camera of 35 mm aperture and 471 mm focus, the whole inclosed in a box supplied with

[1] See Frost on "Coöperation in Observing Radial Velocities of Selected Stars," *Astrophysical Journal*, **16**, 169, 1902.

[2] A detailed description of this instrument was published in the *Astrophysical Journal* for July, 1904 (**20**, 1–20).

# Mars Water Vapour Controversy 1909

# Campbell sceptical

- “Your high velocity for the Andromeda Nebula is surprising in the extreme. I suppose, as the dispersion of your instrument must have been very low, the error of your radial velocity measurements must have been pretty large. I hope you have more than one result for velocity, and no doubt you have.”

# AAS 1914

# Hertzsprung sends congratulations

- The radial velocities show “with great certainty” that the spirals do not belong to the Milky Way

# Campbell



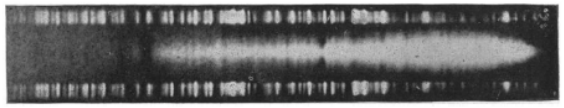


FIG. 3. The Spectrum of the Great Spiral Nebula in Andromeda, photographed by Slipher at the Lowell Observatory.
[The series of bright lines along the upper and lower margins are the reference spectrum. The nebular spectrum runs horizontally through the central area.]

ponderance of stars visible in the Milky Way is due to the greater extension of the stellar system in that direction than in the direction of the galactic poles.

Sir John Herschel, the son, extended the father's search for nebulæ to the southern sky, by observing at the Cape of Good Hope in the 1830's. He later charted all of the known nebulæ, both north and south, upon a sphere representing the entire sky, and found the surprising condition that the nebulæ in general avoid the Milky Way. Several decades earlier William Herschel had noticed within the Galaxy that the nebulæ are the more plentiful where the stars are scarce. When the stars in the eyepiece of his telescope would suddenly change from numerous to few he was accustomed to say to his recording assistant, "Get ready, nebulæ are coming." These general facts of stellar and nebular distribution, where stars are scarce nebulæ abound, and where stars abound nebulæ are scarce, led Herbert Spencer, among others, to emphasize the view that the evidence for a relationship of stars and nebulæ

spectrum). This observation gave a death blow to the hypothesis then prevailing that all the nebulæ would prove to be clusters of stars if only our telescopes were powerful enough, or if the nebulæ were brought near enough to us. The spectroscope said very definitely and with finality: the Draco nebula is unresolvable; it is a mass of glowing gases. A cluster of stars can not give that type of spectrum. Other nebulæ were tested by Huggins's spectroscope. Some of these objects gave bright-line spectra, but the great majority had continuous spectra. Whether the latter were actually continuous or, as in the case of the sun and other middle-aged stars, the apparently continuous spectra of the nebulæ were really interrupted by hundreds and thousands of absorption lines, could not be decided because the nebular spectra were exceedingly faint. The eye could not have seen the absorption lines even if they were present. It is only in the last two decades, through the use of rapid photographic plates and of exposures a great many hours in length, that the existence of absorption lines in the continu-

# Kapteyn 1910

| Spectrum or Object | Peculiar Radial Velocity | | Number |
|---|---|---|---|
| B to B9 | 6.5 km | | 64 |
| A to A5 | 12.6 (11.2) | | 18 |
| F to F8 | 14.5 | | 17 |
| G to G5 | 12.6 | 14.5 | 26 |
| K to K5 | 15.4 | | 55 |
| Ma | 19.3 | | 6 |
| Planetary nebula | 26.8 | | 13 |
| *Orion* nebula | 0.1 | | 1 |
| N | 13.1 | | 8 |
| L | 3.7 | | 2 |
| Total | | | 210 |

FIG. 3. J. C. Kapteyn's 1910 table showing the increase of peculiar radial velocity when moving from the Orion (B) stars to the Sirian (A) stars to the stars of spectral type F to K, and finally to the M type stars. (From Kapteyn, *op. cit.* (ref. 54).)

