speaking of the death of Turenne. There are those who see in the accidents of good or evil fortune the hand of fate; but it is hard to discern in the fall of the brave or the triumph of the unworthy the hand of Heaven. The Countess Potocka was at last driven by circumstances to submit to a divorce, and the prince-bishop exerted his influence with the Pope to obtain it. But even before it arrived, within three months of the death of her gallant husband, the marriage of Helen Massalska and Count Vincent Potocki was solemnised in the chapel of the Bernardines, near Werky, at midnight.

It would have been better for the reputation of this brilliant, vain, heartless, and profligate woman if these memoirs had not seen the light. They present to us a series of vivid pictures of a state of society which has happily ceased to exist; and whatever may be the foibles and follies of our own times, they fall short of the abuses of wealth and privilege, the disunited marriages, and the defiance of domestic duties, which contributed to the destruction of society in the last century. But these were, it seems from the pages before us, the results of the education of the Abbaye-aux-Bois.

ART. II.—1. *La Photographie Astronomique à l'Observatoire de Paris et la Carte du Ciel.* Par M. le Contre-Amiral E. MOUCHEZ. Paris: 1887.

2. *An Investigation in Stellar Photography conducted at the Harvard College Observatory.* By EDWARD C. PICKERING. Cambridge, U.S.: 1886.

3. *First Annual Report of the Photographic Study of Stellar Spectra conducted at the Harvard College Observatory.* By EDWARD C. PICKERING, Director. Cambridge, U.S.: 1887.

4. *The Applications of Photography in Astronomy.* Lecture delivered at the Royal Institution, Friday, June 3, 1887. By DAVID GILL, LL.D., F.R.S. (The Observatory, July and August, 1887.)

5. *Die Photographie im Dienste der Astronomie.* Von O. STRUVE. (Bulletin de l'Académie Impériale des Sciences de St.-Pétersbourg, Tome xxx. No. 4: 1886.)

THE application of photography to astronomical research is rapidly transforming its destinies. The more closely the exquisite sky-prints recently taken at Paris and elsewhere are studied, the more opulent of promise they appear.

Their pictorial beauty is the least of their merits. In the eyes of the astronomer their eminent value lies in their capability of exact measurement. Upon this basis of fact rest anticipations which to unaccustomed ears sound exaggerated, but which the future will, unless we are much mistaken, amply justify. We can have no hesitation in admitting that what has been done, not by chance, but on system, can be done again. Results already obtained can be repeated and multiplied. It needs no more—although much more will probably be accomplished—to ensure a new birth of knowledge regarding the structure of the universe.

The scientific importance of Daguerre's invention was perceived from the outset. In formally announcing it to the Academy of Sciences, August 19, 1839, Arago characterised it as 'a new instrument for the study of nature,' the manifold uses of which must baffle, and would assuredly surpass, prediction. 'En ce genre,' he added significantly, 'c'est 'sur l'imprévu qu'on doit particulièrement compter.' * And it is indeed the unforeseen which has come to pass. Arago himself, with all his readiness to admit incalculable possibilities, would have been staggered by a forecast of the work now actually being done.

Celestial photography, as was natural, made its first essay with the moon. The broad, mild face of our satellite, diversified with graduated lights and intense shadows, formed a tempting subject for the nascent art. At Arago's suggestion, accordingly, Daguerre exposed one of his sensitive plates to the lunar rays, but with a disappointing result. Nothing worthy the name of a picture made its appearance. Professor J. W. Draper, of New York, however, obtained early in 1840 some little prints, not altogether characterless, of the lunar surface, after which the subject dropped out of sight during ten years. It was resumed at Harvard College Observatory by George P. Bond, one of whose lunar daguerreotypes attracted deserved attention at the Great Exhibition of 1851. The light employed to produce them was concentrated by a telescope fifteen inches in aperture, equatorially mounted, and kept fixed by a clockwork movement upon the moving object to be depicted.

Bond's pictures marked the close of the first or tentative period in celestial photography. In 1851 the collodion process was introduced by Frederick Scott Archer, and rapidly superseded all others. Daguerreotypes, lunar, solar,

* Comptes Rendus, tome ix. p. 264.

and terrestrial, began to assume an antiquarian interest and aspect.

Collodion is a colourless, semi-viscous fluid produced by dissolving gun-cotton in a mixture of alcohol and ether. Spread upon glass, it forms a transparent membrane rendered susceptible to the action of light by impregnation with salts of silver. The 'sensitiveness' of these substances is due to their possessing a molecular equilibrium so delicate as to be overturned by the quick ethereal impacts of the vibrations of violet light. The metal they contain, thus partially released from the bonds of chemical combination, is ready to attract further deposits; and the opportunity of exercising this power of appropriation is afforded by the processes of developement.* A photograph is hence a picture painted in metallic silver under the regulating influence of light.

Mr. Warren De la Rue was the first to turn Archer's improvement to account for astronomical purposes. He began his photographic work towards the close of 1852 with a thirteen-inch reflector of his own construction which gave him successful pictures of the moon, one inch across, in ten to thirty seconds. Some taken later with improved means bore enlargement to eight inches, and clearly showed details representing an actual area on the moon's surface of about two and a half square miles. The distribution of light and shade in them differed so notably from that perceived with the eye as to afford hints (it was thought) towards a science of lunar geology, formations of different epochs being distinguished by their varying powers of reflecting the actinic rays.† The marked deficiency in chemical power of the so-called 'seas,' in especial, suggested that they might in reality be plains clothed with vegetation, the vital needs of which were supplied by a dense, low-lying atmosphere.

Mr. De la Rue showed further that, by the stereoscopic combination of two photographs taken at opposite phases of the moon's libration, something might be learned as to the relative age of lunar craters. The deep furrows diverging from Tycho, for instance, were perceived to run right through some craters, but to be overlaid by others.‡ Obviously, then, the dislocated craters were already in existence when

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* Some kinds of developement merely complete the 'reducing' process begun by the action of light, without adding any fresh metallic supplies.

† Report British Association, 1859, p. 145.

