Art. III.—On the Visibility of Venus to the Naked Eye.—By Principal A. Cameron, Yarmouth.

(Read May 9th, 1892.)

Astronomers tell us that Venus is always visible through the telescope. Not always from any one station on the earth's surface, because of course she cannot be seen when below the horizon; but always from somewhere on the earth, and always from any given place while she is above the horizon of that place and in a clear sky. When these two conditions are satisfied the telescope will show Venus whether the time be noon or night and whether the planet be at greatest elongation or at either conjunction—barring only those rare occasions when she passes directly behind the sun at superior conjunction.

So, if one has a telescope, he may see Venus every day in the year,—weather permitting of course, which is a very important practical consideration and must always be so in such matters until our meteorologists get the whip hand of the weather fiend and make him keep his clouds out of the way. If, however, one has no telescope, nor any other optical instrument except the naked eye, on how many days of the year may he see Venus? This is a question which every star-gazer finds himself asking at times; and closely connected with it is this other one,—When and for how long a period can Venus be seen in the day time with the naked eye?

These questions form the subject of this paper, which may be described as a contribution towards procuring answers to them. When I first became interested in them I sought for answers in the pages of astronomical books and periodicals and by sending letters of inquiry to astronomers, but these methods of research proved fruitless. Then I applied to Venus herself, and jotted down the bits of information which from time to time she was kind enough to give me. After I had been at this for a year or two I learned that M. Bruguiere of Marseilles had been engaged

on the very same work for several years and had made and recorded a large number of observations. These he was good enough to send me, and in this paper I have made use of them as well as of my own and of any others that I have been able to lay hands on.

As seen from the earth, Venus completes a revolution around the sun in 584 days. During one half of this time she is evening star, and during the other half morning star. By way of a few preliminary and explanatory remarks, let us consider her motion and the various changes she undergoes during the 292 days of her season as evening star, and for the sake of simplicity let us suppose that both she and the earth are at their mean distances from the sun. Both orbits differ but very little from circles, and the results got from considering only the mean distance will be quite correct enough for the present purpose.

At the beginning of an evening star season Venus is in superior conjunction on the further side of the sun from us, and is in the same part of the sky as the sun is. She cannot then be seen by day because she is hidden in the sun's rays, and she cannot be seen in the evening because she sets at sunset. After superior conjunction she moves off to the east of the sun. In 39 days she is 10° away, in 78 days 20°, in 120 days 30°, in 166 days 40°, and 220 days after superior conjunction she reaches her greatest elongation of 46° 20.′ Only 72 days are left for her to get back, less than a third of the time she takes to swing out. Half of the 72 days are used up in working back to 40°, 14 days more to 30°, 9 days more to 20°, and in another 13 days she is again in line with the sun, this time on the hither side of him and in inferior conjunction. In so far then as her visibility depends on her elongation, it is apparent that she can be seen at a shorter interval of time from inferior than from superior conjunction. It is always perfectly easy to see her when 20° out, and if this were the limit of her visibility we would have to wait 78 days after superior conjunction before getting a glimpse of her, but we could see her every evening after that until 13 days before inferior conjunction.

While her elongation is changing, her brilliancy is changing also. At greatest elongation she is three times as bright as at superior conjunction. This does not mean that it is only three times as easy to see her in the former position as in the latter—it is infinitely more easy to do so. No eye can see her in the one case, and no eye can fail to see her in the other. What is called brilliancy is a something quite independent of elongation, and it is lack of elongation and no lack of brilliancy that makes Venus invisible at superior conjunction. If, when at superior conjunction, she had the brilliancy which she has at greatest elongation, she would still be invisible to the naked eye; and if, when at greatest elongation, she had only the brilliancy of superior conjunction, she would still be the brightest gem in the sky.