# DREYER NEBULA NO. 584 INCONCEIVABLY DISTANT

## Dr. Slipher Says the Celestial Speed Champion Is 'Many Millions of Light Years' Away.

By Dr. VESTO MELVIN SLIPHER,
Assistant Director of the Lowell Observatory, Flagstaff, Ariz.

FLAGSTAFF, Ariz., Jan. 17.—The Lowell Observatory some years ago undertook to determine the velocity of the spiral nebulae—a thing that had not been previously attempted or thought possible. The undertaking soon revealed the quite unexpected fact that spiral nebulae are far the most swiftly moving objects known in the heavens. A recent observation has shown that the nebula in the constellation Cetus, numbering

# Eddington, *The Mathematical Theory of Relativity,* 1923

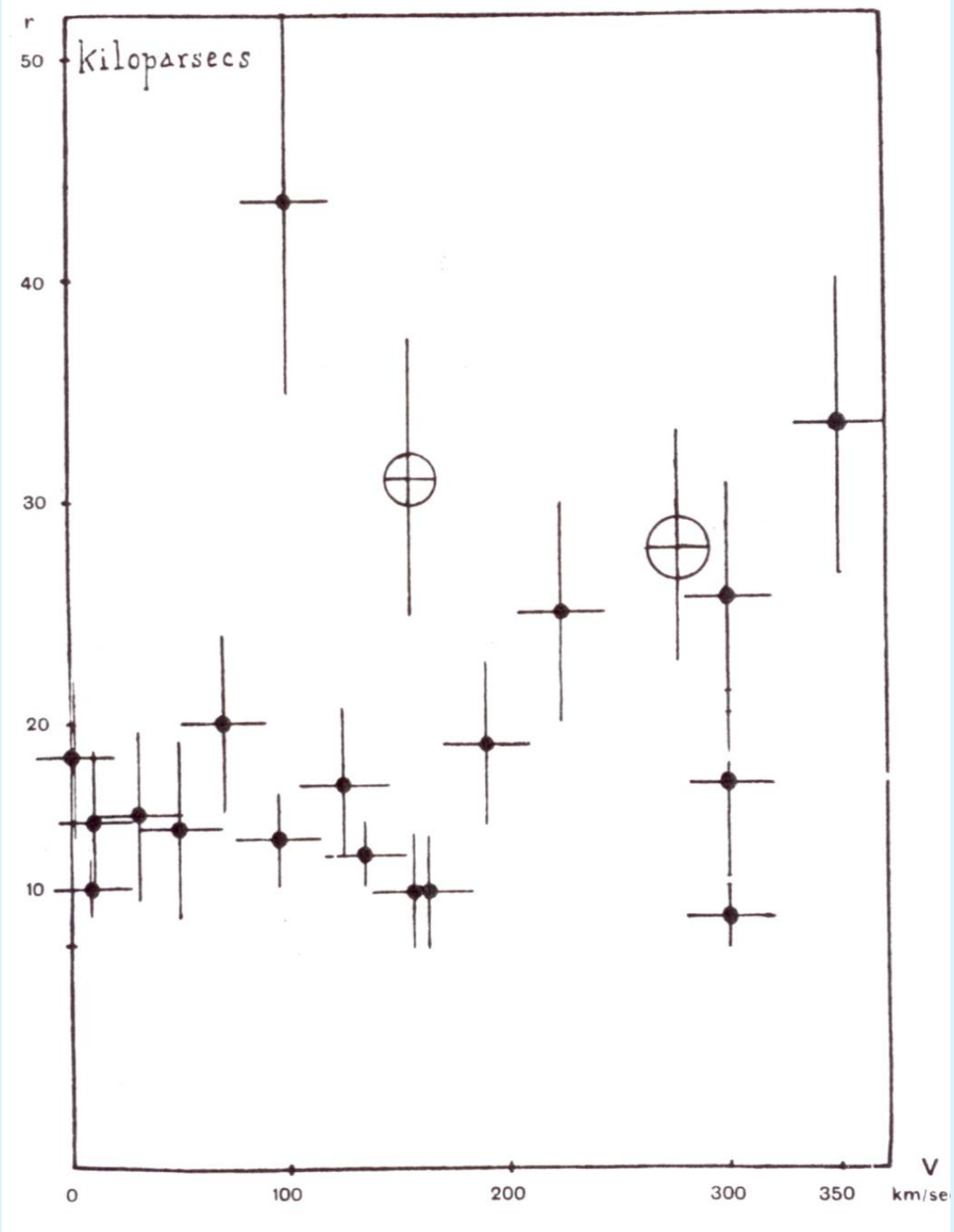
## Radial Velocities of Spiral Nebulae

+ indicates receding, − approaching

| N.G.C. | R.A. h m | Dec. ° ′ | Rad. Vel. km. per sec. | N.G.C. | R.A. h m | Dec. ° ′ | Rad. Vel. km. per sec |
|---|---|---|---|---|---|---|---|
| 221 | 0 38 | +40 26 | − 300 | 4151* | 12 6 | +39 51 | + 980 |
| 224* | 0 38 | +40 50 | − 300 | 4214 | 12 12 | +36 46 | + 300 |
| 278† | 0 47 | +47 7 | + 650 | 4258 | 12 15 | +47 45 | + 500 |
| 404 | 1 5 | +35 17 | − 25 | 4382† | 12 21 | +18 38 | + 500 |
| 584† | 1 27 | − 7 17 | +1800 | 4449 | 12 24 | +44 32 | + 200 |
| 598* | 1 29 | +30 15 | − 260 | 4472 | 12 25 | + 8 27 | + 850 |
