I & I News

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In *I&I News* New Series No. 7 (10 July 2012) I included an article on William Huggins' twin equatorial – the first of four manufactured by Grubb – and some of his spectroscopic apparatus. These were used in his endeavours of later years, when he was well known as a leading astrophysicist; but his reputation had been established many years earlier. On 29 August 1864 – exactly 150 years ago – he solved 'the riddle of the nebulae'. This was a time when stellar spectroscopy was in its infancy and was entirely visual, and when instrumentation for this type of work had to be newly designed and constructed. Nowadays, of course, spectroscopic equipment is much more readily available. Therefore, I hope that the present article provides inspiration, and I would be pleased to receive spectroscopic observations of the Cat's Eye nebula (which should also be sent to the Director of the Deep Sky Section) and details of the instruments and methods by which they were acquired.

Bob Marriott, *Director*

William Huggins and the Cat's Eye nebula

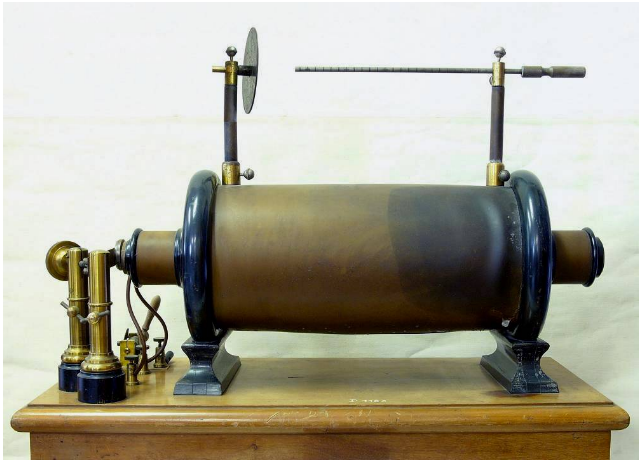
Bob Marriott

William Huggins set up his first observatory, equipped with a 5-inch Dollond refractor, in 1856, and two years later he acquired an 8-inch Alvan Clark object-glass, with a mount and drive supplied by Thomas Cooke. Eventually, however, routine observation dulled his interest, and in 1862 he began work in collaboration with William Allen Miller, Professor of Chemistry at King's College, London, in comparing spectra of chemical elements with stellar spectra. This work required newly designed spectroscopic apparatus, and the utilisation of an induction coil (transformer), a Leyden jar (capacitor), and a Smee battery for the production of sparks to generate comparison spectra.

On 29 August 1864, Huggins turned his spectroscope to the planetary nebula 37 H. IV (catalogued later as NGC 6543) – the Cat's Eye nebula, in Draco. On obtaining a single bright line and two fainter lines he realised that the light was monochromatic: the spectrum of a luminous gas, and not of unresolved stars. This was the first time that a spectrum of a nebula had been obtained – an observation confirmed by the spectra of several other nebulae acquired subsequently.

Thirty-three years later, Huggins wrote: 'The light of the nebula was monochromatic, and so, unlike any other light I had as yet subjected to prismatic examination, could not be extended out to form a complete spectrum ... The riddle of the nebulae was solved. The answer, which had come to us in the light itself, read: Not an aggregation of stars, but a luminous gas ... There remained no room for doubt that the nebulae ... are the early stages of long processions of cosmical events, which correspond broadly to those required by the nebular hypothesis in one or other of its forms.' (*Nineteenth Century Review*, 41 (1897), pp. 916–17.)

The following extracts from two of Huggins' papers describe the equipment and observational techniques that led to this epochal discovery.



An induction coil: a later model dating from *c.*1900.

A Leyden jar.

A Smee battery. (Photograph: National Museums Scotland.)

Director: Bob Marriott | ram@hamal.demon.co.uk | 01604 765190 | http://britastro.org/iandi

On the spectra of some of the fixed stars

William Huggins and William Allen Miller

Philosophical Transactions of the Royal Society, 154 (1864), 413–35 (extract, 413–17).

