Moonlight

Susanne Klein and Ben Goodman

ABSTRACT

The moon is the biggest object in the night sky. Its light has always fascinated. That special quality of light invites all kinds of superstition, from the healing power of the waning moon to good luck during full moon, from disabled children to pots of gold. Sometimes the moon appears blue, white, yellow or red. In the middle of the night, its light turns everything silver. How can we make an analogue print on paper and capture this ever-changing companion of our lives? How can we show the fickle quality of moonlight? In this paper we explain why the moon has so many colours but is mostly seen as silver to the human eye and we chart the progress of our attempts to translate this special optical feature into print by exploring different ink formulations, and their influence on the optical appearance of a wood engraving of the moon.

INTRODUCTION

The moon is the biggest object in the night sky. It can be even seen in light-polluted urban areas. Away from human habitation, when full, it illuminates the landscape with an eerie light which has always fascinated. Its earliest appearance in literature can be traced back to the poems of Homer in the eight century BCE where the radiance of the moon is an important topic (ní Mheallaigh 2020). Today some people believe in lunar therapy and travel to the Arizona desert to cure illnesses by bathing in the light of a full moon ("Lunar Therapy or Moonlight Madness?" 2009).

The poem 'Silver' by Walter de la Mare describes how moonlight turns everything silver:

Slowly, silently, now the moon
Walks the night in her silver shoon;
This way, and that, she peers, and sees
Silver fruit upon silver trees;
One by one the casements catch
Her beams beneath the silvery thatch;
Couched in his kennel, like a log,
With paws of silver sleeps the dog;
From their shadowy cote the white breasts peep
Of doves in silver feathered sleep
A harvest mouse goes scampering by,
With silver claws, and silver eye;
And moveless fish in the water gleam,
By silver reeds in a silver stream.

De la Mare and Ardizzone, 1946

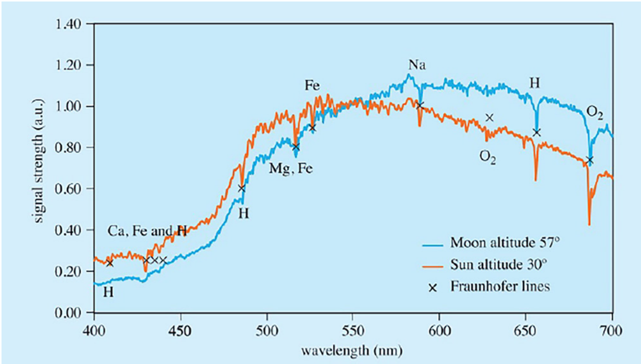

Figure 1

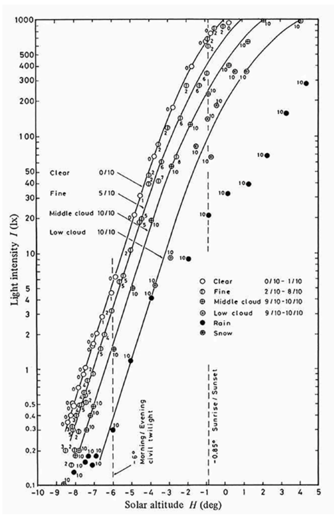

Figure 2

Figure 1. The spectra of sunlight (red) and moonlight (blue) from (Ciocca and Wang 2013)
Figure 2. Ambient light intensity as a function of solar altitude, from (Kishida 1989)

Close to the horizon or when in the earth shadow during a total lunar eclipse, the moon can appear red. That special quality of light and its changing colour invites all kinds of superstition, from the healing power of the waning moon for tooth ache to good luck or bad luck bringing procedures during full moon, from disabled children to pots of gold (Baechtold-Staeubli and Hoffmann-Krayer 2000). For example, in book six of 'Cause et Curae' Hildegard von Bingen, the famous saint and healer of the 11th century describes the influence of the moon on the human character and constitution from the date of conception until death. Creating a visual representation of moonlight poses a special technical difficulty when depicted in print. It is changing all the time and therefore hard to capture.