| 936 | 2 24 | − 1 31 | +1300 | 4486† | 12 27 | +12 50 | + 800 |
| 1023 | 2 35 | +38 43 | + 300 | 4526 | 12 30 | + 8 9 | + 580 |
| 1068* | 2 39 | − 0 21 | +1120 | 4565† | 12 32 | +26 26 | +1100 |
| 2683 | 8 48 | +33 43 | + 400 | 4594* | 12 36 | −11 11 | +1100 |
| 2841† | 9 16 | +51 19 | + 600 | 4649 | 12 40 | +12 0 | +1090 |
| 3031 | 9 49 | +69 27 | − 30 | 4736 | 12 47 | +41 33 | + 290 |
| 3034 | 9 49 | +70 5 | + 290 | 4826 | 12 53 | +22 7 | + 150 |
| 3115† | 10 1 | − 7 20 | + 600 | 5005 | 13 7 | +37 29 | + 900 |
| 3368 | 10 42 | +12 14 | + 940 | 5055 | 13 12 | +42 37 | + 450 |
| 3379* | 10 43 | +13 0 | + 780 | 5194 | 13 26 | +47 36 | + 270 |
| 3489† | 10 56 | +14 20 | + 600 | 5195† | 13 27 | +47 41 | + 240 |
| 3521 | 11 2 | + 0 24 | + 730 | 5236† | 13 32 | −29 27 | + 500 |
| 3623 | 11 15 | +13 32 | + 800 | 5866 | 15 4 | +56 4 | + 650 |
| 3627 | 11 16 | +13 26 | + 650 | 7331 | 22 33 | +33 23 | + 500 |
| 4111† | 12 3 | +43 31 | + 800 | | | | |

# But Slipher is out of the hunt for the radial velocities of spirals by about 1923

- A new direction: correlating radial velocities with properties of spiral nebulae, but Slipher was left behind


r
kiloparsecs
50
40
30
20
10
0
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200
300
350
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km/se