The recent discovery by Kirchhoff of the connexion between the dark lines of the solar spectrum and the bright lines of terrestrial flames, so remarkable for the wide range of its application, has placed in the hands of the experimentalist a method of analysis which is not rendered less certain by the distance of the objects the light of which is to be subjected to examination. The great success of this method of analysis as applied by Kirchhoff to the determination of the nature of some of the constituents of the Sun, rendered it obvious that it would be an investigation of the highest interest, in its relations to our knowledge of the general plan and structure of the visible universe, to endeavour to apply this new method of analysis to the light which reaches the earth from the fixed stars.

The investigation of the nature of the fixed stars by a prismatic analysis of the light which comes to us from them is surrounded with no ordinary difficulties. The light of the bright stars, even when concentrated by an object-glass or speculum, is found to become feeble when subjected to the large amount of dispersion which is necessary to give certainty and value to the comparison of the dark lines of the stellar spectra with the bright lines of terrestrial matter. Another difficulty, greater because it is in its effect upon observation more injurious, and is altogether beyond the control of the experimentalist, presents itself in the ever-changing want of homogeneity of the earth's atmosphere, through which the stellar light has to pass. This source of difficulty presses very heavily upon observers who have to work in a climate so unfavourable in this respect as our own. On any but the finest nights the numerous and closely approximated fine lines of the stellar spectra are seen so fitfully that no observations of value can be made. It is from this cause especially that we have found the inquiry, in which for more than two years and a quarter we have been engaged, more than usually toilsome; and indeed it has demanded a sacrifice of time very great when compared with the amount of information which we have been enabled to obtain.

Previously to January 1862, in which month we commenced these experiments, no results of any investigation undertaken with a similar purpose had been published. Fraunhofer recognised the solar lines D, E, *b*, and F in the spectra of the Moon, Venus, and Mars; he also found the line D in Capella, Betelgeux, Procyon, and Pollux; in the two former he also mentions the presence of *b*. Castor and Sirius exhibited other lines. Donati's elaborate paper contains observations upon fifteen stars; but in no case has he given the positions of more than three or four bars, and the positions which he ascribes to the lines of the different spectra relatively to the solar spectrum do not accord with the results obtained either by Fraunhofer or by ourselves.

Early in 1862 we had succeeded in arranging a form of apparatus in which a few of the stronger lines in some of the brighter stars could be seen. The remeasuring of those already described by Fraunhofer and Donati, and even the determining the positions of a few similar lines in other stars, however, would have been of little value for our special object, which was to ascertain, if possible, the constituent elements of the different stars. We therefore devoted considerable time and attention to the perfecting of an apparatus which should possess sufficient dispersive and defining power to resolve such lines as D and *b* of the solar spectrum. Such an instrument would bring out the finer lines of the spectra of the stars, if in this respect they resembled the Sun. It was necessary for our purpose that the apparatus should further be adapted to give accurate measures of the lines which should be observed, and that it should also be so constructed as to permit the spectra of the chemical elements to be observed in the instrument simultaneously with the spectra of the stars. In addition to this, it was needful that these two spectra should occupy such a position relatively to each other, as to enable the observer to determine with certainty the coincidence or non-coincidence of the bright lines of the elements with the dark lines in the light from the star. Before the end of the year 1862 we had succeeded in constructing an apparatus which fulfilled part of these conditions. With this, some of the lines of the spectra of Aldebaran, α Orionis, and Sirius were measured; and from these measures, diagrams of these stars, in greater detail than had then been published, were laid before the Royal Society in February 1863. Since the date at which our note was sent to the Royal Society our apparatus has been much improved, and in its present form of construction it fulfils satisfactorily several of the conditions required.