SILVERY MOON AND TRICKS OF VISION BY SUSANNE KLEIN

Why does the moonlight seem blueish silver? Just from looking at the technical spectrum of moonlight from a moon visible high in the sky, it should not be so (Figure 1).

The signal strength, or intensity, of moonlight from 550 nm to 700 nm (the part of the visible spectrum, which is perceived as red) is in fact higher than that for sunlight. Furthermore, the blue part of the spectrum, between 400 and 550 nm, is weaker in moonlight than in sunlight. The whole spectrum of moonlight is shifted to the higher wavelength, that is to red. In fact, we should see moonlight as yellow light, but we do not, at least most of the time.

THE ILLUSION OF COLOUR

Spectra are not colour; they represent energies. Only the interaction of spectra with the human eye generates the perception of colour, and this interaction is complicated. There were over 150 years between the discovery that white light is a wild mixture of different wavelengths by Isaac Newton (Newton 1704) and the identification of the three colour receptors in the human eye by Hermann von Helmholtz (von Helmholtz 1867). The colour receptors in the retina of the eye are called cones. Originally, they were named red, green, and blue cones, because of their sensitivity in different parts of the spectrum which coincide roughly with the spectral ranges that generate a blue, a green and a red colour in the human brain. When hit by electromagnetic radiation, that is, light of certain wavelengths, the cone cells translate the energy of the radiation into an electric signal which is transmitted to the visual cortex in the human brain via the optical nerve. There the electric signal is processed into the perception, or shall we call it the illusion, of colour.

A MIX OF RECEPTORS

Colour perception is a subjective experience, different for everyone. No one sees the same colour (see for example (Malkoc, Kay, and Webster 2005)). The cone cells do most of the spectral reception when the light intensity is above 2.72 cd/m2 (Table 1), equivalent to the amount of light at dawn when the sun is still below the horizon (see Figure 2). After sunrise, they are the only cells responsible for human vision. We have a second type of detector, rods. Rod cells are more sensitive to electromagnetic radiation, but tend to register only overall intensity and saturate after sunrise. We cannot see colour with rod cells, only black and white. They are the cells which are able to respond to the smallest amount of light. In starlight, all cats appear grey. There is a time when both cell types are active: when we wander by the light of the moon. The spectrum of the light reflected by the moon and the signal ratio between rods and cones sent to the visual cortex determines how we perceive the colour of the moon.

Table 1: Scotopic, mesopic and photopic luminance regions for the human eye, based on Zele and Cao, 2015

	Scotopic	Mesopic	Photopic
Photoreceptors	Rods only	Rods and cones	Cones only
Luminance in cd/m^2	0.0003 to 0.05 Starlight 0.0091	0.05 to 2.72 Full moon ~0.1496	More than 2.72 Average sunlight ~ 340000
Rod saturation			37
Colour vision	Only rods: greyscale	Cones and rods	Only cones

The illusion of a red moon close to the horizon is due to the following process. When the moon is low in the sky, the sunlight reflected from its surface travels through a thick layer of the earth atmosphere and the blue part of the light is scattered away from the line of sight by Rayleigh scattering (see (MetOffice)). The spectrum shifts towards red. In addition, the sky at moonrise is still quite light. Light intensities after sunset and during moonrise can be between 3 and 600 cd/m2 (see the twilight and sunrise line for fair and clear weather conditions in Figure 2), which are well in the range of photopic vision, that is full colour vision (see Table 1). Therefore, the moon appears red or yellow.

As the moon rises, the background intensity of the whole sky drops below 1cd/m2 and the mesopic region is reached, where rods and cones are working together. The sensitivity of the rods in the mesopic range is much higher than that of cones and provides the majority of the signal to the brain. The blueish, silvery tint of moonlight is explained in (Khan and Pattanaik 2004) as a coupling of the rod cells to the 'blue' or S cone cells, but not to the 'red' or 'green' cone cells. Moonlight is therefore perceived as silvery blue and not just white when the moon is high in the sky. With this in mind, how shall we approach the capture of this special light in a print?