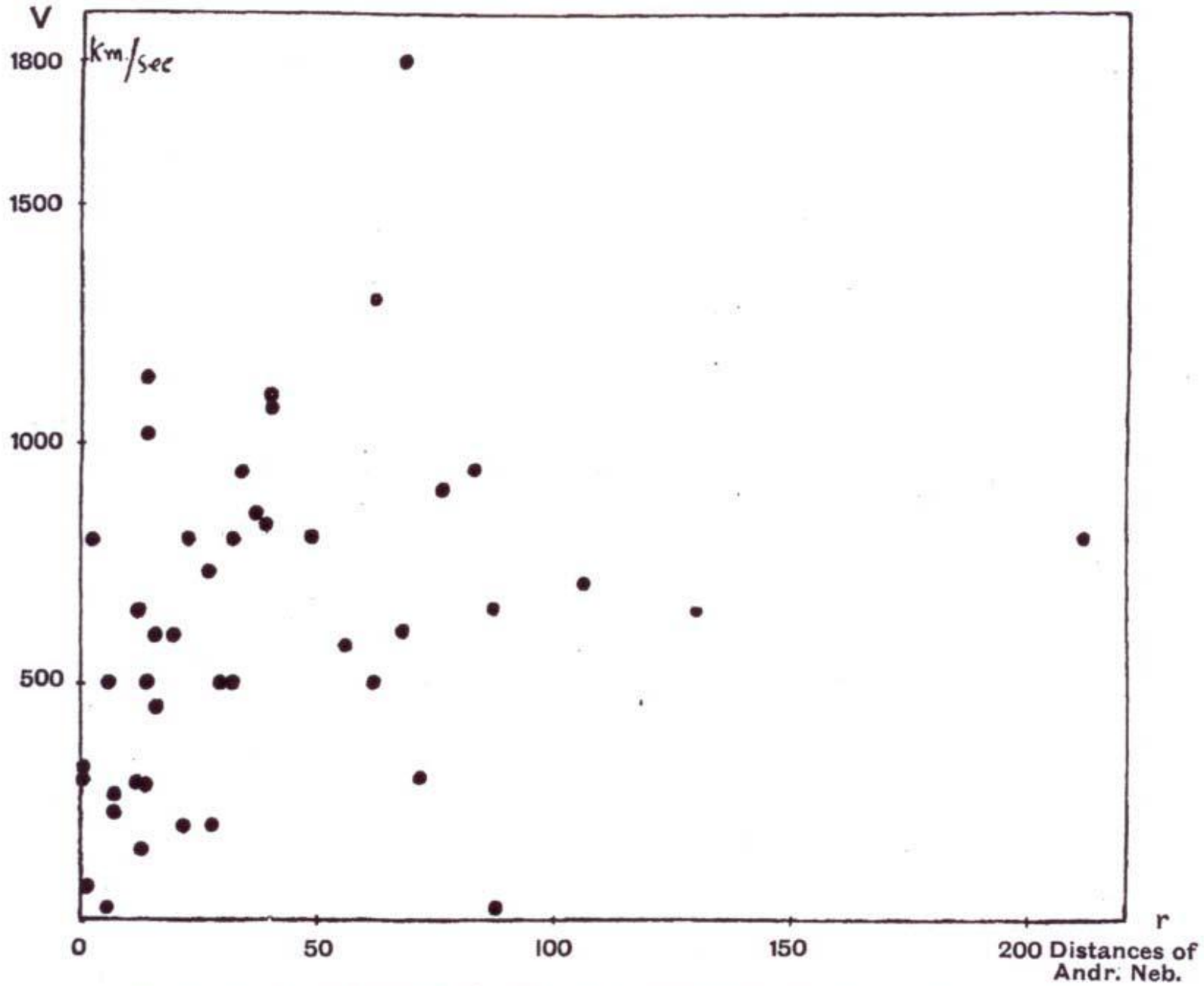


FIG. 5.—Relation between the relative distances (the unit is the distance of the Andromeda nebula) and the measured radial velocities of spiral nebulæ.