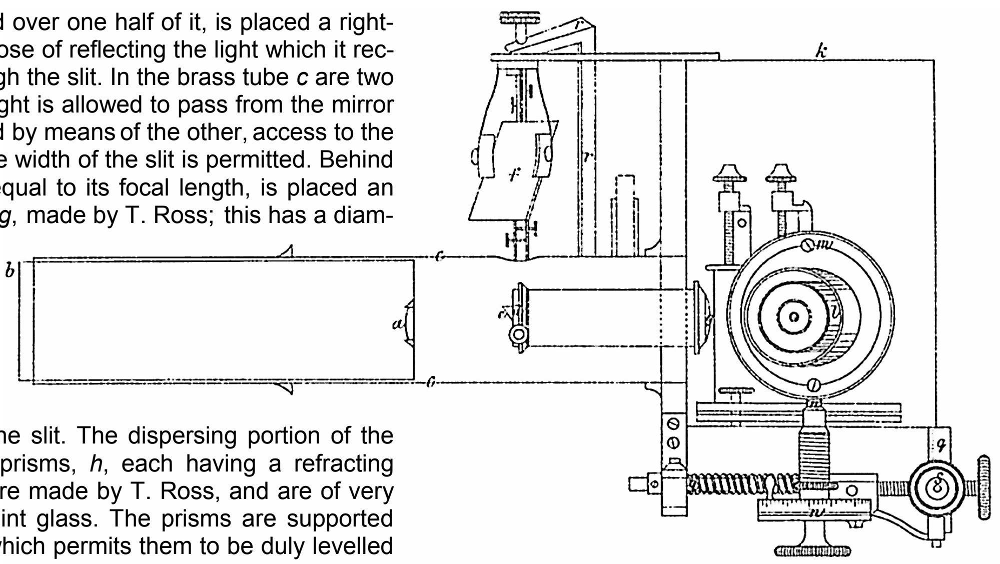
The specially constructed spectrum apparatus is attached to the eye end of a refracting telescope of 8 inches aperture and 10 feet focal length. The object-glass is a very fine one, by Alvan Clark of Cambridge, Massachusetts; the equatorial mounting is by Cooke of York; and the telescope is carried very smoothly by a clock motion.

As the linear spectrum of the point of light which a star forms at the focus of the object-glass is too narrow for the observation of the dark lines, it becomes necessary to spread out the image of the star; and to prevent loss of light, it is of importance that this enlargement should be in one direction only; so that the whole of the light received by the object-glass should be concentrated into a fine line of light as narrow as possible, and having a length not greater than will correspond to the breadth of the spectrum (when viewed in the apparatus) just sufficient to enable the eye to distinguish with ease the dark lines by which it may be crossed. No arrangement tried by us has been found more suitable to effect this enlargement in one direction than a cylindrical lens, which was first employed for this purpose by Fraunhofer.