‡ Monthly Notices, vol. xxiii. p. 111.

these clefts opened, while the unaffected ones were of later production. With the improved photographic methods now in use, it is quite possible that the real position in Jupiter's atmosphere of the great red spot adhering to his southern belt may in this way be determined; perhaps even indications derived as to the nature of the mysterious Martian canals.*

The immediate followers of De la Rue in lunar photography were two gifted Americans, Dr. Henry Draper and Lewis M. Rutherfurd of New York. The moon, as seen with the naked eye, is about one-tenth of an inch in diameter; that is to say, it is just covered by a disc of that size held at the ordinary distance for clear vision.† One of Draper's pictures, taken with a fifteen-inch silvered glass reflector, September 3, 1863, and subsequently enlarged, showed it as three feet across, or on a scale of about sixty miles to the inch. The spectator was virtually transported to a point six hundred miles from the lunar surface.

Reflectors possess the great advantage of being perfectly achromatic; undulations of all wave-lengths are collected by them at a single focus. In refractors, on the other hand, there is always a certain amount of dispersion. Opticians have to choose which rays to unite, leaving the others to shift for themselves. They in general, of course, bestow exclusive attention on those of greatest visual intensity. Ordinary achromatics have hence no sharp chemical focus. Rutherfurd, however, took the more rapid vibrations alone into account in calculating the curves of an object-glass of eleven inches designed expressly for photographic use. He thus set the example of deliberately constructing a telescope totally unserviceable to the eye. By its means were obtained in 1865 lunar photographs which marked the culmination of the art in its second, or 'wet-collodion,' stage.

Yet the result, striking as it was in some respects, somewhat disappointed expectation in others. The details of structure were not so distinctly given as to serve for a criterion of future change; nor has any lunar photograph yet taken shown the crispness of the best telescopic views. The reason is obvious. Atmospheric shiverings, which the eye

* The rotation of the planets gives the differences in the point of view requisite for obtaining stereoscopic relief. Photographs taken at intervals—for Jupiter of twenty-six, for Mars of sixty-nine minutes—combine with the proper effect. De la Rue, 'Report Brit. Ass.' 1859, p. 148.

† H. Draper, 'Quart. Jour. of Science,' vol. i. p. 381.

can to some extent eliminate, produce their full effect on the sensitive plate. The resulting picture is the summation of a multitude of partial impressions due to evanescent distortions and displacements of the image.

It was perhaps owing to a sense of partial failure that lunar photography fell into neglect during twenty years. Now at last there are signs of revived interest in it. Recent improvements afford great advantages for its cultivation. Owing to the high sensitiveness of modern plates the images thrown upon them can be strongly magnified, while the time of exposure is still kept extremely short. The MM. Henry have accordingly adopted the plan of photographing the moon in sections, six or eight of which cover the visible hemisphere, and are united to form a map one and a half to two feet in diameter. A repetition of the process at intervals will test the occurrence of variations in lunar topography extending over not less than one and a half square mile.

The finest telescope in the world for the purposes of moon-portraiture is undoubtedly the giant refractor of the Lick Observatory in California. With an aperture of three and a focal length of fifty feet, it gives a direct image of the moon six inches in diameter, negative impressions of which may be enlarged with advantage to perhaps twelve feet. But the third lens, by which the correction of this superb instrument can be modified at pleasure to suit the actinic rays, has yet to be provided; and perfect glass discs of thirty-six inches are not to be had for the asking. They may be bespoke a long time before they are forthcoming.

The sun can now be photographed in the inconceivably short space of the one hundred thousandth part of a second!* A short exposure, followed by a long and strong developement, gives the best results; and it is difficult to see how those obtained by M. Janssen at Meudon during the last eight or nine years can be much improved upon. It might, however, be found possible to work on a larger scale. Advantage for the exhibition of details would probably be derived from the use of a solar image more highly magnified than has hitherto been customary.

The historical starting-point of solar photography is a daguerreotype taken at Paris by MM. Foucault and Fizeau, April 2, 1845. The attempt, though not unsuccessful, remained isolated for a number of years. The eclipsed sun

* Janssen, 'Annuaire du Bureau des Longitudes,' 1883, p. 809.

was the subject of the next experiment. Busch and Berkowski of Königsberg obtained a slight but distinct impression of the corona during the total eclipse of July 28, 1851. But the triumph of practically establishing the value of photography as a means of investigating the solar appendages was reserved for Mr. De la Rue and Father Secchi. By the comparison of photographs taken at various stages of the eclipse of July 18, 1860, the status of the 'red protuberances' was settled for ever. The advance of the moon *over* them proved beyond cavil that they belonged to the sun.

The camera is an encroaching instrument. So surely as it gains a foothold in any field of research, so surely it advances to occupy the whole, either as adjunct or principal. Telescopic and direct spectroscopic observations during solar eclipses are now altogether subordinate in importance to photographic records of them. Fleeting appearances, likely either to escape or to mislead the eye during the lapse of those counted and crowded moments, are stored up for leisurely interpretation; and the whole working power of the mind can thus be devoted to the collection of materials for subsequent discussion. The discovery of a comet close to the sun, May 17, 1882, is a picturesque incident of eclipse-photography. 'Tewfik,' as the object was named in compliment to the reigning Khedive, made its first known appearance to terrestrial spectators during the seventy-four seconds of total obscurity at Sohag. It was caught with beautiful distinctness on Dr. Schuster's plates of the corona, and its place was measured from them; but, for lack of previous or subsequent observations, it must for ever remain unidentified.

But we must hurry on, lest time fail us to describe the latest developements of this marvellous art. They are due to improvements of a fundamental kind in photographic processes. Collodion-plates can practically only be used in a wet state. This narrowly limits the time of exposure. Moreover, the preparation of each plate must immediately precede and its developement immediately follow exposure—conditions which inconveniently hamper the operations of the astronomical photographer. In 1871, however, gelatine was by Dr. R. L. Maddox substituted for collodion, silver bromide being exclusively used as the sensitive substance. The advantages of the new process were quickly perceived and improved. Gelatine is not, like collodion, a merely neutral vehicle. It possesses a reducing power of its own which

, *La Photographie Astronomique à l'Observatoire de Paris et la Carte du Ciel. Par M le Contre-Amiral E. Mouchez. Paris: 1887* , Edinburgh Review, 167:341 (1888:Jan.) p.23

steps in as an effective auxiliary to that of light. Hence the extraordinary rapidity of the 'gelatino-bromide' plates now universally employed. Chief among their recommendations to 'astrographers' are the faculties of keeping indefinitely, and gaining fivefold sensitiveness by drying. They can thus be prepared at leisure, exposed with constantly accumulating effect for an unlimited period, and developed when convenient.

