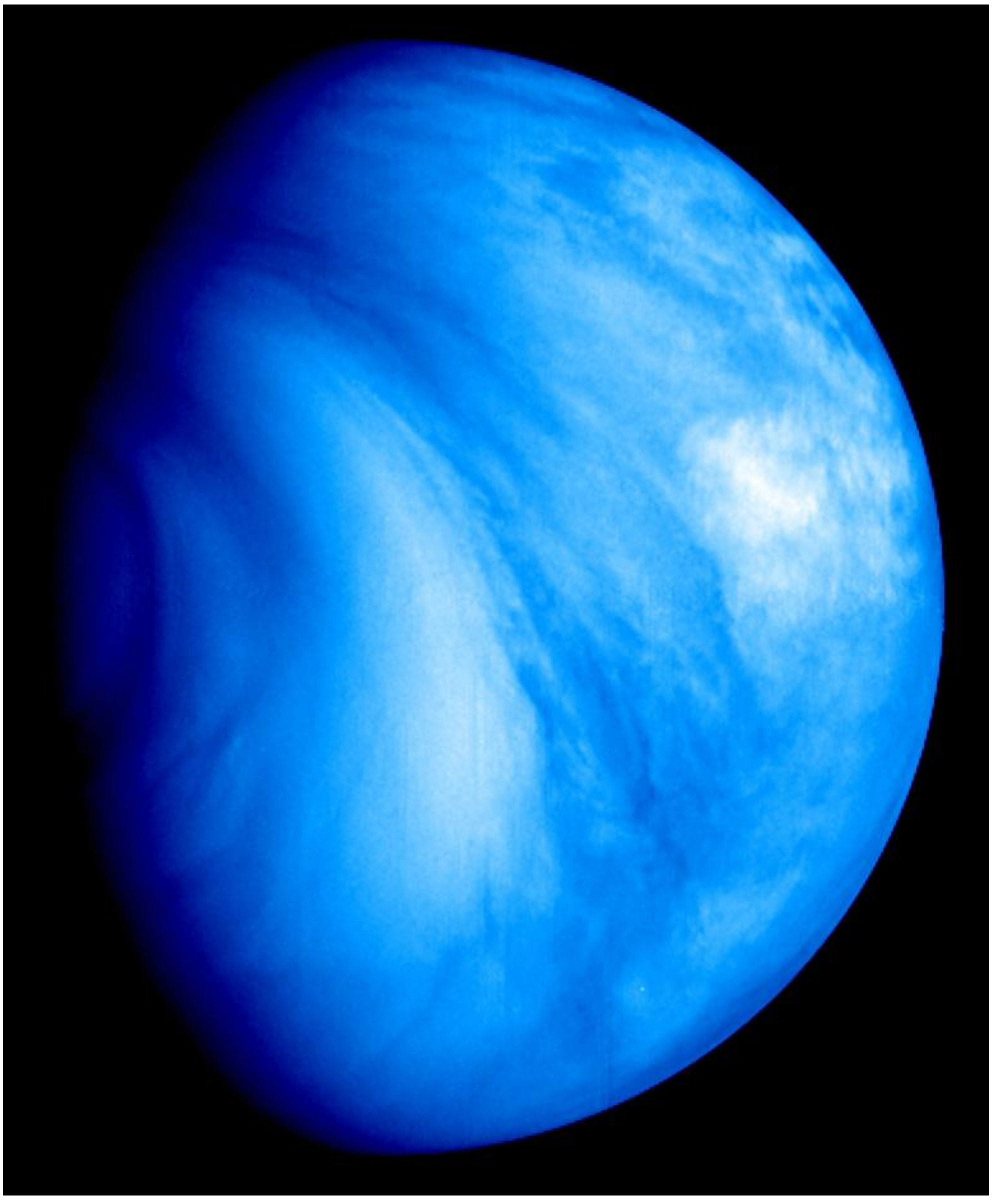
# A Guide to Observing the Planet Venus

A publication of the BAA Mercury and Venus Section





Paul G. Abel, Chris Dole, Peter Tickner and Martin Lewis

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# Preface

The British Astronomical Association was founded in 1890 as an organization to support amateur astronomers. The Association established a number of observing sections, and in 1895 the Mercury and Venus Section was created with Henry McEwan as its first director.

At the time the Mercury and Venus Section was founded, very little was known about Venus. The impenetrable cloud cover permanently hid the surface, and speculation was rife: was the planet a lush tropical paradise, or a hot world with hydrocarbon lakes? The uncertainty continued until the first spacecraft arrived in the 1960s and revealed that most of our ideas about Venus were completely wrong. Today we now know that Venus is a dramatic world and the clouds probably conceal active volcanoes on the surface.

For much of the Section's existence, telescopic observation of Venus was purely visual. Some observers could see features in the clouds, while others could not. Photographs by amateurs were often blurred and showed little or no detail, but photographs taken in the ultraviolet by professional astronomers showed patterns in the clouds and a smaller phase than in visible wavelengths.

This remained the state of play until the last decade when imaging cameras and filters for the infra-red (IR) and ultraviolet (UV) started to become cheaper and more easily accessible to the amateur astronomer. Venus observers today frequently image the planet in IR and UV wavelengths and have captured a variety of phenomena that are still not fully understood. Images of the night-side surface occasionally show small brighter spots that suggest volcanic activity may still be occurring on the planet.

With this in mind, it was clearly time for a new Venus observing guide; one which covers all of the new techniques now employed in the study of Venus. In this guide you will find information about the planet and its orbit, together with help on making visual observations which are still important. There are also sections on UV imaging, IR imaging and a new area of research for the Section: making observations of the nightside.

This guide would not have been possible without the expertise of Chris Dole (UV chapter), Peter Tickner (IR chapter) and Martin Lewis (observing the night side); I am grateful for the hard work they put into writing their chapters. Finally, I would like to thank Chris Hooker who kindly agreed to take on the unenviable task of proof reading and editing the final version.

Whatever telescope and equipment you have, whether you're a digital observer or a visual one, you'll find that Venus has plenty to offer you as we try to understand our mysterious neighbour in space!

**Paul G. Abel, Director, BAA Mercury & Venus Section, Leicester 2026.**

# 1. Introduction

***Paul G. Abel***

## 1.1 Introduction to Observing Venus

After the Sun and Moon, Venus is the brightest object in the sky. When seen in the early morning or late evening sky, the planet looks like a brilliant beacon and is quite unmistakable. Indeed, when the planet is at its brightest (or greatest brilliance), it can actually cast shadows. Venus is a challenging object to observe. Its brilliance is due to a highly reflective and rather dense atmosphere whose poisonous clouds never clear away, permanently obscuring the surface. It is not surprising that even up until the 20$^{th}$ century, very little was known about the planet.

It was Galileo who first turned a telescope to Venus and made systematic observations of the planet. In 1610, he recorded the phases of Venus and correctly deduced that they could only be explained if Venus was closer to the Sun than the Earth and that, crucially, the Sun must be at the centre of the Universe. Thus began the decline of the old Ptolemaic model of the solar system which had the Earth at its centre.

During the 18$^{th}$ and 19$^{th}$ centuries, the manufacture of optics and telescopes improved greatly, but even with these advances, Venus still revealed little in the way of detail. Vague markings were seen but not in an ordered consistent way like those of Mars or Jupiter. In 1790, the German astronomer Johann Schröter made a number of observations including extensions of the crescent when the planet was near the Sun in the sky. This was correctly explained as the result of a dense atmosphere scattering the light.

It was only when the space age arrived and the first space probes flew past Venus that the true situation was revealed. On 5$^{th}$ February 1975, Mariner 10 made its closest approach to Venus. In ordinary light, the atmosphere looked featureless, but the UV cameras showed quite striking cloud patterns and formations. A series of Russian Venera spacecraft managed to soft-land on the surface, although the harsh conditions meant that none of the spacecraft lasted for more than 90 minutes. In 1990, NASA's Magellan spacecraft entered orbit around Venus and used radar to provide the first high resolution images of the surface.

Given that Venus has been visited by a number of spacecraft, and with more missions planned for the future, it would be tempting to think that there is little more for the amateur astronomer to do. In fact, nothing could be further from the truth! For one thing, the spacecraft missions provide us only with a snapshot of Venus over a short period of time, and our understanding of Venus depends upon systematic, long-term surveillance.

Moreover, amateur astronomers today have a much wider variety of filters and equipment at their disposal, so that observations can be made not just in the visible but also in the UV and IR. Professional astronomers rarely look at Venus but amateurs can observe it whenever their skies are clear, so it is not hard to see the active role amateur astronomers will continue to play in revealing the mysteries of our nearest neighbour. It is the task of the Mercury and Venus Section of the British Astronomical Association to analyse these observations and provide help and support to the amateur community.

This guide aims to introduce all the modern observational techniques required for observing Venus. The rest of Section 1 looks at how Venus is structured geologically, the make-up of the atmosphere and how Venus's orbit affects its movement in the sky and overall visibility. In Section 2, we consider the various different aspects of visual observation while Section 3 discusses how to image Venus in the UV. Section 4 is concerned with imaging cloud features in the IR. Finally, Section 5 discusses imaging the night side surface of Venus in IR. It is hoped that this brings the Section observing guide for Venus fully up to date, incorporating all of the latest methods employed by both visual and digital observers.

## 1.2 Venus as a Planet

Venus is a terrestrial planet: such planets have rocky surfaces and semi-solid interiors. Figure 1.1 shows the interior of Venus as we currently believe it to be. We have the thick atmosphere and below this the hot surface which forms the upper layer of the crust. Below the crust we have a mantle and then the core.

The core may be molten like the Earth's or it may be solid. The lack of a strong magnetic field may indicate that the core is solid but there is still considerable debate about this and the internal structure of Venus, although most scientists agree it must be differentiated like the Earth.

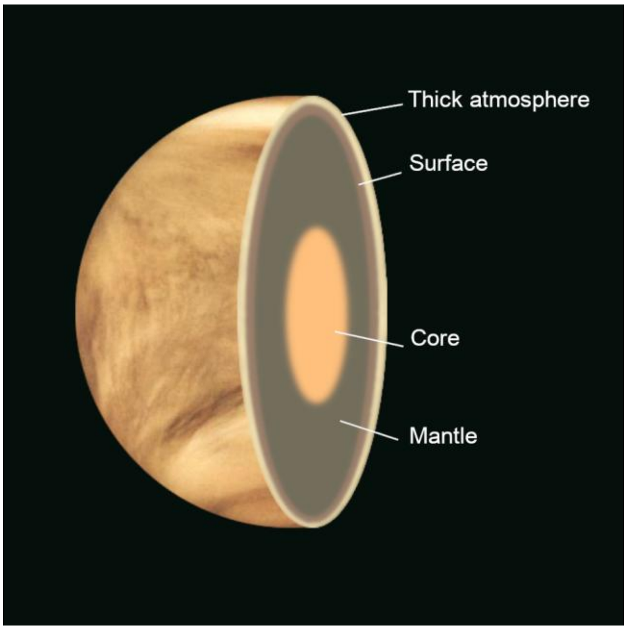



Figure 1.1. Graphic showing the internal structure of Venus as we currently believe it to be. (*Paul G. Abel)*

Our information about the surface comes from various spacecraft like Magellan which have used radar to penetrate the clouds and map the surface of the planet. A NASA map of the surface is given in figure 1.2 with the features labelled. Higher resolution images than this have been taken which show the surface is covered in volcanic features.

The surface of Venus seems to be quite different from other terrestrial planets. In general, when we look at Mercury, the Earth, Mars and the Moon we see that their surfaces present regions of different ages; older regions tend to be heavily cratered while newer regions show little cratering by comparison. The surface of Venus has a fairly even distribution of craters suggesting that the surface is all the same age. The reason for this is a complete mystery and suggests the planet may have undergone a violent resurfacing event in the past.

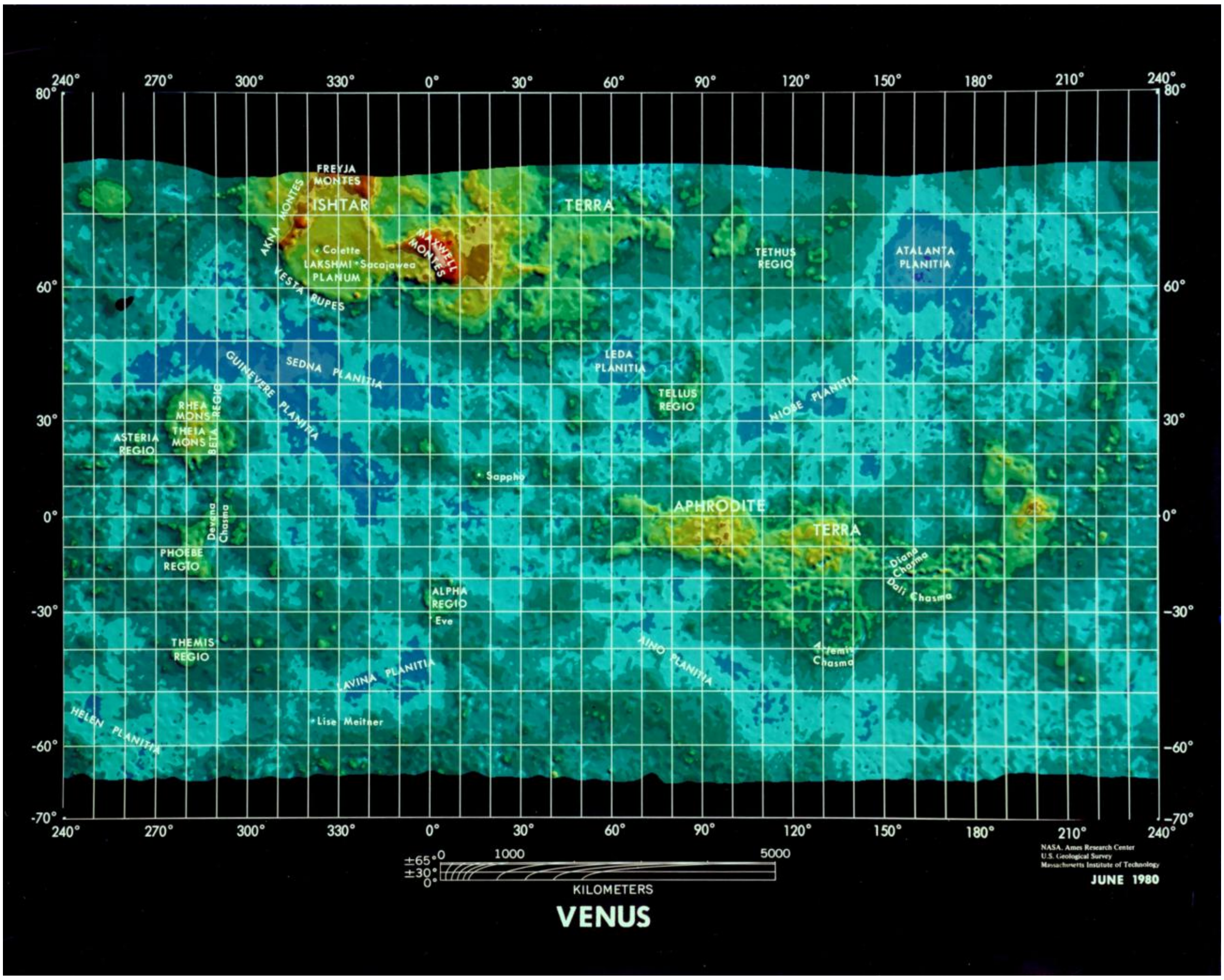


Figure 1.2. A map of Venus showing the various features. Red areas have the highest elevation, blue areas the lowest. Longitude used is System 1: the rotation of the surface. (*NASA Ames Research Centre)*

Recent analysis of the Magellan data by David Sulcanese and colleagues of the International Research School of Planetary Sciences, Università d'Annunzio (Italy) has found substantial changes to various volcanic features on the surface which indicates that the planet is still volcanically active.

## 1.3 The Venusian atmosphere

Venus has a substantial atmosphere which is composed primarily of about 95.5% carbon dioxide, with 3.5% nitrogen and trace amounts of sulphur dioxide and other gases. Figure 1.3 shows the structure of the atmosphere. The primary feature of the atmosphere of Venus is the dense cloud layer composed of sulphuric acid droplets.

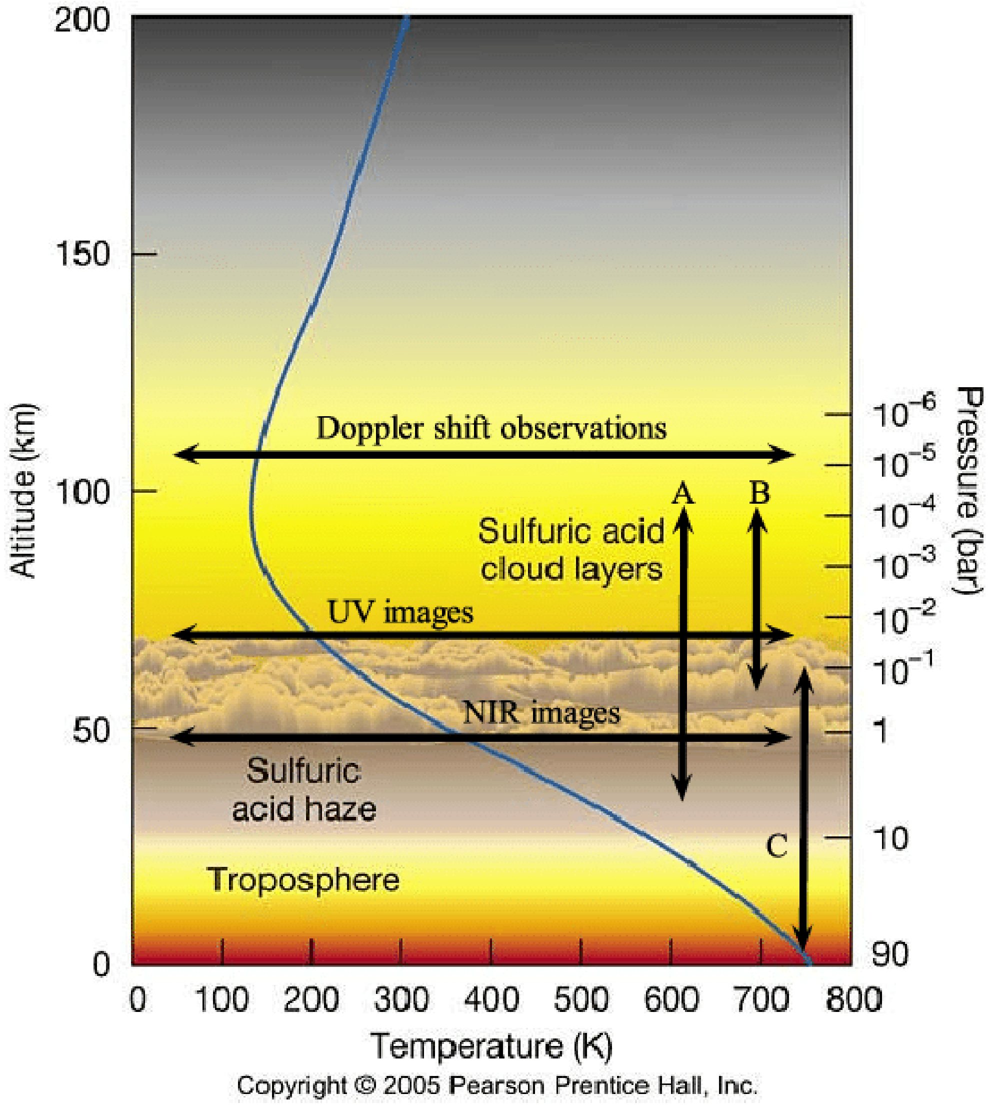



Figure 1.3. A graphic showing the atmosphere of Venus. Tracing the blue curve, one can see the temperature at any given altitude.

The dense cloud deck along with the water vapour in the atmosphere are also responsible for the extreme heat on the surface (some 500°C); they allow longer wavelength radiation to become trapped and so cause a run-away greenhouse effect. As can be seen in figure 1.3, the atmospheric pressure in the cloud deck at 50 km altitude is rather Earth-like, but down on the surface is about 100 times that at sea level on the Earth.

The upper atmosphere of Venus undergoes super-rotation; this means that it circulates faster than the planet rotates. The rotational period of Venus is 243 days, but the atmosphere rotates around the planet in just over 4 days. To allow for this the Mercury and Venus Section uses two systems of longitude for Venus:

- System 1 (denoted CM1 or $\omega_1$): this is the rotation of the surface and has a value of 1 rotation in 243 days.
- System 2 (denoted CM2 or $\omega_2$ ): this is the rotation of the atmosphere and has a value of 1 rotation in 4.2 days.

### 1.3.1 Ultraviolet (UV) images

Imaging Venus in UV is now routinely done by observers and Section 3 explains how to make such observations. It is worth making a few general points about UV observations of the planet here, however. In fact, the clouds of Venus can exhibit some very distinctive markings, but these are in the UV and extreme violet end of the visible spectrum. Visual observers who are sensitive to shorter wavelengths will also be able to see the markings, albeit less well defined than in UV images.

As can be seen in figure 1.3, when Venus is observed with a UV filter we are effectively looking at the cloud tops of Venus some 70km above the surface of the planet. The cloud markings can be very striking with complex structure.

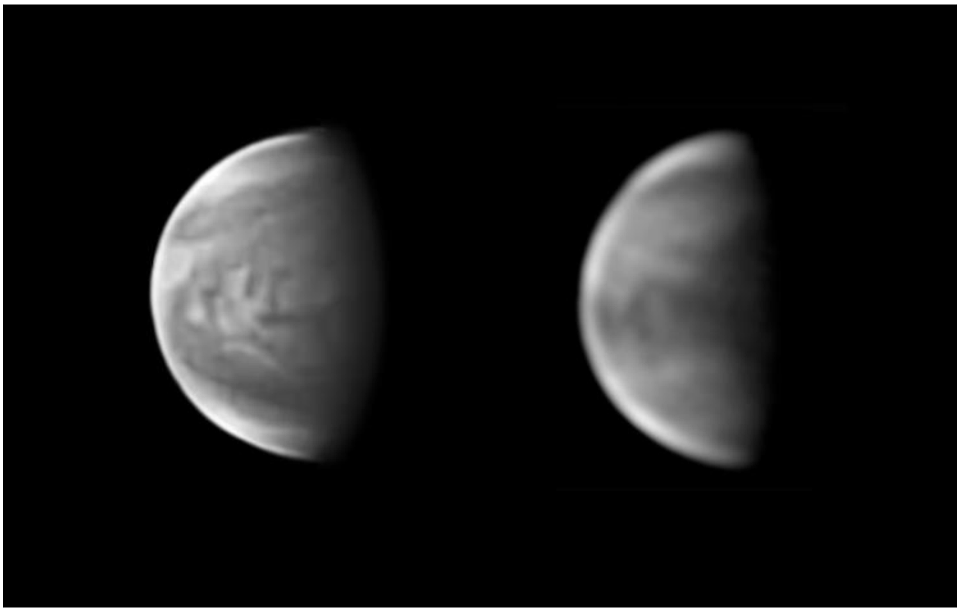


Figure 1.4. Two observations of Venus in UV showing complex cloud markings. The left image was taken by Peter Tickner on 2023 April 25 at 1759UT using a 356mm SCT with a Baader UV filter. The image on the right is by Clyde Foster, taken on 2024 December 12 at 1714UT with a 355mm SCT and a Chroma Bessel U filter.

Two UV observations can be seen in figure 1.4, and the image by Tickner in particular shows a lot of delicate detail which would only be visible in a UV image. For more information about how to image Venus in the UV, see Section 3.

### 1.3.2 Infra-Red (IR) images

If we turn our attention again to figure 1.3, we see that when we examine Venus in the near IR, we are looking much deeper into its atmosphere and observing the lower layers of the cloud deck. Section 4 of this guide describes the equipment and procedures needed to image Venus in the near-IR, and discusses the kind of features that can be observed at those wavelengths.

There is one interesting phenomenon which can only be observed in the infra-red: this is the so-called Cloud Discontinuity. This feature takes the form of a thin dark line, usually running roughly north to south, crossing the equator. It is thought to be a gravity wave in the atmosphere of the planet, perhaps caused by volcanic activity. It is not always present, and has been observed in some elongations more frequently than others. Figure 1.5 shows its general appearance as recorded by three observers.

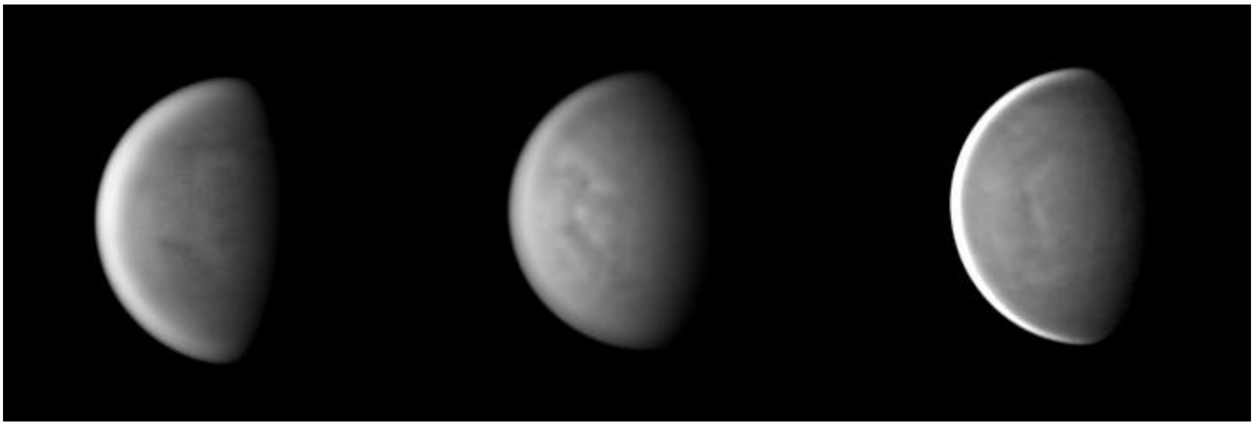


Figure 1.5. Infra-red images of the Cloud Discontinuity by (left) Clyde Foster; (middle) Luigi Morrone; (right) Antonio Cidadao.

## 1.4 Venus in the Sky

### 1.4.1 Orbits and Elongations

Venus is an inferior planet: this means that its orbit lies closer to the Sun than the Earth's. As a result of this, the behaviour, appearance and motion of Venus in the sky is very different from that of the superior (or outer) planets. Venus only ever appears in the morning or evening sky: it does not come to opposition, and when it is in the evening sky it always sets before midnight. When Venus is in the morning sky it always rises well after midnight and so unlike the outer planets, it cannot be observed throughout the night.

When Venus is in the morning sky, we call this a western elongation as it lies on the western side of the sun. Conversely, when the planet is in the evening sky it is said to be an eastern elongation as the planet lies to the east of the Sun. Venus moves alternately between eastern and western elongations.

To terrestrial observers Venus exhibits distinct phases just like the Moon, and to see why this occurs we need to consider our view of Venus as it orbits the Sun. Figure 1.6 shows the orbit of Venus from a point further out in the Solar System.

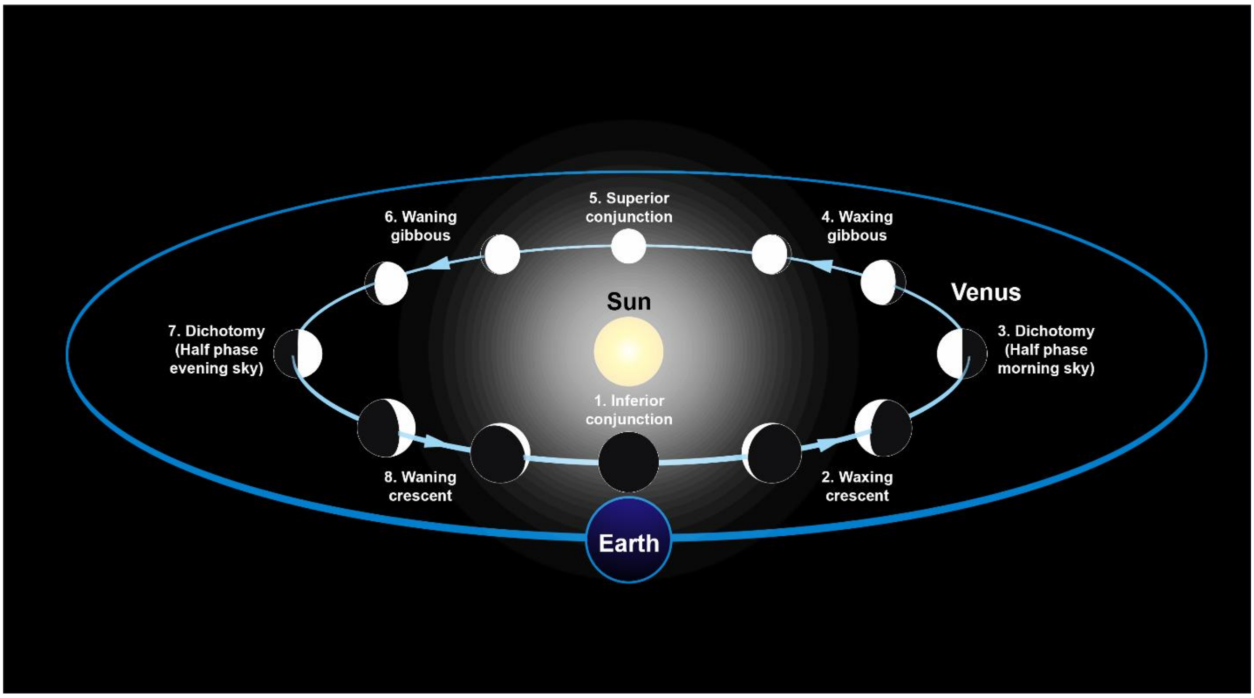



Figure 1.6. Schematic view of the orbit of Venus around the Sun. Graphic by Pete Lawrence

At position 1, the planet lies between the Sun and Earth at inferior conjunction, and at this point its phase is new so it cannot be seen, except on very rare occasions when it transits across the face of the Sun. As the orbit of Venus is tilted by 3.4° from the ecliptic, this means that transits of Venus are extremely rare. Inferior conjunction marks the start of a western elongation, and the planet moves into the morning sky. As Venus moves away from the Earth, telescopically it becomes a waxing crescent as shown in position 2. As Venus continues to move away from the Earth, its phase increases and its apparent diameter decreases. Eventually it reaches dichotomy (position 3) and at this point telescopically it appears to be 50% illuminated. The planet continues to move away from us, and the phase becomes waxing gibbous (position 4). Finally, Venus reaches position 5: this is superior conjunction, and at this point the Sun lies between the Earth and Venus, which is once again unobservable.

Superior conjunction marks the end of the western elongation: Venus moves into the evening sky and a new eastern elongation begins. The planet now starts to move closer to the Earth and its phase is waning gibbous (position 6). Eventually the planet reaches dichotomy (position 7) and continues to move closer to the earth. After dichotomy, the planet appears telescopically as a waning crescent (position 8) until eventually it comes to inferior conjunction once more. The planet moves back into the morning sky at this point and the whole cycle starts again.

The time between successive inferior conjunctions or successive superior conjunctions is called the *synodic period*. For Venus, this is about 584 days. Interestingly, five synodic periods of Venus are almost exactly 13 Venusian sidereal years and 8 Earth sidereal years. This has the interesting effect of returning Venus to about the same point in the sky every 8 years. Thus the 2024-2025 eastern elongation is comparable to the 2017 eastern elongation and so on.

Not all elongations will be equally favourable. For northern hemisphere observers, when Venus is located in the evening sky during the winter and spring months it will reach a reasonable altitude towards greatest eastern elongation, however eastern elongations over the summer and autumn will see the planet low in the sky even at greatest eastern elongation. When the planet is located in the morning sky during the summer and autumn, it reaches a reasonable altitude towards greatest western elongation but is poorly placed in the morning sky during the spring and winter months. This is due to the angle the ecliptic makes with the horizon. For southern hemisphere observers the rule of thumb is the same: Venus is best placed for observation on spring evenings during eastern elongations, and on autumn mornings during western elongations.

## 1.4.2 Locating Venus in the Daytime Sky

### *1.4.2.1 Finding Venus in Twilight*

Venus is so bright that locating it in twilight is usually fairly easy. Observing Venus in the dawn or evening sky is by far the easiest and safest way to observe the planet against a bright sky, particularly if you feel unsure about locating it in daytime, and/or the planet is close to the Sun.

I would recommend using planetarium software to see where Venus is located in the sky. For evening observations, **wait until the Sun is below the horizon** then take a pair of binoculars and scan the area of sky where Venus should be. You should soon pick it up, and when you have it, you can turn the telescope on to it.

If Venus is in the morning sky and the sky is still fairly dark, it will be obvious. Simply put Venus into the telescopic field and track it as the Sun rises. If the sky is fairly light, but **the Sun has not yet risen**, use a pair of binoculars to locate the planet then move the telescope to it.

### *1.4.2.2 Finding Venus in Daytime*

The general idea is to use the Sun as a reference point in the sky. Aim the telescope at the Sun initially, taking proper safety precautions to avoid damage to your eyes or the telescope. Then move the telescope by a known amount in RA and Dec to point it at the position of Venus.

Method 1. Using the finder

This method requires the kind of finder that is a small telescope with cross-hairs in the eyepiece, rather than a red-dot or target-projection type. It's a good idea to check that the image is correctly focused when you look through the finder at a star or distant daytime object. Some observers defocus their finders slightly so stars are small discs which can be seen more easily behind the cross-hairs, but for daytime use on Venus it is better to be in focus.

Before attempting to find Venus, you need to be sure that the finder is correctly aligned with the field of view of the main telescope. This can be done at night by using a bright star as a target, or in daytime by using a distant object on the horizon, and adjusting the finder mount if needed to aim it at the object when that is seen through the telescope.

It's best if you have a proper solar filter to fit over the finder objective. If you don't have one, make a cardboard cap for the finder with a hole of about 5 mm diameter in the middle to reduce the amount of sunlight entering the tube. This will avoid overheating and damage to the cross-hairs. To locate Venus in daytime, use the following procedure:

1. Open your favourite planetarium software and look up the right ascension (RA) and declination (Dec) of both the Sun and Venus on the date of observation, and write them down.
2. If using a computer-controlled mount, you need to work out the differences in RA and Dec between the Sun and Venus. These differences are the movements needed to shift from the Sun to Venus. Be very careful with your calculations if the Sun and Venus lie on opposite sides of the equator.
3. Make sure the main telescope is capped securely, and put the solar filter or reduced-aperture cap over the finder.
4. Aim the telescope at the Sun and centre it on the finder cross-hairs. If using a solar filter you can do this by viewing through the finder. **IF USING AN APERTURE CAP DO NOT LOOK THROUGH THE FINDER**. Instead, use a white card held 20 cm or so behind the finder and look for the Sun's image, then move the telescope until you see the image is centred on the cross-hairs.
5. At this point, if using setting circles, set them to the coordinates you found for the Sun in step 1. If using a mount with position readouts, write down the RA and Dec values shown on the controller (ignore the seconds figures).
6. Move the telescope to the RA and Dec coordinates of Venus which you found in step 1, as indicated by the setting circles. If using a computerised mount, move the telescope by the amounts you calculated in step 2.
7. Confirm by viewing or using the white card that the Sun is not visible in the finder, then remove the filter or aperture cap.