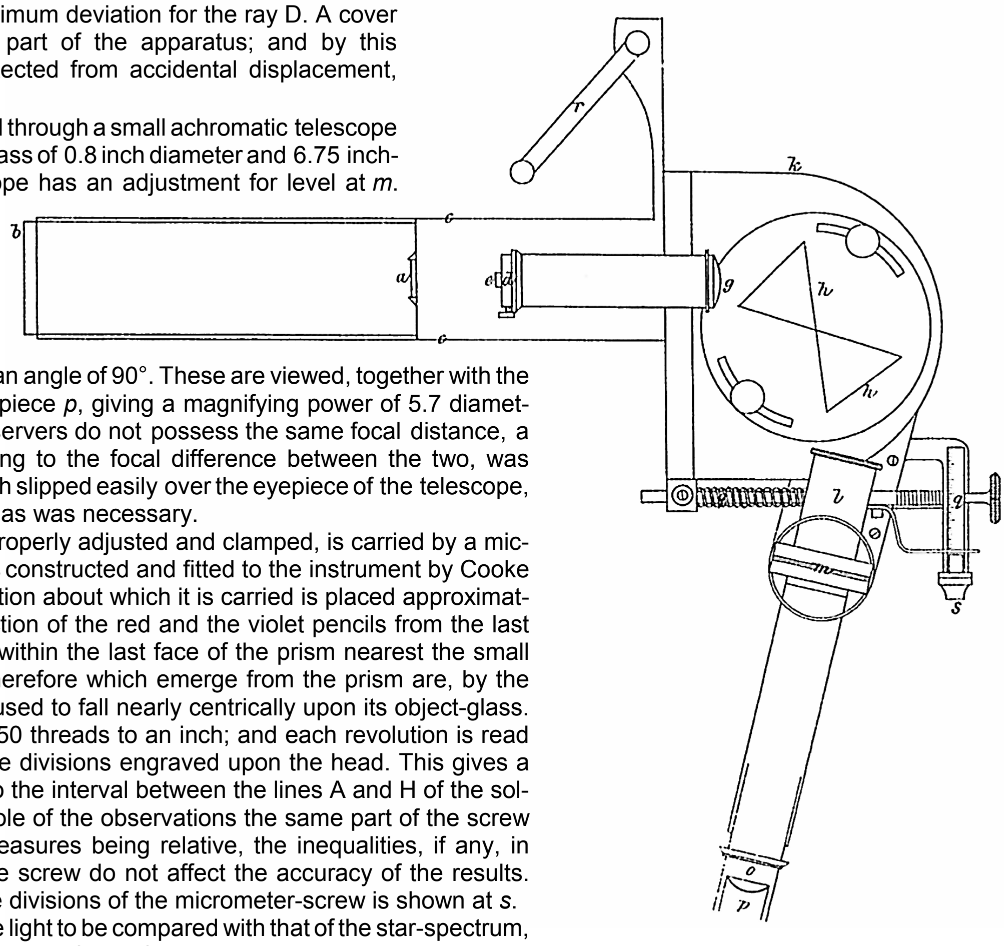
The present form of the apparatus is represented in [the diagrams], where the cylindrical lens is marked *a*. This is plano-convex, an inch square, and of about 14 inches focal length. The lens is mounted in an inner tube *b*, sliding within the tube *c*, by which the apparatus is adapted to the eye end of the telescope. The axial direction of the cylindrical surface is placed at right angles to the slit *d*, and the distance of the lens from the slit within the converging pencils from the object-glass is such as to give exactly the necessary breadth to the spectrum.

In consequence of the object-glass being over-corrected, the red and, especially, the violet pencils are less spread out than the pencils of intermediate refrangibility; so that the spectrum, instead of having a uniform breadth, becomes slightly narrower at the red end, and tapers off in a greater degree towards the more refrangible extremity. The experiment was made of so placing the cylindrical lens that the axial direction of its convex cylindrical surface should be parallel with the direction of the slit. The line of light is in this case formed by the lens; and the length of this line, corresponding to the visible breadth of the spectrum, is equal to the diameter of the cone of rays from the object-glass where they fall upon the slit. With this arrangement, the spectrum appears to be spread out, in place of being contracted at the two extremities. Owing to the large amount of dispersion to which the light is subjected, it was judged unadvisable to weaken still further the already feeble illumination of the extremities of the spectrum; and in the examination of the stellar spectra the position of the cylindrical lens with its axis at right angles to the slit was therefore adopted. A plano-concave cylindrical lens of about 14 inches negative focal length was also tried. The slight advantage which this possesses over the convex form is more than balanced by the inconvenience of the increased length given to the whole apparatus.