PART TWO

MAKING A PRINT THAT DEPICTS THE MOON
BY BEN GOODMAN

A key element of my artistic practice is the pursuit of technical innovation and the desire to push my chosen medium of wood engraving beyond its traditional origins. I am interested in challenging the technical aspects of the engraving and printing process, and also questioning the style and appearance of the final print.

Wood engraving was developed in Northumberland by Thomas Bewick in the late 18th century. It is a type of relief print and a traditional printmaking process that remains largely unchanged to this day. The technique involves cutting the surface of a piece of end-grain wood, using a variety of tools known as gravers. Everything which is cut away does not print. Ink is then rolled onto the surface of the wood before paper is pressed onto it, to form a print.

The challenge of engraving the moon and mimicking its image and colour on paper were part of my ongoing work in showing the potential of wood engraving to go beyond its very traditional use. This print was an opportunity to push engraving away from its origins and to demonstrate how it can be used in new ways.

From the outset I could see that engraving and printing an image of the moon would be challenging. Most, if not all, wood engravings, since the development of the technique in the 18th Century have been printed on white paper, and the vast majority were printed with black ink or occasionally with colour ink. Previous examples of wood engravings of the moon include the woodcut by T. H. E. Palmer (Encyclopedia Britannica 1878) or in the book From the Earth to the Moon (Verne, King, and Mercier 1881) and both used black ink and white paper.

Paper is naturally white (or off-white) and it's relatively straightforward to make a highly opaque black ink that produces a sharp image (usually some kind of black ash mixed with oil such as linseed oil). There's another good reason why artists print black on white. The most common engraving substrates: boxwood, lemonwood, and maple are naturally light in colour. Part of the preparation for engraving a woodblock is to darken the surface of the wood, so that the engraver can see the light colour of the wood shining through the dark surface as they cut. The parts that are cut will not print and will therefore be white when printed onto white paper. So, the light and dark parts of a wood engraving block correspond to the light and dark parts of the final print.

However, with this project, if I were to use black paper, the colours would be inverted. As I cut each line and revealed the white wood, I had to remember that this line would eventually be printed free from ink, and that it would reveal the black of the paper. Conversely, the dark surface of the wood which I was working on would eventually be covered with a paler ink and print a lighter register (Goodman 2018).

Once I had the engraving finished and ready to print, I began my search for printmaking materials. I was aiming for bright, opaque prints with all the details I had engraved clearly visible. I knew from prior experience that the viscosity of most opaque white inks would be too low, and they would flood the tiny cuts of my engraving. My research took me to Hawthorn Printmaker and their *stiff opaque letterpress white* (titanium dioxide) which had the high viscosity I was looking for.

Figure 3

The search for paper wasn't quite as easy. As I have explained, most prints of any kind are printed onto white or off-white paper. Lack of demand means lack of choice, and I was limited to one option: *Somerset Black Velvet 280gsm*. Wood engravings print best on smooth, thin paper and this paper wasn't suitable. The thickness and texture of the paper resulted in faint prints with very little detail. All was not lost, and I soon came across another black paper: *Plike 240 gsm*. Manufactured by the Italian papermill Cordenons, it is described as a luxury paper for packaging and foil blocking (not for wood engraving). However, its smooth rubbery surface seemed ideal for printing engravings.