8. Venus should now be visible through the finder. It may be behind the cross-hairs, so jiggling the telescope slightly will bring it into view. This is why correct focus is important: Venus is bright, but if not properly focused it can still be tricky to spot in a clear blue sky.
9. Centre Venus in the finder. Uncover the main telescope and focus the image, then begin your observations.

Method 2. Using the main telescope.

If your telescope does not have the right type of finder for Method 1, you can use the main telescope instead, with either a solar filter or a cap with a small aperture (no more than 1/10$^{th}$ the diameter of the objective) and if possible a cross-hair eyepiece. The procedure is essentially the same:

1. Centre the telescope on the Sun either by viewing (with a solar filter) or projection.
2. Set the circles or write down the coordinates.
3. Move the telescope to the expected position of Venus.
4. Confirm the Sun is not in the field of view.
5. Remove the filter or aperture cap and look for the planet.

Potential difficulties in addition to those of Method 1 include incorrect focusing so Venus is blurred and may be harder to see, and the smaller field of view of the main telescope, meaning greater positioning accuracy is necessary.

If you cannot see Venus, do not sweep the telescope randomly hoping to find it. Go back to the start and check the coordinates and your calculations. Failure to find Venus is usually due to mistakes in noting the coordinates or using the setting circles, or errors in the calculation of how far to move the telescope.

Method 3. Using an automated mount.

Observers with observatory setups and permanent mounts can simply command the telescope to slew to the correct position. Provided the polar alignment is good and the time is set correctly, this should locate Venus immediately.

Remember that if you are in any doubt at all, use the first method of finding Venus during the twilight skies when the Sun is safely hidden below the horizon. It is not worth taking a risk as far as the Sun is concerned!

# 2. The Telescopic View of Venus: making visual observations

***Paul G. Abel***

It might seem that there is little for the visual observer to do in an era dominated by robotic telescopes and splendid images of Venus in a range of different wavelengths. In fact this is completely untrue and there are a number of observations the Section still requires which can only be achieved by visual observers. In this section we will look at what observations are required, and the various methods and techniques which can be used to obtain them.

## 2.1 Equipment

From a visual perspective, Venus is one of the few planets in our solar system which does not require a large telescope to make meaningful observations. Although my primary instrument is a 300mm Newtonian, I generally use my 203mm Newtonian (stopped down to about 75mm) to make all of my Venus observations and Richard McKim gets excellent results with a 75mm refractor. A 75mm aperture is probably the smallest aperture telescope which can be used to make useful observations of the planet.

You will probably find it helpful if your telescope is on an equatorial mount with setting circles, particularly if you wish to locate and observe Venus during the daytime. A driven mount is very useful as it keeps Venus within the telescopic field. This is not an essential requirement however; excellent results have been obtained with Dobsonian telescopes. Fundamentally so long as your telescope is of 75mm aperture or more, you should make good progress if you use it regularly. Other equipment you will find useful includes some of the following:

- *A selection of eyepieces:* have a very low power (say around 40x) which can be used to help find Venus in the daytime. Powers in the range of x120 to x200 are usually sufficient, particularly when the planet is in the crescent stage.
- *Venus blanks:* The Mercury and Venus Section uses 50mm diameter blanks to represent the disk of Venus. If you go to the BAA website you will find blanks on the report form. You will also find Venus Observation Cards on the website; these are designed to be used at the telescope- simply print them off and cut them to size. I use a small clipboard to put them on when drawing Venus.
- *Filters:* Most telescopes today come with optical filters. These are small, coloured glass disks which screw into the base of an eyepiece. On the side of each filter you will usually find a number printed: this is the Wratten number and identifies the filter. The Section recommends a W15 (yellow) filter for general viewing. Other useful filters include a W21 (orange), W47 (violet) and W38 (dark blue): see Table 2.1 for examples.

- *Pencils and eraser:* A selection of pencils, B, 2B and 3B are helpful for drawing the cloud markings and capturing the general hue of the disk. An eraser is also helpful.
- *A notebook:* I cannot stress the importance of keeping a notebook too much! I have a notebook for each of the planets, the Moon, and variable stars. A notebook will allow you to keep your observations in chronological order, and will also be a permanent record which will let you see how your observational skills have developed over time. You can also use it to record what filters and eyepieces work best for you, and keep track of what you have observed from one elongation to the next. I'm currently on my 4th Venus notebook and find it invaluable!

No doubt over time you will collect more equipment and materials which suit your own particular interests, however the items listed here are the ones I have found to be essential after many years of visual planetary work.

## 2.2 The telescopic view of Venus

The initial telescopic view of Venus may not show a great deal: a very pale yellow cream disk with a phase is likely to be your first experience. As with all things, seeing the various details takes time and practice, but it will not be long before you are seeing the primary features associated with Venus. Figure 2.1: shows the main telescopic features.

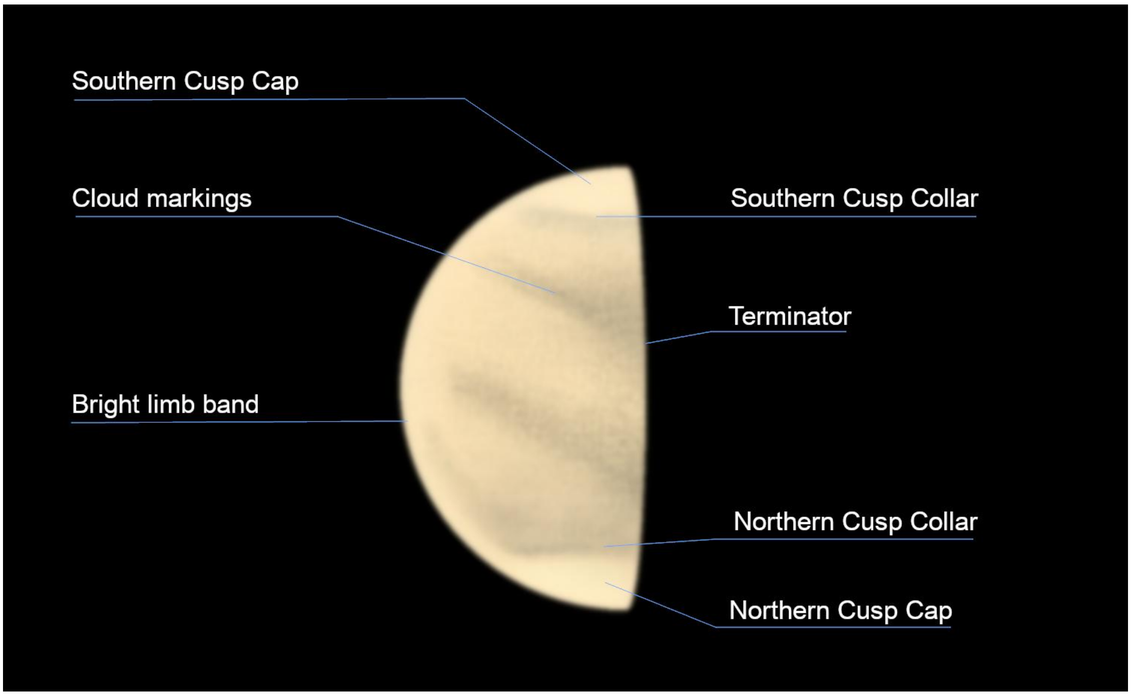



Figure 2.1. The general appearance of Venus in the telescope with the different features identified. This is the view through a Newtonian reflector with north at the bottom and south at the top. The proceeding side is on the right, so cloud markings move from left to right.

### 2.2.1 The cloud markings

As we have seen, UV images of Venus show striking cloud patterns, but visually they have a more subtle appearance, and only those observers who are sensitive to the bluer end of the spectrum are likely to see them in a striking way. In general the cloud markings take the form of streaks, although they can appear 'Y' shaped at times.

Occasionally bright spots have been seen on the disk, usually near the limb. The spots have also been imaged in UV suggesting that they are a real phenomenon.

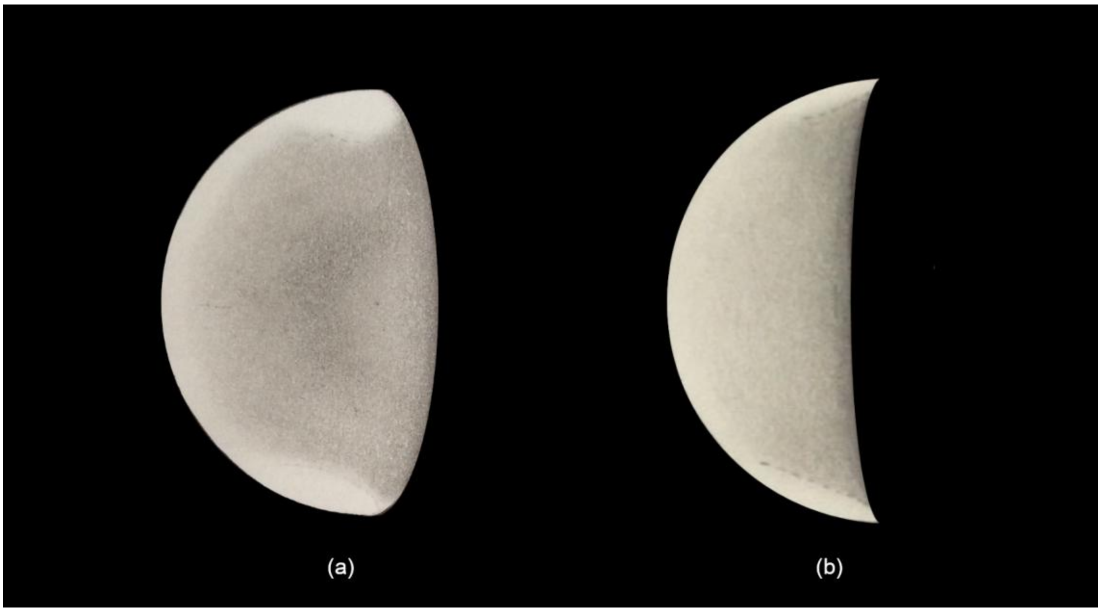



Figure 2.2. Two drawings of Venus by Richard McKim showing subtle markings and a difference in appearance between the northern and southern cusp caps. (a) 2023 April 17, 1906UT with a 75 mm OG, x120. (b) 2025 January 30, 1615UT with a 75mm OG, x120.

### 2.2.2 The cusp caps and collars

The north and south poles of Venus are highly dynamic. We know there are vast permanent hurricanes here which are thousands of kilometres wide. A region of extremely cold air surrounds these vortices keeping them permanently at the poles. Telescopically the poles of Venus are usually covered by bright cusp caps. These are neither constant in size or brightness; sometimes they are of equal size but one cusp cap might be much larger and brighter than the other. At other times one or both may be absent, and figure 2.2 shows a differing appearance between the two cusps. It is useful to keep track of their behaviour over the course of an elongation.

The cusp collars are darker cloud bands which appear below the southern cusp cap and above the northern cusp cap when Venus is viewed telescopically with north at the bottom. Like the cusp caps there can be quite a bit of variability in their appearance. Sometimes they may be absent, while at other times fairly obvious to see.

## 2.2.3 The terminator

This is the line which divides day and night. Images of Venus usually show the terminator is a little blurred due to the thick atmosphere. Visually it is usually better-defined, appearing as a uniform line. Near dichotomy when the planet is 50% illuminated, darker clouds on the terminator can make it appear somewhat 'jagged' and irregular in appearance.

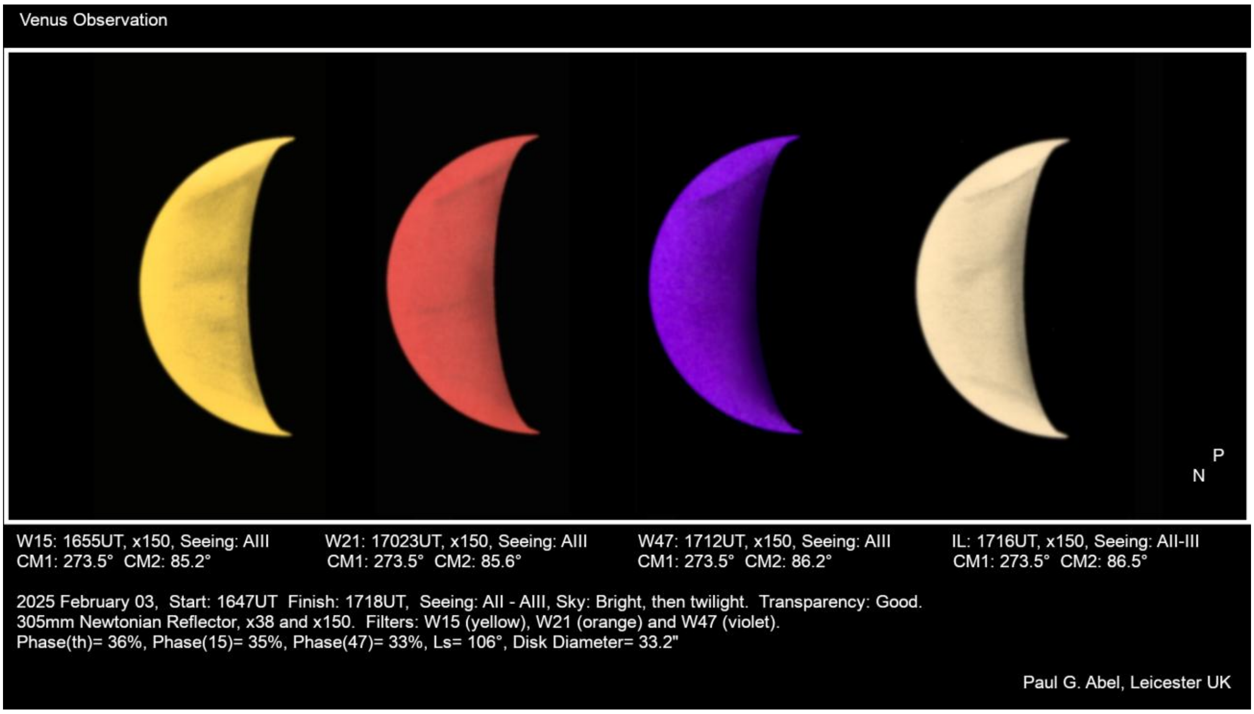



Figure 2.3. Four drawings showing the cusp terminator anomaly in white light and in filters. As can be seen, the terminator is noticeably flatter at the poles. The effect was a little more obvious in the W47 violet filter.

## 2.2.4 Cusp terminator anomaly

There is a phenomenon which observers should watch out for when Venus is in the crescent phase: this is the *cusp terminator anomaly* (CTA). Usually, the terminator of Venus has a normal elliptical shape as can be seen in figure 2.2. However, there are times when the terminator is notably flatter at the poles of the planet: this is the cusp terminator anomaly and my observation of it can be seen in figure 2.3.

The CTA has been recorded in images of Venus, but it does not appear during every elongation. When the CTA does appear, it generally occurs when Venus has a phase of 40% or less. When the CTA has been observed, it lasts only a few days or a week and is not present for the entire crescent stage. This suggests it might be the result of some sort of temporary atmospheric phenomenon at the poles of Venus.

## 2.2.5 The Ashen Light

We come now to a somewhat controversial phenomenon: observations of the rather elusive Ashen Light. When Venus is in its crescent phase, some astronomers have reported seeing the night side faintly glowing. These observers report that the effect looks rather similar to earthshine on the moon, although with a more coppery hue. Sometimes the whole of the nightside is visible, at other times, just patches of it can be seen.

The effect was first recorded in 1643 by the Italian astronomer Giovanni Riccioli and has been seen on and off since then by several observers. The phenomenon is difficult to observe since it can only be seen when Venus is set against a dark sky, and as a result, rather low down. It is not visible in every elongation, and there have been large gaps between sightings.

The existence of the ashen light has been difficult to explain until recently. In July 2020, NASA's Parker Solar probe imaged the nightside of Venus in deep-red wavelengths accessible to the human eye. Remarkably the hot glowing night side and surface details could be seen. Perhaps then, if there is a period of volcanic activity, and the atmosphere on the night side thins, the night side may be perceived by visual observers on Earth as the Ashen Light. The matter will no doubt only be completely settled when a visual observation is made at the same time as digital ones, particularly those made in the IR.

## 2.3 The importance of filter work

An optical filter is a piece of glass which allows some wavelengths of light to pass through while stopping others. As we have seen already, filters are included with many telescopes, and many colour filters are uniquely identified with the so-called Wratten number printed on the side of the mount.

As we saw in figure 1.3, filters allow us to look into different depths of the Venusian atmosphere. When imaging the planet, if we use a UV filter, this restricts our view to the upper atmosphere where the cloud patterns can be seen, whereas IR filters allow us to look deeper into the atmosphere. While filters used for imaging are different from visual filters, the fundamental principles are the same, and so blue and violet filters give us views of the upper atmosphere, while red and orange ones allow us to look at deeper layers. Not surprisingly then, the view of the planet can look somewhat different visually when different filters are used.

When making general observations for a disk drawing, I recommend using a W15 yellow filter; this cleans up the image and helps to bring out the cloud markings when they are present. It also sharpens the terminator which is why a W15 yellow filter should be used when estimating the phase of Venus (see section 2.5).

Below is a table which lists some optical filters commonly used by visual observers-most of these come with modern telescopes or can be ordered from most astronomy outlets at a fairly reasonable price.

| Filter (Wratten) Number | Colour | Phenomena |
|---|---|---|
| 12/15 | Yellow | A good general filter which helps sharpen the image. This filter should be used for phase estimates. |
| 25 | Red | Allows views deeper into the atmosphere. The cloud features may be much harder to see with this filter. It will sharpen the bright limb band and help with daytime observing. |
| 58 | Green | This filter is good for bringing out the cusp caps and collars when present. |
| 47 or 38A | Violet/deep blue | This filter is good for bringing out the cloud markings and will emphasize contrast between the cloud layers. The phase anomaly will be at its greatest in this filter. Note: these are dense filters and will only be useful for 203mm (8 inch) apertures and larger. |
| 80/80A | Light blue | A good filter for small telescopes: it will help reduce the glare from the disk and help increase the contrast of the cloud markings. |

Table 2.1. Some common optical filters and their use for visual observation of Venus

A number of advanced observers have tried stacking optical filters; that is to say combining two of them together. If you do attempt this make sure you record the results in your notebook- indeed you should record the results of all your observations even if they are routine.

## 2.4 Making a drawing

Making a drawing of Venus is straightforward. The BAA Mercury and Venus Section uses blanks which are 50mm in diameter. I use BAA Venus observing cards (see figure 2.4), which contain a Venus blank and spaces for all the relevant information which needs to be recorded for each observation. You can find them on the BAA website; simply print them off and cut them to size. You can attach them to a small clipboard and they are much easier to use at the telescope compared to drawing directly into a notebook.

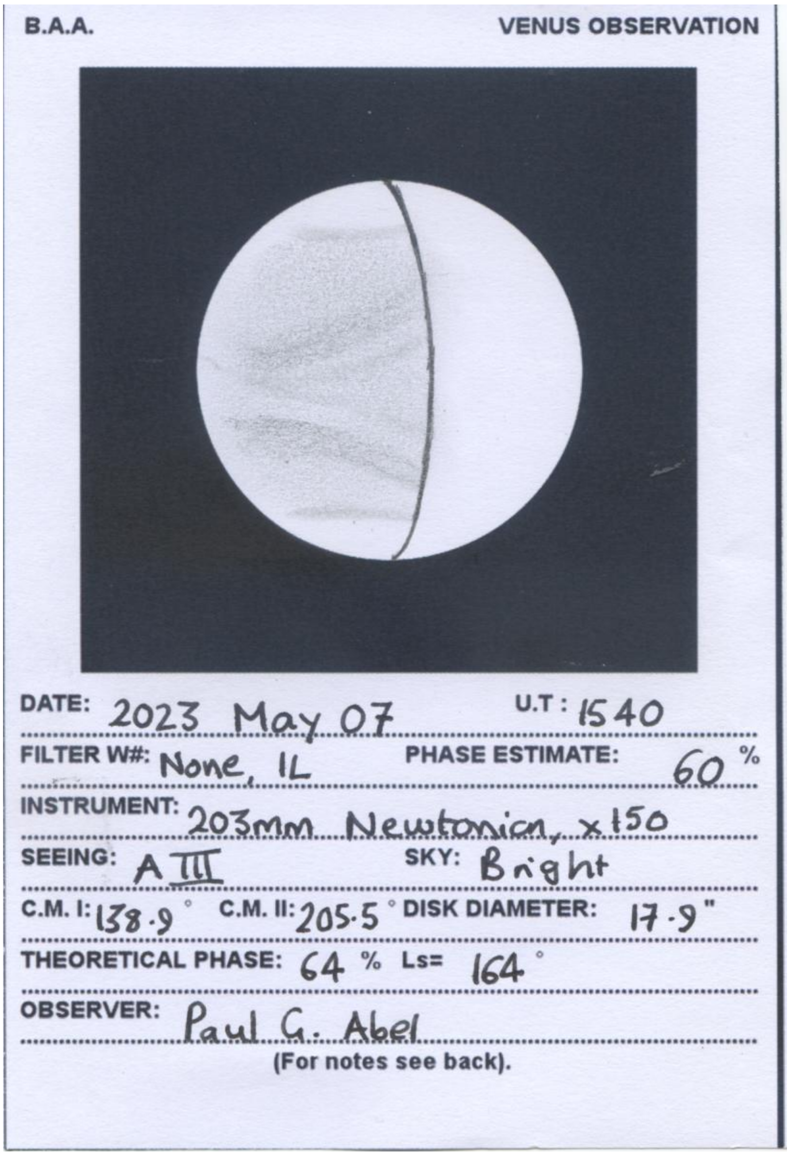



Figure 2.4. An observation of Venus made at the telescope using an observing card. All of the necessary observing details have also been recorded.

Before making a drawing, it is a good idea to spend some time finding a suitable magnification and looking at the disk to see what features are present. Your first drawing should be in W15 yellow or white light. The first thing you should do is accurately draw in the terminator. Next, draw in the obvious features like the cusp caps (if present) or any cloud markings. It is worth spending a little time to see if any other faint details become apparent. The drawing should take about 15 minutes to complete; once you have finished make a note of the date, time (in UT), telescope details, magnification and any filters used. The Venus observing card has places for you to put this and other information like the theoretical phase, disk diameter and Ls. The quantity Ls stands for 'solar longitude' or longitude of the Sun, and this essentially tells us where Venus is located in her orbit. At Ls=0 it is the spring equinox in the northern hemisphere of Venus, Ls=90 marks the summer solstice in the northern hemisphere, Ls=180 is the northern autumnal equinox while Ls=270 marks the winter solstice in the north. The value of Ls on any particular date can be obtained from the free software WinJupos, as can the values of the Central Meridan (CM1 and CM2). WinJupos is an excellent program which will give you all these details for all the planets in the solar system as well as showing you what can be seen at any given time on any planetary body from your location.

Once you have made your first drawing you should continue to observe Venus and record your observations on the main features shown in figure 2.1. You should note down comments on:

- General cloud markings: Are there any present or are any markings particularly dark? Are any bright spots present?
- Bright Limb Band: Is the bright limb band visible and complete, only partially complete or entirely absent?
- Terminator: Is the terminator geometrically regular or does it appear to have a somewhat 'jagged' appearance in places? Is the Cusp Terminator Anomaly visible?
- Cusp Caps: Are both cusp caps present? Are they of equal size or is one larger than the other? Are they of equal brightness?
- Cusp Collars: Can both collars be seen, or is one more prominent than the other? If neither the cusp caps nor the collars can be seen you should record this.

Once you have made the observation in W15 (or white light if you don't have a yellow filter), it's a good idea to observe Venus with the filters discussed in section 2.3. I would recommend making drawings of Venus for any filter that you use and recording your observations of the limb band, terminator, cusp caps and collars using filters as they may well appear quite different in various wavelengths.

Once you have made your observations, make sure you put your drawings in a notebook along with your other observations made at the telescope. You will find it very helpful to look back at previous observations you made during the elongation, and eventually over many elongations. Finally, please send your observations to the Mercury and Venus Section Director! This can be done just by scanning your drawing and notes, or scanning your drawing and emailing them any observations you have made about the features discussed.

## 2.5 Phase Estimates and the Phase Anomaly

The observed phase of Venus is always slightly less than the predicted or theoretical one. This phenomenon is called 'the phase anomaly of Venus' and was first observed and recorded by Johann Hieronymous Schröter in 1793. The effect is more pronounced in blue light and can be seen in images as well as through the eyepiece. The exact cause of the phenomenon is not completely clear although it seems probable that the thick Venusian atmosphere might play a part by scattering light and making the terminator less well defined.

Measuring the phase of Venus is actually easier with drawings than from images; generally the terminator of Venus is somewhat diffuse in images due to light being scattered by the dense atmosphere. Estimating the phase of Venus from your drawings is very easy, and I do this myself with every drawing of Venus I make in an elongation. To estimate the phase of Venus, simply measure the distance along the centre of the disk from the limb to the terminator- this is the distance x in figure 2.5 below.

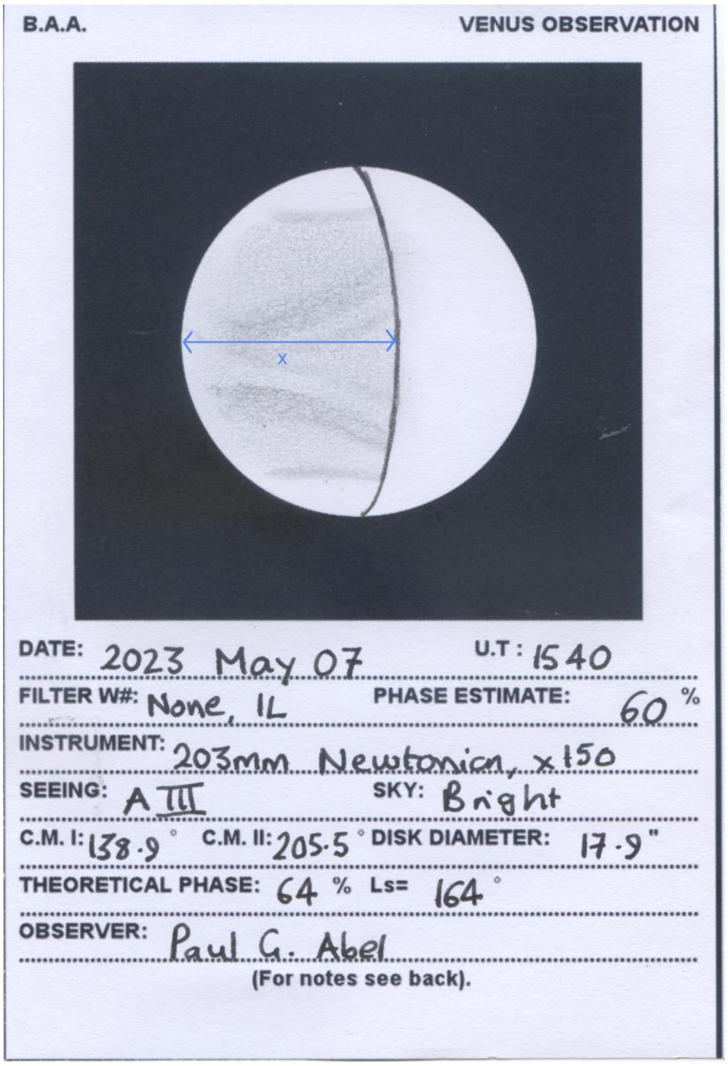



Figure 2.5: Measuring the phase of Venus from a drawing. We measure the distance from the limb to the middle of the terminator; this is the value x. We then divide this length by the diameter of the blank to get the phase.

The observed phase is then found from the formula

$$phase = \frac{x}{D}$$

In figure 2.5, the length of the line x is 30mm, and D is the diameter of the blank, which is 50mm, hence the observed phase of Venus in figure 2.5 is

$$phase = \frac{30}{50} = 0.6\,,$$

i.e. the phase of Venus at the time of observation is 60%.

Notice in figure 2.5 that the theoretical phase predicted for this date was 64%, so the observed phase is smaller (as we would expect) at 60%. Most members who do phase work do so when Venus is between 70% to 10% as it is during this time the phase anomaly is most noticeable. Once you have your phase estimates, you can plot them on a graph of date vs phase to see how the phase changes over the whole elongation.

Dichotomy is the time when Venus appears to be exactly 50% illuminated, however the phase anomaly means that the observed date of dichotomy is always different from the predicted one. So, when Venus is in the evening skies, because the observed telescope phase is always less than the theoretical one, dichotomy is always a few days earlier than predicted. Conversely when Venus is in the morning sky, dichotomy is always later than predicted. It is interesting to note that the difference between the date of observed dichotomy compared to the date of theoretical dichotomy is not constant. It can be as little as three days or as much as seven.

Recording the observed date of dichotomy has been one of the primary aims of the Mercury and Venus section for many decades. To estimate the date of dichotomy, start observing Venus about ten days before the date of predicted dichotomy. You should observe Venus using a W15 yellow filter as this will help sharpen the terminator. Keep observing the planet until the terminator becomes a straight line.

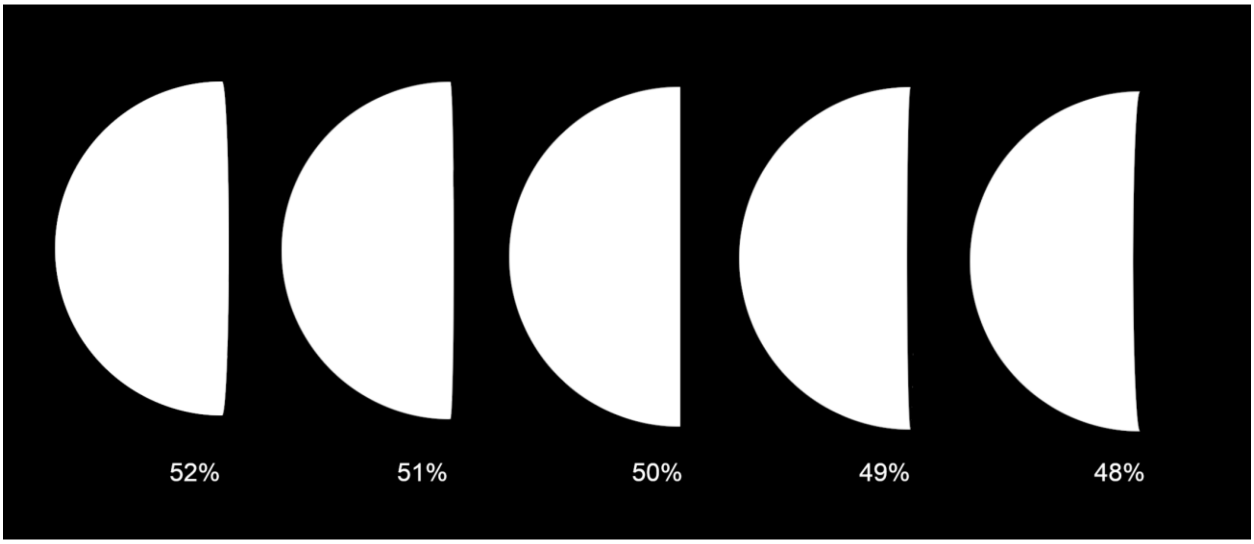



Figure 2.6. A graphic showing Venus from 52% to 48% - as can be seen these phases look very similar so care must be taken when estimating the date of observed dichotomy. (Paul Abel)

A word of caution when estimating the phase of Venus should be given here. Venus at 51% or 49% does look very similar to Venus at 50%, particularly if the seeing is poor, so care must be taken to ensure that the terminator really is a straight line indicating the planet is truly at dichotomy. Figure 2.6 shows Venus at phases from 52% down to 48%: as can be imagined, if the seeing is poor then a 51% phase might easily look like 50%. Using a yellow filter will help, but also try to observe when seeing is as good as it can be on the day as this will help to reduce errors.

This concludes the sections on visual observing. As can be seen in this chapter, visual observations of Venus are still very important and I would encourage everyone to make them. Above all else, make sure you record your observations in a systematic and orderly way (the logbook is a tried and trusted method!) and of course, send your observations regularly to the Mercury and Venus Section Director!

# 3. Observing Venus in the Ultraviolet.

***Chris Dole***

In visible light the thick white clouds that surround the planet Venus show very little detail. To most the view at the eyepiece is that of a featureless, white globe. Perhaps a hint of contrast can be discerned around the polar regions but even that can be very difficult to be sure of.

It is interesting to note though that some observers report that they can see more in the way of features than others. It has been established that this is due to these observers having eyes that are more sensitive to the blue part of the visible spectrum. It is indeed the case that as we go into, and beyond, the shorter blue wavelengths then cloud structure does become apparent. When observations are made in the ultraviolet then structure can be more readily seen.

The darker areas seen are due to an ultraviolet absorber which is present in the Venusian clouds. The precise identity of this absorber is currently a mystery but research is ongoing. The human eye has no sensitivity to the UV part of the spectrum which means that imaging needs to be employed.

## 3.1 Equipment

### 3.1.1 Telescopes

The choice of telescope can have a significant effect on the result when imaging in the UV. The best suited type of telescope will be one of a purely reflective design if possible. This is due to the fact that most commercially manufactured telescopes that include refractive elements are optically corrected to operate in visible light, and will introduce optical aberrations when used outside this region. However, it must be said that these effects can be fairly mild, and often poor atmospheric seeing in the UV can make the impact of these aberrations less noticeable.

Perhaps more of a problem can be the types of glass used in these refractive elements and the anti-reflection coatings employed on the surfaces of the lenses and correctors. Some glass types have poor transmission in the UV, and this is also true of the coatings used. This combined reduction in UV transmission leads to a fainter signal which can be problematic when recording data. However, this does not totally exclude catadioptric designs, and many observers obtain good results with Schmidt Cassegrain and Maksutov type telescopes as the aforementioned disadvantages can be overcome to some degree, as will be covered later in this article.

The least suitable type of telescope for UV observation is the refractor. This design maximises all the negatives outlined above, i.e., correction for visible light, glass types that are poorly transmissive in UV and multiple surfaces which may have coatings which reduce UV throughput. Unfortunately, obtaining the full specifications of the glasses and coatings used is notoriously difficult when dealing with the main manufacturers of mass-produced telescopes. This may be due to the materials changing over time due to cost and availability. Refractors have the added disadvantages of relatively small aperture and shorter focal length. The latter would require the use of a Barlow lens or telecentric amplifier to increase image scale, which would add even more problems regarding glass and coatings.

In summary, pure reflectors such as the Newtonian, Classical Cassegrain and planetary Dall-Kirkham types are well suited to UV imaging. Catadioptric designs such as SCTs and Maksutov telescopes can be used successfully but are at a slight disadvantage. Refractors are the least suitable for UV imaging.

It must be said at this point that over recent years 'enhanced aluminium coatings' have become available. These mirror coatings provide increased reflectivity in the visible and greater durability than the traditional aluminium coatings but suffer a significant reduction in reflectivity below 400nm. If the telescope to be used has these enhanced mirror coatings, then this could be a possible issue, and it is advisable to contact the coating company for advice before spending money on a filter.