In front of the slit *d*, and over one half of it, is placed a right-angled prism *e*, for the purpose of reflecting the light which it receives from the mirror *f* through the slit. In the brass tube *c* are two holes: by one of these the light is allowed to pass from the mirror to the reflecting-prism *e*; and by means of the other, access to the milled head for regulating the width of the slit is permitted. Behind the slit, and at a distance equal to its focal length, is placed an achromatic collimating lens *g*, made by T. Ross; this has a diameter of 0.6 inch and a focal length of 4½ inches. These proportions are such that the lens receives the whole of the light which diverges from the linear image of the star when this is brought exactly within the jaws of the slit. The dispersing portion of the apparatus consists of two prisms, *h*, each having a refracting angle of about 60°; they were made by T. Ross, and are of very dense and homogeneous flint glass. The prisms are supported upon a suitable mounting, which permits them to be duly levelled and adjusted. Since the feebleness of the light from the stars limits the observations for the most part to the central and more luminous portions of the spectrum, the prisms have been adjusted to the angle of minimum deviation for the ray D. A cover of brass, *k*, encloses this part of the apparatus; and by this means the prisms are protected from accidental displacement, and from dust.



The spectrum is viewed through a small achromatic telescope *l*, furnished with an object-glass of 0.8 inch diameter and 6.75 inches focal length. This telescope has an adjustment for level at *m*. The axis of the telescope can be lowered and raised, and the tube can be also rotated around the vertical axis of support at *n*. At the focus of the object-glass are fixed two wires, crossing at an angle of 90°. These are viewed, together with the spectrum, by a positive eyepiece *p*, giving a magnifying power of 5.7 diameters. As the eyes of two observers do not possess the same focal distance, a spectacle-lens, corresponding to the focal difference between the two, was fitted into a brass tube, which slipped easily over the eyepiece of the telescope, and was used or withdrawn as was necessary.



This telescope, when properly adjusted and clamped, is carried by a micrometer-screw *q*, which was constructed and fitted to the instrument by Cooke and Sons. The centre of motion about which it is carried is placed approximatively at the point of intersection of the red and the violet pencils from the last prism; consequently it falls within the last face of the prism nearest the small telescope. All the pencils therefore which emerge from the prism are, by the motion of the telescope, caused to fall nearly centrically upon its object-glass. The micrometer screw has 50 threads to an inch; and each revolution is read to the hundredth part, by the divisions engraved upon the head. This gives a scale of about 1,800 parts to the interval between the lines A and H of the solar spectrum. During the whole of the observations the same part of the screw has been used; and the measures being relative, the inequalities, if any, in the thread of this part of the screw do not affect the accuracy of the results. The eye lens for reading the divisions of the micrometer-screw is shown at *s*.

The mirror *f* receives the light to be compared with that of the star-spectrum, and reflects it upon the prism *e*, in front of the slit *d*. This light was usually obtained from the induction spark taken between electrodes of different metals, fragments or wires of which were held by a pair of small forceps attached to the insulating ebonite clamp *r*. Upon a moveable stand in the observatory was placed the induction coil, in the secondary circuit of which was inserted a Leyden jar, having 140 square inches of tinfoil upon each of its surfaces. The exciting battery, which, for the convenience of being always available, consisted of four cells of Smee's construction, with plates 6 inches by 3, was placed without the observatory. Wires, in connexion with this and the coil, were so arranged that the observer could make and break contact at pleasure without removing his eye from the small telescope. This was the more important since, by tilting the mirror *f*, it is possible, within narrow limits, to alter the position of the spectrum of the metal relatively to that of the star. An arrangement is thus obtained which enables the observer to be assured of the perfect correspondence in relative position in the instrument of the stellar spectrum and the spectrum to be compared with it. The satisfactory performance of this apparatus is proved by the very considerable dispersion and admirably sharp definition of the known lines in the spectra of the Sun and metallic vapours. When it is directed to the Sun, the line D is sufficiently divided to permit the line within it, marked in Kirchhoff's map as coincident with nickel, to be seen. The close groups of the metallic spectra are also well resolved.

On the spectra of some of the nebulae

William Huggins

Philosophical Transactions of the Royal Society,
154 (1864), 437–44 (extracts, 438 and 442–3).

A supplement to the paper 'On the spectra of some of the fixed stars'.

37 H. IV, RA 17h 58m 20s, NPD 23° 22' 9".5. A planetary nebula; very bright; pretty small; suddenly brighter in the middle, very small nucleus. In Draco.