Their singular adaptation to the exigencies of celestial research was first perceived by Dr. Huggins, who used 'dry 'plates' in his experiments on photographing stellar spectra in 1876; and his advice and example were followed, a few years later, by Draper and Gould in America, by Common and Janssen in Europe. The change has proved of the highest moment to science.

We have heard much lately of the power and promise of the 'new astronomy,' and celestial physics have indeed, in our day, entered upon a splendid career. Like 'England's 'great Chancellor,' it 'has taken all knowledge to be its 'province.' No truth regarding the material universe is indifferent to it. It assimilates every variety of information. Scarcely an experiment can be performed in a laboratory without directly or indirectly promoting its interests. The labours of electricians, meteorologists, geologists, mineralogists, chemists, are all made available. No science can be its rival, because each one is its colleague and ally. The results have been commensurate with this vast extension of resources. Knowledge, ample and assured, has been accumulated of a kind which, previous to the middle of the present century, appeared to the profoundest thinkers for ever unattainable. Undreamt-of analogies between celestial and terrestrial phenomena have been disclosed. Above all, boundless prospects of future discovery have been thrown open, and the keenest stimulus to persistent effort has thus been supplied.

The new astronomy has accordingly found eager and numerous votaries in all its various branches. Yet its popularity seemed attended by a twofold danger. The majestic elder astronomy—the astronomy of Hipparchus, Bradley, and Bessel, of Newton, Leverrier, and Adams—might, it was to be feared, suffer neglect through the predominant attractions of its younger, more versatile, and brilliant competitor; or its lofty standard of perfection might become lowered through the influence of workers more zealous than precise, recruited from every imaginable quarter,

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inventive, enthusiastic, indefatigable, but unused to the rigid requirements of mathematical accuracy.

Both these perils have been happily averted. The prospect has suddenly cleared and brightened. The new astronomy has submitted to bear the yoke of the old. The old astronomy has adopted the new methods, and is even now anxiously fitting them to its own sublime purposes. It has enlarged its boundaries without departing one iota from its principles. By an effort which shows it to be still young and elastic, it has seized the key of the situation, and now stands hopeful and dominant before the world.

This union of the two astronomies has long been in remote preparation. Artists and experimenters innumerable have unconsciously urged it on. It has been promoted by improvements in the manufacture of glass, in the shaping of lenses, in the grinding, polishing, and silvering of mirrors, by the growth of intimacy with the peculiarities of salts of silver, and by the growth of skill in their employment for the purposes of light-portraiture. The meeting last year at Paris of an International 'Astrophotographic' Congress marked its accomplishment. This event will undoubtedly prove to be of the 'epoch-making' description. Future ages will look back to it as the beginning of great achievements. To have been concerned with it will in itself be counted as giving a title to fame. Circumstances concurred to bring it about just at the right moment.

Stellar photography originated with a daguerreotype of Vega (*a* Lyræ) taken at Harvard College July 17, 1850. The oval shape of an image of Castor obtained about the same time indicated its duplicity; but these impressions were very faint, and none at all could be derived from objects of inferior lustre, such as the pole-star. Then the collodion process was introduced, and with its aid the younger Bond, in 1857, extended the depicting powers of the camera to stars of the sixth magnitude. Still more significantly, he demonstrated the applicability of photography to the astronomy of double stars by executing upon prints of *Mizar* in the Tail of the Great Bear a set of measures which proved superior in accuracy to those of the ordinary visual kind. He also led the way in photographing what are called 'star- 'trails.' When Vega, the clock being stopped, was allowed to 'run' upon the plate by its own diurnal motion, its passage remained marked by a fine line. The principle of 'trails' has been turned variously to account in recent investigations.

, *La Photographie Astronomique à l'Observatoire de Paris et la Carte du Ciel. Par M le Contre-Amiral E. Mouchez. Paris: 1887* , Edinburgh Review, 167:341 (1888:Jan.) p.23

Rutherfurd reached the limit, in this direction, of what was possible to be done with wet plates. In and after the year 1864 he secured photographs of a number of clusters, including stars down to the ninth magnitude, from one of which Dr. Gould deduced places for nearly fifty Pleiades, agreeing so closely with Bessel's, of a quarter of a century earlier, as to put beyond doubt the extreme minuteness of the relative motions of those stars. When it is added that quantities of $\frac{1}{50000}$ of an inch were measurable on Rutherfurd's negatives, it becomes clear that the era of observations 'of 'precision' by photographic means was fast approaching.

With the introduction of dry plates it may be said to have arrived. They were indeed indispensable, no less for charting than for exploring the skies. Photography is of service for these purposes just in proportion to the number of faint stars it can register. But here length of exposure is all-important; and long exposures are impossible with plates subject to change by evaporation.

Impressions on the sensitive plate are cumulative as well as permanent. Those on the living retina are neither. The maximum effect of a luminous object on the human eye is produced in one-tenth of a second. Beyond that limit there is continual effacement and renewal. Were it not for this faculty of rapid obliteration, we should see, with the strangest results of visual confusion between time and space, not what we were actually looking at, but what had met our eyes some short time previously. A vast gain in penetrative power would, however, ensue upon a very moderate extension of the time during which the eye can collect impressions. By lengthening it to one second the brightness of visual images would be nearly decupled, and the whole heavens would appear, like the Milky Way, dimly luminous with minute stars.*

This retentive power is possessed, in an eminent degree, by a sensitised gelatine film. No limits have, so far, been set to the time of useful exposure. Successively, as the rays continue to impinge upon it, all the orders of the stars, all the secrets of the sky, disclose themselves to its patient stare. It has thus become possible to photograph stars too faint to be seen with the same optical aid. Some of those sprinkled over the Orion nebula, in Mr. Common's beautiful picture of it, were probably beyond the reach of direct observation with the 36-inch mirror employed; and Dr. Draper at the time

* Janssen, 'Annuaire,' p. 809. Paris: 1883.