### 3.1.2 Cameras

The imaging technique used for this kind of work is the same as for planetary imaging generally, which is sometimes referred to as 'lucky imaging'. This involves the recording of high frame rate video, then extracting the best frames and stacking them to produce a final image. Both CCD and the more modern CMOS planetary cameras are suitable. Cameras from ZWO are a very popular choice among amateur astronomers, as well as those produced by such companies as QHY and Player One. Mono cameras are the preferred choice, because the Bayer filter matrix used in colour cameras absorbs significantly in the UV, reducing the image brightness, which will make an acceptable result harder to achieve.

Even mono cameras tend to have lower sensitivity in the blue/UV part of the spectrum than in the visible, although CMOS types are better in this regard. The published graphs which show the sensitivity of the chips tend to neglect the UV sensitivity and concentrate on the visible/IR range, but the relative UV sensitivity is typically from 30%-50% of the peak, depending on which camera model is used.

Another small issue can be that some cameras use a 'cover glass' to protect the chip. This can have anti-reflection coatings which hamper UV transmission. They can be removed but the effect is generally small and removal may not make a significant difference. It will also render the camera more liable to dust landing on the sensor cover-glass, and may void the warranty of the camera.

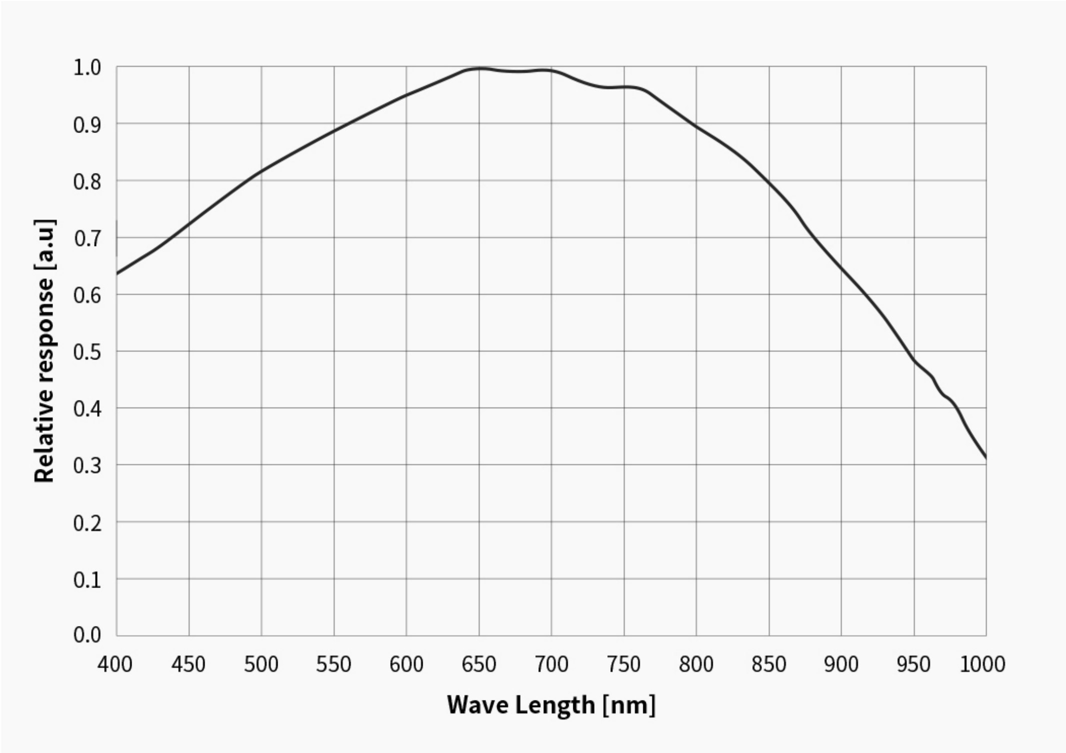



Figure 3.1. An example of a relative response graph produced by ZWO for its mono cameras. It gives a good indication of the sensitivity of the camera at visible wavelengths. The curve can be extended into the UV to estimate the sensitivity there.

### 3.1.3 Filters

For successful imaging in the UV, a suitable filter must be used. This type of filter only allows a fairly narrow bandwidth to pass through, generally about 60nm in width and centred at around 350nm-360nm wavelength. Producers of these filters include Optolong, Astrodon, Player One and Baader among others. There is some relatively small variation in performance regarding transmission and bandwidth but all can produce satisfactory results. These filters are available in the familiar sizes of 1.25" and 2" and are fitted to the nosepiece of the camera being used in the usual way. They are unfortunately somewhat expensive and generally fall in the £200+ price range currently. This is due to it being quite difficult to produce a filter of this kind, with many different layers of material needing to be deposited on the glass substrate. Figure 3.2 shows an example of a Baader UV (Venus) filter.

Some of the earlier filters that were produced suffered from what is known as an infrared 'leak'. That is to say that some IR light would also pass through the filter. This would produce a secondary image that would appear as a displaced 'ghost' image. This displacement is caused by atmospheric dispersion. If this second image were to overlap the UV signal, then contrast would be lost. Improvements in the manufacturing processes employed with the more recent filters seems to have all but eliminated this issue, but those who possess older filters or buy one second-hand should be aware of it.

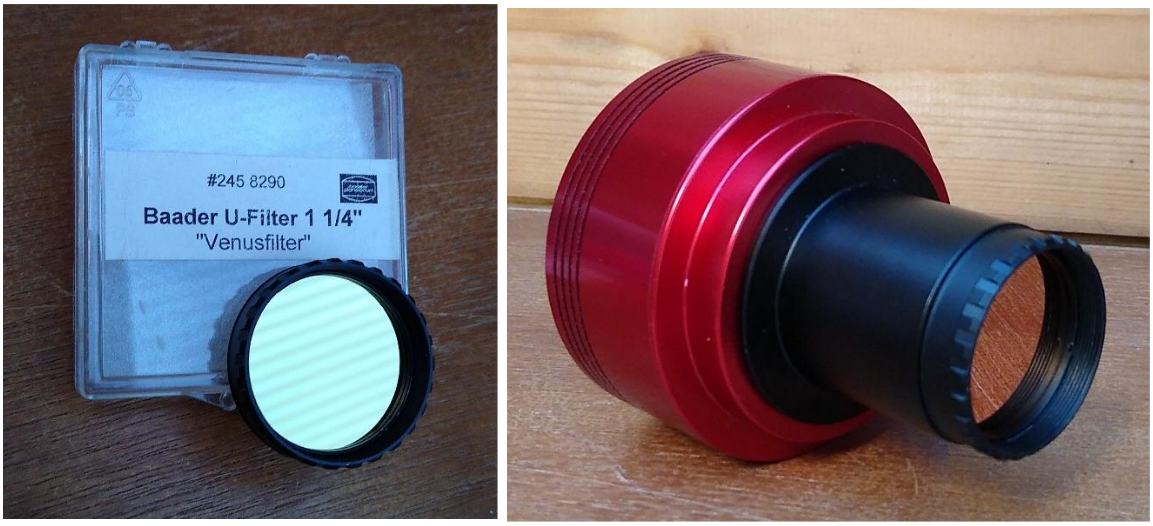



Figure 3.2. (Left) An early Baader UV filter and (right) fitted to the nosepiece of a ZWO ASI290MM mono camera.

As mentioned earlier in this article, the commonly used catadioptric telescope types such as SCT and Maksutov designs are somewhat less suited to UV imaging. Most correcting plates are made from glass types with fairly good UV transmission, but coatings can be problematic and optical correction is a further problem. The optical correction for visible light can lead to a soft image when imaging in the UV. This situation can be improved though by the choice of filter. The use of a filter which passes a blend of UV and visible violet can be useful for SCT and Maksutov telescopes. The image is brighter due to the wider passband and the fact that the planet itself has an increase in brightness above 400nm. The telescope is also better corrected for the visible part of the transmitted wavelengths.  The resulting image won't have quite the contrast of a pure UV filter but good results can be achieved. These filters are not available in the standard 1.25” and 2” sizes that we usually see in amateur astronomy as they are produced for scientific work by companies such as Thorlabs and Edmund Optics. Some kind of custom filter holder would need to be made but this can be done with a little ingenuity. They are also a little more affordable than the pure UV filters, costing around £130 at the time of writing.  The Thorlabs filter #FBH400-40 is a good example of these UV/Visible filters.

Perhaps the cheapest filter solution is to use a Wratten #47 violet filter which are quite commonly used by amateurs for visual planetary observing. Cloud details can be seen using this filter but contrast is much lower. This is due to the #47 having quite a broad bandpass. It also suffers from a noticeable IR leak which means it needs to be used with an IR blocking filter, which is likely to block UV light. These factors together mean that the resulting image will be of very low contrast but some of the cloud features can be seen.

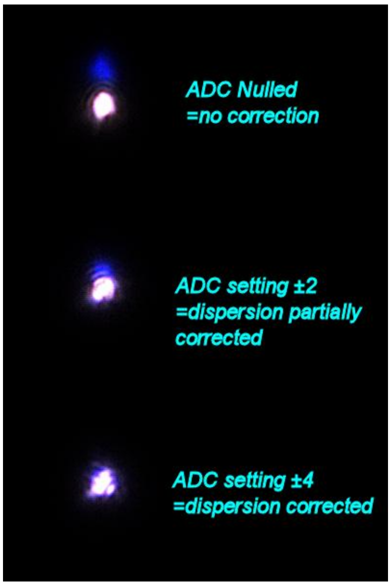



Figure 3.3 is an example of the effect of using a filter with an infra-red leak for UV images. It shows images of a star taken using a colour camera through a Wratten No 47 filter, with the two components clearly separated by atmospheric dispersion. The upper UV component is fainter due to the lower sensitivity of the camera in the UV. It also shows how such an issue can be corrected using an atmospheric dispersion corrector (ADC) as described in Section 3.2 below. For imaging Venus in the UV it is of course far better to block the infra-red light, or use a filter with no IR leak, than to superimpose the IR image on the UV image, where it would reduce the contrast of the UV features.

Figure 3.3. Star images taken through a Wratten No. 47 filter, showing separated UV (upper) and IR images of a star at around 28 degrees altitude, and how an ADC can be used to correct the separation. (Image courtesy of Martin Lewis).

### 3.1.4 Data Capture

The video capture software that is used by planetary imagers is perfectly suitable for UV imaging. Perhaps the most popular are the excellent FireCapture and SharpCap. These are very feature rich and free for the user to download.

Although visually Venus is a very bright object, in the UV the planet is considerably fainter, as can be seen from the spectrum of the planet (Figure 3.4), and this can be worsened by the equipment being used. All this makes for a relatively weak signal which will require a higher gain/exposure to be used. The upper clouds, which are being observed when using UV light, rotate about the planet once in about four days. This means that rotational blurring is not a major problem and data recording can last for several minutes. The poor seeing quite often encountered when observing in UV light does necessitate the capture of a high number of frames to increase the chances of capturing those all-important moments of good seeing.

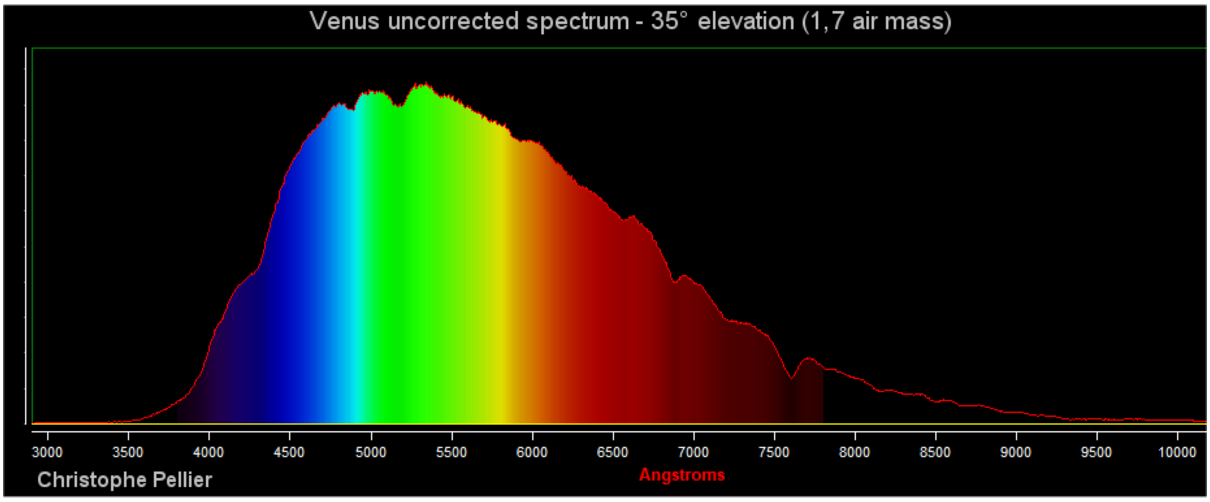



Figure 3.4. Spectrum of Venus captured by Christophe Pellier showing the drop in brightness in the UV beyond 400 nm.

The processing of the video is also similar to the general approach employed for planetary imaging, and each observer will develop their own particular method. It will usually be found that the sharpening part of the process will need to be more aggressive than for other targets in order to tease out the low contrast features. Each observing session will likely differ and this will affect the processing approach employed.

## 3.2 The Atmospheric Dispersion Corrector

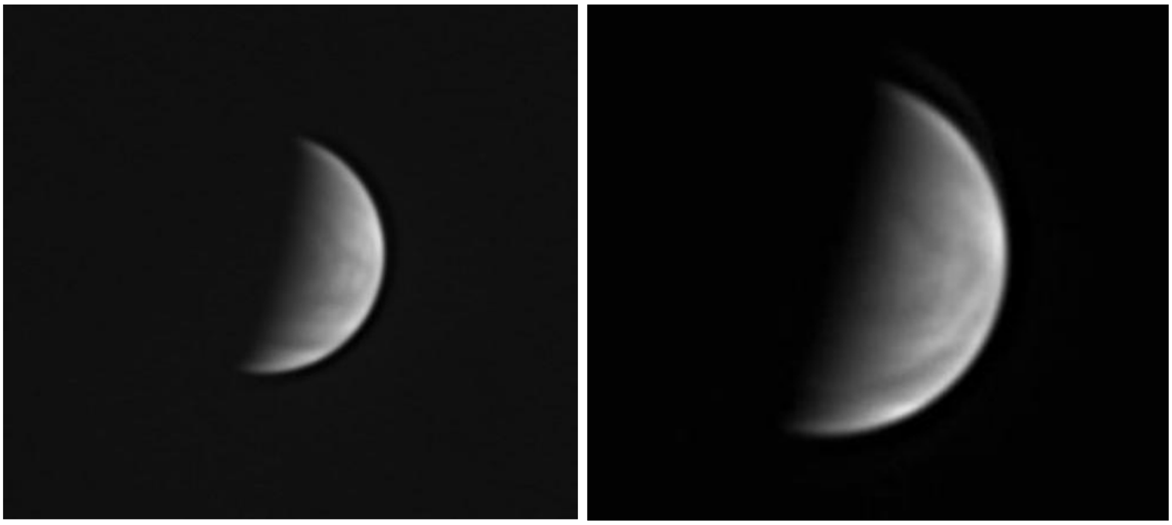
A piece of equipment which is very useful when imaging planets is the atmospheric dispersion corrector, or ADC. This device uses a pair of thin prisms which are rotated relative to each other to correct the blurring caused by atmospheric dispersion. When observing away from the zenith the Earth's atmosphere acts as a prism and refracts different wavelengths to different degrees causing a blurring effect. When observing in the UV we are using a fairly narrow bandwidth, but because shorter wavelengths are more greatly dispersed, using an ADC can be beneficial. This raises the question of whether the glass and coatings used in the ADC will be detrimental, but it seems that the materials used by the manufacturers of the popular models have been chosen with UV use in mind, and the effect on transmission is minimal. This is certainly true for the ZWO and Pierre Astro units. ADC models from other manufactures seem to be regularly used successfully but a little research could be useful if unsure. Figure 3.5 shows an example of an ADC from ZWO.

Figure 3.5. An atmospheric dispersion corrector (ADC) from ZWO.

Setting the ADC can be done by first using a colour camera to adjust the prisms and minimise the colour fringing, and then switching to the mono camera for data capture. Another effective method is to use the mono capture camera but use a Wratten #47 violet filter. Adjust the camera exposure/gain until the IR leak is visible, then adjust the ADC until the two images merge. Then change back to the UV filter to be used for data capture. This can be a little fiddly in cold weather when wearing gloves but one solution is to mount the filters in a filter wheel.

## 3.3 When to Observe

It is generally the case that observations of Venus can be carried out during broad daylight when the planet is higher in the sky, but this is not true when imaging in the UV. Scattered UV light in the Earth's atmosphere makes the sky very bright and renders the planet barely visible with the Sun high above the horizon. Just as significant is the issue of the often very poor daytime seeing. This situation is made considerably worse as the shorter wavelengths being observed are affected even more than visible light. A good time to observe is around the time of sunrise/sunset. The twilight period offers a darker sky and an often much improved chance of better seeing conditions. In some apparitions Venus can also be quite high in the sky, so improving the chances of success even more. Under good conditions the results can be very pleasing, as shown in Figures 3.6 and 3.7.



Figures 3.6 & 3.7. Two examples of UV images of Venus taken by the author. They were taken with a 180mm aperture Maksutov Cassegrain, and demonstrate that although not the best instrument for UV imaging, good results can be achieved.

It is often said that when it comes to planetary imaging the seeing conditions are the most important factor of all. This is especially true when imaging in the UV. On many occasions the terrible seeing will thwart any attempt. Patience really can be a virtue in this pursuit!

## 3.4 In Conclusion

UV imaging of Venus is something which can be readily attempted, especially by observers who are familiar with planetary imaging in the visible, as the principles and procedures are very similar. It can be challenging due to the difficulties introduced by equipment design and sensitivity and the often poor seeing encountered in this part of the spectrum. There is also the fact that the planet itself can be a challenge as it spends significant periods of time close to the Sun and/or low in the sky. However, when all those difficulties are overcome, it is well worth all the effort to reveal the details in the upper clouds of one of the Earth's nearest neighbours.

# 4. Making IR images of Venus

***Peter Tickner***

## 4.1 Introduction

Anyone who has tried telescopic imaging of Venus with an infrared (IR) filter in addition to RGB imaging may well wonder whether there is any point, as at first glance images taken in the near IR can look as devoid of features as any colour image of the planet. Despite this, there are many fine details in the clouds on Venus to be found at the infrared end of the spectrum, provided the observer is careful in their processing of captured video data to enhance the image while at the same time avoiding introducing artefacts from over-sharpening. Infrared imaging also comes to the fore when Venus is close to the Sun at inferior conjunction, when it is possible with care to detect the thin crescent and horns of Venus, which at other wavelengths such as visible light will be lost to the glare of the Sun.

Before going any further it is important to note that while it is perfectly possible to take a still image of Venus either with a traditional DSLR or using a single frame from any CCD or CMOS astronomy camera, this is not a route to obtaining the best quality images of Venus or to detect subtle details that can be found in its clouds at IR wavelengths. By far the best means is to capture video data at the shortest exposure times and fastest frame rates possible with one's setup. Lucky imaging techniques can be used to select the best images from each video to produce a stacked result that will be far superior to any single shot taken with a conventional camera or a still from a video.

The lower clouds and surface of Venus at 475° C are extremely hot and that is where infrared filters come into their own, as heat radiation is detectable at the infrared end of the spectrum and any variation in that radiation will be detectable as lighter and darker areas in the image. Infrared imaging can also enable some beautiful images of Venus with steadier seeing than at visible wavelengths between 400 and 700 nm; the example below from Martin Lewis in 2020 using an 807 nm long pass filter shows how even a straightforward infrared image can have impact.


Figure 4.1. Venus imaged in the infrared in May 2020 by Martin Lewis.

The infrared wavelengths that amateurs can detect with their imaging equipment fall within the part of the spectrum known as near infrared, which covers wavelengths invisible to the human eye between approximately 700 nm and 2,500 nm. In this section we will be discussing using equipment to image successfully at the infrared wavelengths between approximately 650 nm and 1,000 nm. There are specialist cameras capable of imaging near infrared wavelengths from 1,100 nm to 1,700 nm, but they are not suitable for amateur astronomy, as except through an extremely large telescope the resultant image is both noisy and lacking in detail.

Long pass filters and band pass filters of various bands between 740 nm and 1000 nm have been successfully used by amateurs to detect cloud features and potential anomalies in the cloud patterns around Venus. Clouds have also been detected at much shorter wavelengths in the ultraviolet, and this topic is covered in detail in section 3 of this guide. The advantage of detecting clouds in infrared over ultraviolet is that the image is far steadier at the longer IR wavelengths and that can enable far more subtle detail to be captured.

We know from some of the missions that have visited or orbited Venus that it has complex layers of clouds that rotate at differing speeds to each other and at a significantly faster speed and opposite direction to the spin of Venus. The faster clouds appear to rotate around Venus every 3-4 days and the slower clouds around every 5 days, although cloud patterns have been measured with rotation periods as long as 8 days.

The next illustration demonstrates some of the cloud features that it is possible to detect with larger amateur instruments imaging through near infrared filters, in this case using a ZWO 850 nm IR pass filter.

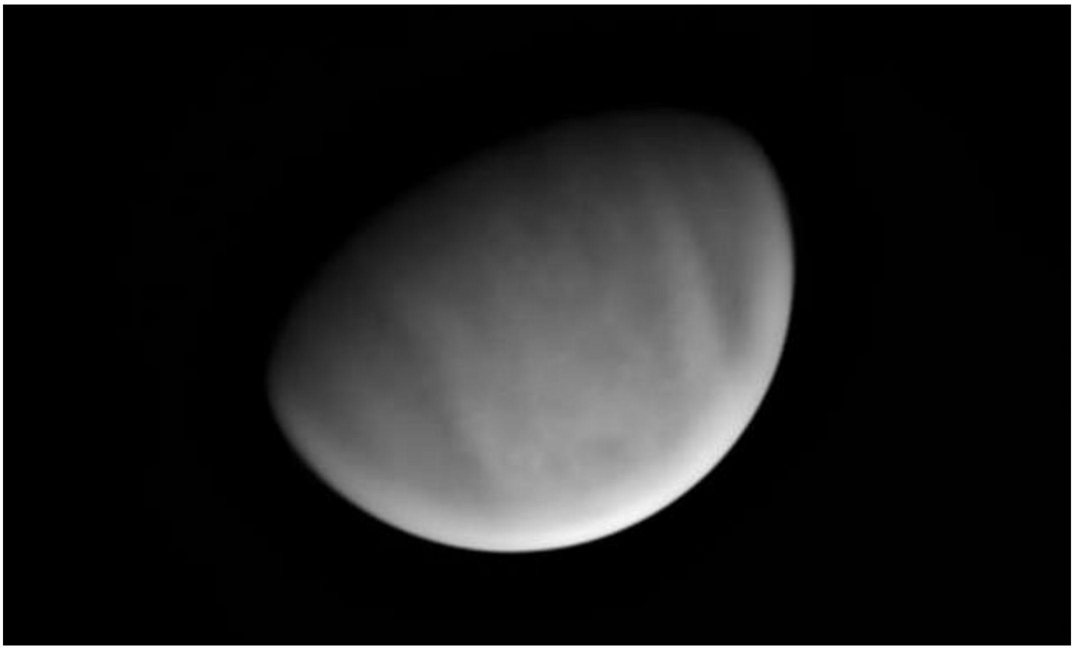


Figure 4.2. Venus through a 16 inch Dobsonian, 3x Barlow, ADC and ZWO 850 nm pass filter and ZWO ASI462MM camera, April 2023 (Tom Williams).

### 4.1.1 When to image Venus in the IR

The resonance of Earth's orbit to that of Venus creates a repeating pattern over time. As a rule of thumb each alternate elongation to West or East of the Sun will lead to a pair of opportunities for observing Venus either side of inferior conjunction. The two opportunities are not equal. For UK observers (and Northern Europe in general) one will result in Venus rising in the East or setting in the West at a favourable angle and being visible relatively high in the sky. The other will result in Venus rising or setting at a shallow angle to the horizon and for all practical purposes almost horizontal to the Sun as well as being seen through more of the Earth's atmosphere than if it were higher in the sky.

All observers of Venus - whether imaging or observing visually – need to bear in mind that for a significant proportion of the orbit of Venus it is relatively close to the Sun and either a dawn and daytime object or a daytime and dusk object. Venus is always at its best for those wishing to image in infrared when it is in the arc from maximum elongation through to its closest to the Sun at inferior conjunction. While it is perfectly feasible to obtain infrared images of Venus throughout most of its orbit it is always harder to detect details or obtain a better quality image when it is on the further side of the Sun to the Earth.

The good news for those wishing to image Venus in infrared is that because of its brightness it is possible to image it in full daylight, at dawn or dusk as well as at night-time when its angular separation from the Sun permits. Experience has taught us that while daytime imaging is feasible, Venus is often affected by the light from the Sun scattered in our atmosphere when the two are visually close to each other. Equally, when the Sun is at its highest in the sky, the Earth's atmosphere can be at its least steady for any attempts to image Venus however far from the Sun. As a rule of thumb it is best to attempt to image Venus at dawn or dusk or when the Sun is relatively low in the sky and Venus relatively high.

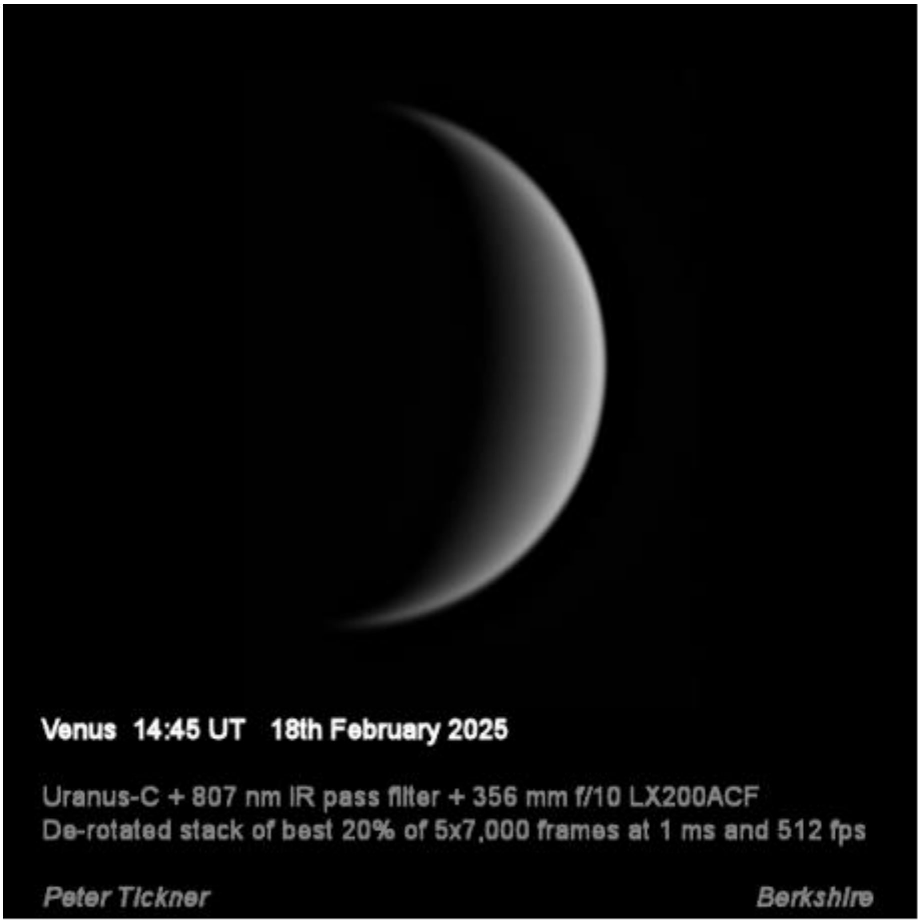



Figure 4.3. An image taken in afternoon daylight with an 807 nm long pass filter. The best 20% of 35,000 video frames of 1 ms exposure were stacked to create a smooth final image.

### 4.1.2 Protecting the telescope

When Venus is approaching or leaving inferior or superior conjunction it will be necessary to shield the telescope from the Sun. This is particularly important for SCTs and Maksutovs with their front corrector plates and primary mirrors that need to avoid direct sunlight, but also applies to any scope where the optical chain may be compromised by a direct hit from the Sun's rays. Most dew shields are not long enough to perform this function effectively without assistance. An example of an appropriate additional shield is one that can be easily and cheaply made from readily available lightweight foam display board stocked by most hobby shops (figure 4.4).

Figure 4.4. Using a suitable lightweight shield with a 14inch SCT when Venus is close to the Sun, to protect the imaging chain from direct sunlight. (Peter Tickner)

## 4.1.3 Imaging Venus near inferior conjunction

As Venus reaches inferior conjunction the infrared imager has the opportunity (if conditions permit and appropriate safety precautions are taken) to image Venus at its very thinnest, a thin arc in the sky at a point when it will be 50% larger than Jupiter usually appears. On rare occasions amateurs have not only imaged the so called horns of Venus but even been able to image a complete halo.

**WARNING: Both the horns and the halo present a challenge and a significant risk to the observer and their equipment. The scope and imaging chain must be protected from direct sunlight as the Sun will be very close to the field of view. Locating Venus under these conditions requires great care, and should be attempted only by observers who understand the risks and are fully aware of the techniques for mitigating them.**

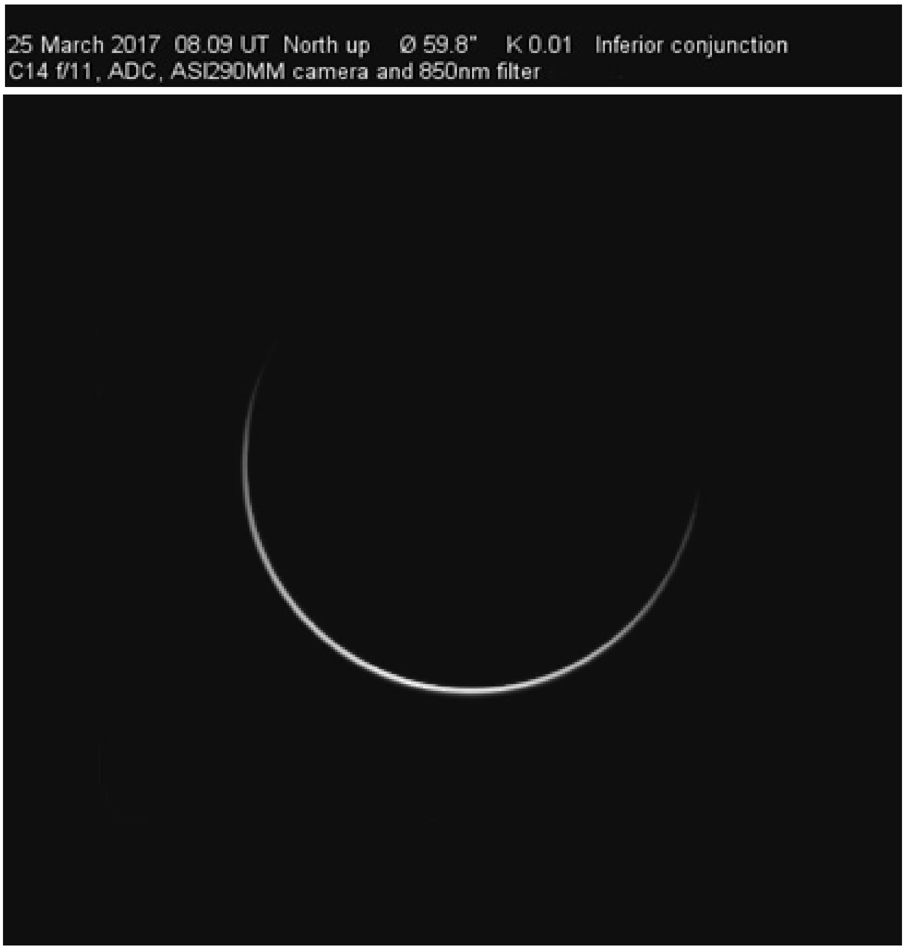


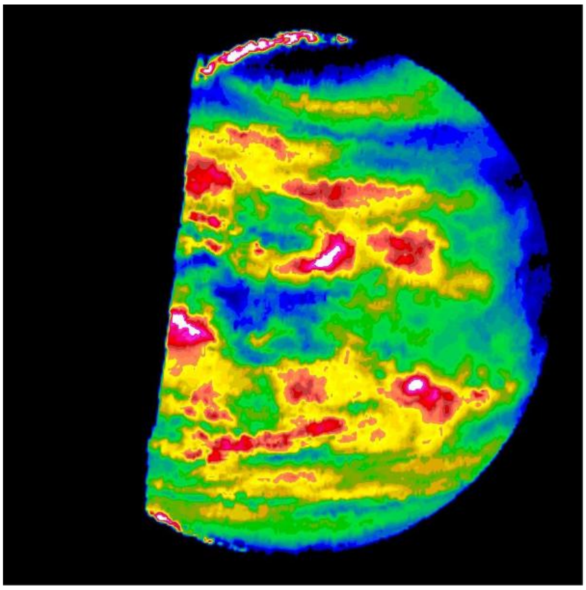

Figure 4.5. John Sussenbach's superb image of the horns of Venus near inferior conjunction in 2017.


Figure 4.6. A rare complete halo of Venus using a 742 nm long pass infrared filter. (Pete Lawrence)

## 4.1.4 Imaging in longer wavelengths

Professional observatories and space missions monitor Venus at wavelengths in the near infrared end of the spectrum from 1.1 microns upwards with specialist cameras beyond the pockets of most amateurs. Two planetary camera manufacturers (ZWO and QHY) also market cameras capable of detecting near infrared light in the range between 1.1 and 1.7 microns but these cameras are not suitable for amateur astronomy. Aside from their prohibitive pricing at well over £12,000 each, they have large pixels and relatively low sensitivity. This means they can only produce noisy low resolution images lacking detail unless used with large aperture telescopes of the type found in professional and university observatories.

The space missions that have targeted Venus have concentrated on looking at Venus in the near infrared and infrared at wavelengths significantly longer than those used by amateurs. In 2007 the European Space Agency's VIRTIS mission obtained a simultaneous night and day side image of Venus by using a combination of data at 1.7 microns for the night side and 3.8 microns for the day side.



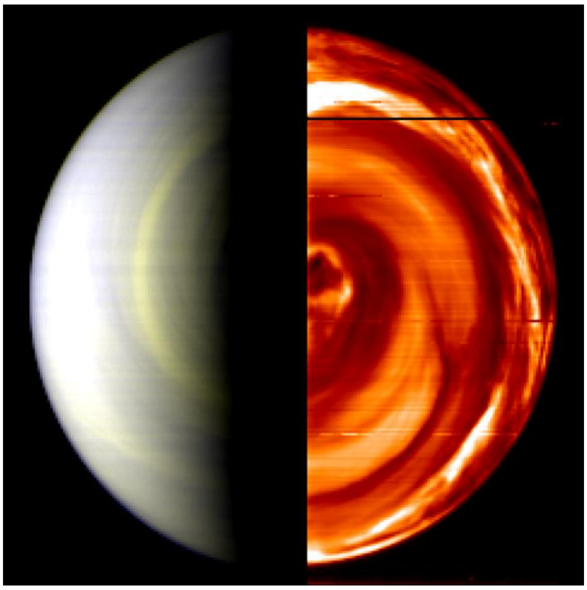


Figure 4.7(a) (left). Venus imaged by the near infrared spectrometer aboard the Galileo spacecraft, February 10th 1990. The image shows a mix of surface features and low-level clouds. (NASA)

Figure 4.7(b) (right). The false colour ESA VIRTIS image shows the day and night sides from above the south pole of Venus in 2006. © ESA/CNR-IASF, Rome, Italy, and Observatoire de Paris, France.