On August 29, 1864, I directed the telescope armed with the spectrum apparatus to this nebula. At first I suspected some derangement of the instrument had taken place; for no spectrum was seen, but only a short line of light perpendicular to the direction of dispersion. I then found that the light of this nebula, unlike any other ex-terrestrial light which had yet been subjected by me to prismatic analysis, was not composed of light of different refrangibilities, and therefore could not form a spectrum. A great part of the light from this nebula is monochromatic, and after passing through the prisms remains concentrated in a bright line occupying in the instrument the position of that part of the spectrum to which its light corresponds in refrangibility. A more careful examination with a narrower slit, however, showed that, a little more refrangible than the bright line, and separated from it by a dark interval, a narrower and much fainter line occurs. Beyond this, again, at about three times the distance of the second line, a third, exceedingly faint line was seen. The positions of these lines in the spectrum were determined by a simultaneous comparison of them in the instrument with the spectrum of the induction spark taken between electrodes of magnesium. The strongest line coincides in position with the brightest of the air lines. This line is due to nitrogen, and occurs in the spectrum about midway between *b* and F of the solar spectrum.

The faintest of the lines of the nebula agrees in position with the line of hydrogen corresponding to Fraunhofer's F. The other bright line was compared with the strong line of barium 2075: this line is a little more refrangible than that belonging to the nebula.

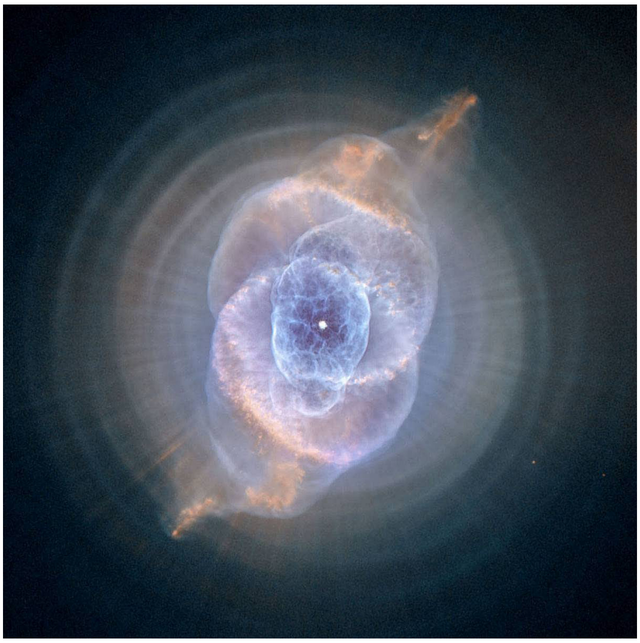
Besides these lines, an exceedingly faint spectrum was just perceived for a short distance on both sides of the group of bright lines. I suspect this is not uniform, but is crossed with dark spaces. Subsequent observations on other nebulae induce me to regard this faint spectrum as due to the solid or liquid matter of the nucleus, and as quite distinct from the bright lines into which nearly the whole of the light from the nebula is concentrated.

It is obvious that the nebulae 37 H. IV, 6Σ, 73 H. IV, 1 H. IV, 57 M, 18 H. IV, and 27 M can no longer be regarded as aggregations of suns after the order to which our own Sun and the fixed stars belong. We have in these objects to do no longer with a special modification only of our own type of suns, but find ourselves in the presence of objects possessing a distinct and peculiar plan of structure.