The actual brilliancy at any moment depends on several conditions, some physical and others geometrical. Of the physical conditions we know too little to be able to make them the subjects of calculation; but from the geometrical conditions we can calculate the relative theoretical brilliancy for any position in her orbit, and this is found to agree quite well, as a general rule, with the actual observed brilliancy. These geometrical conditions are three in number: the distance of the planet from the sun, the distance of the planet from the earth, and the phase of the planet—that is, the illuminated part of its disc. To get a general idea of the changes in Venus's brilliancy, we may, as before, suppose her to be always at her mean distance from the sun, and then the changes will depend only on her distance from the earth and her phase. It will be convenient also to select some standard in terms of which to express her different brilliancies. For this I shall take her greatest brilliancy as it always would be if both she and the earth were always at their mean distances and if the reflective powers of all parts of the surface of Venus were equal and constant, and I shall use the number 100 as the value of this mean greatest brilliancy.

At superior conjunction she presents the same face to the earth as she does to the sun, so that the value of her phase is 1—she is "full," as we say of the moon. But her distance from

the earth is then so much greater than when she is brightest that her brilliancy is only 24. As she moves out from superior conjunction her distance decreases, and so does her phase; but the increase of brilliancy due to the decrease of distance is greater than the decrease of brilliancy due to the lessening phase, and so she grows gradually brighter. When she reaches greatest elongation, her distance is only $\checkmark\frac{1}{6}$ of what it was at superior conjunction; and as brilliancy varies inversely as the square of the distance, it would now be six times what it was at superior conjunction if the phase remained full. But at greatest elongation the phase is only $\frac{1}{2}$—Venus looks now like a half moon in the telescope—and so the brilliancy is only three times as great as at superior conjunction; more precisely, the value in terms of our standard is now 73.

Not 100 yet, for Venus is not brightest when she is farthest from the sun in the sky. For five weeks after she begins her inward swing her brightness continues to increase and reaches its maximum value of 100 when she gets back to elongation 40.° This happens 256 days after superior conjunction and only 36 days before inferior conjunction, and when the phase is just about $\frac{1}{4}$. The decrease of brilliancy due to the lessening phase is henceforth greater than the increase due to the shortening distance, and the brilliancy goes down, and at a much swifter rate than it went up. In 16 days it goes down to where it was at greatest elongation; in 12 days more it is down to where it was at superior conjunction. Thus in the 27 days after greatest brilliancy Venus loses all the increase she gained in the 256 days before. Nine days later she is at inferior conjunction, and phase and brilliancy are each 0. This last statement is strictly true only when she makes a transit across the sun's face; at all other inferior conjunctions she appears in the telescope as a very thin crescent,—a mere thread of light—a little north or south of the sun.

Besides elongation and brilliancy, there is one other condition that affects the visibility of Venus, viz., her declination. In northern latitudes the farther north she is, the higher she rises, and the easier it is to see her in daylight. For observation in

the evening about the time that the other conditions are beginning or ceasing to be favorable, it is not so much her absolute declination that is important as the difference between hers and that of the sun. The longer the interval of time between sunset and the setting of Venus, the easier it is to pick her up at these critical seasons; and the length of this interval depends not only on the elongation, but also on this difference of declination. When Venus is farther north than the sun the interval is longer than that due to elongation, and when farther south it is shorter. When the elongation is 15° and the declination of both objects is 0°, the planet will set an hour after sunset; but if her declination were then 5° north she would remain above the horizon in this latitude a quarter of an hour longer, if 5° south a quarter of an hour shorter.

All of the above is just as true for the morning star season as for the evening star season if allowance be made for the fact that in the former case the season begins with inferior conjunction and ends with superior conjunction, instead of *vice versa* as in the case considered.

And now to answer the questions which form the subject of my paper, so far as the observations in hand admit of their being answered. In giving the particulars of elongation, brilliancy, etc., in connection with the observations, the hypothesis of mean distances used in the above prefatory matter is no longer retained. The actual distances of both Earth and Venus for each date, as given in the Nautical Almanac, are the ones that have been used. In the matter of brilliancy the same standard is used as above, and each value given is a percentage of the mean greatest brilliancy. All hours mentioned in the paper are standard time of the 60th meridian W. Long.