## 4.1.5 The Cloud Discontinuity

It is one of the curiosities of Venus that the clouds rotate in a matter of days in the opposite direction to the slow spin of the planet, which takes 243 Earth days to complete one rotation. Sometimes this conflict seems to cause great rifts or ridges to appear in the clouds, as if they have been torn apart like a pair of curtains. Known as the Cloud Discontinuity (CD), this feature was first identified in 2016 by the Japan Aerospace eXploration Agency (JAXA) Akatsuki mission (Javier Peralta et al, 2022). Such rifts or ridges are rare but when they do occur they are visible in IR as a split or dark wave running broadly from North to South that will rotate within a day or so and may either disappear for four or five days before reappearing or may vanish after one day's sighting.  On several occasions in recent years amateur imagers have been able to record and track over a day or two these instances of the cloud discontinuity by using infrared filters (figures 4.8 & 4.9).

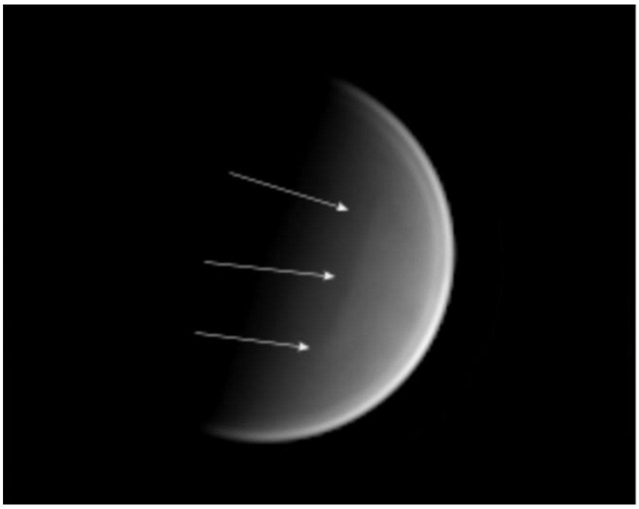


Figure 4.8 (a). Venus cloud discontinuity detected in 2020 by Nick Haigh using an 807 nm filter.

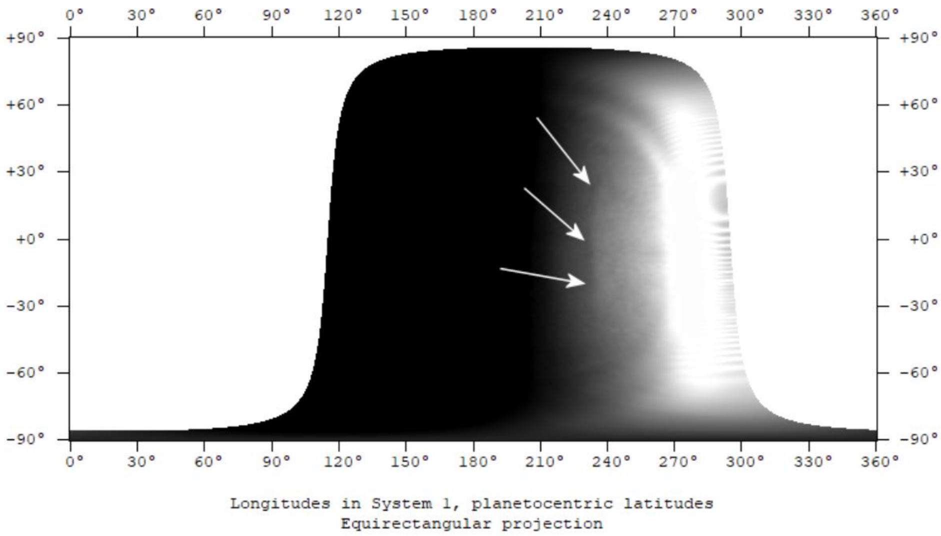



Figure 4.8 (b). The same image as Figure 4.8 (a), projected onto Venusian coordinates.


Figure 4.9. Cloud discontinuity images recorded by amateurs using IR filters (Peralta et al, 2022).

For the amateur observer imaging Venus in the near infrared there is a myriad of possibilities from the 'holy grail' of detecting a cloud anomaly through to capturing beautiful images of a crescent Venus or the horns of Venus when close to inferior conjunction.

## 4.2 Choosing the right equipment to image Venus in the near infrared

### 4.2.1 Cameras with IR sensitivity

Commercial CMOS and CCD cameras sold for security and machine vision applications are unable to detect anything of significance at wavelengths greater than 1 micron. Examination of the performance of many CMOS cameras for sale to the amateur astronomy market will show that from around 800-900 nm the sensitivity of the camera rapidly reduces and by around 1 micron is close to zero. Happily for those wishing to observe Venus at near infrared wavelengths there are cameras that have reasonable sensitivity at the required wavelengths. By near infrared for the amateur observer we are talking about wavelengths overlapping with visible red light (around 650 nm) through to around 1 micron (1,000 nm).

Not all cameras are equal in their ability to detect light efficiently in the near infra-red and it is important to check the quantum efficiency (QE) of any camera intended to be used in this part of the spectrum, as their performance can vary significantly. Generally the latest generations of planetary CMOS cameras, particularly those with the Sony Pregius range of sensors and Starvis 2 technology tend to be far more sensitive in the near-IR than their predecessors. But even among this family of sensors there is wide variation in their efficiency to detect the longer infrared wavelengths.

Most camera manufacturers will supply QE plots for their camera's performance and these are a good (but not infallible) guide as to which camera to choose for IR work on Venus. Sensor suppliers such as Sony guard their technical secrets and can sometimes provide approximate data for public consumption at variance from actual camera and sensor performance. A combination of QE plots and user forums can help confirm whether a particular camera is likely to be a good one at infrared wavelengths.

Figures 4.10 (a) and 4.10 (b) below are examples of QE plots provided by manufacturers for particular sensors. QE plots are graphs of the relative efficiency of the sensor as a function of wavelength over the range where the sensor is likely to be useful. In the case of colour cameras the QE values include the transmission properties of the filters in the Bayer matrix. The QE plot in figure 4.10 (a) is an example of a latest generation Sony Pregius sensor that has relatively good QE for near infrared wavelengths between 700 nm and 1000 nm with the QE dropping from around 75% in the red at 700 nm to around 18% in all colours at 1000 nm. Note that at a certain point all (around 850 nm in this instance) all the filters become transparent, and beyond that wavelength the colour sensor is for all practical purposes functioning as if it were a mono sensor. Figure 4.10 (b) shows the QE curve for an older mono sensor, the Sony IMX174, which is significantly less sensitive in the IR than the newer colour sensor.

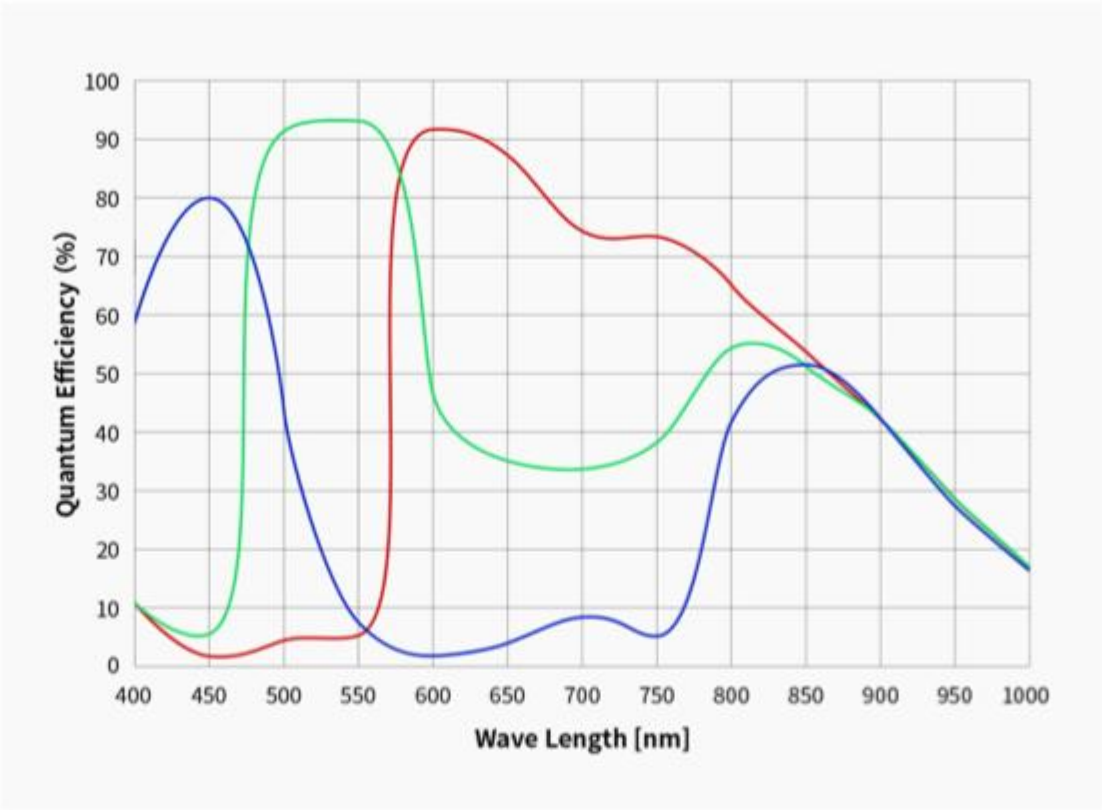



Figure 4.10 (a). The QE chart for a camera with the colour Sony IMX662 sensor. The coloured lines refer to the red, green and blue colour channels. At wavelengths of 850 nm or greater all three colour channels have essentially equal sensitivity.

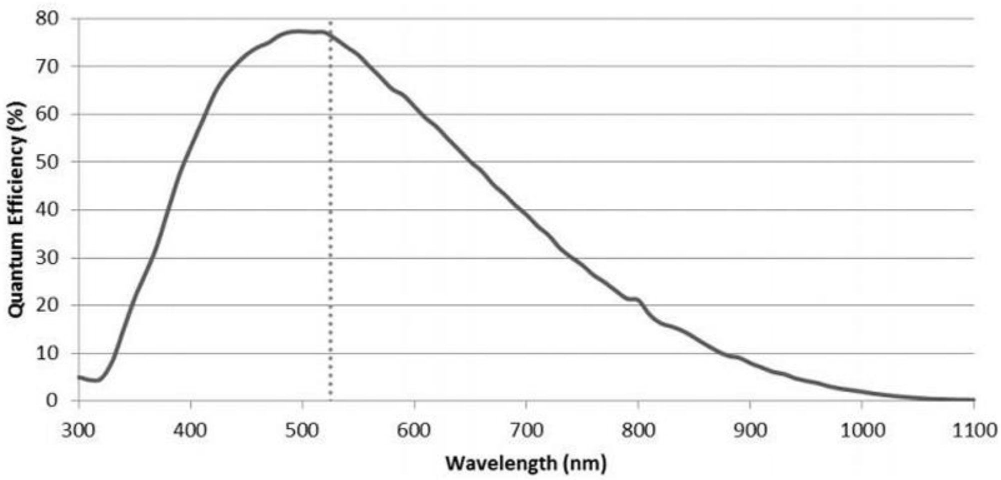



Figure 4.10 (b). The QE chart for a camera with the first generation Sony IMX174 mono sensor. Note how the efficiency drops sharply away at shorter visible wavelengths and by 900 nm in the IR is less than 10%, dropping to 2.5% at 1,000 nm and zero by 1,100 nm.

Any camera capable of detecting light beyond 700 nm can be used to image Venus at infrared wavelengths. It is worth noting at this point that DSLR cameras intended for normal daytime photography have a built-in filter in front of the camera sensor that blocks infrared light. If that filter wasn't there most cameras would see what we perceive to be white light as pink light. For use on Venus at infrared wavelengths the DSLR camera either has to be modified by the removal of the IR blocker or to be one of a limited number made by some manufacturers (e.g. the now discontinued Canon 60DA) without the IR blocker in place to begin with. However there are plenty of CMOS cameras available today from the security or astronomy world that have no such restrictions when looking at infrared. A word of warning here, some cooled CMOS One-Shot Colour (OSC) cameras are fitted with a built-in UV/IR cut filter to block wavelengths longer than 700 nm[4]. Mono CMOS cameras do not have this filter, nor do most OSC cameras intended for planetary or guiding use.

When wishing to image Venus in the IR range 650-1000 nm all that is needed is any modern planetary or guiding camera without cooling. As cooled cameras are generally more expensive that is good news for a would-be purchaser of a suitable camera. Small sensors are best for this work and enable the camera to record images as fast as possible to beat the seeing. Best of all, such cameras are among the cheapest available to the amateur astronomer, with most costing between £200 and £400.

Another technical property of a sensor that is very important is the well depth. Sometimes users may believe a new camera on the market is particularly sensitive in infrared, when in fact it is no better than other cameras but its small well depth means it gives bright images. More than one well-known amateur was taken in a few years ago by a new camera on the market which appeared to be extremely sensitive at the IR end of the spectrum only to be disabused when the apparent superiority over its rivals turned out to be because of a very small well depth compared to similar planetary CMOS cameras.

Well depth matters far more than most camera users ever realise. The camera with the smaller well depth will very quickly have oversaturated pixels when used on any bright light source such as Venus. The consequence of oversaturation is to ruin the quality of the final image as details will be lost and light may bleed into adjacent pixels as the well bucket overflows. For Venus IR imaging it is a distinct advantage to pick a planetary camera with a good well depth. Well depths are described in the manufacturer's specifications in terms of the full well depth in Ke (kilo-electrons). For instance the ZWO ASI174MM using the Sony IMX174 mono sensor (see above QE chart) has a reasonable full well depth of 32Ke. Well depths larger than 40Ke are good, such as that of the Uranus-C at 47Ke with a Sony IMX585 colour sensor. Even better, cameras such as the ZWO ASI432MM using the Sony IMX432 sensor have an excellent full well depth of 97Ke . At the other end of the scale cameras fitted with the Sony IMX678 mono sensor have a low full well depth of just over 11 Ke and the QHY5111200M (which has the SC2210 sensor) a full well depth of just 8Ke. This can easily lead to pixels becoming saturated, which causes problems when trying to sharpen the image later. This is a problem exacerbated by the brightness of Venus in any image. Large full well depths mean that the camera is less likely to have oversaturated pixels but it also means that the image will appear dimmer than with a camera that has a much smaller full well depth. If possible, avoid cameras with a full well depth less than 15Ke or more than 90Ke.

### 4.2.2 Choosing an appropriate camera for the work

As a rule of thumb this is a job for cameras that are marketed as planetary/guiding cameras. They have small sensors and can operate at the fast frame rates that produce the best results when imaging Venus in infrared. Cameras with larger sensors intended for deep sky can be set to a smaller Region of Interest (ROI) to imitate planetary cameras but if they are either intended to be used with USB2 rather than USB3 or have a built in limitation to their maximum frame rate in their firmware they will not be suitable for infrared use on Venus.

The camera market is always moving forward but at the time of writing this section of the guidance the following uncooled cameras are examples of some of the latest generation cameras that are suitable for this work:

Player One:

Uranus-C, Uranus-M, Neptune-664M, Neptune-C, Neptune-M, Mars-M II, Mars-C II

ZWO:

ASI462MC, ASI462MM, ASI482C, ASI585C, ASI678M, ASI662MC

QHY:

5111200M, 5111462C, 5111585C, 5111585M, 5111678M

All of these cameras will work with the standard video capture software packages used by amateurs, provided the appropriate camera driver has been installed. Two of the most popular freely available programs are SharpCap and FireCapture. For a small fee SharpCap's freeware version can also be upgraded to release additional features and suppress any annoying adverts.

A point to bear in mind when imaging in the infrared is that most planetary cameras have protective glass windows that have anti-reflection coatings for visible light. As mentioned above, some OSC cameras are even fitted with protection glass acting as an IR cut filter, cutting off wavelengths above 700 nm. Removing these is usually fairly easy, although doing so may void any warranty, and will ensure that the infrared wavelengths above 700 nm are not blocked.

## 4.2.3 Imaging tips and techniques

### *4.2.3.1 8-bit or higher? (E.g. 12-bit or 16-bit.)*

Most planetary imagers capture videos at 8-bit as it is difficult to detect any obvious benefit in improved detail above 8bit - and video file sizes become significantly larger at 12-bit and above. However, with the delicate work to tease out detail in IR imaging of Venus there is a potential benefit in using bit depths of 12 and above since this will give more shades of grey tones in the image and reveal more of the cloud structures at these wavelengths.

### *4.2.3.2 To Bin or not to Bin?*

In the same way that it is usually better to aim for 12-bit or 16-bit for Venus it is also better not to use binning, which is the process of combining blocks of 2 x 2 (occasionally 3 x 3) pixels into one pixel when capturing the data. In the days of CCD cameras, which had high levels of read noise, binning was an effective way to increase the signal-to-noise ratio, as the combining took place in the camera at the point of image capture. In modern CMOS cameras the process happens after image capture. Although binning improves the signal-to-noise ratio by a factor of 2, it also brightens the image and reduces the resolution, and neither of these effects is desirable when trying to capture fine detail in an IR image of Venus.

### *4.2.3.3 Mono or colour cameras?*

While it is feasible to use OSC (One Shot Colour) cameras for IR planetary imaging, and that is why I have included some in the list of suitable cameras, they can have drawbacks compared to using a mono CMOS camera. Most obviously they use a Bayer filter matrix to capture separate colour channels using different pixels. This means, firstly, that in post-processing image stretching to bring out fine details in the IR, there is a risk of the matrix pattern appearing in the background like a giant grid overlaying the image. Secondly, OSC cameras capture two green pixels for every one red and one blue pixel. The near IR is next to the red end of the spectrum, so three out of four pixels are less sensitive to the IR. In practical terms this can lead to a less well defined image for stretching in post processing. The exception is for wavelengths longer than around 850 nm, where all the Bayer filters become equally transparent.

### *4.2.3.4 Setting the exposure*

Modern CMOS cameras are generally much more sensitive in IR than those of earlier generations. This gives the opportunity for the imager to reduce exposure times and collect more data in the same time. There is a lot to be said for this, as long as the exposures do not become so short that they risk failing to catch sufficient photons to detect any features. Exposure times shorter than 5 ms are likely to run that risk for Venus. But shorter exposures on Venus in IR generally work better, enabling more ‘lucky images’ that beat the seeing and improving the chances of obtaining a clear image.

It is worth remembering that the more good frames that can be combined the stronger the signal becomes compared to the noise. Each successive addition of another frame in the stack increases the signal in a linear fashion while the noise in each frame only increases at the rate of the square root of the signal. This is why bigger stacks are smoother provided that enough lucky images of good quality are captured.

Larger scopes will gather more light when pointed at Venus, and this may tempt the user to reduce exposure times to less than 5 ms or even less than 1 ms if an image can be clearly detected. Despite Venus's intrinsic brightness it is generally far better to keep the exposure times at no less than 5 ms and to reduce the gain. Very short exposures run the risk of not capturing enough photons to detect finer detail as the image stacking software may mistake the fainter signal for noise.

#### *4.2.3.5 Setting the gain level*

Venus is unique in its high surface brightness compared to other planets. Only the Moon is brighter at night and only the Sun or the Moon during the day. This has an impact on the significance of the gain setting: it is far less critical for Venus IR imaging than on other planets. Most CMOS cameras have a built-in noise reduction routine which cuts in when the gain is set to a certain level, the optimal point. This means that for gain settings lower than the optimal, the noise is larger relative to the signal for any given exposure. At or above the optimal point the noise is suppressed compared to the signal, resulting in a less noisy looking signal. Turning up the gain above the optimal point appears to the naked eye to increase the noise but in fact that is not so. What actually happens is that with the increase in gain both signal and noise are increased at the same rate, but by making both the signal and noise brighter the noise becomes more apparent to the human eye. Too short an exposure time and turning up the gain will also appear to increase the noise dramatically. Because of Venus's inherent brightness, provided the exposure time is sufficient to capture the signal the gain can be turned down as far as possible (even below the optimal gain point and all the way down to zero) to avoid over-saturating individual pixels on the camera.

A risk to avoid with the chosen camera is over-exposing the original recording. If the image looks normal for planetary then it is probably overexposed for pushing the infrared image on Venus. One useful trick is to turn the gain on the camera to zero and rely on changing the exposure if necessary. Look for an image that is a little faint in live video where you can still see Venus clearly enough. Although this is not the advice that I would normally recommend for planetary imaging it is a technique that has proved successful when attempting to detect features in infrared images of Venus.

#### *4.2.3.6 Trying to beat the seeing when it is just too turbulent*

On some occasions either the jet stream is at its worst or heat from the Sun just too much for the location of Venus when trying to image it. Even at longer IR wavelengths the image may simply be too unsteady to allow the stacking of a smooth Venus image. On these occasions it is best to leave as long a gap between sessions as possible and test again to see if Venus has settled or is still boiling away in the field of view. A good test here is to try to change focus either side of the optimum image. If this is hard to do and the point of focus seems to be constantly moving then it is time to admit defeat and wait for a better day for imaging.

### 4.2.4 Choosing the right filter for the job

Infrared filters available to the amateur can be broadly classed as those that are designed to pass all wavelengths longer than a specified value (known as IR long pass filters) and those designed only to pass a specific range of wavelengths within the near infrared spectrum (known as IR band pass filters).

#### *4.2.4.1 Long pass filters*

Starting at around 650 nm, long pass filters enable the imager to capture a much steadier image of Venus in any given circumstances than is possible in the visible light spectrum or at ultraviolet wavelengths. The longer the wavelength is then the steadier the image in any particular circumstance, although the longer wavelength will yield an image of lower resolution than shorter wavelengths due to the larger Airy disc.

The long-pass filter options generally available to the amateur astronomer for imaging in near infrared are:

- **642 and 650 nm long pass**: probably the most common IR filters in most astronomers' kit boxes. Long pass images with these filters (which transmit some red light) can be steady without the loss of resolution that occurs at longer wavelengths, and are fine if you wish to capture a bland but well defined white image of Venus. The passband is too broad to show much of the interesting cloud detail that can be found in the IR unless there is a large scale event happening in the clouds of Venus. Such events are rare and I would not recommend the use of 650 nm long pass infrared filters or the widely available long pass filters at 642 nm without combining them with a blocking filter to restrict the bandwidth.

- **742 nm long pass**: the next most common filter. This can produce good results in the right conditions (see figure 4.11 below). Effectively narrowing the detectable bandwidth from 500 nm to 400 nm makes a significant difference to the potential detail to be detected.

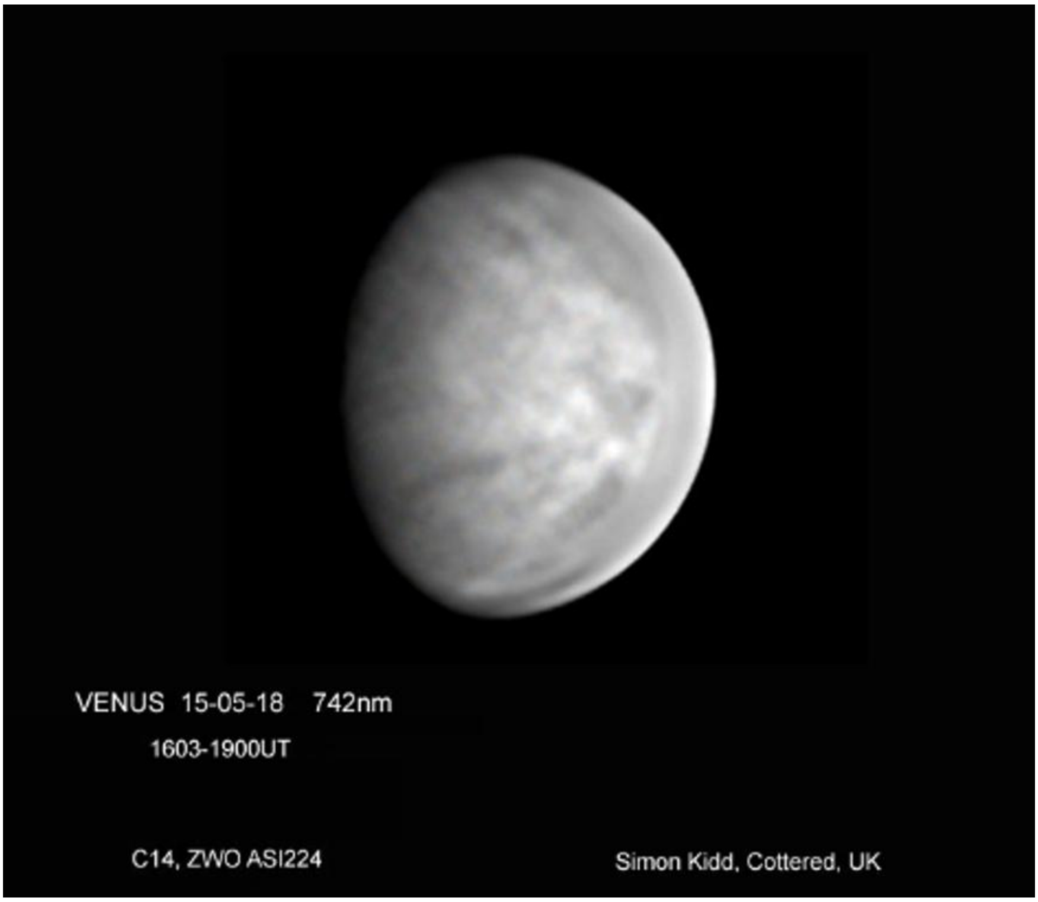



Figure 4.11. Image of Venus by Simon Kidd using a 742 nm long pass filter.

- **807 nm long pass:** This is getting closer to the ideal range. One of the issues of course with seeking a longer wavelength starting point is that less light is gathered. Because Venus is so bright this is not the problem that it would be with, say, Saturn.

- **850 nm long pass:** These are a good choice for detecting the cloud discontinuity. Although various IR pass filters have been used successfully to detect the CD, as shown in figure 4.9, experts think that it is at its most detectable between 850 and 950 nm, making an 850 nm long pass almost the perfect choice in such a scenario. Personally I don't use either an 850 nm or 900 nm long pass but that is because I have a custom IR band pass filter from 840-1020 nm that effectively does the job of both these filters. Such filters are usually very expensive and I wouldn't recommend them unless other uses were planned in addition to Venus.

- **900 nm long pass:** similar to 850 nm long pass. Potentially good for detecting the cloud discontinuity, although the image will be fainter than with an 850 nm filter.

- **1000 nm long pass:** usable on Venus but needs a large aperture scope or the image will be so faint that the exposures will be a lot longer than ideal. I have two such filters, one was quite cheap but the cut-off is a little out from 1,000 nm and transmissibility percentage is less than my better quality one – a Thorlabs FELH1000 (their better standard) which has a sharp cut-on at 1,000 nm. The sharp cut-on is only really needed if you are planning to use the filter as part of a night side detection kit or a specialist project with exact measuring requirements, otherwise a cheaper lower quality 1,000 nm cut on is fine for general IR usage on Venus.

#### *4.2.4.2 Bandpass and specialist filters*

Bandpass filters are more complex than long pass filters because they have to restrict the spectrum between two wavelengths, and consequently tend to be more expensive. A band pass filter will generally have a better chance of detecting a specific feature in Venus's clouds unless the passband is very narrow, such as a methane band filter around 880-900 nm. The small amount of transmitted light may make it difficult to detect anything in the clouds just as much as a broad long pass filter starting around 650 nm.

It is possible to buy specialist bandpass filters directly from a number of scientific companies, for example Thorlabs (Europe) based in Germany and Edmund Optics or Salvo industries in the USA. Very good quality band pass filters are also made by Semrock in the US but their pricing matches the quality and can be a little beyond the pockets of some. My own Semrock 935/170 nm filter (a band pass between 840 nm and 1020 nm) cost £450 a few years ago. Details of all such specialised filters can be obtained by visiting the manufacturers' websites. The filters from specialists will also need to be mounted for astronomy use. They generally have diameters of 25 or 50 mm and need a custom holder to convert them for 1.25" or 2" use.

Some of the filters in the Sloan series can also be used in this way, for instance the Sloan 'z-s' filter neatly captures the bandwidth from around 840 nm to 940 nm. This will need a camera with good IR sensitivity but gives good coverage where IR features might be detected. Such filters are usually cheaper to buy than those from specialist scientific companies although not as cheap as long pass filters around the same starting wavelength.

Methane band pass filters. These are sold for imaging Jupiter and Saturn, among other objects, and have a restricted bandwidth, usually between 880 and 900 nm. There is a significant drop in light levels by using such a restricted bandwidth but any clouds detected are likely to be relatively clearly distinguished. Methane band filters are more expensive than long pass filters.

One interesting and relatively inexpensive option is to combine a shorter wavelength IR long pass filter with a standard UV/IR cut filter often used with colour cameras. For instance the 642 nm with a UV/IR cut would effectively create a band pass filter with a bandwidth of

58 nm from 642-700 nm although strictly this is not the infra-red but deep red. While not as narrow as a methane band and therefore more transmissive it will still be quite dim compared to wider bandwidths and is better suited to larger instruments. However, the sensitivity of the camera will be higher at these wavelengths than in the methane band. Tom Williams in Wiltshire has successfully used a 610 nm long pass with a UV/IR cut filter creating a bandwidth of 610 - 700 nm (figure 4.12).

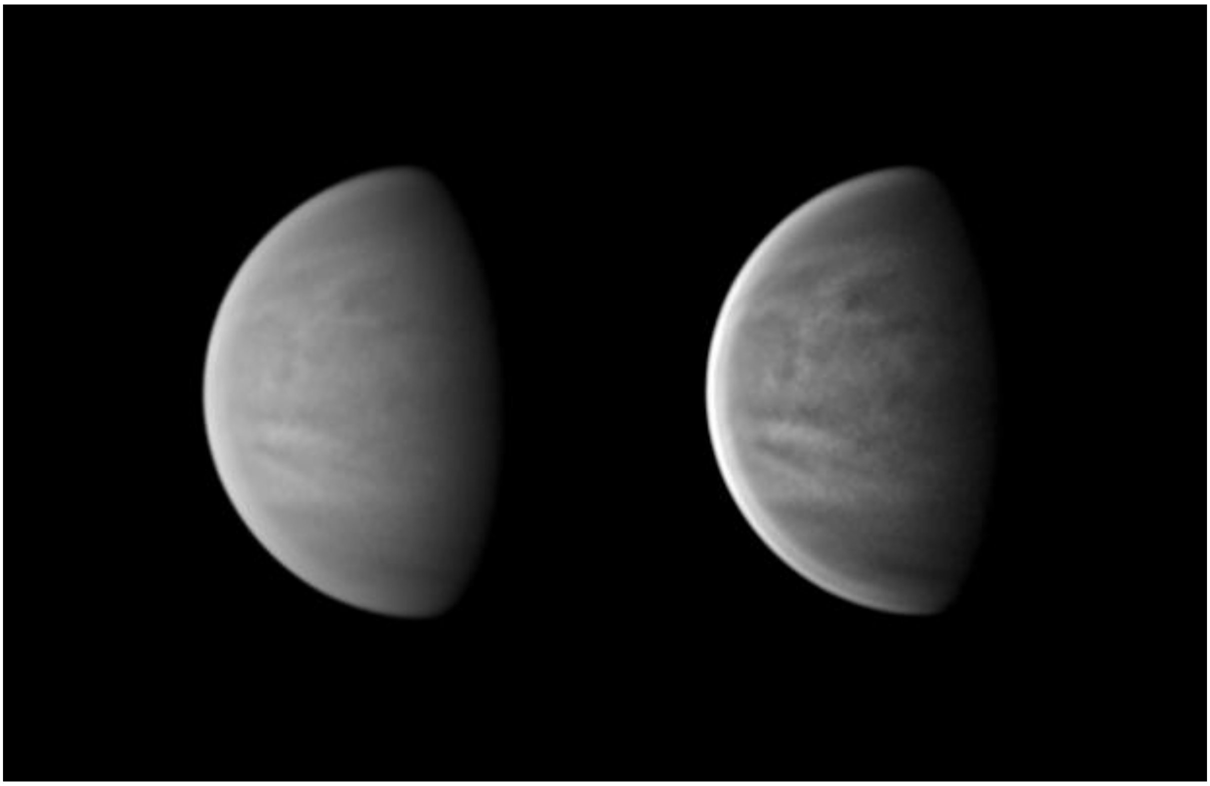


Figure 4.12. Image by Tom Williams with a 16-inch Dobsonian and 610 to 700 nm filter combination.

To help the reader judge the relative merits of different filters, figure 4.13 below shows a set of images captured on a day of good seeing, using a colour camera with three different long pass filters and a bandpass filter.

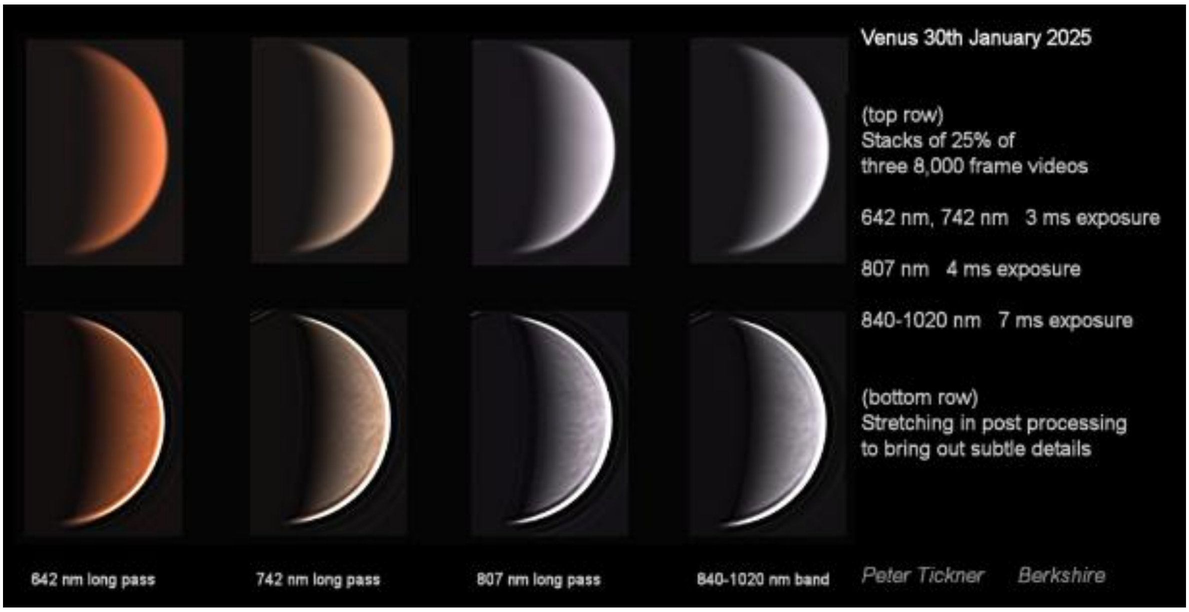



Figure 4.13. Comparison of IR long pass and band pass filters often used successfully on Venus.