The first print was detailed and sharp, but quite faint. Increasing the ink quantity only flooded the engraving. So, I was left with the only option of over printing a second impression of the same print on top of the first. However, when I tried this, the two impressions were misaligned. I checked my registration jig and my method of laying the paper down and found no errors. The misregistration must have been due to the paper expanding. I built another jig to measure the paper dimensions, and after a few days of observation I discovered that Plike paper was indeed changing in size. I found that it was perfectly stable while in the original packaging, but once removed it expanded by 1mm within 15 minutes. It then fluctuated by a fraction, never settling down completely. The solution that I came upon was to hang each new sheet vertically by one edge with a clip for 15 minutes until the main expansion had stopped. Then print two or three layers of ink in very quick succession. This resulted in a thick, opaque layer of ink and a bright image with all the fine details of the original engraving (Figure 3).

However, this test image lacked the luminescence of the real moon, and once framed behind glass the white appeared muted. I wanted to discover if I could make an opaque white ink that would print a bright image with one layer, without the need to overprint multiple times.

I started with opaque white (titanium dioxide) and tried mixing an ink that might transfer more easily from woodblock to paper. The theory being that if more ink was transferred to the paper, then the print would have a thicker layer of ink and therefore be more opaque, removing the need for a second layer. In his book 'Understanding Paper' (Williams, 2021), Graham Williams quotes William Savage (1770-1843) who recommended the addition of turpentine soap to aid the transfer of ink. I tried his suggestion but found no improvement in opacity. It may have been due to the fact that Savage recommends printing with dampened paper and, although I tried, Plike does not

Figure 3. Moon printed with two layers of Hawthorn Stiff Opaque Letterpress White, Ben Goodman

absorb enough water to soften the surface, so isn't compatible with this technique.

I also tested different oils of varying viscosities. A mixture of 50% Titanium Dioxide with 50% Stand Oil 50 poise produced faint prints with a lot of spread (Figure 5) which reduced the detail and looked uneven.

Next, I addressed the issue of the print's luminance. I wanted to make it appear more like the moon we see above us in the sky. Standard opaque white cannot achieve this because the pigment titanium dioxide is deductive[1] by nature. For the print to mimic the moon's luminescence I needed a pigment that is additive[1]. For this I turned to the Spectraval™ pigments made by Merck. They describe their pigments as 'optimized for the RGB printing process. Our … pigments in red, green, blue, and white, make RGB printing possible. The result is prints that literally capture light, making the printed image appear with extraordinary brilliance and depth.' (Merck).

I started with Spectraval™ white pigment and used the same ratio as before, 70% pigment to 30% stand oil (200 poise). The resulting ink was so dry it had a fibrous, papery texture and was completely unsuitable for printing. I changed the ratio to 50/50 and found the ink's viscosity too low but with a lot of tack. A single layer of this ink printed well, with good definition and no ink spread, but wasn't as bright as I had hoped. However, two layers produced a very bright print, still with good definition and no ink spread. The final image appeared white yet lacked the warmth of a moon low in the horizon or the silvery blue of a moon high in the sky.

So, I mixed a warm yellow ink with 27.8% red pigment, 22.2% green pigment and 50% stand oil (200 poise). The resulting print was a surprisingly realistic rendition of a creamy yellow moon that you might see low in the sky on a summer evening. Another print with three layers gave an even stronger and brighter image (Figure 6 and 7).

After this I tried to create a moon with a silvery bluish appearance, similar to one you might perceive high in the sky on a clear night. I used 25% white pigment, 25% blue pigment and 50% stand oil (200 poise). This produced a brilliant cold white print that shone brighter than any of the others and had deep blue shadows (Figure 8 and 9).

I then combined the two pigments (titanium dioxide & the Spectraval™ RGB pigments) to see if I could produce a print that is bold and opaque like Figure 3 but also has the luminescence of Figure 7 and Figure 9. First, I tried a mix of 50% Hawthorn Stiff Opaque Letterpress White (because this produced the best definition out of the opaque white inks) with 50% Spectraval™ White ink (50/50 Spectraval™ White pigment and 200 poise copper plate oil). The resulting print wasn't as bright and opaque as my original print (Figure 3) because of the reduced percentage of titanium dioxide. It also didn't have a strong reflection like Figure 7 and Figure 9, probably because the Spectraval™ pigment was being blocked by the titanium dioxide.