I have said that it is always perfectly easy to see Venus with the naked eye when her elongation from the sun is equal to or greater than 20°, and that this happens on the average at an interval of 78 days from superior conjunction and 13 days from

inferior conjunction. If this were the limit of eye-visibility there would be 91 days out of every 292 during which she would be invisible, and 200 during which she would be visible. If then there are any eyes so poor that they can't see Venus when nearer than 20° to the sun, even those eyes can see her for more than two-thirds of the time, that is for eight months out of every twelve on the average.

I have no particular reason for selecting 20° elongation as the upper limit of perfectly easy visibility except that 20 is a nice round number, and that something of this sort may be found convenient to refer to afterwards. As to the "perfectly easy" character affirmed of Venus in this position, that is a matter that every one can verify for himself. The first opportunity to do so will occur on the evening of June 25, and the next on the morning of July 22 this year. On these dates Venus will be 20° out from inferior conjunction. This is the easier of the two 20° positions. In general the phase is then only $\frac{6}{100}$ but the brilliancy is 45. At 20° from superior conjunction the phase is, in general, $\frac{94}{100}$, but the brilliancy is only 27. The first opportunity for an observation of this last kind will occur on the morning of February 10, and the next on the evening of July 14, 1893.

Our business now is to see how much nearer to conjnnction than 20° the naked eye can see Venus, and at how small a phase and how low a brilliancy.

I shall take up the observations near superior conjunction first.

In 1888 Venus was in superior conjunction on July 11. About a month later I began trying to pick her out in the sunset sky, but the weather was against me and it was August 23 before I got the first glimpse of her. That was 43 days after conjunction. The elongation was then $12\frac{1}{4}°$, the phase $\frac{98}{100}$, and the brilliancy 24.4. The observation was made at 7.30 p.m., 15 minutes after the sun had dropped below the sea-horizon and when Venus was 3° above it. I learned afterwards that M. Bruguiere had seen her at Marseilles on August 12. This was only 32 days after

conjunction, when the elongation was 9°, the phase $\frac{99}{100}$ and the brilliancy 24.

Here we are already well within the 20° and 78-day limit, even with my 43-day and 12° observation, to say nothing of M. Bruguiere's still better one. As to mine, it was easy enough to make, any one might have made it if he had happened to be looking that way at that time. It was the result of a mere random search, for I had not prepared myself by any previous observations of sun or stars to know the exact spot in my sky where Venus would be at the time. I felt sure that the 43 days and the 12° could be cut down considerably, but I had to wait a year and a half before there was another chance to try.

The next superior conjunction occurred in 1890 on February 18 at 7 a.m. There is, of course, an opportunity *before* as well as *after* each conjunction to try how close to conjunction one can push his observations, and, if other things were equal, the before one would be the better of the two; for the observer would have each day's observation to help him in making that of next day. But other things are not equal. It is not that there is any difference in the astronomical or other conditions of the thing observed, the difference arises from the personal habits of the observer. Observations of Venus before superior conjunction have to be made in the morning before sunrise; after superior conjunction, in the evening after sunset; and under the social conditions of modern life the latter can be made much more conveniently and comfortably than the former. Some time or other —perhaps before next superior conjunction in the spring of 1893 —I may make up my mind (and my body) to try what can be done by morning observations, but I have nothing of that sort as yet that is worth recording in the present connection. And M. Bruguiere seems to be in much the same condition. The best observation made before superior conjunction that I find in his list is that of December 15, 1889, 65 days before the conjunction of February 18, 1890.