The top row is as aligned and stacked from the best 25% of 24,000 video frames per filter. The bottom row shows the features that can be brought out by pushing the data hard in post-processing. All images were treated identically. Both the 642 nm long pass and the 742 nm long pass still picked up part of the red end of the spectrum whereas the 807 nm and the 840-1020 nm band pass results were beyond the camera's capability to detect colour. The 642, 742 and 807 nm long pass filters were all from the same manufacturer, Astronomik.

The 840-1020 nm was a specialist band pass filter made by Semrock. As expected the least effective result is from the 642 nm long pass. The most effective at picking out distinctive cloud features, in this test on a day of good seeing with Venus 31.6" in diameter and just a few weeks away from inferior conjunction was the 807 nm long pass, with the 742 nm long pass and the 840-1020 nm band pass a close second.

### 4.2.5 Telescopes and accessories suitable for Venus IR imaging

The minimum requirements for the telescope are a Newtonian, Dobsonian or catadioptric scope (such as a SCT) with (ideally) an aperture of at least 200 mm. Telescopes with smaller apertures will not resolve the finest details in Venus's clouds, due to the larger Airy disc size in the IR, but will be able to show some features. Stretching the image contrast to reveal subtle details without introducing artefacts requires a sufficiently bright image, and apertures less than 200 mm may not capture enough light to achieve this. Most commercially available refractors are unsuitable as they are unlikely to have apertures large enough for this work. Higher focal ratio SCTs and Maksutovs often have a good flat field for planetary imaging but Maksutovs can be tricky to use at dawn and dusk as they are the most prone to being affected by changes in temperature, because the thicker corrector plate can take longer to equilibrate.

Slower (ideally no faster than f/5) Newtonians and Dobsonians are well suited to this work but very fast set-ups at f/4 down to f/2 can struggle with both image scale and depth of field to focus on Venus. Dall-Kirkham designs, which are a variant of a classical Cassegrain without the corrector plate, generally have longer focal ratios, often f/10 or even longer. At f/15 and longer they make excellent planetary scopes for Venus but below f/10 a combination of a larger central obstruction and smaller image size can make them even less effective than the equally unsuitable faster Newtonian designs.

### 4.2.6 Other equipment

Here we are thinking about focal reducers when Venus is relatively large and Barlows when relatively small. For a fast Newtonian or Dobsonian a Barlow of some type will almost certainly be needed, and it is worth testing the IR transmission of the glass in the Barlow. With SCTs at f/10 or f/11 a large Venus image may benefit from a reducer. Again it is worth testing their IR transmission. I had three reducers tested, the f/3.3 (0.33x) had T ≤ 65% at 1 micron, the f/6.3 (0.63x) had T = 94% and the 0.5x reducer came out top at T = 96%.

## 4.3 Processing tips and techniques for IR imaging of Venus

### *4.3.1* Software to stack the best image data from each video.

The most commonly used software for this purpose is Emil Kraaikamp's Autostakkert! program and certainly one I would recommend. The version shown in figure 4.14 below is Autostakkert!3, which is the one I prefer as it has more user control. The latest version is Autostakkert!4.

On the left-hand panel, select 'Planet' and set a quality estimator. I have used Laplace A and a mid-value of 5 for noise robustness. Pick a lower value than this when the image is steady, and higher when the seeing was poor. Select 'local' rather than 'global' for alignpoints. Then click 'Analyse' and Autostakkert! will sort and rank the images in quality order.

The quality graph in the middle shows the percentage of frames above 50% compared to the selected best frame, in this case 25%. I normally ignore this unless the percentage is very low, as I am picking a stack of fewer better frames than the ones picked as 'good' in this example. The Stack Options menu allows you to choose the frame percentage (or number of frames) to stack and the output file type. The data was captured with a colour camera so I leave RGB Align selected, although almost all the data is effectively monochrome.

In the image on the right I have drawn a single alignment box. This works best for bright bland images, where using multiple smaller alignment points can confuse the stacking software and introduce artefacts. Click 'Stack' and the selected percentage or number of frames will be stacked and saved in a separate folder.

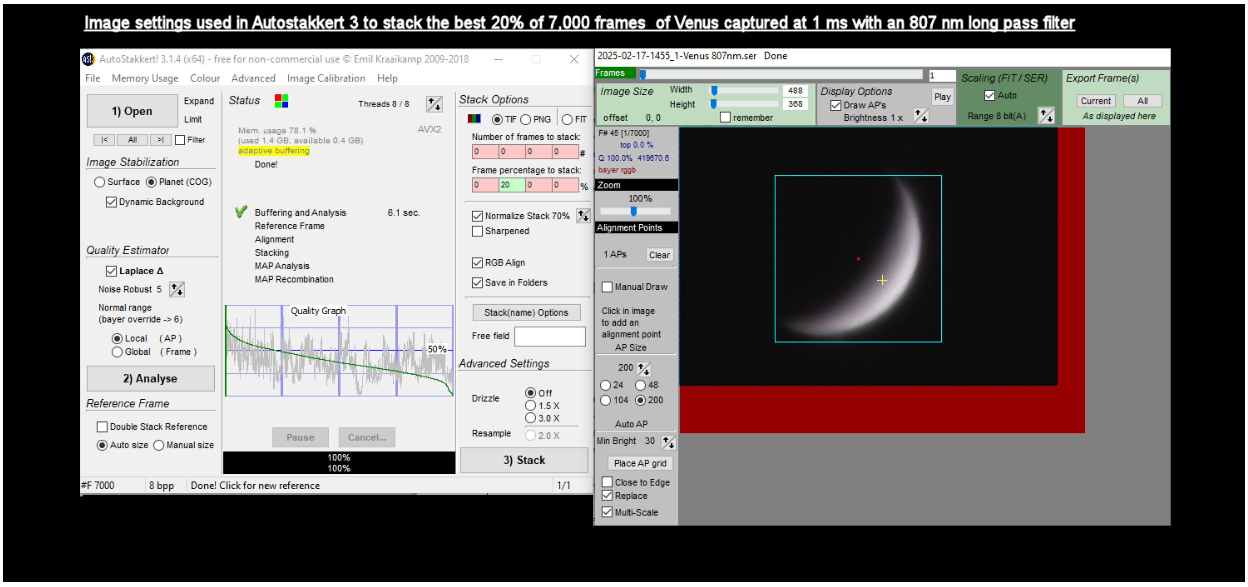



Figure 4.14. Screenshot from Autostakkert!3 in use for the image seen in figure 4.3.

### 4.3.2 Software to sharpen the image after stacking

The most widely used program for this purpose is a freeware program called Registax. Its latest version, Registax 6, is a 32 bit program well over a decade old since its last update but still very effective. Registax 6's author, Cor Berrevoets, released an updated 64 bit program called WaveSharp in December 2023. The current version of WaveSharp at the time of writing is 2.0 Beta. WaveSharp concentrates on the wavelet sharpening processes that were the best part of Registax, and no longer has the Registax stacking functions that Berrevoets himself has agreed are better done by Autostakkert. The jury remains out on whether WaveSharp has yet significantly moved forward from the wavelet sharpening functions in Registax 6.

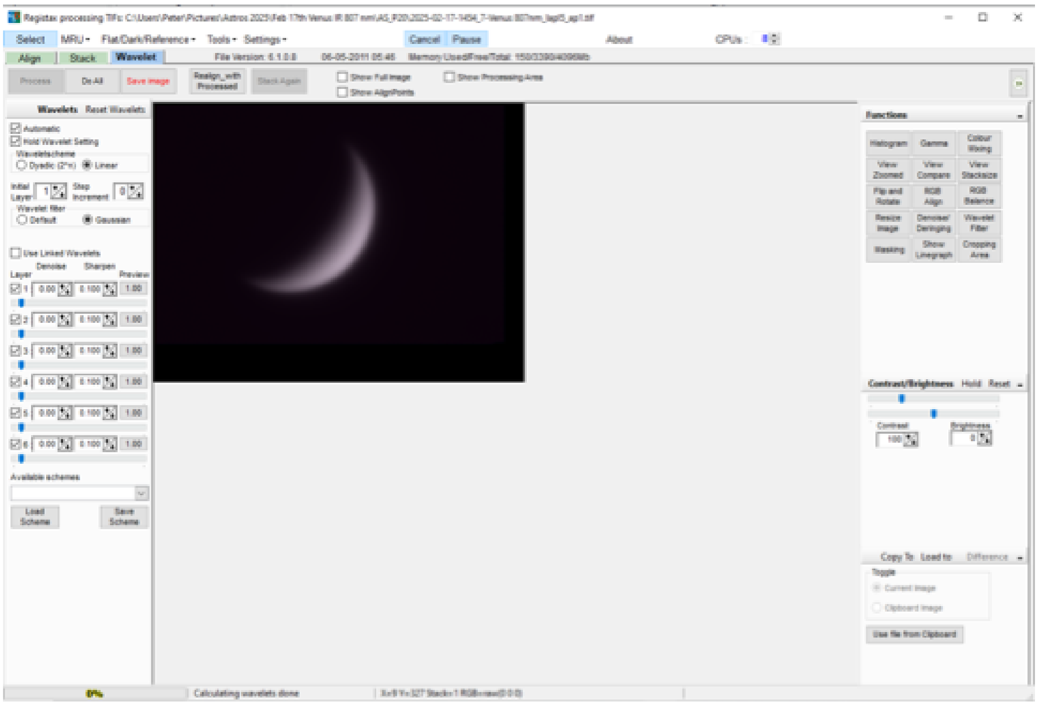


Figure 4.15 (a). An image from Autostakkert loaded into Registax without any processing.

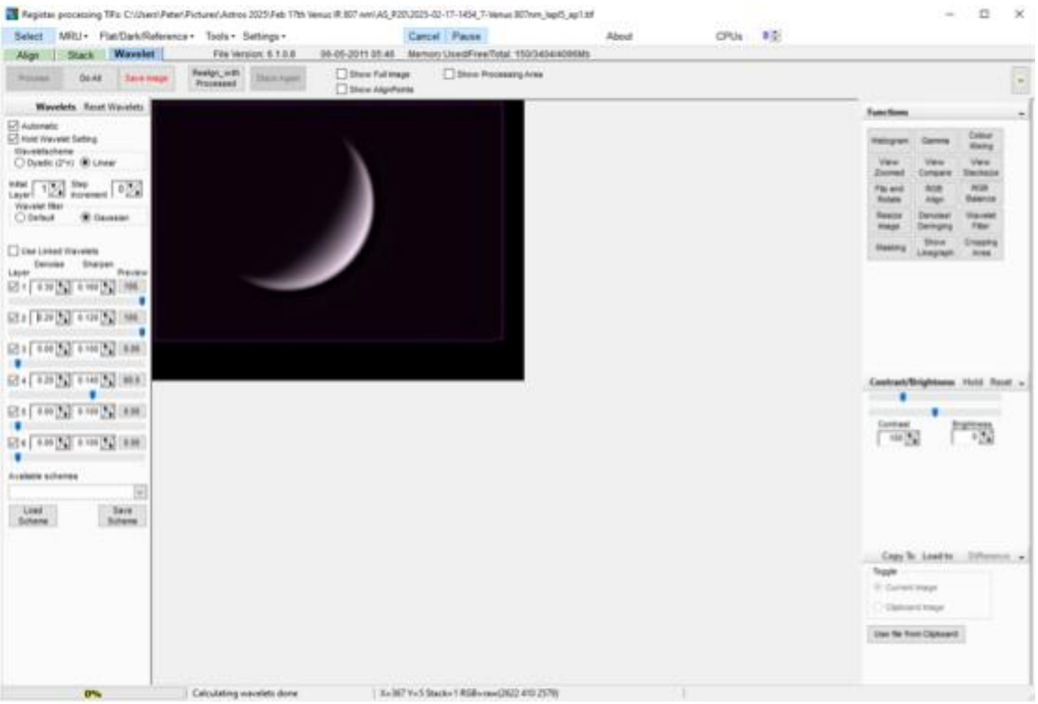


Figure 4.15 (b). Gentle wavelet settings applied to sharpen the image without over-sharpening.

### 4.3.3 Processing pitfalls

The biggest risk comes after stacking one's initial best data and then using sharpening tools such as Registax. There are however several pitfalls along the way. We can all make these mistakes so I've spelt out the more obvious as a warning from my own experience!

#### *4.3.3.1 Overdoing the contrast when sharpening the image.*

Keep a careful eye on the histogram and try to keep contrast as low as possible while sharpening. It is very easy to introduce an apparent vertical split in the cloud cover with too much contrast before sharpening. The rim of Venus is always apparently brighter than the main surface and if the contrast is too great to start with between the rim and the body any further sharpening will cause false ripples to appear just in from the brighter rim area.

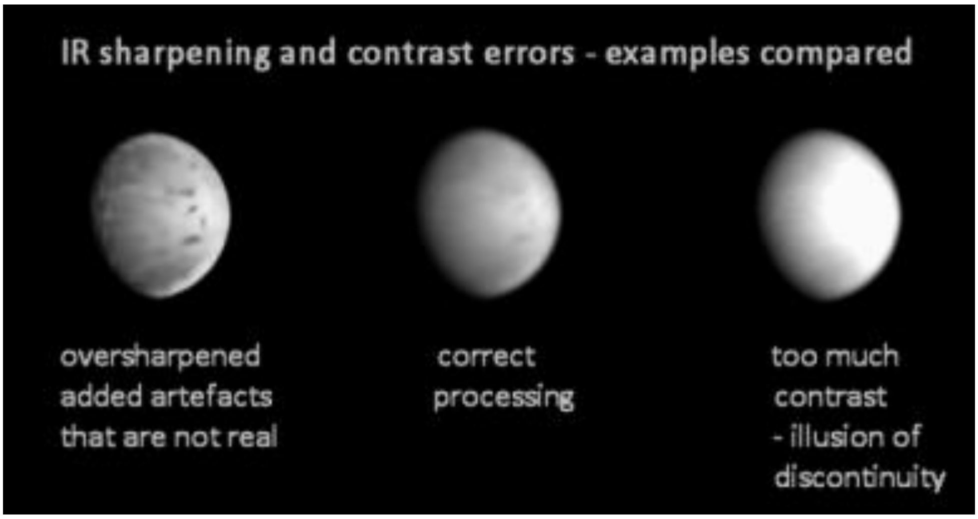



Figure 4.16. The effects of over-sharpening or too much contrast on an IR image.

#### *4.3.4.2 Not stacking enough video data to obtain a smooth image for sharpening.*

Generally with Venus the percentage of frames stacked is relatively low compared to other planets as Venus is much more likely to be slightly unsteady when being imaged. Its brightness however usually ensures that short exposures and fast frame rates can capture a large number of video frames very quickly so that the stack, although a small percentage of images captured, can still be a significant number of frames which ensures the signal is

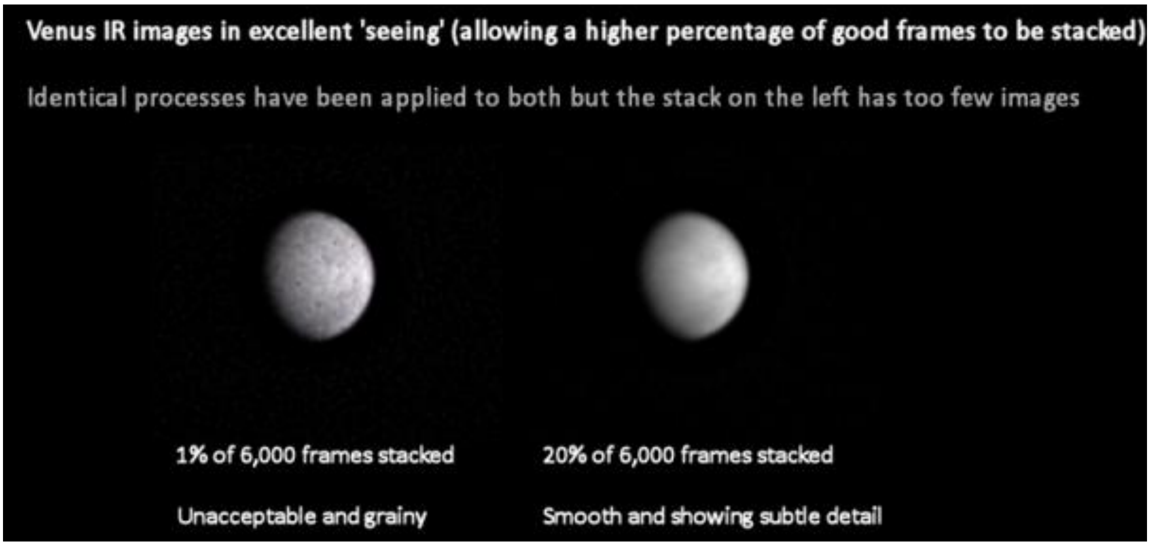



Figure 4.17. Stacking too few images compared with the right size of stack.

much stronger than the noise. However if the number of frames in the stack is too small then the result will be too grainy to push to bring out IR features. The solution is to make sure that the original video is long enough that there are many thousands of frames to select from. This is more feasible on Venus than other planets because it is so intrinsically bright for its size and far brighter than any other planet.

#### *4.3.4.3 A foolproof way to test for artefacts in processing IR images*

Provided you have at least an hour of time to image Venus in IR it is possible to confirm whether or not the effects seen are an artefact or a genuine cloud feature. Stacks of the best video data at half hour intervals (or longer if possible) when 'blinked' or created as a sequential gif image should show any detected features drifting in the direction of cloud rotation on Venus.

## 4.4 Conclusions and Summary – imaging Venus in infrared

Imaging Venus in infrared can be a rewarding challenge for the amateur astronomer, whether capturing a thin crescent as Venus approaches conjunction or seeking to detect subtle cloud features. There is the opportunity at certain wavelengths in the infrared to detect rare ripples in the clouds of Venus, known as cloud discontinuities.

In this section we have discussed imaging in the short wavelength end of the near infrared spectrum, which can be detected by cameras available to the amateur astronomer. Almost all the latest generation of planetary cameras have good sensitivity in infrared from 600 nm up to 1,000 nm although some tail off quite sharply from around 900 nm.

Venus is best imaged when it is in the arc between maximum eastern or western elongation and inferior conjunction as that is when it is at its nearest and largest to view from Earth. Although it can be imaged when on the farther side of the Sun it is less likely that details can be detected when it is a smaller and more distant target.

The nature of the orbit of Venus means that it is often best imaged in twilight at either end of the day when the Sun is either below the horizon or low in the sky. Its brightness and imaging in infrared allow the observer to image Venus as much during the day as at night, although it is advisable to avoid times when the Sun is high in the sky as that can often be when the seeing is at its poorest.

Close to and around both inferior and superior conjunction Venus becomes dangerously close to the Sun in the sky and it is important to take adequate precautions to avoid damage either to the telescope and equipment in use or the observer themselves. This article describes a simple shield that can be made to extend the protection offered by dew shields when the target is close in the sky to the Sun.

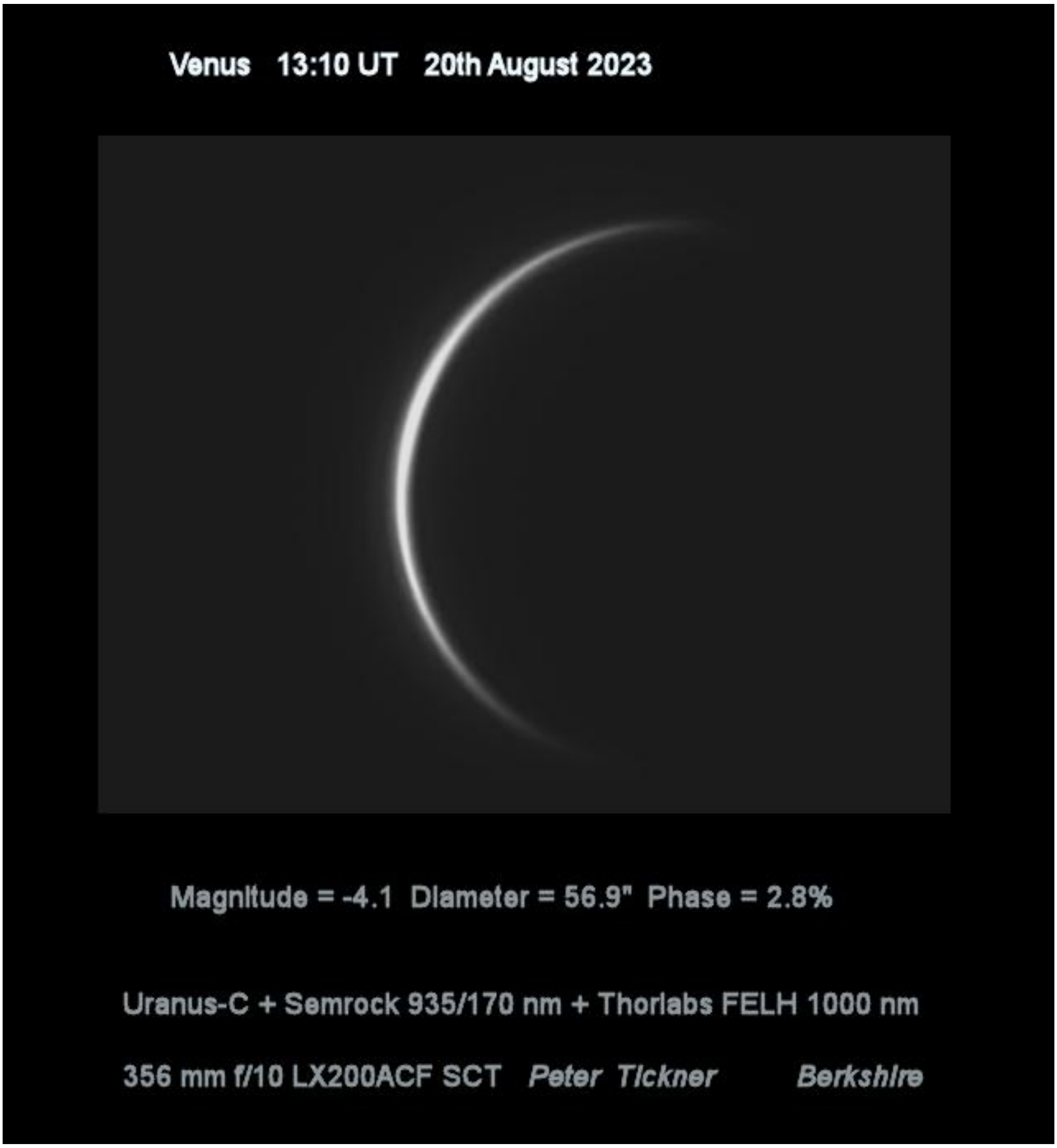



Figure 4.18. A 2.8% illuminated Venus captured by the author in the bandwidth from 1000 -1020 nm.

There are a number of filters readily available that can help restrict the data gathered to the infrared end of the spectrum. Long pass filters will gather the most light although if seeking cloud details it is probably best either to have a long pass filter passing at a relatively long wavelength or to use a bandwidth filter or combination of filters instead. Bandpass filters above 650 nm can be particularly useful although narrow bandwidths such as the methane band can restrict the detail that might be captured.

It is important to choose the right equipment for imaging Venus in infrared. In addition to planetary cameras with modern CMOS capabilities, Newtonian, Dobsonian and catadioptric type telescopes with apertures of 200 mm and above are best for standing a chance of capturing subtle detail in infrared.

This section discusses some of the techniques of capturing and processing detail with infrared filters, including some useful tips such as keeping the gain to a minimum, using ROI capabilities to capture the fastest sensible frame rate with at least 5ms per exposure so that lucky imaging techniques can be used to stack the best video to process. Freely available software such as Sharpcap and FireCapture can be used to capture the video data.

Software programs such as Autostakkert are recommended for stacking the best percentage of any videos captured. Once an image is produced from each video the result can be enhanced by the use of wavelet sharpening programs such as Registax or WaveSharp before any final post processing by the user’s preferred software application, whether Adobe PhotoShop, Corel Paint Shop Pro or more expensive solutions such as Maxim DL.

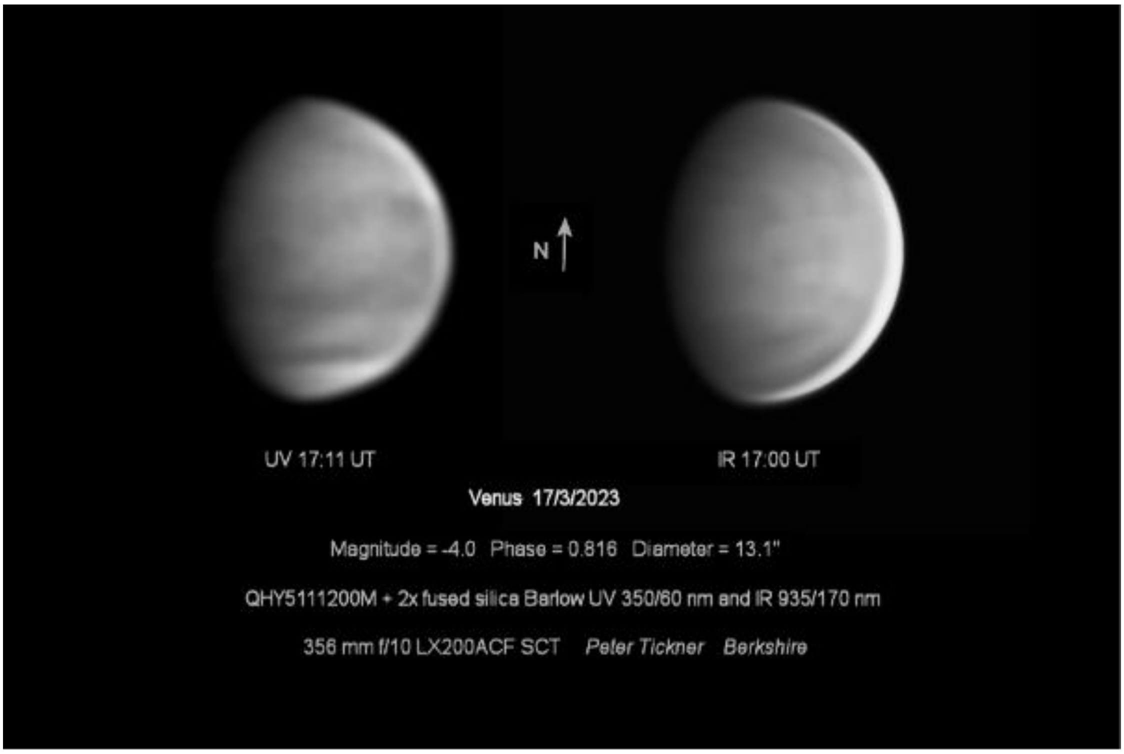



Figure 4.19. A comparison of UV and IR detail captured by the author in 2023.

## 4.5 Further reading

1) Amateur Observers Witness the Return of Venus’ Cloud Discontinuity. *Atmosphere*, *13*(2), 348.

Kardasis, E., Peralta, J., Maravelias, G., Imai, M., Wesley, A., Olivetti, T., Naryzhniy, Y., Morrone, L., Gallardo, A., Calapai, G., Camarena, J., Casquinha, P., Kananovich, D., MacNeill, N., Viladrich, C., & Takoudi, A. (2022). https://doi.org/10.3390/atmos13020348

https://www.mdpi.com/2073-4433/13/2/348

2) Venus cloud discontinuity in 2022 - The first long-term study with uninterrupted observations

J. Peralta, A. Cidadão, L. Morrone, C. Foster, M. Bullock, E. F. Young, I. Garate-Lopez, A. Sánchez-Lavega, T. Horinouchi, T. Imamura, E. Kardasis, A. Yamazaki, S. Watanabe

A&A 672 L2 (2023) DOI: 10.1051/0004-6361/202244822

https://www.aanda.org/component/article?access=doi&doi=10.1051/0004-6361/202244822

# 5. Amateur Imaging of the Night-side of Venus

***Martin Lewis***

## 5.1 Introduction

When Venus is imaged in a narrow band of infra-red light centred around a wavelength of 1010 nm, its thick and densely opaque atmosphere appears partly transparent. Because Venus's surface temperature is ≈ 460°C it also emits significant amounts of radiation in that same region of the electromagnetic spectrum. These two facts, combined with the presence of a window in the Earth's atmosphere matching this same wavelength range, mean that for the planet's unilluminated (night-side) portion it is possible to capture infra-red images of the actual surface. In the right conditions significant amounts of detail can be seen in a thermal night-side image; darker features can be recorded, corresponding to cooler topographical features of higher elevation. Additionally, one can occasionally also detect intriguing transient features including darker areas, brighter spots and streaks.

The thermal night-side of Venus is a relatively new target for amateur planetary imagers and the methods used and equipment available are improving with each apparition. Even with these improvements, recording the night-side of Venus is likely to remain a significant challenge, especially obtaining good feature-rich images. Despite the difficulties, if you are familiar with standard planetary imaging and have a telescope with an aperture of 250 mm or more, you should be able to capture night-side features yourself. This section will help you in that quest, giving details of when best to image, what equipment to use, and what capture settings to employ.

### 5.1.1 Venus Night-side and the Ashen light

Although imaging in these specific infra-red wavelengths might allow you to capture the night-side of Venus, it is important to remember that you are working in a wavelength range which is invisible to the human eye. Venus's Ashen light, reported by experienced observers over many decades, is a different phenomenon where the night-side of the planet is faintly seen when visually observing the crescent in a nearly dark sky.

What causes the Ashen light is unknown, but it is certainly not a naked eye view of the hot surface of the planet, as its atmosphere is opaque at optical wavelengths. The Ashen light, if real and not an optical artefact, is much more likely to be a phenomenon of the Venusian atmosphere rather than a view of the planet's hot surface.

### 5.1.2 Venus Night-side - The Challenges

Planetary imagers striving to image Venus's thermal night-side will face an array of familiar and less familiar practical challenges. The main issues generally arise from the fact that the thermal radiation from the night-side is relatively weak and that you are imaging this faint region next to one of the highest surface brightness objects in the sky - the sunlit clouds of the dayside of Venus. The dimness of the night-side also means you will need to image with the Sun below the horizon in order not to be overwhelmed with the wash of light from the background sky.

The need to minimise this wash of twilight sky, and also the problem of the dayside glare, means the best time to image the night-side will be when Venus is a crescent of phase 15%-35%, and at a time just before sunrise or after sunset. Unfortunately, this means the planet will then be close to the Sun, as it will be away from maximum elongation (where the phase is 50%), and consequently at a relatively low altitude. This lower altitude generally means poorer seeing, as you will be then looking through a greater thickness of the Earth's atmosphere.

You can get an idea of some of the challenges in Venus night-side imaging by referring to the plot shown in figure 5.2. This figure shows a brightness profile though a Venus night-side image during an optimum imaging period in early September 2023. The location of the line profile used for the plot in figure 5.2 is shown in figure 5.1. The line starts in the middle of the overexposed dayside, runs across the night-side and finally extends into the background.

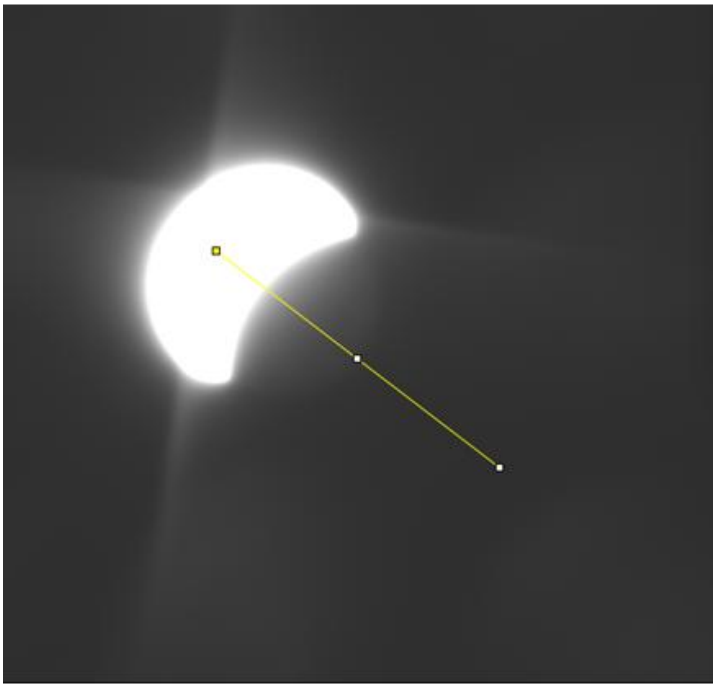


Figure 5.1. Line profile through an example stacked Venus image from the optimum imaging period in early September 2023.

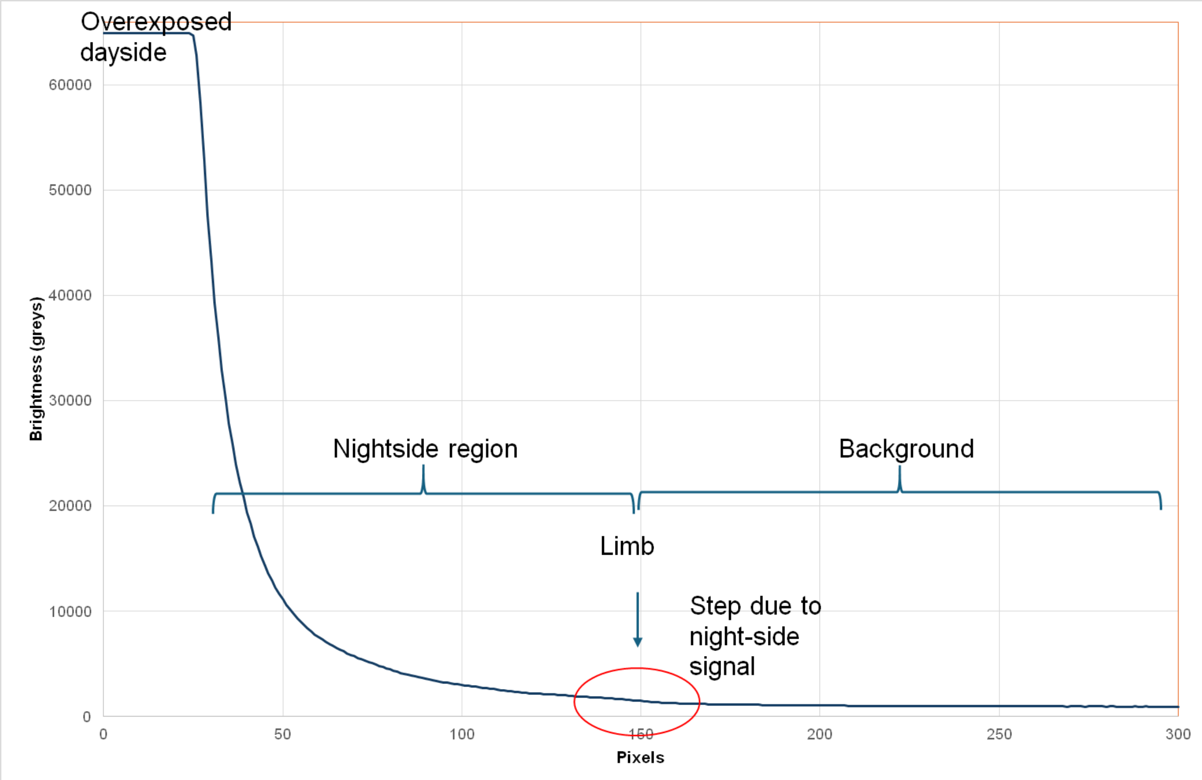



Figure 5.2. Plot of brightness with position for the line shown in figure 5.1 during the optimum imaging period, with the crescent at 17%. The night-side signal is the tiny step of 200 grey levels at the limb, circled. This has to be picked out of the background wash whose level is ≈1000 grey levels as well as the glare from the dayside, which rapidly rises as you move towards the over-exposed crescent. A third of the way in from the limb (at the 100 pixel position) the glare and the background wash are together at ≈3000 grey levels. This means the night-side signal represents just 7% of the total brightness at this location, and an even smaller fraction as you get closer to the dayside.