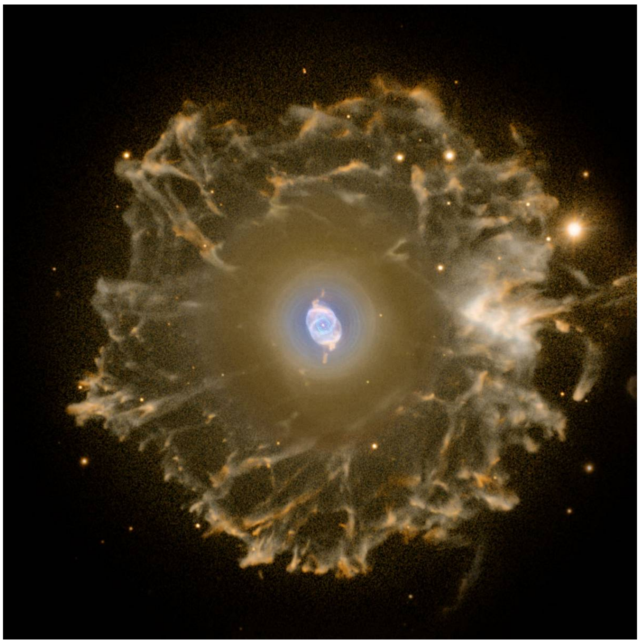
In place of an incandescent solid or liquid body transmitting light of all refrangibilities through an atmosphere which intercepts by absorption a certain number of them, such as our Sun appears to be, we must probably regard these objects, or at least their photo-surfaces, as enormous masses of luminous gas or vapour. For it is alone from matter in the gaseous state that light consisting of certain definite refrangibilities only, as is the case with the light of these nebulae, is known to be emitted.

It is indeed possible that suns endowed with these peculiar conditions of luminosity may exist, and that these bodies are clusters of such suns. There are, however, some considerations, especially in the case of the planetary nebulae, which are scarcely in accordance with the opinion that they are clusters of stars. Sir John Herschel remarks of one of this class, in reference to the absence of central condensation: 'Such an appearance would not be presented by a globular space uniformly filled with stars or luminous matter, which structure would necessarily give rise to an apparent increase of brightness towards the centre in proportion to the thickness traversed by the visual ray. We might therefore be inclined to conclude its real constitution to be either that of a hollow spherical shell or of a flat disk presented to us (by a highly improbable coincidence) in a plane precisely perpendicular to the visual ray.'

This absence of condensation admits of explanation, without recourse to the supposition of a shell or of a flat disk, if we consider them to be masses of glowing gas. For supposing, as we probably must do, that the whole mass of the gas is luminous, yet it would follow, by the law which results from the investigations of Kirchhoff, that the light emitted by the portions of gas beyond the surface visible to us, would be in great measure, if not wholly, absorbed by the portion of gas through which it would have to pass, and for this reason there would be presented to us a *luminous surface* only.

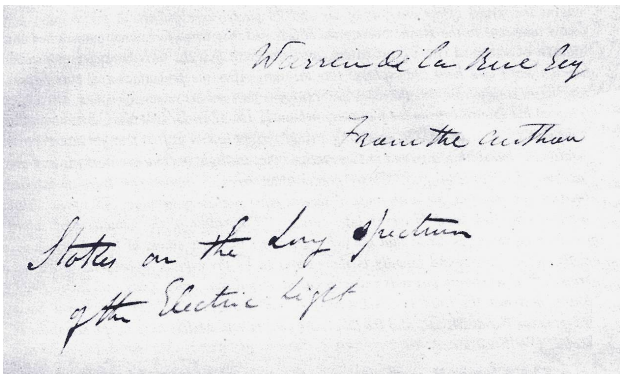


Credit: NASA, ESA, HEIC, and The Hubble Heritage Team (STScI/AURA).



Credit: Nordic Optical Telescope and Romano Corradi.

William Huggins, 1824–1910. (© Royal Astronomical Society.)



George Gabriel Stokes' inscription on a presentation copy of his 'On the long spectrum of electric light' (1862), with the title inscribed by Warren de la Rue, (bound with) inscribed copies of Thomas Romney Robinson's 'On spectra of electric light' (1862) and Huggins' 'On the spectra of some of the chemical elements' (1864) presented to de la Rue, and Huggins and Miller's 'On the spectra of some of the fixed stars' (1864) and Huggins' 'On the spectra of some of the nebulae' (1864) presented to Admiral W. H. Smyth. (Author's collection.)