of his death in 1882 was making arrangements for exposing plates during nearly six hours, by which he hoped to get notified of the existence of stars sunk in depths of space hopelessly inaccessible to telescopic vision.*

But the decisive impulse towards the greatest astronomical undertaking of this century came otherwise. The Royal Observatory at the Cape of Good Hope was, in 1882, unfurnished with any photographic appliances. The activity reigning there was of a rigorously orthodox kind. The ample programme of work in course of execution included nothing for which Halley or Maskelyne would have been unprepared. 'Astrophysical' tendencies, of whatever description, were absent from it. Nor did any such exist in the mind of the Royal Astronomer. Dr. Gill belonged to the strict school of Bessel; in the use of the heliometer he was Bessel's legitimate successor. His leading title to distinction at that time was a masterly determination of the sun's distance, for which the opposition of Mars in 1877 had given the opportunity; and he was engaged upon a set of measures for stellar parallax of unsurpassed excellence, and now of standard authority. His energetic administration was mainly directed towards promoting the interests of practical astronomy in the southern hemisphere; and he was far from suspecting that in the camera an instrument was at hand more rapidly effective for the purpose than the transit or the heliometer. He was not, however, slow to avail himself of it.

The splendid appearance, at the Cape, of the great comet of 1882 challenged photographic portrayal; and Dr. Gill employed for that end the apparatus, and profited by the experience, of Mr. Aldis, a local artist. An ordinary portrait-lens, of only two inches aperture and eleven focus, was attached to the stand of the Observatory equatorial, the telescope itself serving as a guide to the small corrections needed of the clockwork following motion during exposures lasting from half an hour to two hours and twenty minutes. A series of pictures resulted, one of which was exhibited by Dr. Gill in the course of his lecture at the Royal Institution, cited, from its importance to our present subject, among our authorities. They were remarkable, not only for the strength and fidelity with which their principal subject was represented, but for the accessory wealth of stars they displayed. The entire background was thickly strewn with them.

* Rayet, 'Bulletin Astronomique,' tome iv. p. 320.

Forty or fifty, down to the ninth magnitude, shone across the interposed film of the comet's tail.

The sight of the Cape photographs set the whole astronomical world upon the business of stellar chartography. They emphasised the advantages to be derived from the use of lenses of short focus and wide field, giving small, bright images of tolerably extensive sky-landscapes.* To Mr. Common they 'came as a revelation of the power of photo-'graphy' for star-charting purposes; and he proposed to Dr. Gould, then (in 1883) at Cordoba in South America, a joint photographic survey of the whole heavens, which it was not however found practicable just then to undertake. Investigations of relative stellar brightness by photographic means were almost simultaneously executed by Professor Pickering at Harvard and by Mr. Espin in Lancashire; and Mr. Roberts of Liverpool began, and has made considerable progress with, a detailed chart of northern stars.

But by far the most important of these preliminary enterprises was that of completing, in the southern hemisphere, the great northern star-census executed by Argelander at Bonn above a quarter of a century ago, and lately extended by Schönfeld to twenty degrees south of the equator. The 'Durchmusterung,' comprising in its two sections nearly 458,000 stars, may be described as the roll-call of the stellar army. Stars not entered in it have no official existence; should they fade and vanish, the fact cannot be attested: should they brighten into conspicuousness, we are obliged to regard them as 'new' for lack of previous acquaintanceship. Whatever is known of the distribution of the stars in space is founded on this grand enumeration, which was besides an essential prelude to more refined measurements.

A corresponding enrolment of southern stars was one of the most pressing needs of astronomy; and it is now, by novel means, in course of being supplied by Dr. Gill. His photographic 'Durchmusterung' will extend from the limit of Schönfeld's zones to the south pole, and will include all stars brighter and many fainter than the ninth magnitude. The requisite number of plates will probably have been secured in two or three years; while the Catalogue derived from their measurement, through the disinterested labours of Professor Kapteyn of Groningen, may be completed in

* Mr. De la Rue showed experimentally in 1861 that such instruments were the most proper for mapping the stars. 'Report Brit. Ass.' 1861, p. 95.

five or six. It will give the places (exact to one second of arc) and magnitudes of thirty per cent. more stars per square degree than are contained in the Bonn Catalogue, and will furnish 'working lists' for still more accurate determinations for about the epoch 1900.*

But we have not yet exhausted the results of the comet-pictures of 1882. Thirty-six years have elapsed since Chacornac began, at the Paris Observatory, the laborious task of charting ecliptical stars to the thirteenth magnitude. His object was the detection of asteroids, by obtaining an individual acquaintance with the small stars strewing their route in the sky; but he died in 1873, leaving the work only half finished. For its completion the resources of the newer astronomy had to be called into play.

His successors were MM. Paul and Prosper Henry, two brothers united by a rare community of tastes and endowments, inseparable in their labours, scarcely distinguishable by fame. In ten years they constructed sixteen additional maps out of a total of seventy-two; but they were arrested by encountering, where the ecliptic crosses the Milky Way, a throng of minute objects, totally unmanageable by the ordinary methods. The perplexity in which they found themselves was dissipated by a glance at the starry background of Dr. Gill's comet. They determined to have recourse to photography; their stars should henceforth register themselves. From that hour visual star-charting became a thing of the past.

The unmistakeable success of some preliminary experiments earned for their scheme the warm approval of Admiral Mouchez, Director of the Paris Observatory, the title of whose valuable little book heads this article; and the construction of the largest photographic telescope yet seen was officially sanctioned. In May, 1885, an instrument on a somewhat novel plan, the optical part by the MM. Henry, was mounted in the garden of Perrault's edifice. It consists of two telescopes, one adapted for chemical, the other for visual use, enclosed in a single rectangular tube. The photographic objective is of thirteen inches aperture and eleven feet focus, its curves being computed to enable it to take in a wide area of the sky without sensible deformation of the images. Their complete immobility in the field is secured by a skilful use of the guiding telescope. During the time

* Auwers, 'Monthly Notices,' vol. xlvii. p. 455.

of exposure the eye of the operator is never removed from it, and incipient deviations are checked by his hand.

The results of the employment of this apparatus by the MM. Henry were summed up by Admiral Mouchez before the Academy of Sciences, January 18, 1887.