## 5.2 When to attempt Venus night-side imaging

The best periods for Venus night-side attempts are when Venus's phase is between approximately 15% to 35% and the ecliptic makes a steep angle with the horizon - putting the planet higher in a darker sky just before sunrise or just after sunset. For northern hemisphere observers this means evening apparitions when inferior conjunction occurs in spring or early summer, and morning apparitions when inferior conjunction occurs in late summer or autumn.

With five inferior conjunctions in almost exactly an eight-year period, Venus apparitions go through a repeating cycle. The best apparitions for Northern hemisphere imagers in coming years are given in the table below for observers at 52° N. Altitudes at sunset/sunrise are when the phase is about 25%, approximately one month from inferior conjunction and in the middle of the optimum 15% to 35% phase period:

| Optimum NS imaging - Evening | Altitude of Venus at 25% phase in Evening at sunset | Optimum NS imaging -Morning | Altitude of Venus at 25% phase in Morning at sunrise |
|---|---|---|---|
| April-May 2028/36/44 | 31° | Sept. 2031/39/47 | 29° |
| Feb. 2033/41/49 | 34° | Nov-Dec 2026 2034/42/50 | 26° |

Table 5.1. Good evening and morning apparitions of Venus in coming years seen from 52°N.

Close to inferior conjunction the phase changes rapidly and the window of opportunity is short, with only just over 3 weeks between the 15% and 35% phases. Outside of this window the favourability of the conditions drops off rapidly. When the phase is too small (<15%), although Venus appears larger and the dayside glare is less, Venus is much closer to the Sun. This means it is then rather too low in a sufficiently dark sky - leading to poor seeing and very short imaging sessions. At the other extreme with the phase too large (>35%), the glare from the proportionally larger dayside starts to seriously swamp the proportionally smaller night-side, even though Venus is higher in the sky and the seeing generally better. Additionally, at such times the planet is further from the Earth, reducing the angular size of surface features.

One's location has a bearing on the exact geometry of the apparition and at lower latitudes, where the ecliptic makes a steeper angle with the horizon, imaging may be possible down to a phase of 10% or even lower, as Venus will be higher in a sufficiently dark sky here - helping noticeably with the seeing.

### 5.2.1 Shot Noise

When imaging the Venus night-side at the right time and with the right equipment, the level of detail seen is determined by two main factors - resolution and noise. The best images are well-resolved *and* have low levels of noise.

Resolution depends on factors such as aperture, optical quality, atmospheric seeing effects, scope thermal effects, and optical image scale. However, even if you have great potential resolution, if the image is plagued by noise then the finer detail will be lost in that noise. Imaging the night-side of Venus is difficult but is aided by a proper understanding of how to reduce noise in your images.

In planetary imaging, with its relatively short exposures compared to those in deep sky imaging, the two main types of noise to contend with are read noise and shot noise. Read noise is essentially a small random electrical signal added to each pixel by the sensor electronics on readout, often manifesting itself as lines of noise in the x or y direction. With modern digital video cameras working at medium or high gain, the levels of read noise are relatively low, and generally much more important than read noise is the level of so-called *shot noise* in images.

Shot noise, also known as quantum noise, arises from the statistical variation in the arrival time of individual photons at the sensor. The photons from a source don't arrive at a steady rate; instead, they arrive at random intervals, meaning that there is a natural variation in the number captured per unit of time (i.e. noise). Because the photon arrival distribution follows Poisson statistics, for any given number of photons arriving, the quantum variation in that number of photons is given by the square root of the number of photons. Thus, if a pixel on average captures 100 photons per frame, the range of variation (noise) is ± 10 photons – some frames the pixel may capture 110 photons, in other frames only 90 photons, although on average it will capture 100. In this case the ratio of the signal to the noise (SNR) is 100:10 or 10:1. If instead an average of 10,000 photons are captured per frame, the level of variation, given as the square root of the number of photons, is ± 100, which is 10x higher than before. In this second case, however, although the noise is 10x higher, the signal is 100x higher, so the SNR is now 10,000:100 or 100:1, and so 10x better. Thus, the SNR can be improved by capturing more photons, as the signal increases by more than the shot noise.

As just explained, Venus night-side images can suffer from low SNR as the signal is weak (low photon count). Increasing the effective accumulated exposure time by taking more frames and adding them to the stack will effectively increase the accumulated photon count and improve SNR as figure 5.3 shows. SNR improves by the square root of the number of frames stacked. Increase the number of frames by 4x and the SNR improves by 2x.

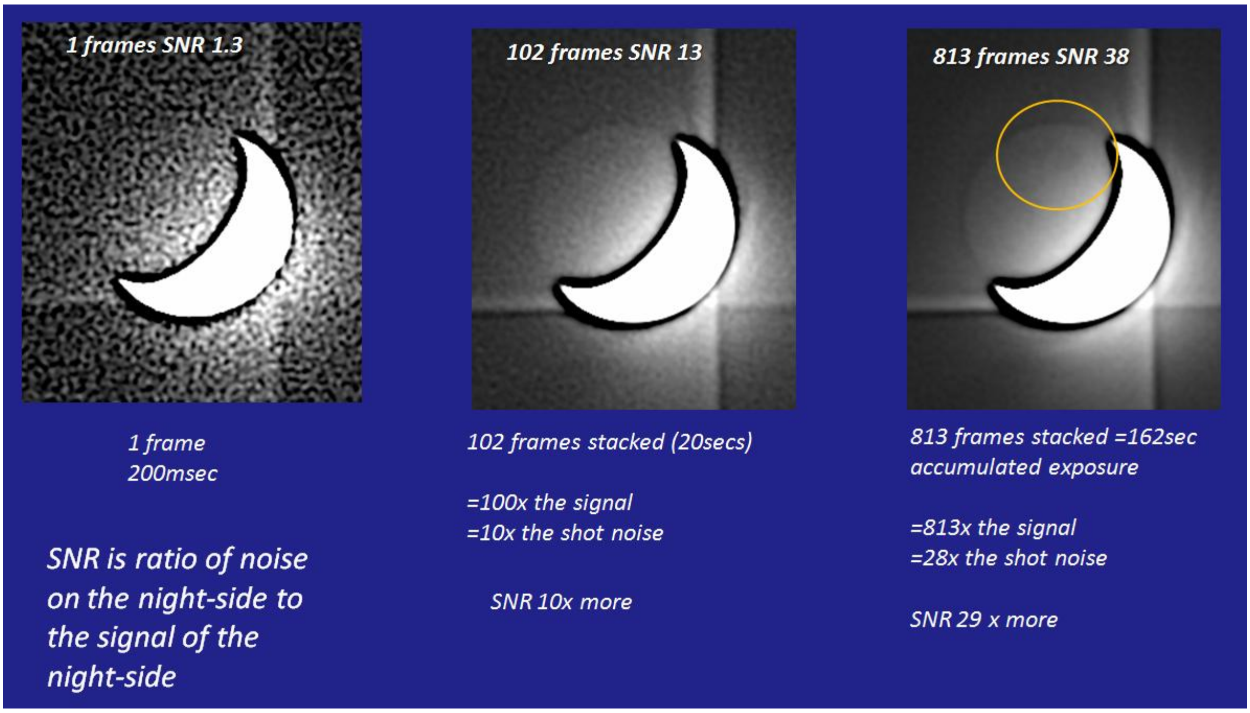



Figure 5.3. See how SNR improves as more frames are stacked and the effective accumulated exposure time increases. It is only in the image with 162 seconds of accumulated exposure time that thermal signal surface features (circled) start to clearly emerge.

Venus night-side imaging is already challenging enough due to the dimness of the night-side signal, but it is made much more difficult by the presence of two big sources of extraneous infra-red radiation which give a wash of light overlying the faint signal. One source is the twilight wash and the second source is the glare from the dayside, which also spreads over the night-side. These are both generally much larger in magnitude than the Venus night-side signal and are highly problematic as the shot noise signal from these sources is correspondingly much larger. You can subtract off the average glare or twilight signal from all pixels in the image but the shot noise signal from those two culprits is left imprinted on the NS data. It is the same problem that deep sky imagers face with light pollution and hopefully is more clearly explained in figure 5.4 below. This is from the perspective of twilight wash, but the principle equally applies to the issue of glare.

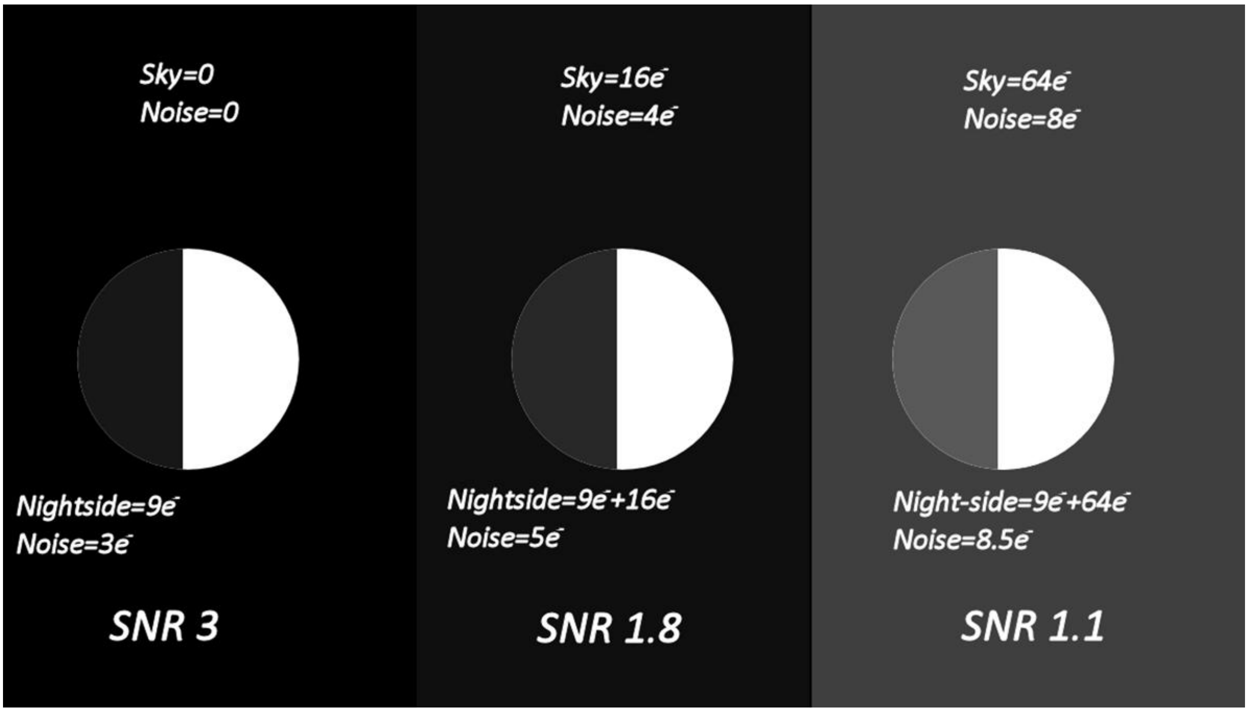



Figure 5.4. Illustrating the effect of a wash of unwanted light across the object and how it causes the SNR to fall. The twilight wash increases from left to right leaving an increasing shot noise imprint on the precious night-side data. The total night-side noise is the square root of the sum of the night-side and sky wash signals.

## 5.2.2 Twilight Wash

In the section on shot noise it was explained how a wash of twilight leaves an imprint of shot noise on the night-side signal. This is why serious night-side imaging needs to be carried out when this twilight wash is minimal. Figure 5.5 below plots real measurements of the background sky brightness as a function of the distance that the Sun was below the horizon. It shows that when the Sun is more than 6° below the horizon the sky is about as dark as it gets as far as Venus night-side imaging goes. Clearly the sky does actually darken further if the Sun is lower than 6° below the horizon but this is not apparent on the plot and probably indicates that some portion of the background brightness comes from glare from the dayside, which changes little with solar altitude.

When the Sun is higher than -6° the sky brightness climbs very rapidly so that at -4° the sky brightness is about 10x what it was at -6° and increasingly dominates over glare and other factors.

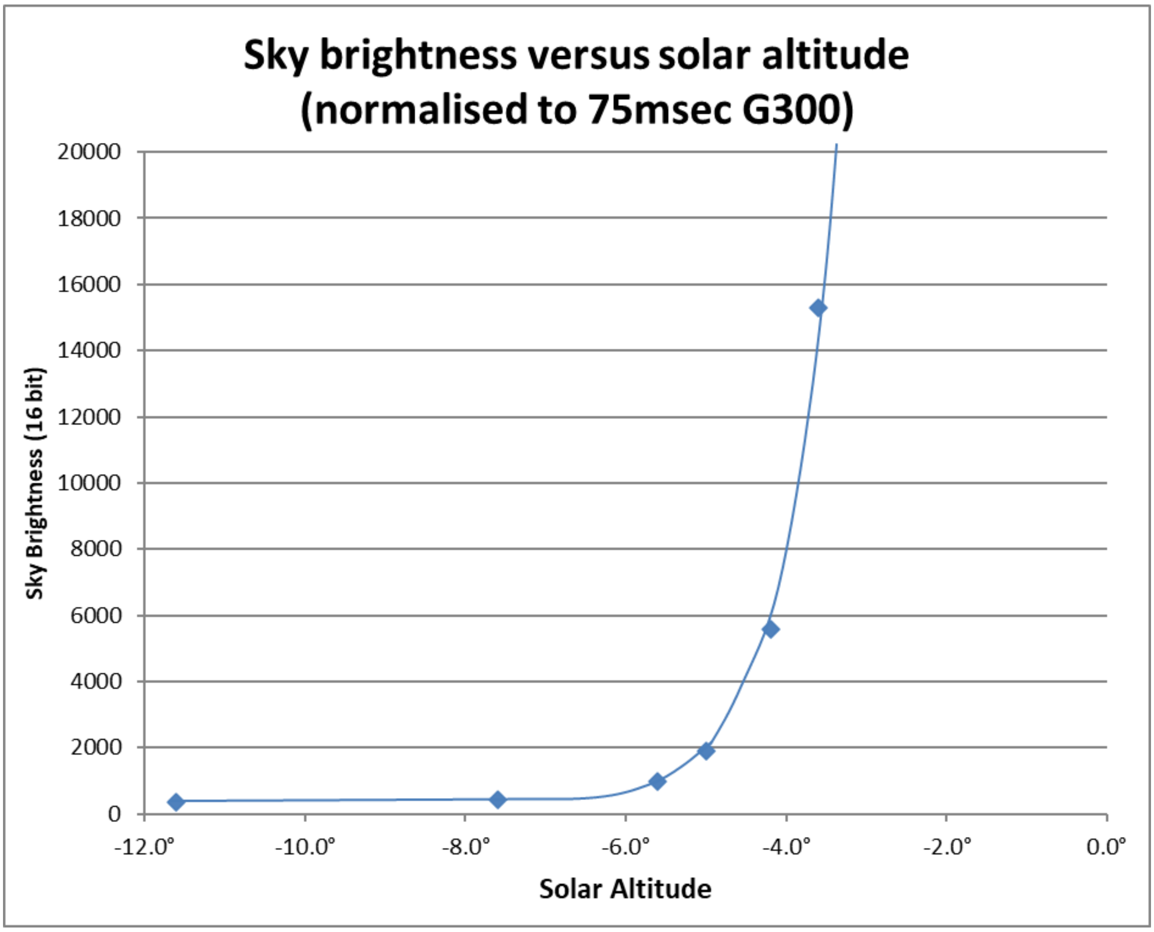



Figure 5.5. Example plot of background brightness with solar altitude during the good Northern hemisphere apparition in early Sept. 2023. The background brightness increases rapidly when the Sun climbs above -6°.

You can see the impact of sky brightness on image quality in the montage below (figure 5.6).

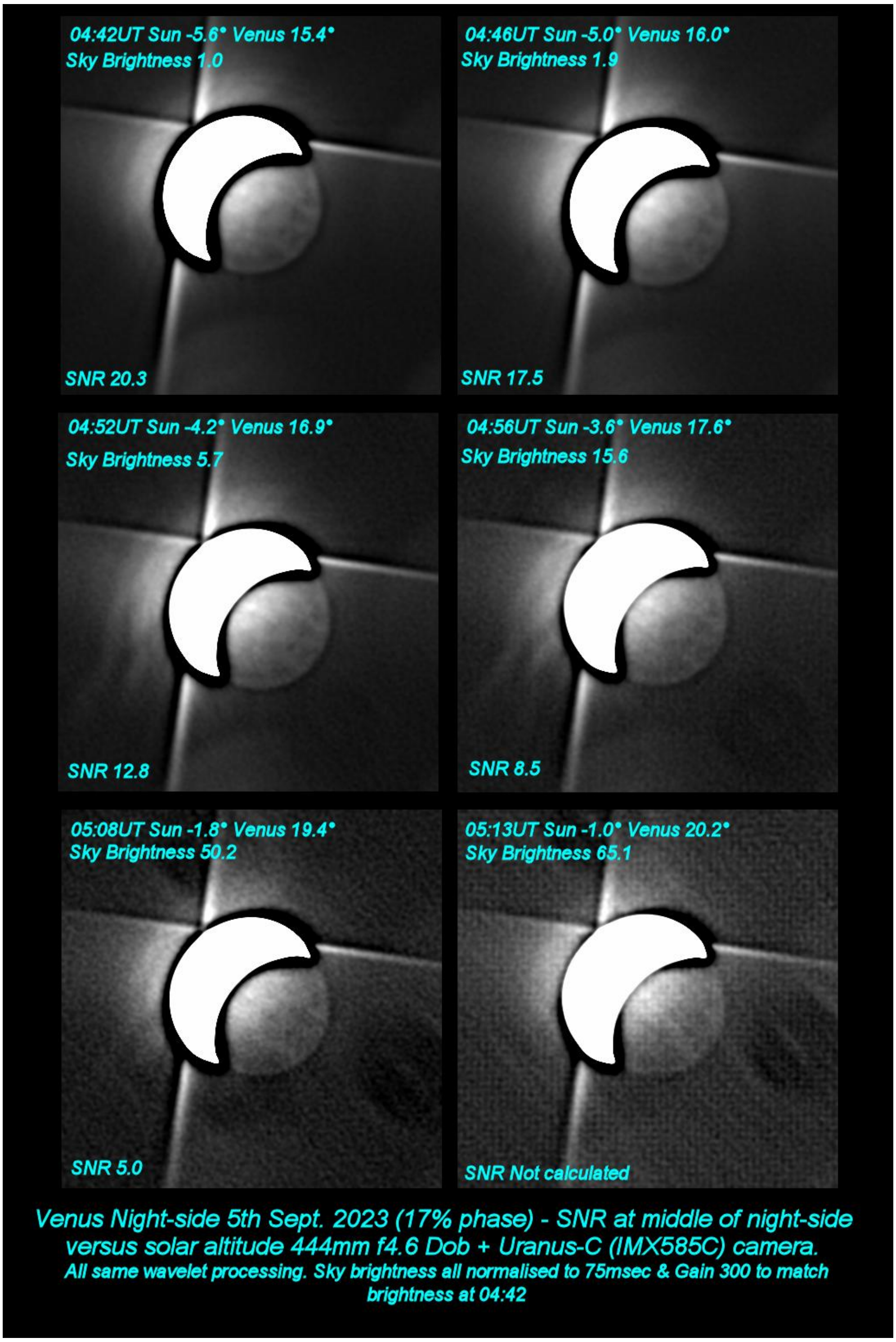



Figure 5.6. Real-world data showing how the rising brightness of the sky as the session progresses leads to increased shot noise and resulting image deterioration. **Note:** At a solar altitude of -1.0° the high sky brightness leads to an 8-pixel weave effect with this IMX585 sensor camera. This is associated with buried metallisation tracking in the sensor becoming evident.

### 5.2.3 Dayside Glare

In good apparitions, during the optimum imaging period and when the Sun is also more than 6° below the horizon, twilight wash is weak and glare from the dayside then becomes the dominant source of shot noise. This glare has many sources and the list below is not exhaustive, but most of it comes from the light spreading into the night-side region from the much brighter, and immediately adjacent, dayside crescent. Sources of glare include:

- Atmospheric scatter from aerosols and dust in the atmosphere
- Scatter and reflection from optical surfaces such as mirrors and corrector plates
- Scatter and reflection from surfaces of Barlows and optical reducers, if used
- Scatter and reflection from surfaces of infra-red filters
- Scatter and reflection from cover glass and protection glass in camera
- Scatter within the sensor material
- Diffraction from secondary spider vanes in a Newtonian scope

As shown in figure 5.2, the glare increases dramatically as you move across the night-side from the limb towards the dayside crescent. In figure 5.7 below, line brightness profile data is given for three dates in Sept. 2023 where the phase increased from 17% to 31%. The over-exposed saturated dayside is the plateau at upper left and the plots are arranged so that the position of the dayside limb is at the left-hand axis (0 pixels) for all dates. The individual curves all terminate at the pixel location where the night-side limb is located on that date - the planet clearly shrinking in size as the phase increases.

As the dayside crescent proportionally grows and the night-side proportionally shrinks, the planet also shrinks in angular size. The glare slope near the dayside becomes steeper too. The net result is that the amount of the night-side not so badly affected by the glare, essentially the flattish portion at the bottom of the plot, becomes smaller and smaller. It is this which sets the upper limit of about 35% on the phase. This is approximately the limit at which there is very little night-side which is not on the steep glare slope running up the left-hand side of the plot. At >35% any night-side data is hard to process due to the steep slope and is much more affected by the shot noise that the glare imprints on the night-side region.

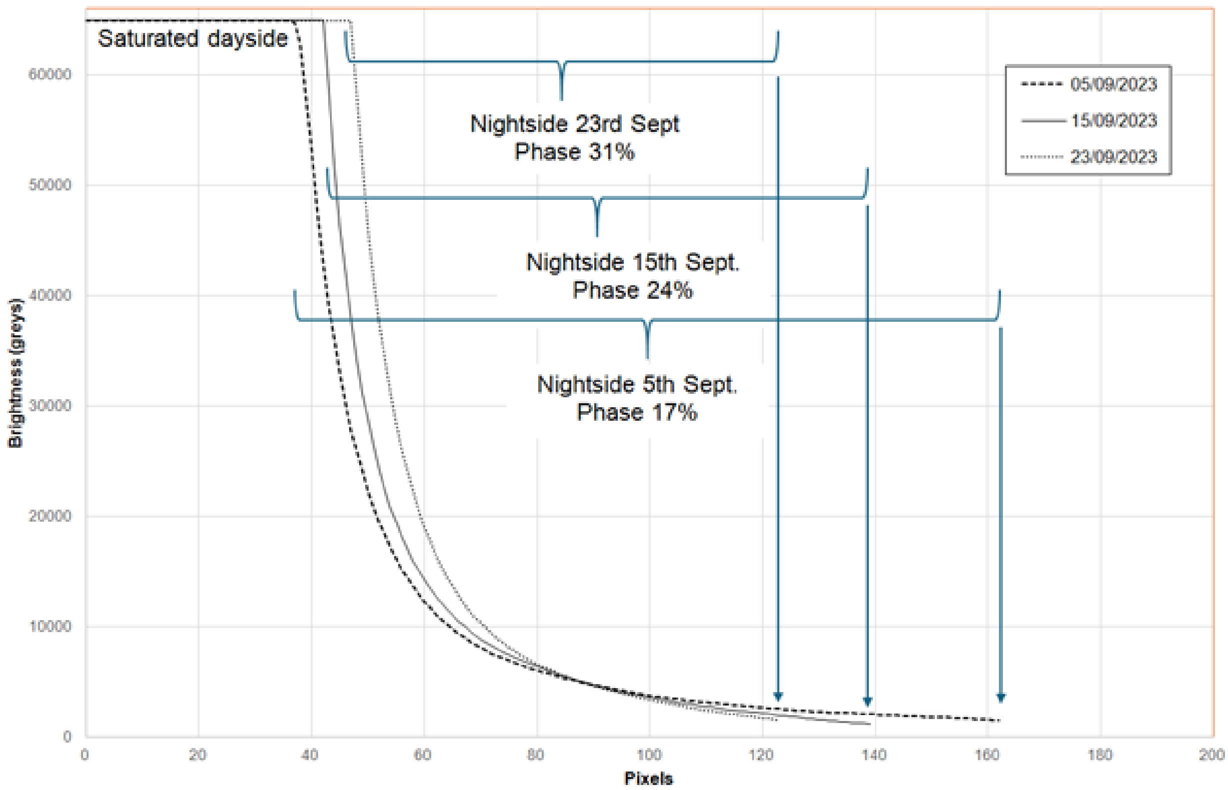



Figure 5.7. Line profiles across Venus on three days in Sept 2023 when the phase increased from 17% to 31%. Curves start on the left at the dayside limb, run across the saturated (overexposed) dayside plateau, then sweep down across the night-side to the night-side limb at the right-hand end of each curve. In each case the night-side signal is just about 200 grey levels on the y-axis and most of the signal in the night-side region is glare from the dayside which drops with distance from the dayside.

## 5.3 Equipment, Aperture, f-ratio and image scale

In the right conditions and with a suitable set-up, the night-side should be detectable in small and medium telescopes, but imaging details on the night-side will likely require a scope of at least 250mm. The larger the aperture the smaller the size of the detail, and the lower the contrast of the details, that can potentially be imaged.

With the night-side so faint, imaging at low f-ratios (<f/10) is recommended to increase the surface brightness of the planet and reduce shot noise. The best amateur night-side images have been obtained with large scopes operating at f/4 to f/7. Large aperture SCTs (280mm to 355mm), which have an inherently high native f-ratio of around f/10, can use focal reducers to reduce the effective f-ratio and increase the night-side image surface brightness.

For a given telescope you might imagine that in choosing the most effective f-ratio it was all about image scale and a 300mm f/5 scope with a 2.9um pixel camera would perform the same as a 300mm scope f/10 scope with a 5.8um pixel camera[1] as these would capture the same number of photons per pixel and have the same arcsecs/pixel. However, the ghost

[1] This could be a 2.9um pixel camera with 2x2 binning mode applied

reflection issue with cameras, described below, complicates things. The physically larger Venus image projected onto the chip with the f/10 scope *may* mean that the night-side image is partly overlapped by ghost reflection images of the dayside. The f/5 scope on the other hand is likely to have better separation between night-side and those nuisance ghost reflections.

The size of Venus on the chip depends on the focal length of the scope, so the bigger the aperture the smaller the f-ratio needs to be to avoid overlaps. This is illustrated in figure 5.8 which shows a Venus night-side image taken with a 508 mm scope operating at f/11. At this f-ratio the night-side overlapped with a nearby ghost image causing degradation of an otherwise excellent image - at f/6 there would have been no overlap as the Venus night-side would have been smaller and the ghost images would have been smaller too - although their separation on the chip would stay the same. It has been observed that the definition of the secondary ghost images increases as the focal ratio increases. This sharpening up of the ghost images likely arises from the narrower cone of light arriving on the sensor surface.

In normal planetary imaging one would choose an optical set-up best suited to the resolving power of the scope. Generally, this is done through matching the camera pixel size with the choice of Barlow or focal reducer so that ≈3 pixels or so covers the smallest feature that the scope can resolve. This is the so-called Nyquist criterion. For planetary imagers the Nyquist criterion is embodied in a simple rule of thumb where you should pick an effective f-ratio for your optical train which, for mono cameras, is 3x to 5x the pixel size in microns[2]. For example, a scope used with a 2.9 micron camera would be best operated at f/9 to f/15, and you would pick your Barlow (or focal reducer) to achieve this.

Venus night-side imaging is not standard planetary imaging, however. The 3x to 5x rule of thumb is based on 550nm (green) light, whereas night-side imaging is done at ≈1000nm. The rule of thumb needs to be amended for Venus night-side imaging to allow for this much longer wavelength and the more appropriate recommendation is to pick an f-ratio which is 1.6x to 2.8x the pixel size in microns. Thus, for the 2.9 micron pixel example this becomes f/4.6 to f/8. Large imaging Dobsonians, which typically operate at a native focal ratio of f/4 to f/5, might therefore benefit from a 1.5x Barlow to improve resolution when the seeing is good, as long as that doesn't mean the planet is then so large that the night-side overlapped by dayside secondary images, as just discussed.

[2] For colour cameras it is 4x to 7x

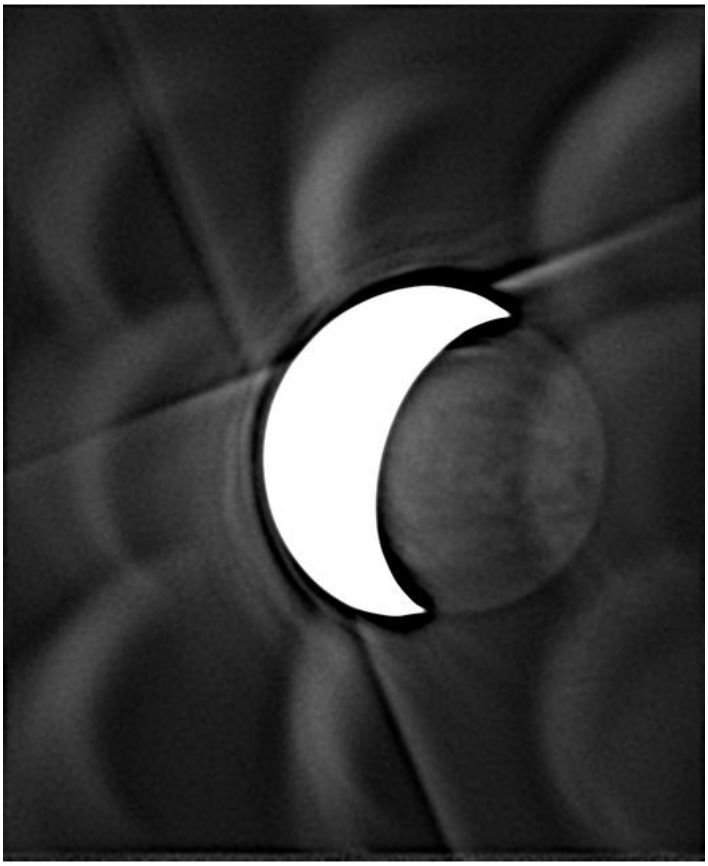


Figure 5.8. A native f3.3 scope of 508mm aperture was used with a 3.3x Barlow to take this image of the Venus NS. At this image scale, however, the night-side was overlapped by one of the ghost images of the dayside crescent (image courtesy of Tom Williams and Sophie Paulin).

### 5.3.1 Equipment - Cameras & Sensitivity

Traditionally the silicon-based sensors used in digital video cameras used by amateurs for planetary imaging had very low sensitivity in the wavelengths used for Venus night-side imaging. At 1000nm the quantum efficiency (QE) was typically just 2% to 3%.

A big push by the sensor maker Sony in the past few years to improve performance in the near IR for machine vision applications has now produced cameras which, although still relatively insensitive at 1000nm, are much better than they were. Cameras are now widely available with QEs of around 15% at 1000nm, dramatically improving SNR and also allowing shorter exposures with commensurate reductions in atmospheric smearing of the image due to poor seeing.

### 5.3.2 Equipment - Cameras & Dayside Ghost Reflections

Although good QE at 1000nm is important, there are other considerations which must also be taken into account when picking a camera for Venus night-side imaging. A key characteristic mentioned earlier is the camera sensor's tendency to exhibit multiple ghost reflections of the much brighter and over-exposed dayside.

Figure 5.9 shows an example of this ghost reflection issue, here with a camera having an IMX178 mono chip.

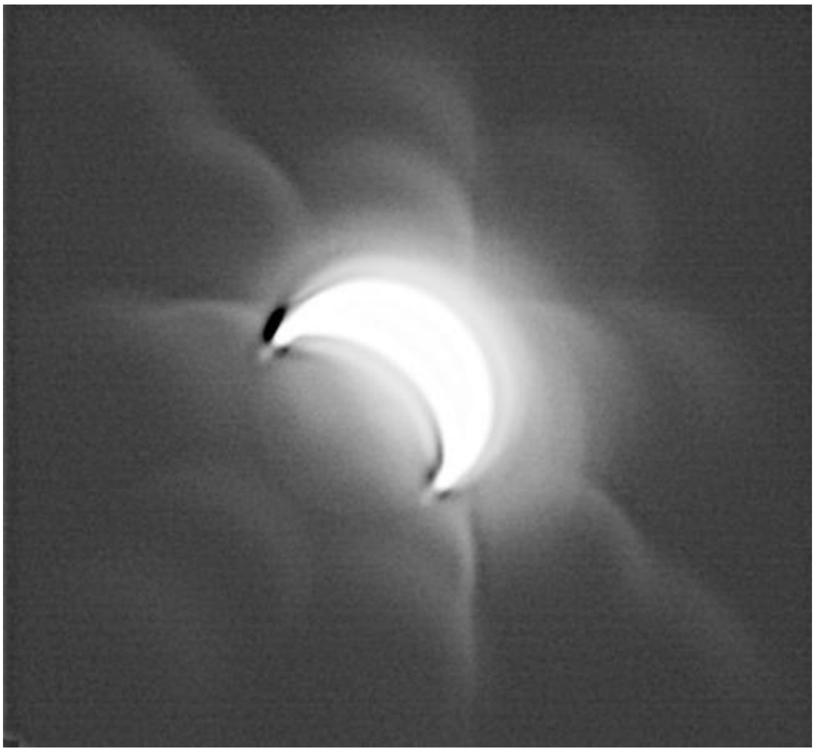


Figure 5.9. ASI178MM with a Sony IMX178 chip showing multiple ghost reflections of the over-exposed dayside crescent. The ghost reflections are distributed in a geometric pattern over the frame and overlap the faint night-side region (image courtesy of Guntram Lambert).

This ghost reflection issue is caused by the regularity of the metallisation pattern in the chip acting like a diffraction grating and so producing multiple diffraction images of the dayside crescent. These reflected diffraction images travel away from the sensor surface, reflect off the inner top side of the coverslip attached to the sensor, and then travel back to the sensor to interfere with the primary image. These ghost images can obscure and confuse the detail in the night-side portion.