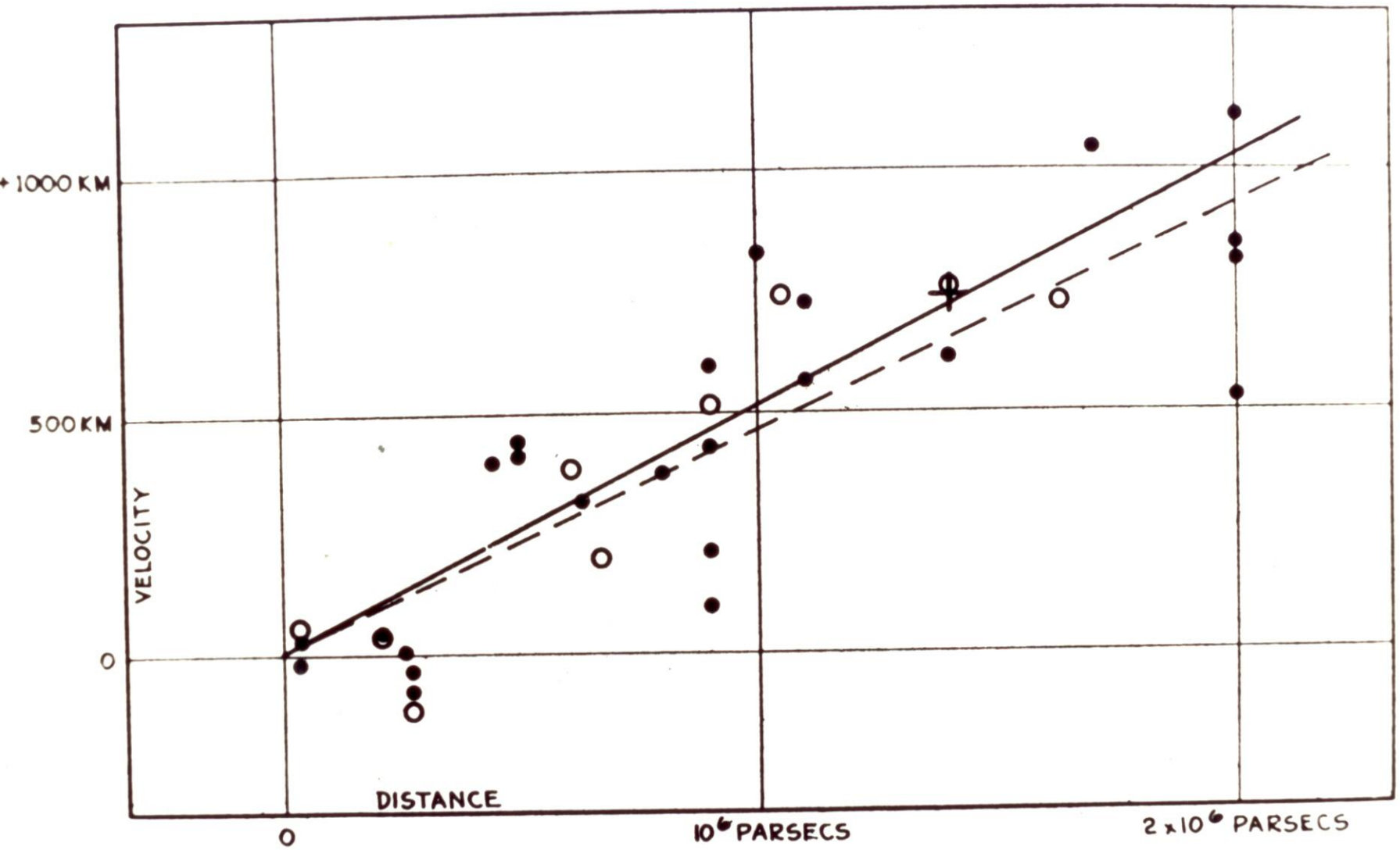


FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.