'At the Paris Observatory,' he stated, 'we now easily obtain, with exposures of an hour, plates upon which thousands of stars down to the sixteenth magnitude are portrayed with the utmost nicety and distinctness over an area of six or seven square degrees. That is to say, the limit of visibility with our best telescopes under the sky of Paris is considerably overpassed, and we have even obtained many seventeenth magnitude stars doubtless never anywhere directly observed. The stellar images, varying in diameter proportionately to magnitude, afford useful data for photometric determinations.

'Objects other than stars, invisible in our most powerful instruments, sometimes appear on the plates. Such is the Maia nebula in the Pleiades, depicted like the tail of a brilliant little comet attached to the star, yet heretofore undetected, notwithstanding the exceptional amount of attention bestowed upon the Pleiades group. Unknown bodies, in sufficiently rapid movement to become sensibly displaced in an hour—minor planets, for instance, comets, the problematical trans-Neptunian planet, or undiscovered satellites—may reveal their existence by imprinting the line of their route among the fixed stars, as Pallas has been observed to do.

'The distinct visibility, on a photograph submitted to the Academy, of the interval of 0″·4 between the rings of Saturn, gives a prospect of securing impressions of double stars at that apparent distance. The satellite of Neptune has been photographed in every part of its orbit, even when it is only 8″ from the planet.*

'With the consideration before us that stars below the sixteenth magnitude have thus been photographed amid the turbid atmosphere of Paris, it becomes difficult to imagine the prodigious quantity of new objects which would be disclosed on the plates of the MM. Henry could they be exposed under the pure skies of the tropics, or at so favourable a station as the Pic du Midi. Stars of the eighteenth magnitude would then not improbably emerge to view, showing a penetration of the heavens to depths never before sounded. Such plates would doubtless, at a little distance, like the firmament itself in serene tropical nights, assume a uniformly nebulous aspect. We hope then to apply photography not only to the regular prosecution of celestial chartography, but to researches on double stars, and to explorations in search of unknown heavenly bodies.' †

Specimens of the Paris photographs were soon in the

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* No *visual* observations of Neptune's satellite have ever been made at Paris.

† Mouchez, 'La Photographie Astronomique,' p. 37.

, *La Photographie Astronomique à l'Observatoire de Paris et la Carte du Ciel. Par M le Contre-Amiral E. Mouchez. Paris: 1887* , Edinburgh Review, 167:341 (1888:Jan.) p.23

hands of astronomers in all parts of the world. They were received with admiration not unmixed with incredulity. They seemed too absolutely perfect to be wholly genuine. Abundant evidence was however at hand to show that their extraordinary precision was really the fruit of unparalleled skill, and this conviction, once attained, was decisive of the future of astronomy.

On one of the plates, covering an area of about four square degrees in the constellation Cygnus, where 170 stars had previously been identified, some 5,000 were clearly imprinted. Wolf's great map of the Pleiades, founded on laborious observations extending over several years, contains 671 stars; photographs taken in a few hours by the MM. Henry supplied materials for charting 1,421 stars of the same group down to the sixteenth magnitude with an exactitude unattainable by visual means. The significance of such results was not to be mistaken. They pointed to a great task, the execution of which was felt to be imperative so soon as it had become possible; and Dr. Gill gave expression to a universal sentiment when he proposed, June 4, 1886, an International Congress for the purpose of organising a photographic survey on a grand scale of the entire heavens.

Fifty-five delegates of fifteen different nationalities took part in the deliberations of the memorable assembly which met at Paris, April 16, 1887. They were concluded in nine days, and were as harmonious as they were prompt. Enthusiasm for a great end secured unanimity as to the means; differences of opinion vanished as if under the pressure of some supreme crisis. The upshot of the meetings was to set preparations on foot for the charting of over twenty millions of stars! So far have we got by the aid of photography.

The co-operation of ten or twelve observatories in both hemispheres can be reckoned upon, and the work will be executed upon an identical plan with instruments similar in every respect to that of the MM. Henry. About ten thousand plates (duplicated to avoid accidental errors), each exposed during a quarter of an hour, will record the positions of all the stars in the sky to the fourteenth magnitude—the prescribed limit of faintness. This part of the undertaking can scarcely occupy less than five years. For the orientation of each plate, a single 'star-trail' (necessarily running along a parallel of declination) will suffice. The *absolute* places of the imprinted stars will be deduced from accurate measurements of their situations relative to certain 'standard

, *La Photographie Astronomique à l'Observatoire de Paris et la Carte du Ciel. Par M le Contre-Amiral E. Mouchez. Paris: 1887* , Edinburgh Review, 167:341 (1888:Jan.) p.23

'stars,' of which a sufficient number will be found on every plate.

But there is to be a catalogue as well as a chart, and, in Dr. Gill's opinion, 'the work which astronomers of future 'generations will be most grateful for, and which will most 'powerfully conduce to the progress of astronomy, will *not* 'be the chart but the catalogue.' Plates showing fourteenth magnitude stars, however, are necessarily over-exposed for the brighter ones, and are hence not available for the most refined determinations. A set of short-exposure plates, reaching to the eleventh magnitude, are accordingly to be taken with a view to cataloguing about one million and a half stars to serve as reference-points for the twenty millions crowded on the chart plates. Such a catalogue (we again quote Dr. Gill) 'may be considered complete for the practical 'purposes of astronomy, because the eleventh magnitude is 'the faintest which can be measured with accuracy in the 'larger class of equatorials usually employed in working 'observatories.'

The mass of stellar statistics thus collected will include data as to relative brightness. The 'magnitudes' of stars can be derived from photographs either by comparing the size of their images on the same plate, or by measuring the time that elapses before they produce a sensible impression. Estimates founded on the circumstance that the diameters of the photographic discs of stars bear a strict ratio to their lustre have proved accurate (on an average) to one-fifth of a magnitude; and varying length of exposure affords the only fixed standard of brightness at present available for the minuter orders of stars. The photometric range of the eye is somewhat narrowly limited, and large errors attest its incompetence below the eleventh or twelfth magnitude. The sensitive plate, on the other hand, measuring light-intensity as it were by the clock, records its gradations between faint objects more precisely than between bright, because the corresponding intervals of time are larger. Stars of the first, second, and third magnitudes can all be photographed in a small fraction of a second; but stars of the thirteenth magnitude require five, of the fourteenth thirteen, of the sixteenth eighty minutes, before they become perceptible with the apparatus of the MM. Henry. Intermediate positions on the photometric scale can hence, it is obvious, be assigned much more easily and securely towards its lower end.