Different cameras are susceptible in different degrees to this issue; the severity likely depending on factors like the sensor coverslip thickness and reflectivity, as well as the sensor metallisation pitch and layout. Figure 5.10 below shows test images taken through a 1000nm filter on an indoor set-up to mimic the Venus dayside and compare the severity of the ghost reflections present in different cameras.

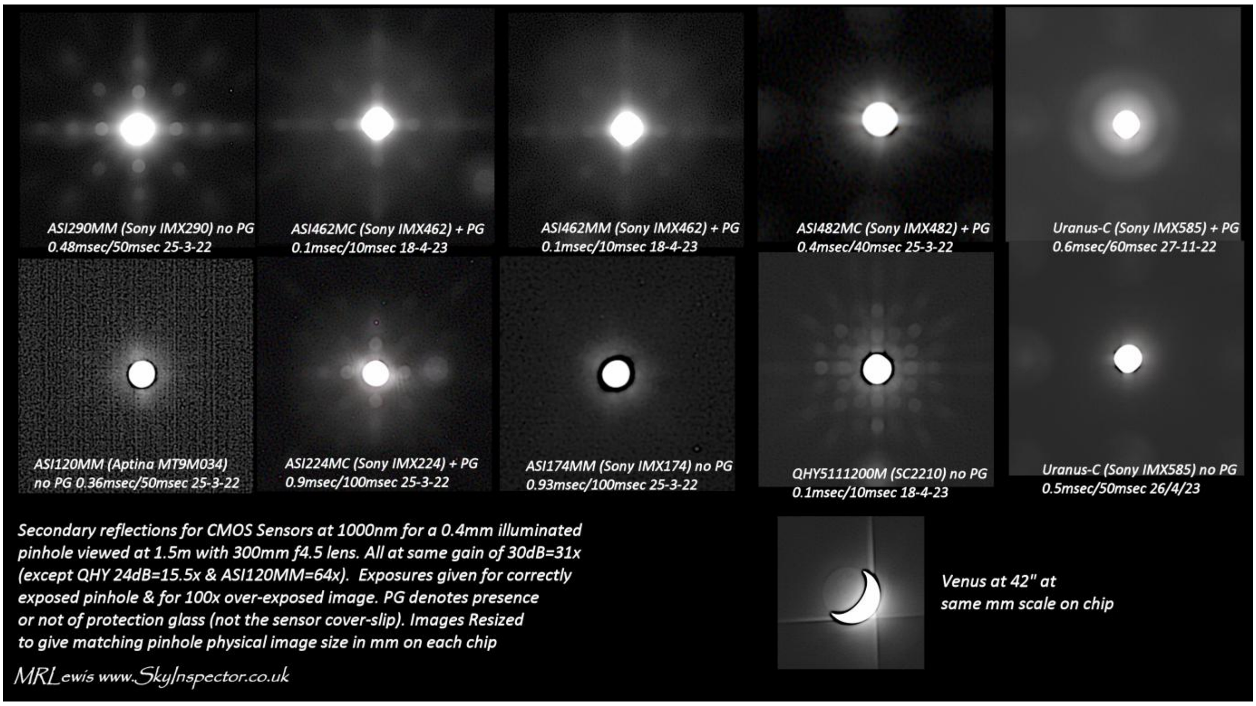



Figure 5.10. Ghost reflections seen in different popular planetary imaging cameras at 1000nm using a test rig designed to mimic the set-up used in Venus night-side imaging. In the rig a 0.4mm pinhole, illuminated with an incandescent bulb, is imaged with a 300mm f4.5 lens at 1.5m and is overexposed by 100x. Venus is included at the bottom at the same chip scale for a 444mm f4.6 scope.

There are three approaches that can be taken to tackling this annoying ghosting issue:

- Find a camera which inherently exhibits no ghost reflections of any significance
- Find a camera where the pattern of secondary reflections is well-separated and away from the night-side
- Modify the camera to remove the coverslip and thereby eliminate the secondary reflections

There are very few cameras which don't show the secondary reflections. One is the very old ZWO ASI120MM, which uses the OnSemi AR0130CS sensor, but this has very poor sensitivity at 1000nm and very high read noise. Another candidate is the ZWO ASI174MM, which uses the venerable IMX174 chip, but again this has a low IR sensitivity (≈2.8% QE at 1000nm). The ASI174MM does have large 5.86 micron pixels, however, and can produce clean night-side images when a lot of data is stacked, as shown in figure 5.11.

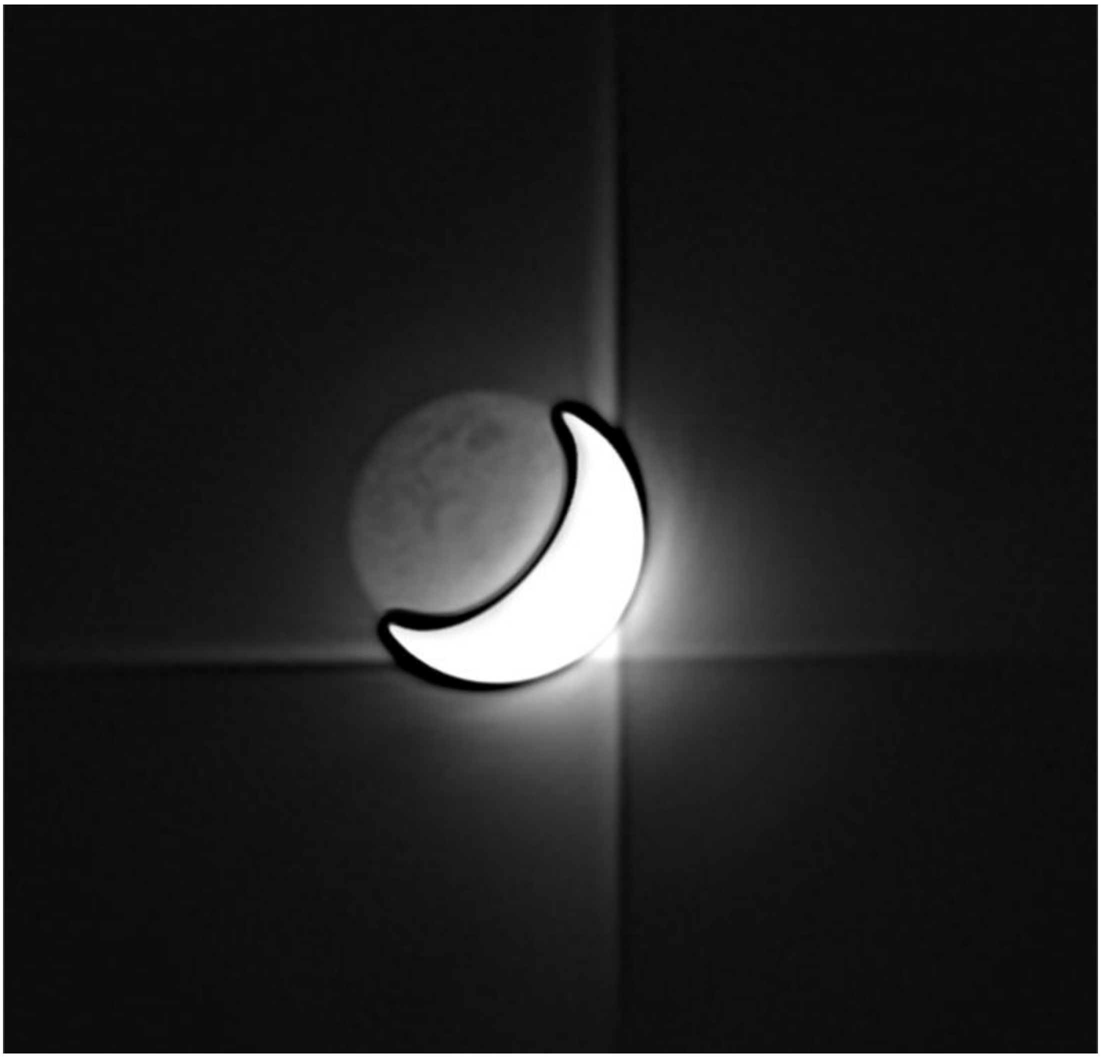


Figure 5.11. Venus image taken using an ASI174MM camera, showing significant night-side detail and no ghost reflections. This is data combined in WinJupos from three sessions on separate days in early May 2020.

Other known ghost reflection free cameras are the FLIR Chameleon3 CM3-U3-31S4M, which uses the Sony IMX265 sensor, and the FLIR Grasshopper3 GS3-U3-32S4M-C using the Sony Pregius IMX252, both which have 3.45um pixels, but again are fairly insensitive at 1000nm. More sensitive is the Lucid Vision Labs Triton TRI051S-MC using a Sony Pregius-S IMX547 sensor and used with some success for NS imaging in 2022, by Anthony Wesley and Phil Miles.

Finding a camera with a sensor which gives widely spaced ghost reflections is a second approach to dealing with this issue. The test image from one such camera is seen in Figure 5.10 at the right-hand end of the middle row. This is the Player One Uranus-C camera with its IMX585 sensor, modified by removing the protection window[3] which sits a short distance in front of the sensor. As of 2024 the Uranus-C is probably the most popular camera for Venus

[3] not to be confused with the coverslip which is attached to the front of the sensor

night-side imaging. New cameras are coming out all the time however, and it is inevitable that a different model will take the 'most-popular' mantle before too long.

The Uranus-C has 2.9 micron pixels and a QE of about 15% at 1000 nm, and surprisingly is a colour camera. Like many recent Sony colour chips, when operating at wavelengths above 850 nm, the red, green and blue colour filters all become highly transparent, and the camera essentially operates as a mono camera. The Uranus-C can give good clean images of the Venus night-side as long as the planet's image is not so large that the night-side image starts to overlap with the ghost dayside images.

As noted earlier, for best operation you will need to carefully open the camera up and remove the protection window, as this causes a lot of scatter and glare otherwise. When you remove the protection window it is recommended to leave the black foam filter locating ring in place in the camera. The foam ring prevents unwanted light entering through gaps in the camera body and reaching the sensor. Store the window safely wrapped in a clean cloth or tissue, as you may want to re-install it later if the camera is to be used for other tasks.

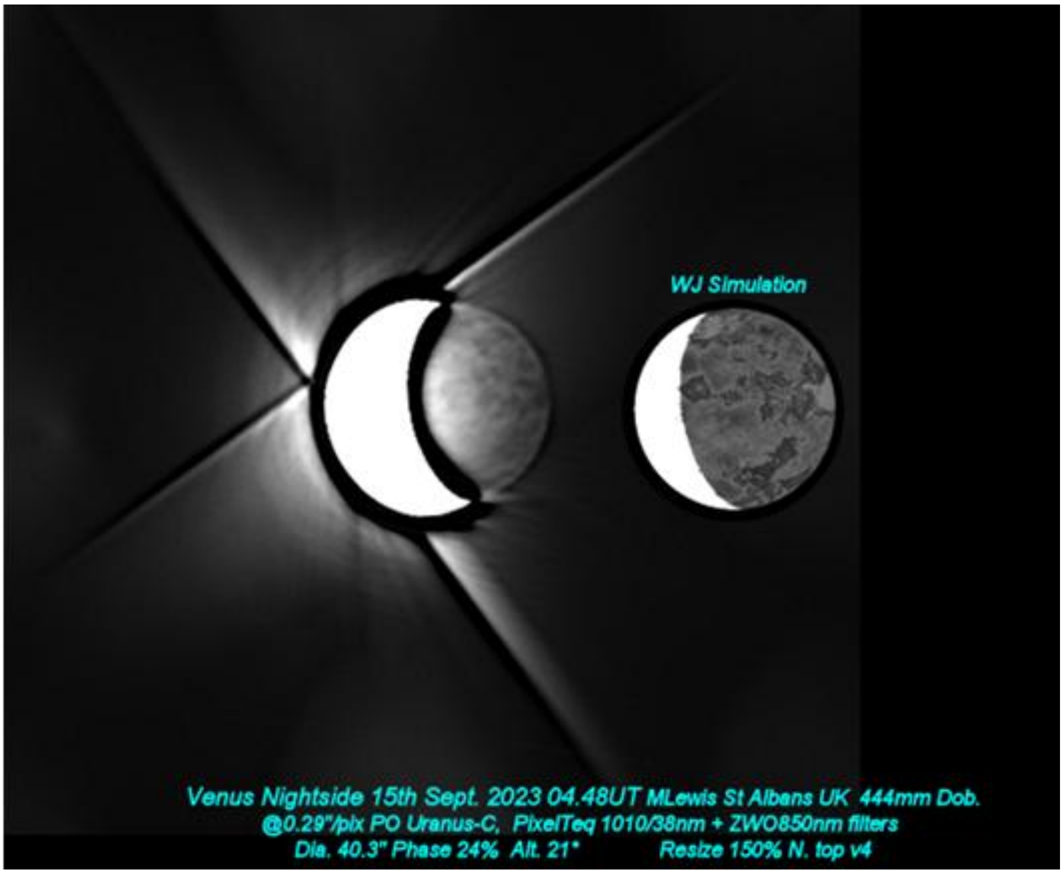



Figure 5.12. Venus night-side image with a Player One Uranus C camera with the protection glass removed. 444mm scope at f4.6 with PixelTeq 1010/38 filter.

### 5.3.3 Sensor coverslip removal

The third approach to dealing with ghost reflections is to remove the coverslip of the front of the sensor. This is no trivial task, but those that have gone down that path have found the resulting camera completely free of ghost reflections. Removing the coverslip gives much greater freedom on camera choice and image scale but does leave the sensor completely unprotected and vulnerable to deposition of dust motes, which are much harder to safely remove. The sensor is also potentially subject to deterioration from moisture ingress.

There are two ways to remove the coverslip. The easiest is to pay Salvo Technologies in the US to remove it from a camera that you supply to them. The cost is about $500 - see: *https://salvoimaging.com/service/cover-glass-removal/* . The other route is to try and remove the coverslip yourself. This is a very difficult task requiring patience, courage and a good deal of technical skill. If you are considering going down this route, then you are advised to first read notes on the task from António José Saraiva da Cunha Cidadão on the Groups IO Venus forum. A good place to start is the following message: *https://groups.io/g/VenusImaging/message/1419*

### 5.3.4 Filters

The key enabling technology that makes it possible to image details in the thermal night-side is the availability of suitable infra-red filters. These need to pass wavelengths within the narrow bandwidth from 960nm to 1030nm, but block wavelengths outside of this. Without such filters, which preferentially select the night-side over the dayside, the night-side would be hopelessly lost in the overwhelmingly bright glare from the dayside.

A number of filters have been used by amateurs for imaging detail in the night-side. These include:

- Edmund Optics 1000nm narrowband filter with 25nm bandwidth
- Edmund Optics 1000nm narrowband filter with 50nm bandwidth
- A combination of a Thorlabs FELH 1000nm long pass filter with a Semrock 935/170[4] filter to create a filter pairing with a bandpass range from 1000nm to 1020nm
- Torrent Technologies, Optical Filter Shop, PixelTeq 1010nm narrowband filter with 38nm bandwidth

Figure 5.13 below shows the thermal night-side emission peak (on the right-hand side of the plot) as recorded by the Cassini probe during a fly-by of Venus:

[4] 935nm middle of bandpass and 170nm bandwidth

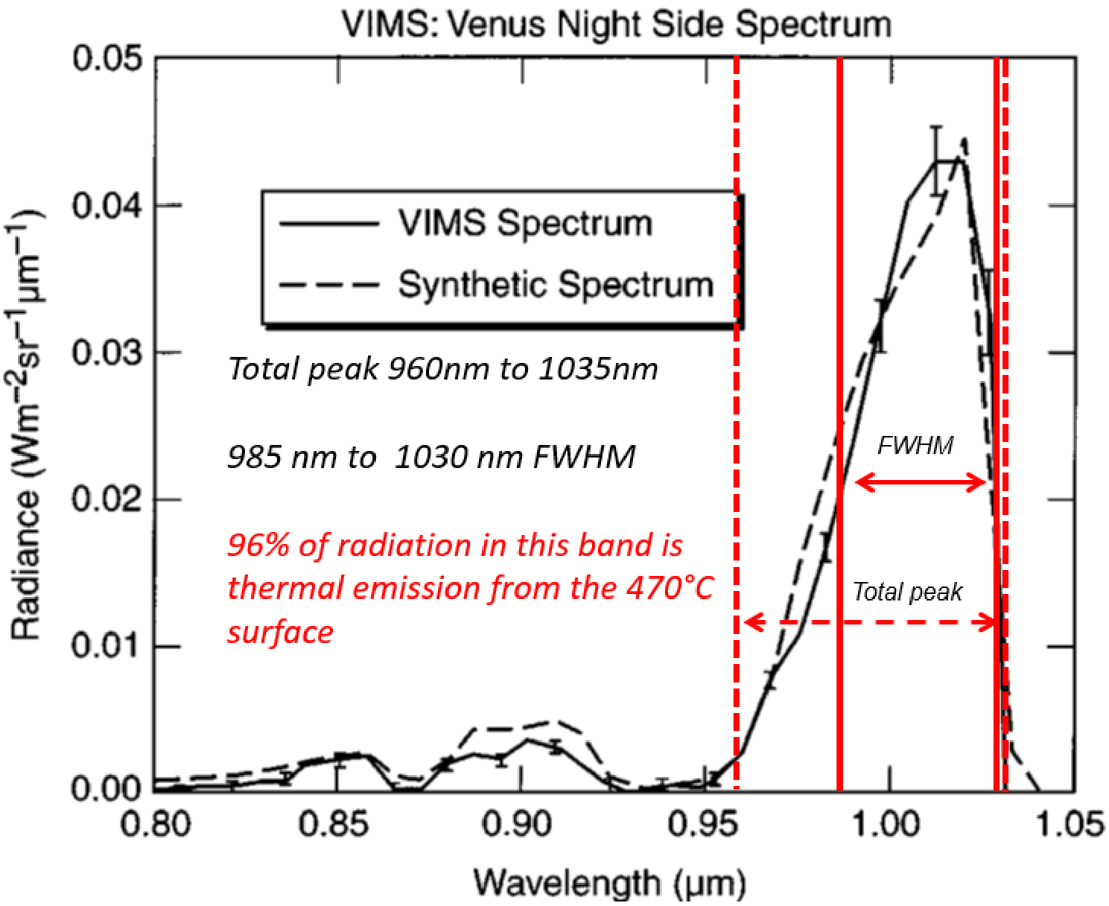



Figure 5.13. Venus thermal night-side emission peak between 960nm and 1035nm. In the full width half maximum (FWHM) region between 985nm and 1030nm, 96% of the radiation is thermal radiation from the hot surface of the planet. In this wavelength range the Earth's atmosphere and the Venusian atmosphere are both essentially transparent. (This base spectrum is from 'Detection of Sub-Micron Radiation from the Surface of Venus by Cassini/VIMS', courtesy of Kevin Baines & others).

Figure 5.14 plots the spectrum of the FELH/Semrock combination against the Venus spectrum shown in figure 5.13. The filter pairing has good discrimination of night-side acceptance versus dayside rejection but does not use all the light available from the night-side. Such a filter pairing has been used very successfully by Wesley and Miles but is an expensive option.

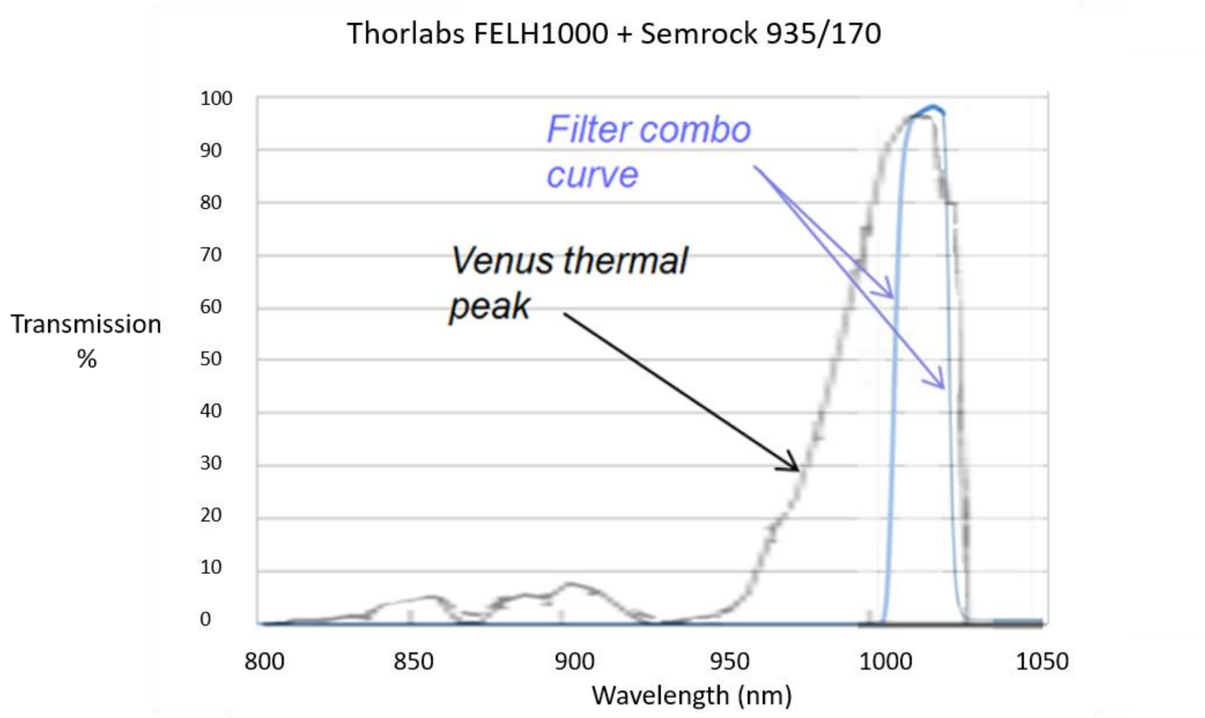



Figure 5.14. Graph of the FELH1000/Semrock 935/170 combination superimposed on the Venus night-side plot.

A lower-cost alternative which transmits a wider portion of the Venus night-side emission and which has been very successfully used by a number of imagers is the PixelTeq 1010/38nm filter with a bandpass from 990nm to 1030nm. The transmission spectrum for this is shown in figure 5.15.

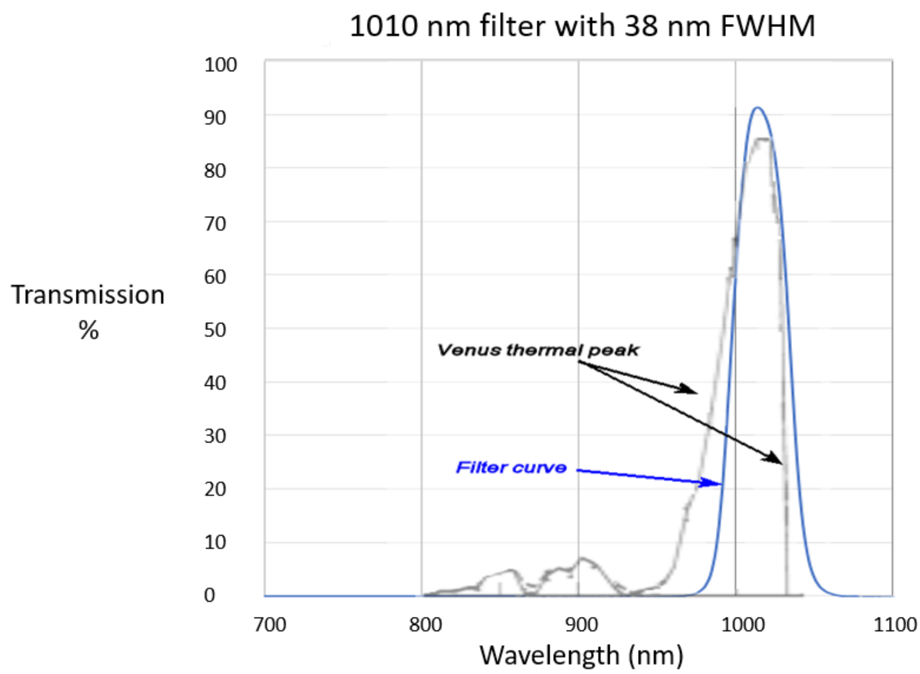



Figure 5.15. The graph of the PixelTeq 1010/38nm filter superimposed on the Venus night-side plot.

When you buy one of these filters you specify the diameter (typically 25.0mm) and have to mount it yourself in something like an unwanted filter mounting ring. There is a small amount of visible light leakage outside of the specified wavelength range for the PixelTeq and this needs to be blocked by using a second filter in series with it. The ZWO 850nm long-pass filter has been successfully used to eliminate this leakage issue from the main filter.

### 5.3.5 Camera settings: Gain and Exposure

In Venus night-side imaging, focusing is easy. Just reduce the exposure and focus on the correctly exposed dayside; get that sharp, then change the exposure time back to that for the night-side.

The camera settings best used for night-side imaging are a matter of individual experimentation as they depend on the particular camera, filter, and telescope being used. Traditionally, long exposures of $\geq$200msecs were used as the signal was so faint, but with higher sensitivity cameras and better filters, exposures can now be significantly less than this. Shorter exposures are less affected by atmospheric smearing, but the stack is more affected by read noise, although with modern cameras as long as the gain is kept above about 25dB read noise is low.

You can get an idea of the variation in the final image for different gain and exposure settings by studying figure 5.16. In this set the 25msec images seem to give the clearest view of surface features.

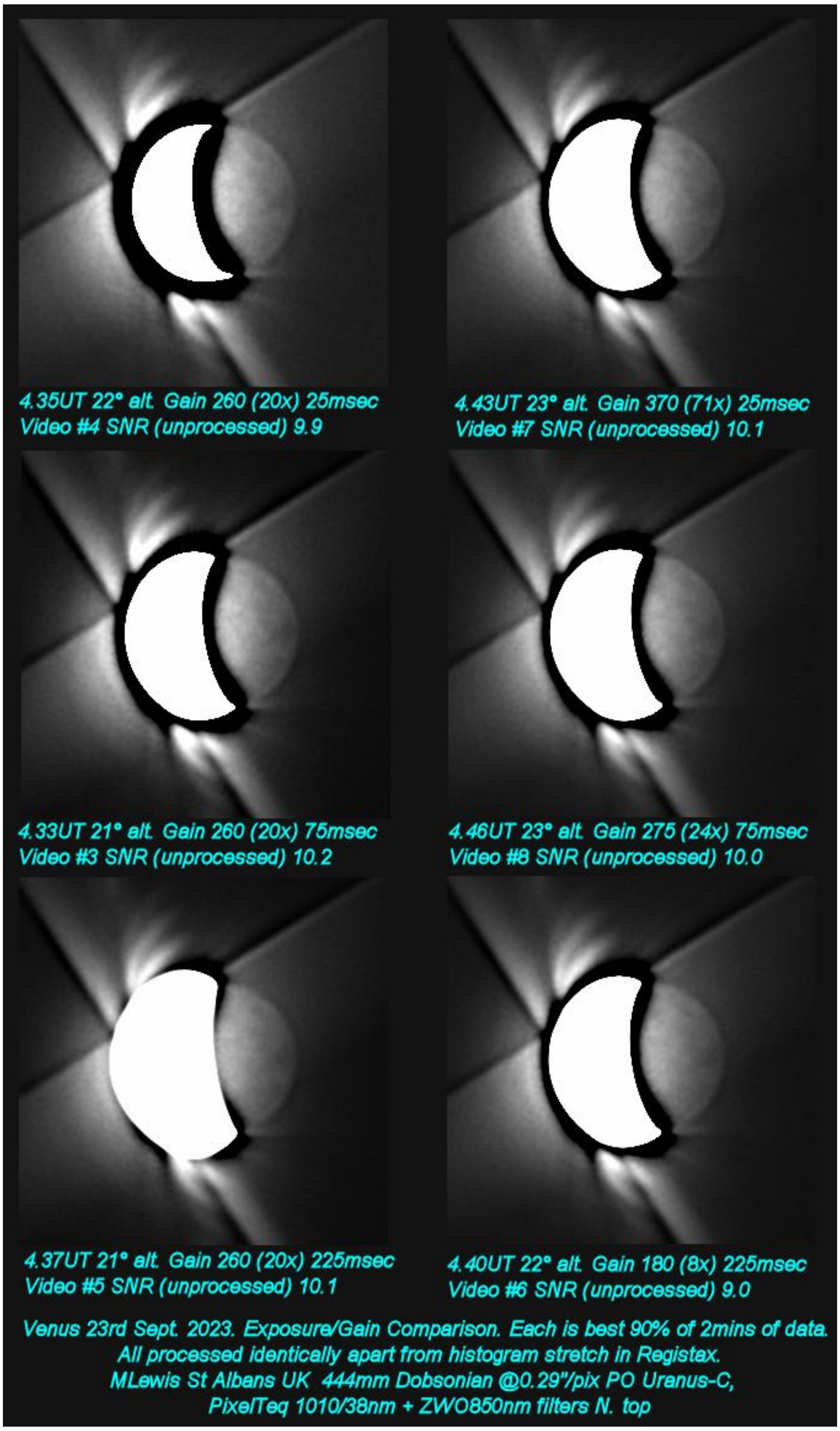



Figure 5.16. Gain and exposure tests with a 444mm aperture f/4.6 scope with Uranus C camera and PixelTeq 1010/38 filter. All processed near identically apart from histogram stretch parameters. Notice the varying size of the bloated crescent and surrounding black halo which together seem to block the same portion of the night-side.

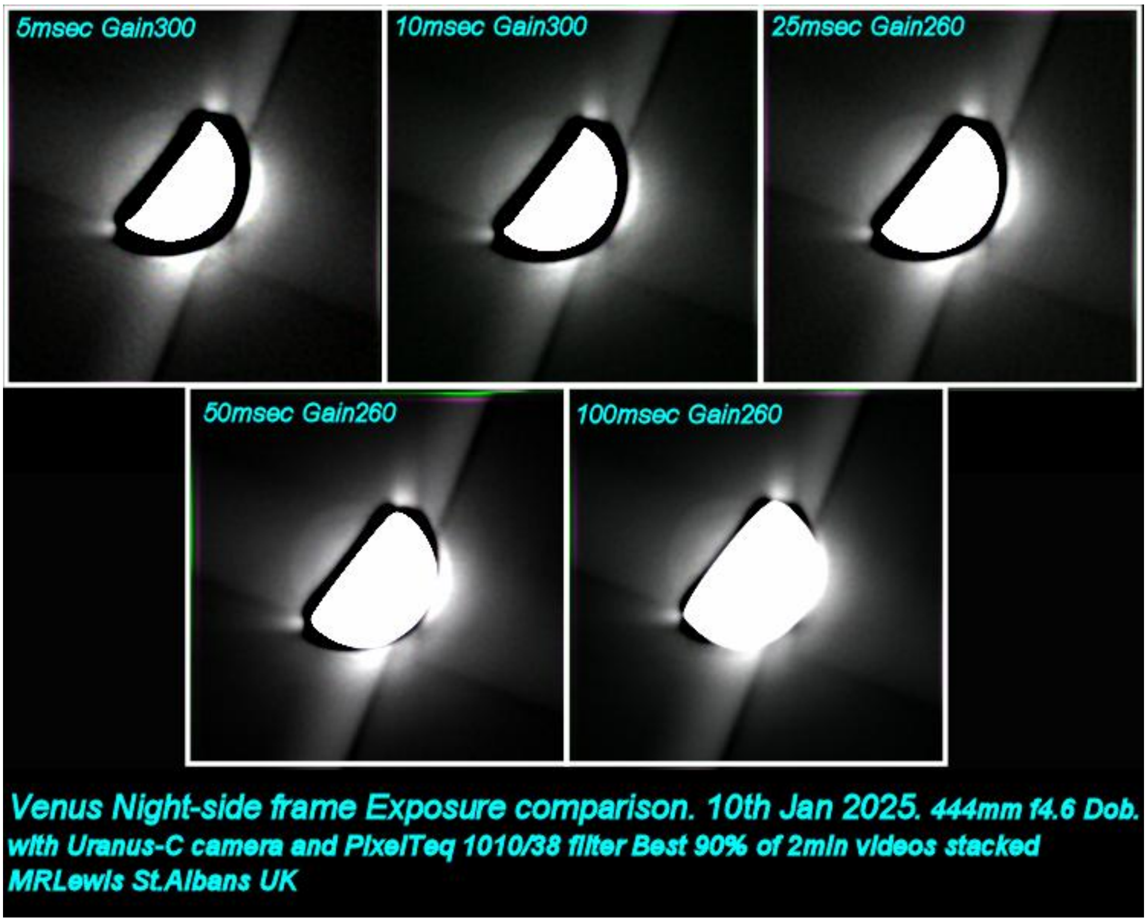



Figure 5.17. Venus night-side exposure comparison with phase at 51% and exposure times from 5msec to 100msec. All processing similar except the histogram stretch.

In figure 5.17 above, we see how, with the most recent low-noise and high-sensitivity cameras, we can use much shorter exposures than have conventionally been used and yet still clearly image the night-side. As the frame exposure time decreases, atmospheric smearing effects will play less of a role, helping with resolution. However, as we see in the montage, the read noise becomes more apparent as we shorten the frame time. The 10msec stack is slightly noisier than the 25msec stack and the 5msec stack much more so. It may be that with modern cameras and large telescopes, operating at f/5 or so, a frame exposure time in the range 10-30msec strikes the optimum balance between noise and seeing.

### 5.3.6 Camera Bit Depth, Offset and Video duration

Although to some extent you can play around with gain and exposure, comparing the different stacked results, one camera setting that you probably want to fix is the bit depth. Changing the camera mode from 8 bit to 16 bit will increase the bit depth from 256 levels to 4096 levels. Even though the night-side is very faint, where normally there might be quantisation errors creeping in with the lower bit depth, there is some discussion about whether 16 bit is strictly necessary, given the gain used and the magnitude of the overlying glare and background wash signal. More experimentation is needed to give a definitive answer on bit depth selection and so for now, as the only downside of 16 bit is a doubling of the data storage requirements, and for Venus night-side imaging those are low anyway, it is easier to leave it enabled.

Another setting you want to pay attention to in your camera control software is the *offset* value (also known as brightness setting). If a pixel has a small signal level and the read noise added on pixel readout happens to be negative and larger than the signal, the resulting pixel output will become negative. Since most analogue-to-digital converters (ADC) are unipolar (e.g. 0V to 1.2V input range only), this will be read as exactly zero by the ADC, so the weak signal information will be lost. The offset is a constant positive electrical signal added to each pixel before the ADC to ensure its output will be greater than zero even if the noise is negative, thus preserving the weak signal information. This avoids distortion of the bottom end of the signal histogram, which would be magnified when you do the important histogram stretch to bring out the night-side in your image as shown later in figure 5.21. Just ensure you have a small offset (brightness) level, say 2%-5% of the maximum offset value, set in the camera control software. Once set, you can then forget about the offset value after that.

Gather as much data as you can in 1 to 2 minute videos, between the times when Venus is too low (<10°) or the Sun is too high (higher than ≈3° *below* the horizon). Although there is no significant rotation of the planet to worry about rotational smearing, in a sky that may be changing brightness, too long a video may have quite a different background brightness at the beginning compared to the end and this may make later processing difficult.