Radial velocities, corrected for solar motion, are plotted against

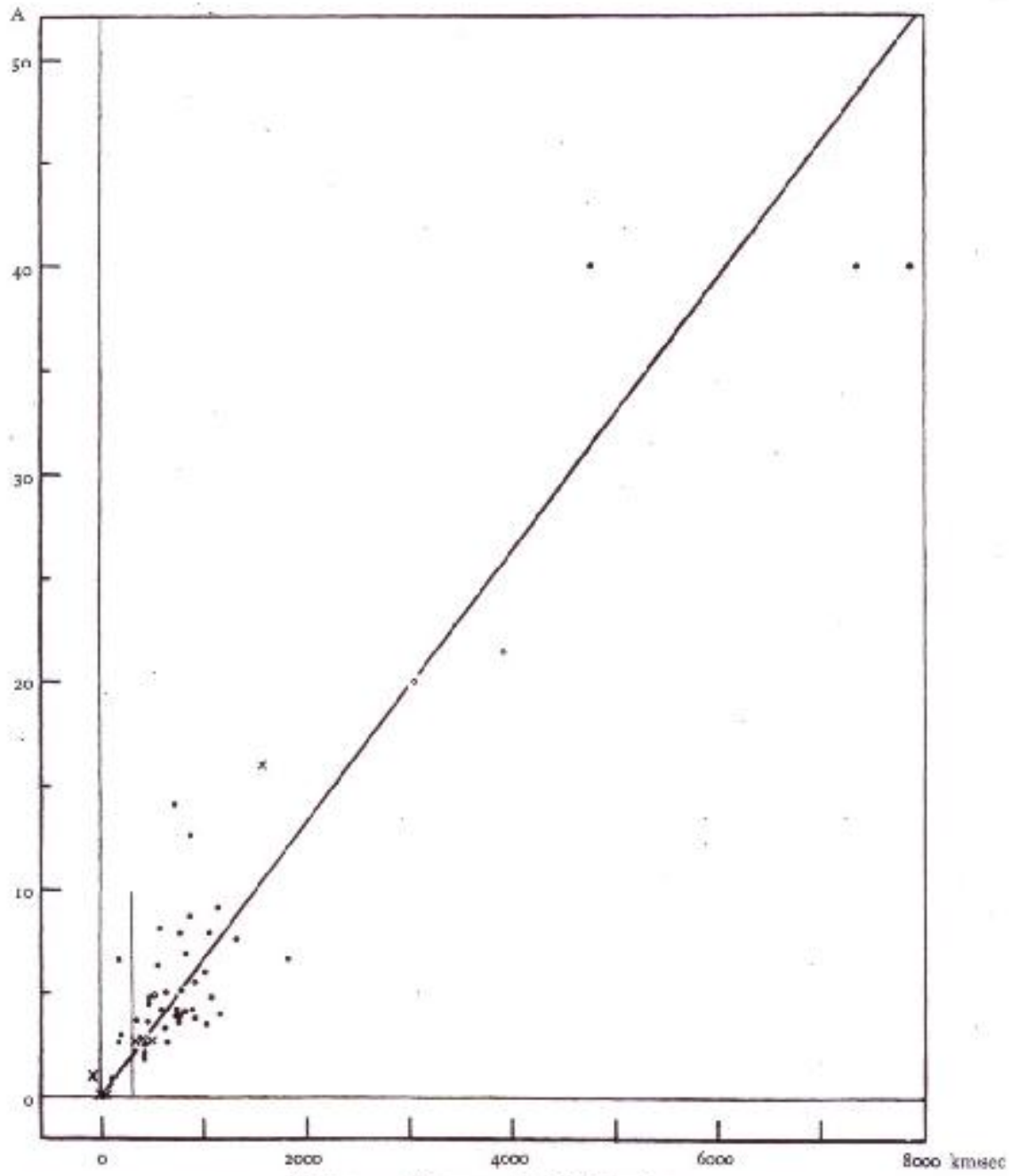


FIGURE 10. Distances and racial velocities.