A star of any given order of lustre emits just two and a half times as much light as a star of the magnitude next

, La Photographie Astronomique à l'Observatoire de Paris et la Carte du Ciel. Par M le Contre-Amiral E. Mouchez. Paris: 1887 , Edinburgh Review, 167:341 (1888:Jan.) p.23

below. One of the sixteenth is accordingly a million times fainter than one of the first magnitude, and under identical conditions takes a million times longer to get photographed. This is the proper and only definite criterion of the rank of such feebly luminous objects, visual estimates of which are little better than guesswork.

It is true that colour exercises a disturbing influence owing to the predominant sensitiveness of silver salts to the more refrangible rays. Aldebaran, for instance, is reduced by the fiery tinge of its light to the fifth or sixth *chemical* rank; and small red stars are frequently missing from photographs which display crowds of objects equally or less bright to the eye. Such discrepancies, however, have an interest of their own, and they do not impair the general correspondence between visual and photographic evaluations of brightness. Nor, even when they differ, is there any valid reason for preferring the former to the latter. Both serve as means to the same ends; and chemical determinations are in so far at least to be preferred that they are authentic over a wider range.

Accurate comparisons of stellar brilliance serve two chief purposes—an individual, so to speak, and a general. Taken separately, they are a direct test of variability; taken together, and on an average, they are a safe guide to distribution.

The great problem of the constitution of the sidereal universe is not one to be solved by a stroke of genius. The generations of men are but as hours for its study; each contributes its little quota of gathered facts, and more or less ineffectual thoughts, and goes to its rest only a shade less ignorant than its predecessors. It was Herschel's great merit to have perceived that no reasoning on the subject could stand unless based on a solid substructure of statistics; and he even made the attempt by his 'gauges,' or counts of stars in various directions, to supply the needful data. But the information attainable by the labours of an individual was as nothing compared with what must be collected before profitable discussions could even begin. Now at last the requisite materials are, it would seem, about to be provided, and a long pause in the progress of knowledge may be compensated by a leap forward. When the photographic survey of the heavens is completed, conclusions of reasonable certainty on some fundamental points connected with the galactic structure will be within comparatively easy reach.

, *La Photographie Astronomique à l'Observatoire de Paris et la Carte du Ciel. Par M le Contre-Amiral E. Mouchez. Paris: 1887* , Edinburgh Review, 167:341 (1888:Jan.) p.23

The mere counting of the stars of various orders on the plates will show whether they give any signs of *thinning out.* Stars of any assigned brightness should, on the supposition of tolerably even scattering, be nearly four times as numerous as those one magnitude brighter. There should be more of them because they occupy a wider shell of space. Thus, a marked scarcity, local or general, of faint stars would afford evidence of an approach to the limits of the system; it would indicate a determinate boundary to the Milky Way.

It is practically certain that such a boundary must somewhere exist. Were the stars agglomerated in the Galaxy infinite in number, they should emit an infinite quantity of light; and (unless on the gratuitous assumption of its extinction in space) our skies should blaze with a uniform and unendurable lustre. But the sum-total of stellar radiations striking the earth is very small. It has been estimated at one-tenth of full moonlight; it is in reality probably much less. The grand aggregate number of stars, however, corresponding to that amount of light comes out, by a recent computation, at no less than *sixty-six milliards*, and the frontier line of the system constituted by them is drawn at the average distance of stars of the seventeenth magnitude.* All this is, of course, largely hypothetical, but it is a certain and a curious fact that we receive much more light from stars invisible than from those visible to the naked eye. All the lucid orbs might, in fact, be withdrawn without sensibly diminishing the general illumination of the sky.†

The concentration of stars towards the Milky Way appears, from the evidence of Schönfeld's zones, to be far less marked in the southern than in the northern hemisphere.‡ Photographic statistics will supply the means of deciding whether any such difference really exists. They will, moreover, test the truth of M. Celoria's interesting theory of a double Galaxy. The sidereal world is, in his view, composed of two rings of stars at widely different distances from us, one inclined at a considerable angle to and including the other, the sun being situated in the plane of neither and excentrically towards both. We shall see whether the twenty millions about to be charted conform to this plan.

The movements of the stars, as tending to reveal the laws governing the stellar commonwealth, are of even higher interest than their distribution; but we are still very much

* Hermite, 'L'Astronomie,' tome v. p. 412. † Ibid. p. 409.

‡ Seeliger, 'Sitzungsberichte,' Heft ii. p. 228. Munich: 1886.

in the dark about them. The impending photographic survey will be a preparatory measure for acquiring extended knowledge on the subject. About the year 2000 A.D. the seed planted in our time will have begun to bear fruit. A fresh determination of their places for that epoch will reveal the amount and direction of their changes in the interim. Something of the meaning of those changes can then hardly fail to become legible. Stars associated by a general 'drift' can be marshalled into systems; others in specially rapid motion —the so-called 'flying' or 'runaway' stars—will show their common peculiarities; an inkling of the purpose of the sun's mysterious journey through space may be gained, and its rate and aim, in any case, ascertained; his companions on the voyage may even be picked out. The motion-harmonies of the Cosmos will begin to sound intelligibly in the ears of humanity.

But present as well as prospective results may be looked for from the contemplated star-enrolment. Its progress must inevitably be attended by interesting disclosures. Now a new asteroid will stamp its light-track on a plate, or a remote giant planet will be distinguished by disappearance from or intrusion into a duplicate record; a comet approaching the sun will announce itself from afar; stars will show unsuspected nebulous appendages; others, too faint for visual separation, will spontaneously divide on the chemical retina.

Our readers can now to some extent appreciate the importance of securing a trustworthy picture of the sky for a given epoch. But this was not the sole care of the astronomers assembled at Paris. The miscellaneous applications of photography also engaged their attention; and by appointing M. Janssen and Mr. Common as a permanent committee for the purpose of studying and promoting them, they made sure, in this direction also, of rapid progress.