### 5.3.7 Equipment: Secondary vane issues

If imaging the Venus night-side with a Newtonian telescope, the four vanes that hold the secondary mirror in place will introduce four diffraction spikes which will radiate out from the processed image of the over-exposed dayside crescent. You can see examples of the spikes in many of the images accompanying this section as these have all been taken with a 444mm Dobsonian telescope, which of course is a Newtonian design.

If you are unlucky with the orientation of the diffraction spikes relative to the orientation of Venus during a given apparition, one of them may unfortunately pass through the night-side portion. With some Newtonians the head of the scope and the offending vane set can be rotated to rectify the matter, but most Newtonian owners will be stuck with the problem.

One possible solution, suggested by Chris Hooker, is to change the distribution of the diffraction spikes by using apodising masks on the offending vane pair. Figure 5.18 shows an apodising mask on two of the vanes of the 444mm scope, whilst figure 5.19 shows the situation before and after fitting the mask. The mask was cut from an opaque PET with a foil backing using an XY-plotter/cutter and effectively eliminates the troublesome spike. It is very important to make the apodising mask accurately, because slight irregularities will introduce stray diffracted light in unwanted directions.

Figure 5.18. Apodising mask consisting of a 30° saw-tooth on 3mm pitch and attached to the two offending vanes of a 444mm scope.

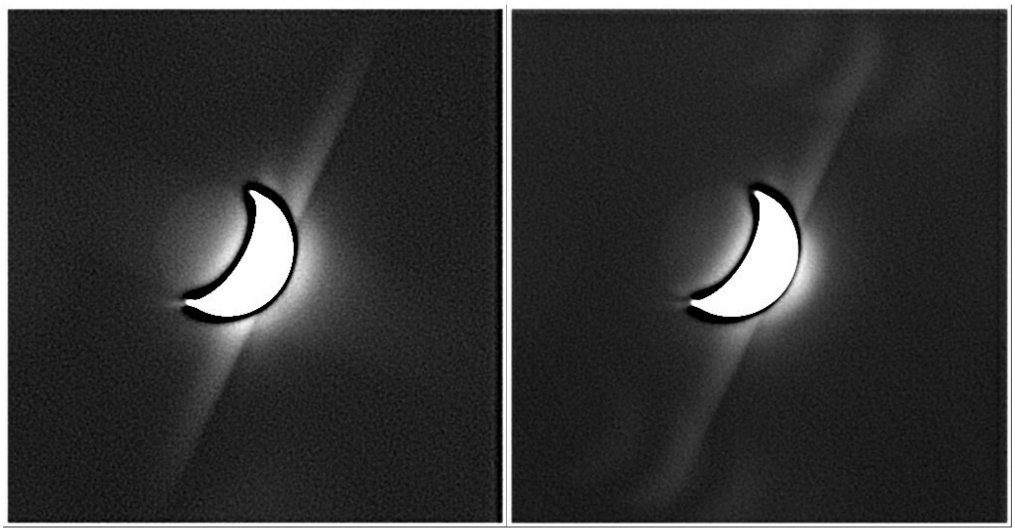


Figure 5.19. Left: Venus without apodising mask, showing wide diffraction spike passing right through the night-side from left to right. Right: with the mask shown in figure 5.18 fitted to one set of vanes - the diffraction spike is changed to become inoffensive secondary images at top right and bottom left

## 5.4 Processing

### 5.4.1 Processing settings in AutoStakkert! and Registax

Captured videos are best processed in AutoStakkert! to quality sort and stack the frames as for normal planetary imaging. It is recommended to use a single alignment box around the planet and stack at least 80% of the frames, without any sharpening, saving the stacked image as a tiff or png file.

After Autostakkert! processing, one should use wavelet processing to enhance the night-side portion and draw out any details present. You will likely need to use completely different wavelet settings to those you would normally employ for planetary imaging, as you need to both suppress the spreading glare from the dayside whilst also bringing out any large real features in the much darker night-side. A number of different programs are available to carry out the wavelet processing, including AstroSurface, WaveSharp, and Registax. As a starting point, it is recommended to try using Registax with the settings shown in figure 5.20.

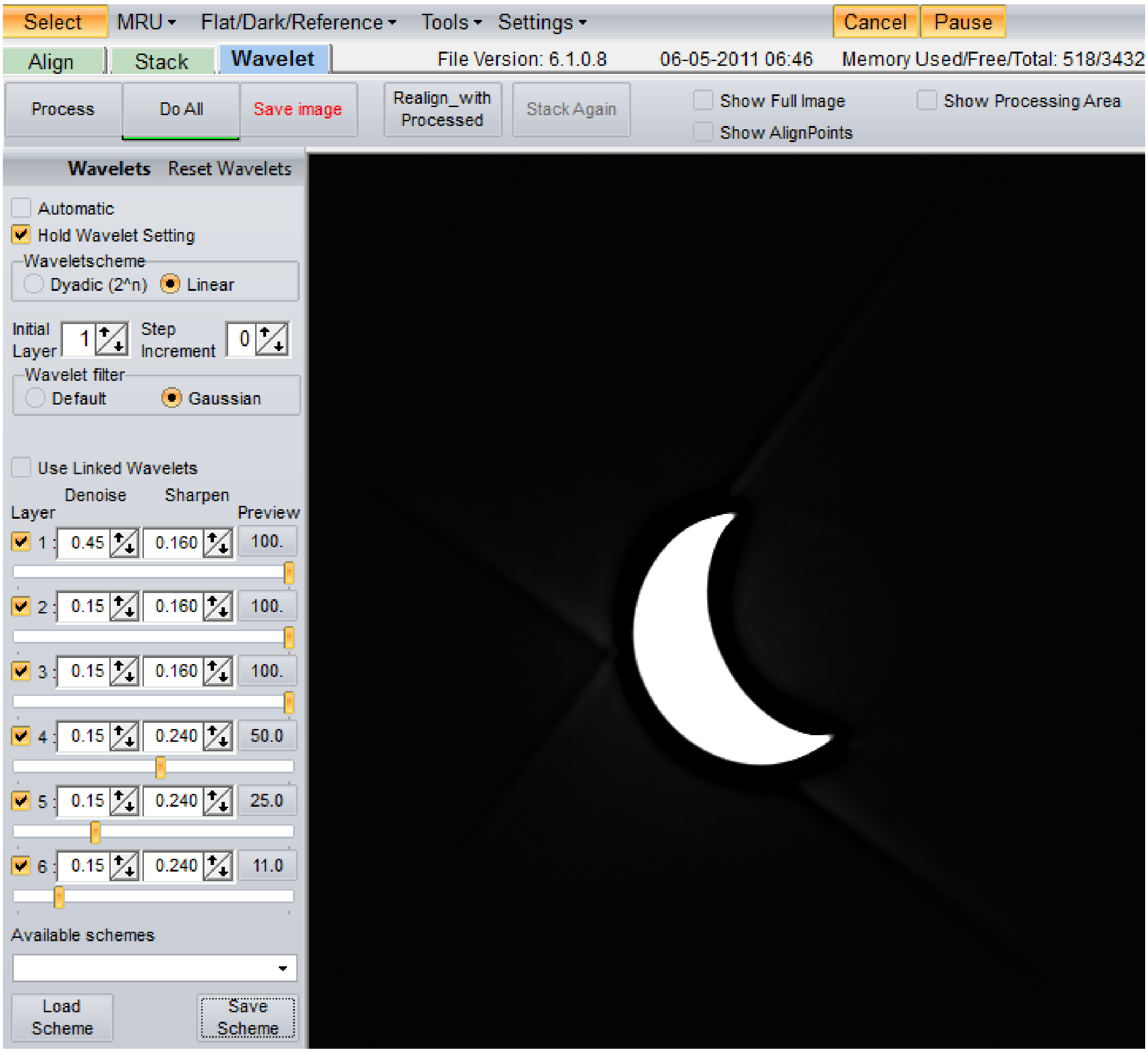



Figure 5.20. Suggested starting wavelet settings in Registax

After applying wavelets, use the histogram stretch function to massively increase the brightness of the night-side. This should bring out any large darker thermal features that might be present. Play around with the settings to get the best results but try setting the lower slider just before the peak and the upper slider just after it, before hitting the 'stretch' button, as shown in figure 5.21.

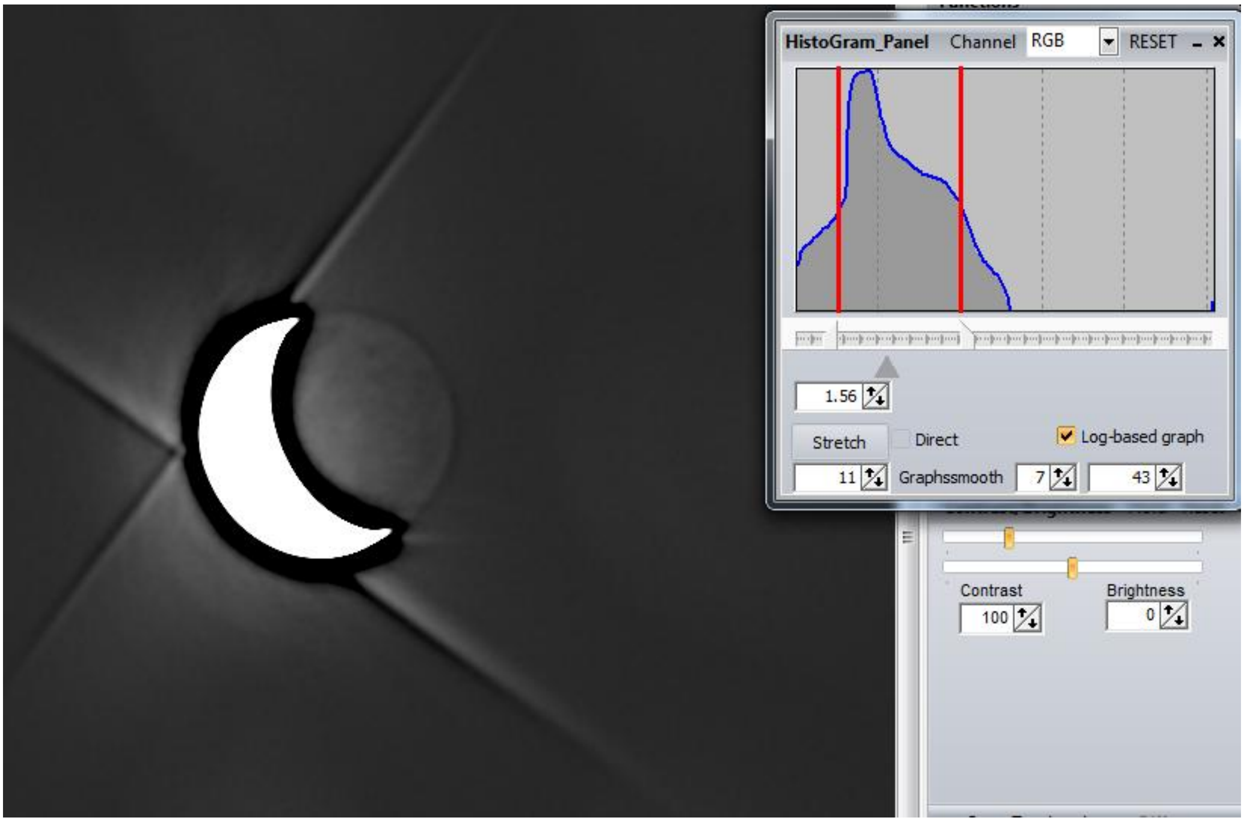



Figure 5.21. Histogram stretch limit positions at upper and lower ends (red lines) to bring out night-side details in Registax. Set upper and lower limits in the Histogram Panel and then hit the Stretch button. *Note: the image of Venus is after the stretch has been applied.*

Repeat the AutoStakkert!/Registax processing for all your capture videos. Once you have good wavelet settings, use the same ones for all your videos but tweak the histogram stretch values according to the exact darkness of the background and the exposure time and gain used for that video.

### 5.4.2 Processing settings in WinJupos

If you have several processed images all showing the night-side you can stack them very simply by dragging and dropping the set of processed images onto the AutoStakkert! control panel. Set the stack percentage to 100% and stack them with a similar alignment box setting as the first time round, to combine the images. Stacking processed images like this will reduce noise and give you the best chance of revealing true surface features. Alternatively, you can combine them in the usual way in WinJupos de-rotate. This is particularly useful if you want to combine images taken a few days apart as it will correct for the slight rotation of Venus from one day to the next.

If you do see some darker features, you can use the Ephemerides feature in the freeware program WinJupos to check if they are likely to be real and related to topographical features on the planet's surface. Set the planet to Venus and set the Options as shown in figure 5.22. Pick the *VenusThermalEmission1micron.jpg* as the texture image, use the time/date of your session, then switch to the Graphics tab and tick *Unillum. Surface* to give a simulated thermal map of Venus's night-side based on Magellan planetary probe height data.

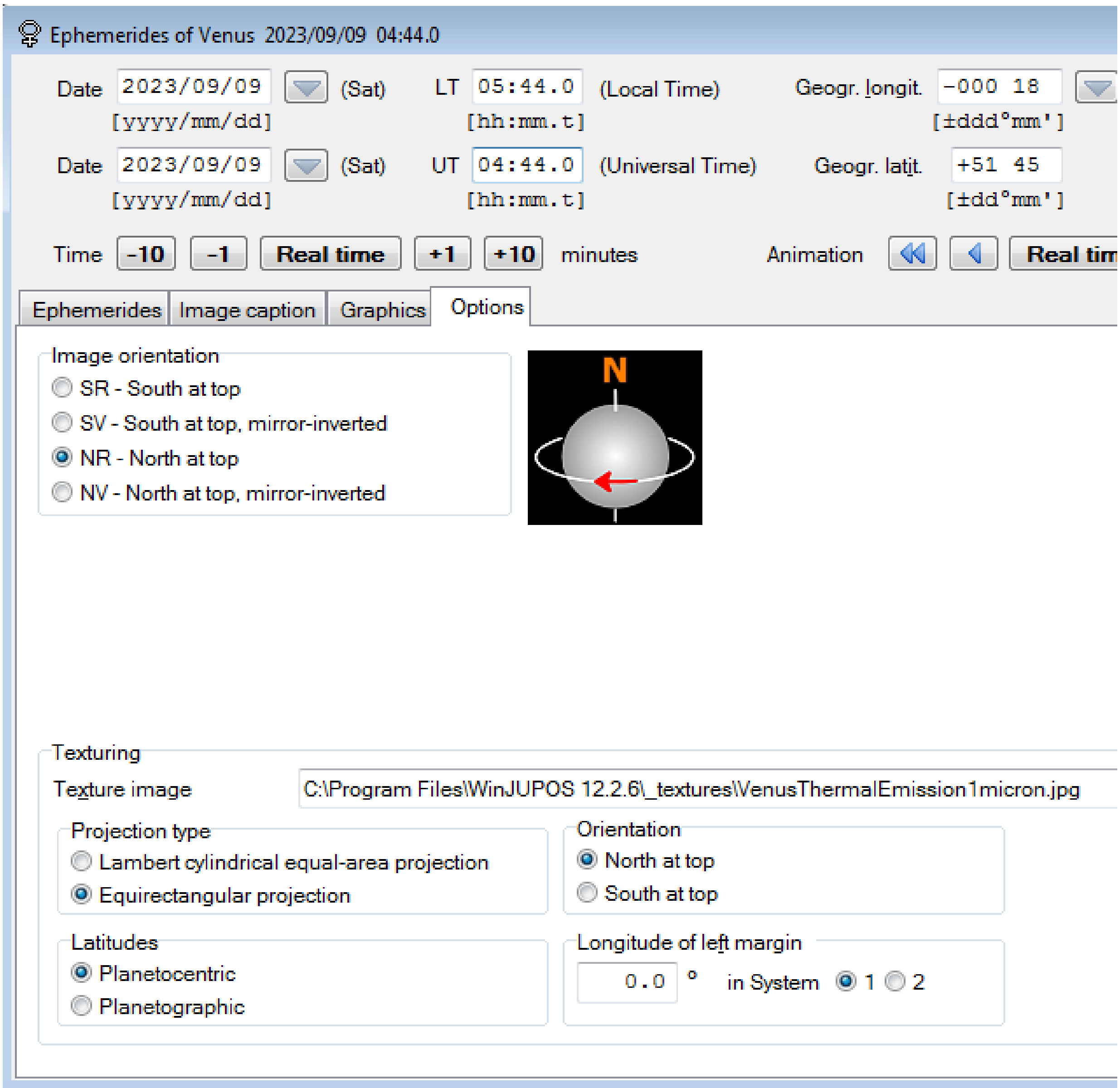



Figure 5.22. WinJupos Settings for correct graphical simulation of Venus' night-side

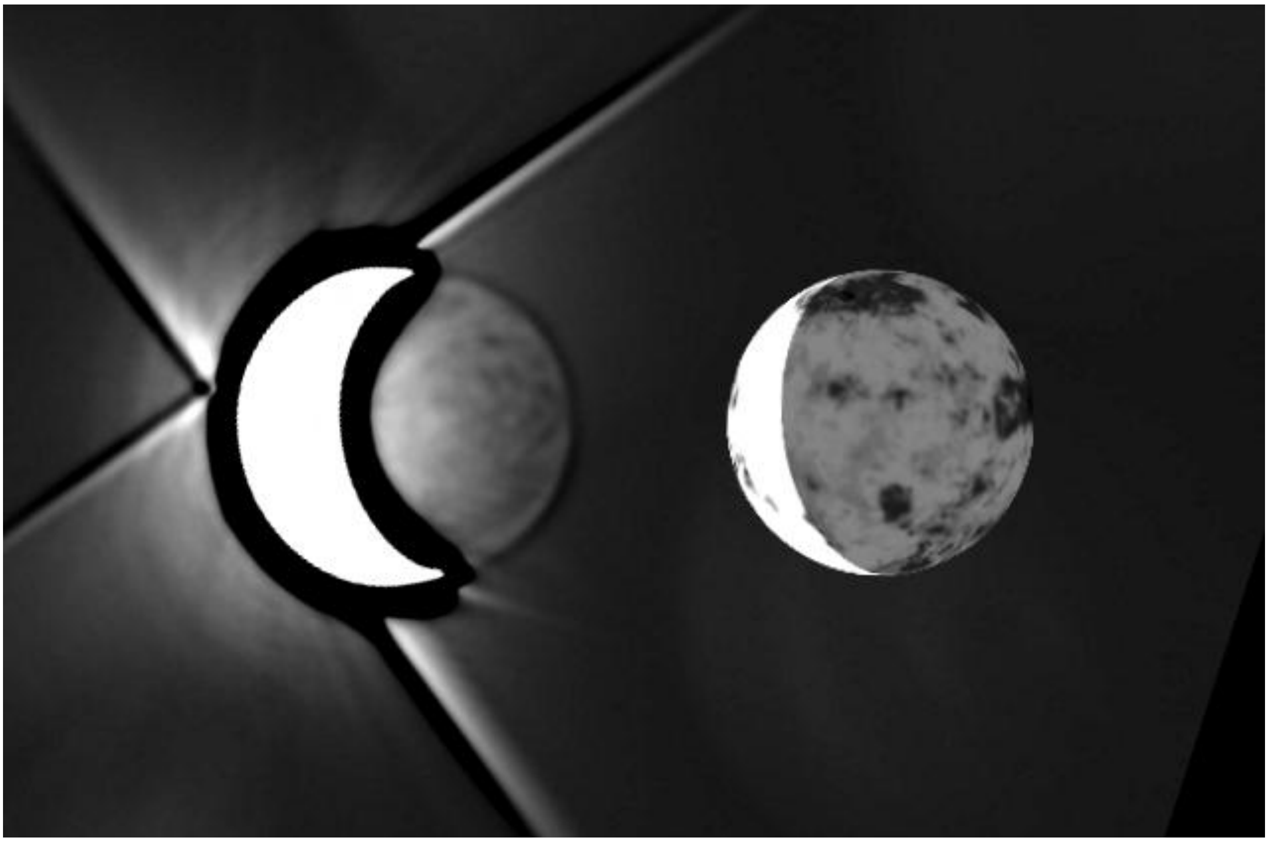


Figure 5.23. Images combined in Autostakkert!3 then compared with WinJupos simulation, showing multiple matching dark (higher elevation) features.

## 5.5 Features to look out for

Most of the features which good images will show are darker areas which generally relate to known higher and cooler areas of the planet's surface. Between consecutive days the central meridian of Venus changes by about 2°. This means that during the 3 weeks of the best part of the apparition, with the phase changing from 15% to 35% (or vice versa), the planet appears to rotate through a total of about 43°, significantly increasing the accessible portion of the night-side during each apparition.

Venus's orbital parameters are such that in 8 years on Earth, Venus goes round the Sun almost exactly 13 times. This also happens to be almost exactly 12 days on Venus. These facts, combined with the planet's retrograde rotation, lead to the surprising result that at every evening apparition, at the same phase, we see pretty much the same face presented to Earth. The same is true with each morning apparition - at the same phase we see the same face - although this is a different one from the evening face. From the 25% phase in the evening, to the 25% phase in the morning, the central median on Venus changes by about 90°. In figure 5.24 you can see how all this comes together to give the sort of coverage you might get of the planet for a set of evening sessions and a set of morning sessions. It shows that although a good proportion of the planet can be imaged by Earth-bound amateurs, some areas of the Venusian surface unfortunately remain inaccessible to imagers with normal lifespans!

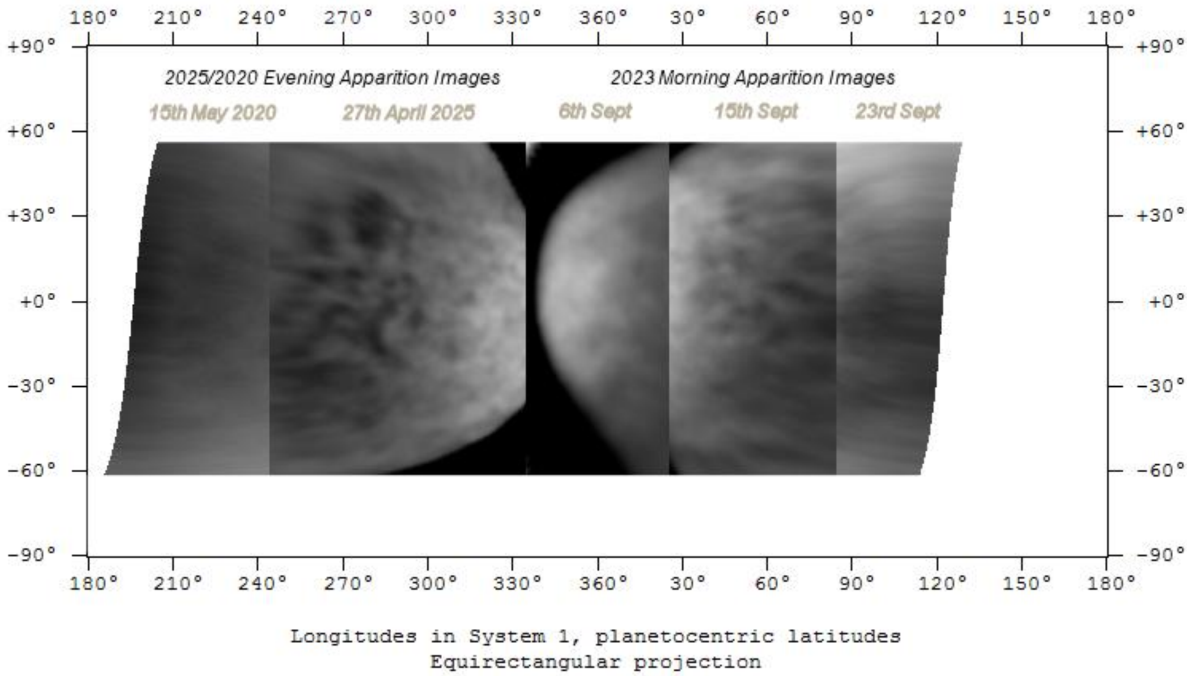



Figure 5.24. Coverage of Venus's surface for a set of evening sessions in 2020 & 2025 (left) and a set of morning sessions in 2023 (right)

As well as permanent dark features relating to higher areas of the surface, imagers have also recorded transient features including darker areas which may relate to absorbing cloud as well as more intriguing lighter features such as bright spots and bright streaks.

You can see an example of a transient darker feature, likely to be low cloud, in figure 5.25 below, where a prominent darker region is circled but does not appear on the WinJupos topographical map.

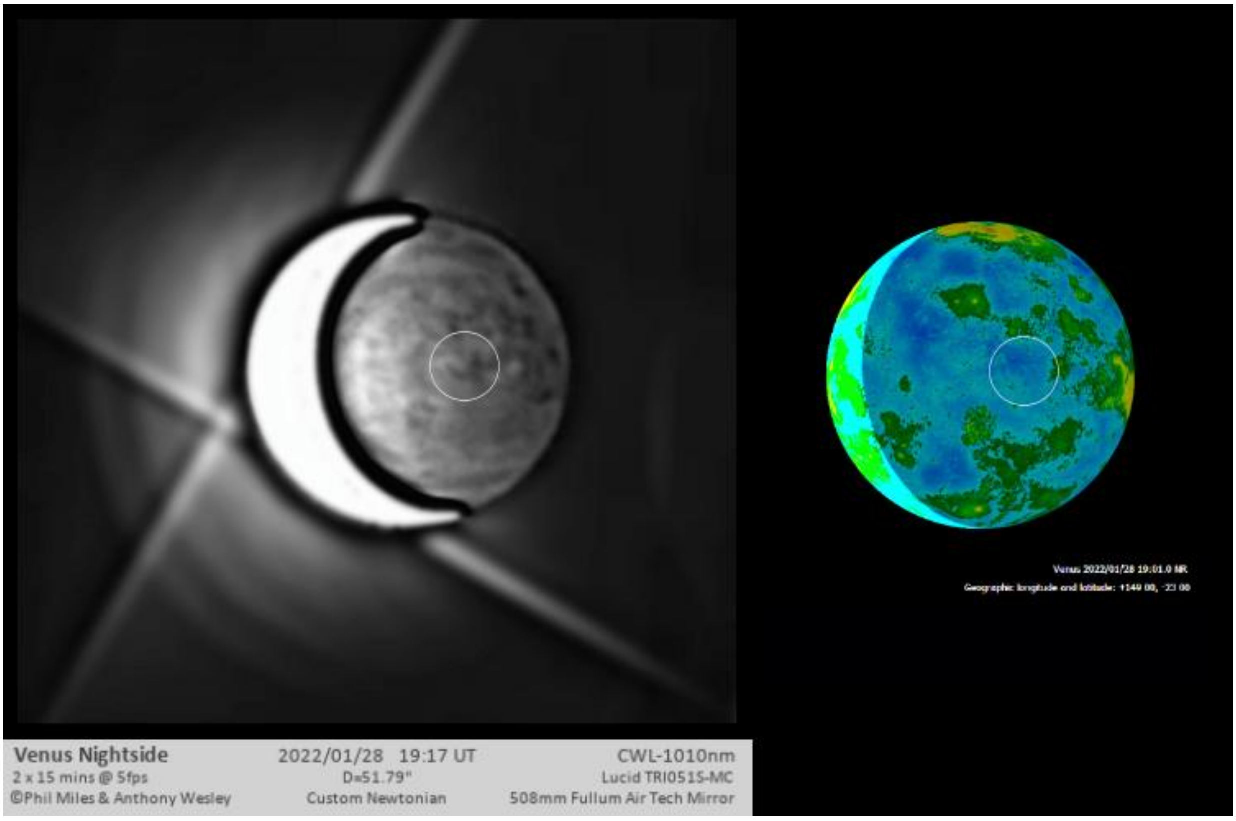



Figure 5.25. A transient dark feature circled in the excellent Wesley and Miles Venus NS image of 28th Jan 2022. The feature is not an area of higher elevation and so is absent on the topographical map on the right.

Repeated non-permanent bright spots have also been regularly recorded, especially at a location just beyond the western end of Aphrodite. You can see an image of a bright spot at this location near Aphrodite in figure 5.26.

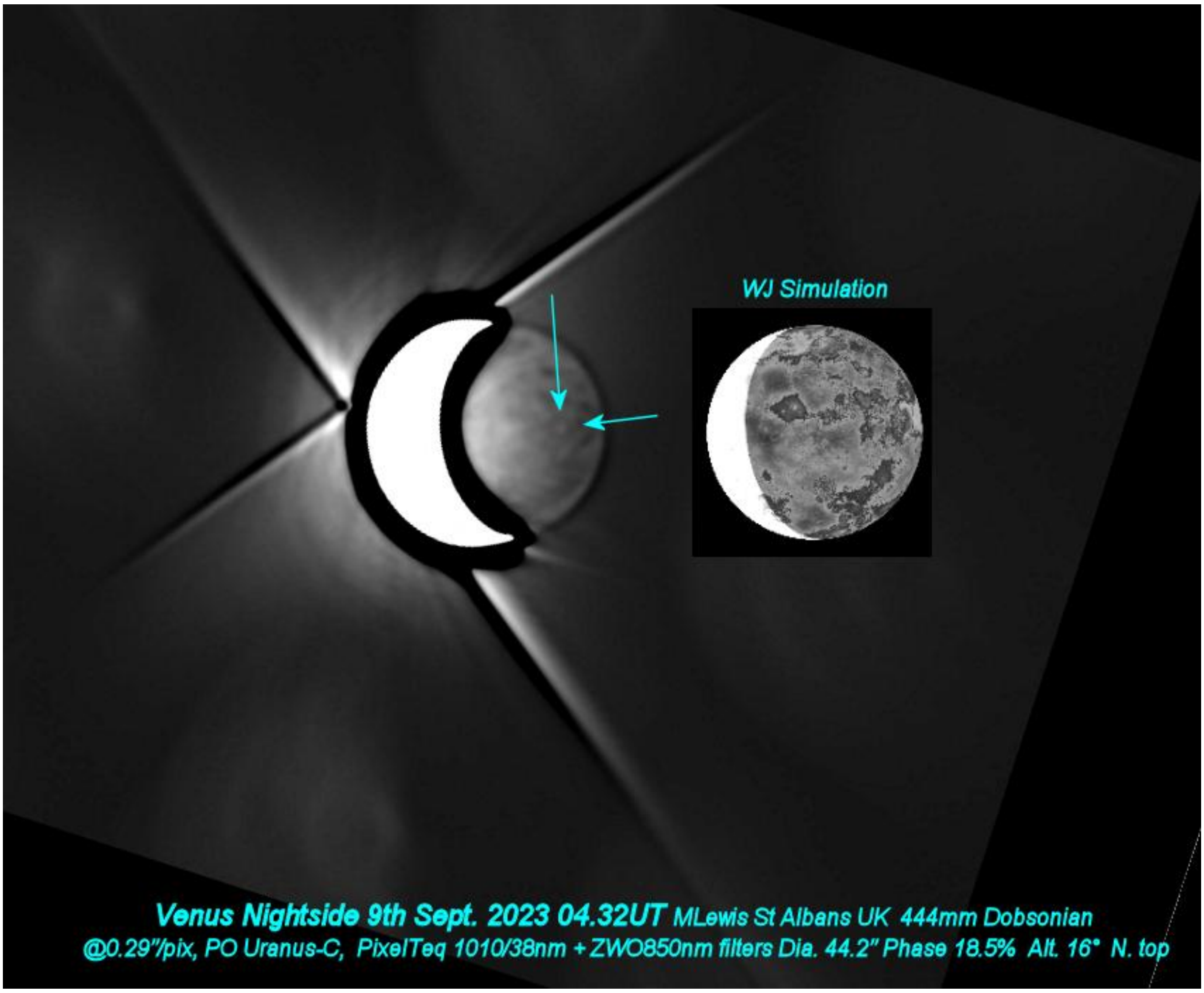



Figure 5.26. The brighter night-side spot regularly seen at the western end of the Aphrodite feature. This image was taken on 9th September 2023. It was absent in the author's images on 6th Sept. It was also absent in the author's image on 15th Sept (figure 5.27) but was again seen at this location in Wesley and Miles image some 15hrs later (see figure 5.28).

Equally mysterious are transient long brighter streaks seen on the night-side. You can see one such streak in figure 5.27, which *may* have moved to a location further north over a period of few hours, as shown in Wesley and Miles' image, figure 5.28.

Figure 5.27. Bright streak in the author's image from 15th Sept 2023 at 04.48UT.

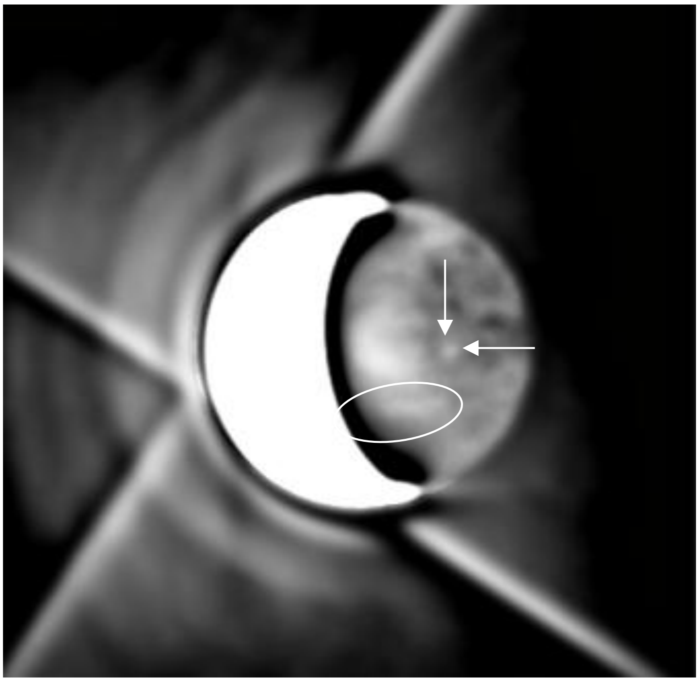


Figure 5.28. Wesley and Miles' image on 15th Sept. 2023 at 19-23UT showing bright streak some distance north of the streak shown in figure 5.27. The bright spot arrowed is seen in the image on the 9th of Sept (figure 5.26) but was absent 14 hours earlier (figure 5.27).

It is hoped further improvements in equipment and methods in coming years, and an increase in popularity of Venus night-side imaging, will together lead to an increase in the frequency and quality of images of these transient features. Better data, more closely spaced in time, enabling study of the evolution of these features, will help planetary scientists in understanding what these features really are - atmospheric, volcanic or something else.

## 5.6 Additional Information

### 5.6.1 Groups IO Venus forum

For more details on capturing and processing Venus night-side images, consider joining the Venus Groups IO forum at https://groups.io/g/VenusImaging. Here you will find much discussion on the latest methods and equipment for imaging the Venusian night-side

### 5.6.2 Further Reading

- *Anthony Wesley and Phil Miles Venus night-side campaigns:*
    - *2017* *http://www.acquerra.au/astro/venus/2017-nightside/*
    - *2022* *http://www.acquerra.au/astro/venus/nightside-2022/*
- *'Imaging the Venus night side at 1000nm', BAA Venus and Mercury section newsletter Messenger No. 4 June 2020*
- *'Imaging the Night-side of Venus - 2023 Evening and Morning Apparitions', BAA Venus and Mercury section newsletter Messenger No. 14 March 2024*
- *'Venus Night-side Imaging - Measuring the Signal to Noise Ratio (SNR)', BAA Venus and Mercury section newsletter Messenger No. 15 August 2024*