Three weeks after this conjunction, on March 10, I made my first attempt to catch Venus in the evening, but did not succeed. The next five days were cloudy. But the next (March 16) was

clear, and, having determined by a sun-observation that about 10 minutes after sunset Venus should be close to a certain chimney on a neighbouring house, I looked there at that time and saw her. A note made at the time says, "6.30 sun's centre in horizon, 6.42 Venus distinctly with eye." This was 26½ days after superior conjunction, the elongation was 6½°, the phase $\frac{99}{100}$, the brillliancy 24. This is the best observation I know of near superior conjunction, and is the best near either conjunction so far as smallness of elongation is concerned. It might have been even better, had it not been for the cloudy evenings on the previous five days. At Marseilles the weather was much worse than here, and it was not until two months later that M. Bruguiere got his first eye-glimpse of Venus after this superior conjunction.

The next one, and the last one to date, occurred at noon on September 18, 1891. The earliest observation after it that I have heard of was made by Miss Beatrice Tooker of Yarmouth on October 17, 29 days after conjunction; but this was with an opera-glass and so we can't count it here. The declination conditions were not as favorable for early eye-observations as on the previous occasion, and my eyes were not in good condition at the time for looking into a sunset sky. As a matter of fact I did not look for Venus at all until the evening of November 9, 52 days after conjunction, and by that time of course she showed up at once, and only five minutes after the sun's upper limb had disappeared below the horizon.

There is quite enough evidence here, I think, to show that our provisional limit of 20° and 78 days can be reduced a good deal. It would perhaps be going too far to say, on the faith of my observation of March 16, 1890, that we can always see Venus in clear weather when only 26 days and 6° out from superior conjunction; and yet that observation was the only one of mine, made near this conjunction, that gave Venus a fair chance to show what she could really do for us in this line. To be quite safe, however, let us allow a liberal margin of 50 per cent. or so to cover adverse declination conditions, and we shall have as

a general limit near superior conjunction an interval of 40 days and an elongation of 10°. Thus no one who wishes to have a daily glimpse of Venus need wait longer than 40 days after superior conjunction to begin having it, and in favorable conditions he may hope to be able to begin as early perhaps as 20 days after. Having once begun, the daily glimpse may be continued, weather permitting, for the next eight months or more, until Venus gets near inferior conjunction.

Nearer than 13 days certainly, for that is the interval of time that corresponds here to an elongation of 20°; and we have already found this elongation to be quite unnecessarily large in the case of superior conjunction, although there the brilliancy is only $\frac{3}{5}$ of what it is at 20° out from inferior conjunction.

Let us now see how near to inferior conjunction the observations at hand show that Venus can be seen.

Owing to several unfortunate circumstances I have never been able to do justice to Venus near any of these conjunctions. Before them, the sky has been cloudy or the early evenings have been required for other engagements; after them, the early mornings have been passed in the unconscious condition and the horizontal position common to most of us at those hours. As will be seen presently, this last unfortunate circumstance seems to have affected other observers as well as myself, and to it may be largely attributed the fact that there are no observations as near to inferior conjunction *after* it as there are *before* it. Then there is the other disadvantage already mentioned in connectien with observations made after superior conjunction; at such a time the observer has no previous day's observation of the same object to help him in selecting the right spot in the sky to look at. He can get over this of course by taking observations of stars having the same declination and the same hour-angle as the planet to be observed, but there still remains the other disadvantage of the inconvenient and uncomfortable hour at which planets must be caught early after passing to the west side of the sun.

The only observation of mine after inferior conjunction that I have kept a record of was made after an interval of 18½ days

when Venus was 26° out from the sun. It would be absurd to accept this as anything like a limit of visibility for this position. The observation was made at mid-day, and it was a purely random one to boot—not a bit of preparation had been made for it. Venus was then so bright as to be readily seen by a couple of friends who were prepared a minute before to swear that it was utterly impossible to see her with the naked eye at such a time. The date was May 19, 1889.

M. Bruguiere saw her two days earlier, on May 17, and his was probably also a midday observation. After the next inferior conjunction on December 4, 1890, he cut his own record down two days by seeing her on December 18 when she was 14 days out. I don't know at what time of the day this observation was made, but I would not be at all surprised to learn that it too was a noon one.