Mr. Common's well-known photograph of the great nebula in Orion, taken at Ealing, January 30, 1883, not only superseded all previously existing delineations of that strange object, but virtually prohibited any such being attempted in future. Changes in its condition, it was made plain, must thenceforward be investigated by a comparison of photographs taken at various dates. No living astronomer has devoted more care to its telescopic study than Professor E. S. Holden, now director of the Lick Observatory. Yet he frankly admits that 'every important result reached' by an assiduous scrutiny of four years with the Washington twenty-

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six-inch equatorial, 'and very many not comprised in it, 'were attained by Mr. Common's photograph, which required 'an exposure of forty minutes only.' *

Since about seven thousand nebulæ are now known, the field of research thus entered upon is sufficiently wide. And its cultivation must be largely disinterested. Time, for the most part, will be needed to ripen its results. Some centuries hence, for example, the examination of a 'vitrified' picture of a spiral nebula dating, say, from 1890, may reveal alterations of form decisive on some leading points connected with the genesis of worlds.† Posterity will not, however, alone reap the benefit of such labours. Some first-fruits have been already gathered. A photograph by Mr. Common of the central portion of the Andromeda nebula showed that the star which blazed out near the nucleus in August, 1885, had no visible existence a year earlier. It was *not*, then, developed by some sudden catastrophe out of one of the minute stellar points powdering the surface of the nebula, but was 'new' in the relative sense in which alone we can safely use the term.

The discovery of the nebulous condition of the Pleiades, again, has been an almost startling illustration of what may be learnt by sheer perseverance in exposing sensitive plates to the sky. Nearly thirty years ago M. Tempel, an exceptionally acute observer, detected a filmy veil thrown round and floating far back from the bright star Merope; and Mr. Common *saw*, with his three-foot reflector, February 8, 1880, some additional misty patches in the same neighbourhood. In general, however, the keen lustre of the grouped stars appeared relieved against perfectly dark space.

Great then was the surprise of the MM. Henry on perceiving a little spiral nebula clinging round the star Maia, on a plate exposed during three hours, November 16, 1885. The light of this remarkable object possesses far more chemical than visual intensity. Were its analysis possible, it would hence doubtless prove to contain an unusually large proportion of ultra-violet rays. It is of such evanescent faintness that its direct detection was highly improbable; but since it has been known to exist, careful looking has brought it into view with several large telescopes. It was first visually observed on February 5, 1886, with the new Pulkowa refractor of thirty inches aperture, and M. Kammer-

* Photography the Servant of Astronomy, p. 10.

† Mouchez, op. cit. p. 61.

mann, by using a fluorescent eye-piece, contrived to get a sight of it with the ten-inch of the Geneva Observatory.

The further prosecution of the inquiry is due to Mr. Roberts of Liverpool. With his twenty-inch reflector he obtained, on October 24, 1886, a picture of the Pleiades that can only be described as astounding. The whole group is shown by it as involved in one vast nebulous formation.* 'Streamers and fleecy masses' extend from star to star. Nebulæ in wings and trains, nebulæ in patches, wisps, and streaks, seem to fill the system, as clouds choke a mountain valley, and blend together the over-exposed blotches which represent the action of stellar rays. What processes of nature may be indicated by these unexpected appearances we do not yet know; but the upshot of a recent investigation† leads us to suppose them connected with the presence of copious meteoric supplies, and their infalls upon the associated stars.

The mechanical condition of globular clusters of stars offers a problem of extraordinary interest and complexity. It can, however, be usefully studied only by the aid of photography. Take as an example the marvellous agglomeration in the constellation Hercules. The many thousands of stars composing it run together towards the centre, into one unbroken blaze, utterly defying measurement of every kind; while the outlying 'grains of bright dust' bewilder the eye so as to incapacitate it for methodical operations.‡ But from the Paris plates all such separate stars can and will be perfectly well mapped and catalogued. Dr. O. Lohse has since 1884 been working at Potsdam with signal success in the same department; and thus data are being stored up for the future detection of interstitial movements in these complex systems. They must, in general, be extremely minute; and a star in the cluster No. 1440, shown as markedly displaced in eighteen years by a comparison of M. Von Gothard's photographs with Vogel's micrometric measures,§ will most likely prove to be accidentally projected *upon* the cluster, and not to form part of it.

Doubts as to the superiority of the photographic method of measurement for double stars can only arise where the components are considerably unequal. In this case the

* Monthly Notices, vol. xlvii. p. 24.

† Described by Mr. Norman Lockyer, before the Royal Society, November 17, 1887.

‡ Mouchez, op. cit. p. 54. § Astr. Nachrichten, No. 2777.

, *La Photographie Astronomique à l'Observatoire de Paris et la Carte du Ciel. Par M le Contre-Amiral E. Mouchez. Paris: 1887* , Edinburgh Review, 167:341 (1888:Jan.) p.23

brighter star, necessarily over-exposed, gives an indistinct and distended image ill suited for precise determinations. The same difficulty impedes photographic operations for ascertaining the parallaxes of large stars. Professor Pritchard has, however, shown conclusively by his successful measures of 61 Cygni that this most exacting problem of stellar astronomy lies for the most part well within the competence of the camera. Its prerogatives in the matter are obvious, and the result of its employment will infallibly be a rapid multiplication of the stars at known distances from our system.

We are far from having reckoned up all the tasks of astronomical photography. They become every year more numerous; their scope widens as we contemplate it, while that of eye-observations dwindles proportionately. Even transits, it appears, can now be taken with increased accuracy on the sensitive plate. It is indeed difficult to set bounds to the revolution in progress by which all the practical methods of celestial science are being swiftly and irresistibly transformed.

The tendency of the camera to usurp the functions of the eye is nowhere more apparent than in the study of stellar spectra. When Dr. Huggins laid before the Royal Society, December 6, 1876, a little print of the spectrum of Vega,* only a prophetic imagination could have anticipated that, within ten short years, so vast a developement would be given to the subject. After the lapse of three years, the same eminent investigator communicated his discovery of the complete ultra-violet spectrum of hydrogen as depicted, dark by absorption, in the analysed light of Vega and other white stars. This rhythmical series of vibrations, repeated, in varied terms, in the spectra of some metals,† may yet serve as a clue out of the labyrinth of speculation regarding the molecular constitution of matter. None of its nine invisible members occur in ordinary sunlight; but they appeared in a photograph of the spectrum of a prominence taken by Dr. Schuster during the total eclipse of 1882. Their presence would seem to be conditional upon a high state of excitement by heat of the hydrogen atoms emitting them; and their strong reversal in the spectra of Sirius, Vega, and their congeners almost compels the belief that the photospheres

* The first photograph of a star-spectrum showing lines was obtained by Dr. Draper in 1872.