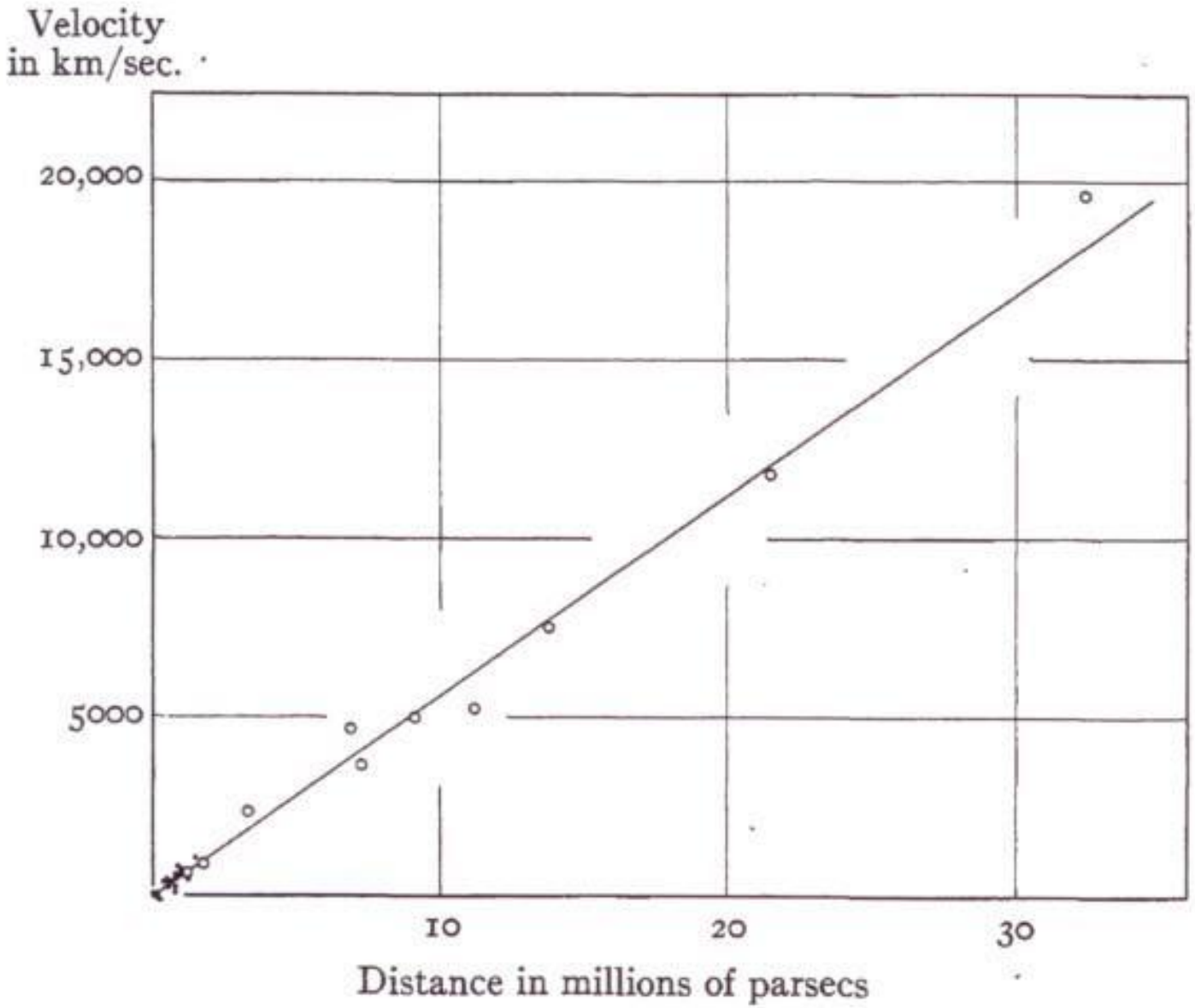


FIG. 5.—The velocity-distance relation. The circles represent mean values for clusters or groups of nebulae. The dots near the origin represent individual nebulae, which together with the groups indicated by the lowest two circles, were used in the first formulation of the velocity-distance relation.

# Slipher on Doppler Shifts

- Initial doubts that the spectral shifts are Doppler shifts but he can not conceive of an alternative

- Contrast with Hubble

# Conclusions

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