Nothing less than 13 days yet, and perhaps it may be thought that it was too rash to pooh-pooh that interval as unnecessarily large for this position. The mere absence of observations made at uncomfortably early hours would not, however, prove that they could not be made; but it fortunately happens that there is no need to urge this plea. December 13, 1890, was the ninth day after the last inferior conjunction. Half an hour before sunrise on that morning Venus was seen with the naked eye by Miss Katharine Travis, of Hampton, N. B. The elongation was then 15°, the phase $\frac{3}{100}$, and the brilliancy 28. This is the best observation I know of after inferior conjunction. I hope some of our early-rising star-gazers will better it after the next one on July 9 this year.

Much better has been done at the more convenient season before inferior conjunction. But not by me. My best observation of this kind was made 8 days before the conjunction of April 30, 1889, on the evening of the 22nd. The elongation was nearly $14\frac{1}{2}°$, the phase $\frac{3}{100}$ and the brilliancy 23. Every evening after that until conjunction was cloudy or foggy; indeed, that evening was cloudy too, and it was only through a break in the clouds that she managed to let herself be seen for a minute or

two about a quarter of an hour before sunset,—*before* sunset not after. She looked bright enough to be good for three or four evenings yet, if the clouds or fog would only let her through.

At Marseilles the skies were clearer then, and M. Bruguiere got his last glimpse of her on the 27th, five days later than mine. At what time of the day I don't know, but as he counts it four days (instead of three) before conjunction, I think it must have been early in the day and probably about noon. In his longitude the time of conjunction was 2 a. m on May 1, so his observation could not very well be more than $3\frac{1}{2}$ days before. That is the closest in point of time that I know of. The elongation for Greenwich noon on the 27th was $7\frac{3}{4}°$, the phase less than $\frac{1}{100}$, and the brilliancy only 6.9. He succeeded in holding her again until about $4\frac{1}{2}$ days before the last inferior conjunction in December 1890, and though the elongation was then nearly 9°, the phase was a little less than before,—$\frac{2}{3}$ of $\frac{1}{100}$ only,—and the brilliancy was only 6.5. In smallness of phase and lowness of brilliancy this is the very best of all the observations that I have a record of, and it is probably as good as can be done. If any one cares to try to equal or better it, the first week in July will afford an opportunity to do so if the weather permits.

Perhaps it may be as well to collect into a couple of sentences the three or four chief facts mentioned above.

Venus's last complete season as evening-star began with the superior conjunction of February 18, 1890, and ended with the inferior conjunction of December 4, in the same year, lasting for a period of 290 days. I saw her with my naked eye as early as March 16, $26\frac{1}{2}$ days after superior conjunction, and M. Bruguiere saw her (in the same latitude) with his naked eye as late as November 29, $4\frac{1}{2}$ days before inferior conjunction; so she was visible to the naked eye during that season on 259 days, that is, on 89 days out of 100. When I saw her first in March she was only $6\frac{1}{2}°$ distant from the sun's centre, when M. Bruguiere saw her last in November the brilliancy was only $6\frac{1}{2}$ per cent. of her mean greatest brilliancy.

There is no reason why as good, if not a better, showing could

not be made for one of her morning-star seasons if some one would only take the trouble to turn out in the mornings and make the necessary observations at the beginning and end of the season.

So far, I have dealt with only one of the two questions that I proposed to treat when beginning to write, but the paper is already longer for the one subject than I hoped to make it for both. The second—as to the visibility of Venus to the naked eye in daylight—is the more interesting of the two, but it must stand over for the present. I may just say, however, that I have learned from Venus herself that it is not at all a rare or extraordinary thing to see her with the eye in broad daylight, and that no keen powers of vision are needed to see her so. On every clear day this year so far she could have been seen even at noon by any eye of average quality that knew where to look for her; and the same sight may be had by the same kind of eye on every clear day from now till the end of the year, excepting only a fortnight or so in July.