† Cornu, 'Journal de Physique,' Mars, 1886.

of such stars are more intensely incandescent than that of our sun.

The work to which Dr. Henry Draper devoted his chief energies during the later years of his life was that of stellar spectroscopic photography; and it is now being prosecuted at Harvard College as a memorial to him, and with funds and instruments provided by his widow. 'The attempt will 'be made to include all portions of the subject, so that the 'final results shall form a complete discussion of the con- 'stitution and condition of the stars, as revealed by their 'spectra, so far as present scientific methods permit.' * There can be little doubt that, under Professor Pickering's direction, this 'attempt' will be successful. Already superb specimens of photographed spectra have been distributed, obtained by methods so expeditious as to enable stars by the score together to stamp the characters of their analysed light on the same plate. And in sidereal astronomy, the subject-matter of which is all but infinite, the quantity of information collected in a given time is nearly as important as its quality. Hence large expectations from the Harvard researches are justly entertained.

The spectroscope supplies information not only about the physical constitution, but about the movements of the stars; and it is safe to say that its messages on this head will henceforth be read almost exclusively by photographic means. The acquisition of power to determine, by the displacement of known lines in its spectrum, whether a heavenly body is moving towards or from the eye, and at what rate, is one of the most considerable of recent additions to the resources of astronomy. Its use as regards the stars, however, has hitherto been hampered by grave difficulties of observation. Small deviations of delicate lines kept continually thrilling and shivering by air-tremors can be but insecurely registered. But on such photographs as Professor Pickering's (once provided with a standard of wave-length) the readings will be sure and easy.

Here we find the natural meeting-place of the old and the new astronomies. Spectroscopy and photography here directly lend themselves to dynamical inquiries, and so help to found the future science of sidereal mechanics. They combine to measure movements otherwise wholly imperceptible. More complete data as to the mutual relations of the stars are thus afforded, and means provided for determining the rate

* Draper Memorial, First Report, p. 3.

of translation of the solar system by contrasting stellar rates of approach or recession in opposite quarters of the sky. Stars sensibly exempt from visual displacement because the whole of their motion is 'end-on' can be discriminated from stars really almost immoveable relative to the sun, because associated with it in a journey towards the same bourne in space. The members of the stellar group to which the sun belongs can in this way be identified, and some insight gained into its structure. And all this in the immediate future. For spectroscopic determinations of movement are complete in themselves. They evade the necessity for exact comparisons after the lapse of tedious years or centuries. They tell us at once *what is.*

Astronomical photography includes tasks of all kinds and suited to every capacity. The Baconian principle of the division of scientific labour will by it be brought into full play. One division of workers will devote themselves to the exposure and developement of plates, another to their measurement. It may even happen that the first set of operations will be conducted in a different part of the globe from the second, as the Cape photographs are now in course of measurement at Groningen, and the Cordoba photographs at Boston. The same negatives may be studied by one astronomer in search of new members of the solar system; by another, for the purpose of detecting displacements due to annual parallax or proper motion; by a third, with a view to eliciting facts relative to stellar distribution; by a fourth, for the sake of information latent in them as to stellar variability. In each branch of sidereal astronomy photographic experts will arise skilled in developing the special conditions favourable to success in a special direction. The picturing of nebulæ is a totally different art from stellar chartography; double stars require modes of treatment not applicable to clusters; impressions for photometric purposes would be wholly useless for measuring displacements; the obstacles met in depicting stellar spectra are of another order than those which impede the photographic sounding of space.

Several magnificent instruments will shortly be available for photographic use. A 'bent equatorial,' twenty-nine and a half inches in aperture, in preparation at Paris, will offer particular advantages for lunar and planetary work from the extremely long focus (fifty-nine feet) which its peculiar form enables it to receive. The Lick object-glass will collect nine times as much light as any actually existing photographic telescope.

'A single exposure,' Professor Holden remarks,* 'will give us a map of the sky comprising four square degrees on a plate twenty-four by twenty-four inches. A few minutes will impress on this plate a permanent record of the position and brightness of all the stars visible in even the largest telescopes. A comparison of two such plates, taken on different nights, will point out any changes which might easily escape the most minute observation by other methods. The sun's image unmagnified will be six inches in diameter; a large sunspot will be the size of one's finger-nail. Beautiful photographs of the planets can be taken so as to register with perfect accuracy the features of their surfaces. Comets and nebulæ can be studied at leisure from their automatic registers, as one studies a copperplate engraving. The variations of refraction from the horizon to the zenith can be made to record themselves for measurement. There is absolutely no end to the problems lying close at hand, and their number and their importance will develope with time. We are merely at the threshold of this subject.'

But even the Lick refractor will be beaten out of the field, as regards luminous capacity, by the five-foot silver-on-glass reflector which Mr. Common is now personally engaged in constructing. Twice as many rays as the other transmits will be concentrated by it, and its other qualities, unless they belie expectation, will correspond to its power. Unfortunately, however, there is another large factor in the account. A bad climate cripples the use of the most perfect instrument. Its size renders it only the more sensitive to atmospheric troubles. And Ealing is half submerged by the fogs of London, while Mount Hamilton, as an observing site, has no known rival in the world.

We have said enough to show that a new and hopeful era is opening for astronomy. It is greeted on all sides with the enthusiasm which the dawning of large possibilities never fails to evoke. The time-honoured problem of 'how the 'heavens move' presents itself under a novel aspect. Novel implements of research are being zealously adapted to its requirements. The shrinkage of films, the vitrification of negatives, the distension of photographic star-discs, devices for modifying the qualities of salts of silver, are being studied with the same patient ardour that Bessel brought to determinations of 'collimation-errors' or 'personal equation.' There is no longer a 'new' and an 'old' astronomy. The two are fused into one, to the enormous advantage of both. It seems hardly possible to be over-sanguine as to the results.

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* Photography the Servant of Astronomy, p. 10.