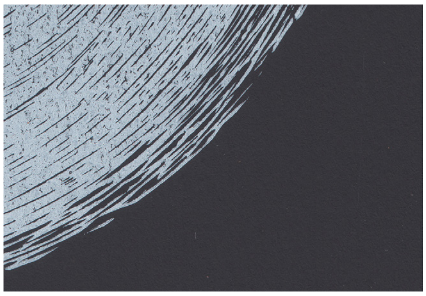

Figure 4

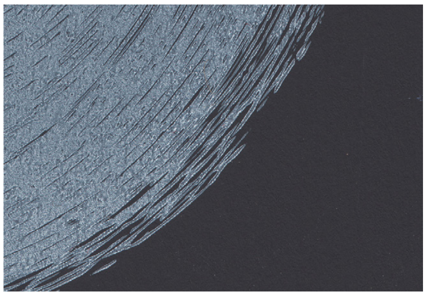

Figure 5

Figure 6

Figure 7

Figure 4. No ink spread [two layers of Hawthorn Stiff Opaque White], Ben Goodman
Figure 5. Ink Spread [two layers of 50% Titanium dioxide + 50% 200 poise copper plate oil, Ben Goodman
Figure 6. Yellow Moon in shadow, Ben Goodman
Figure 7. Yellow Moon with reflection, Ben Goodman

For the next, and final, print I printed two layers of Hawthorn Stiff Opaque Letterpress White to get a bright print with good definition. I then printed another layer on top, using Spectraval™ White ink (50% Spectraval™ white pigment with 50% 200 poise copper plate oil). This print had a strong, opaque and defined image with a subtle but significant reflection (Figure 10). At last, I had a print that met my expectations and for me looked and shone like our moon above.

Figure 8

Figure 9

Figure 10

CONCLUSION

Even though moonlight is reflected sunlight, our perception of its colour is influenced by many factors including signal pathways in the brain. The colours of moonlight are fluid and difficult to approximate with analogue print on paper. Using wood engraving and an unusual method of printing light and reflective colours on black paper, printmaker Ben Goodman explored the influence of different ink formulations and printing methods in the reproduction of the fickle optical appearance of moonlight. The best result was achieved when a white opaque ink was overprinted with a layer of selectively reflective pigments. The white base layer defined the image of the moon against the black paper clearly and the selectively reflective pigment added hue change when the print is viewed at different angles.

FOOTNOTES

[1] "There are two main types of color mixing: additive color mixing and subtractive color mixing. Additive color mixing is creating a new color by a process that adds one set of wavelengths to another set of wavelengths. Additive color mixing is what happens when lights of different wavelengths are mixed. When we add all of the different wavelengths of sunlight, we see white light rather than many individual colors. It is called additive because all of the wavelengths still reach our eyes. It is the combination of different wavelengths that creates the diversity of colors. Subtractive color mixing is creating a new color by the removal of wavelengths from a light with a broad spectrum of wavelengths. Subtractive color mixing occurs when we mix paints, dyes, or pigments. When we mix paints, both paints still absorb all of the wavelengths they did previously, so what we are left with is only the wavelengths that both paints reflect. It is called subtractive mixing because when the paints mix, wavelengths are deleted from what we see because each paint will absorb some wavelengths that the other paint reflects, thus leaving us with a lesser number of wavelengths remaining afterward. So the easy way to remember the difference between additive and subtractive color mixing is that additive color mixing is what happens when we mix lights of different colors whereas subtractive color mixing occurs when we mix paints or other colored material." (J. Krantz & B. Schwartz, 2015)

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Figure 8. Blue Moon in shadow, Ben Goodman
Figure 9. Blue Moon with reflection, Ben Goodman
Figure 10. Two layers of Hawthorn Stiff Opaque Letterpress White with one layer of Sepctraval White on top (with torch shining at the print to show it's reflection), Ben Goodman

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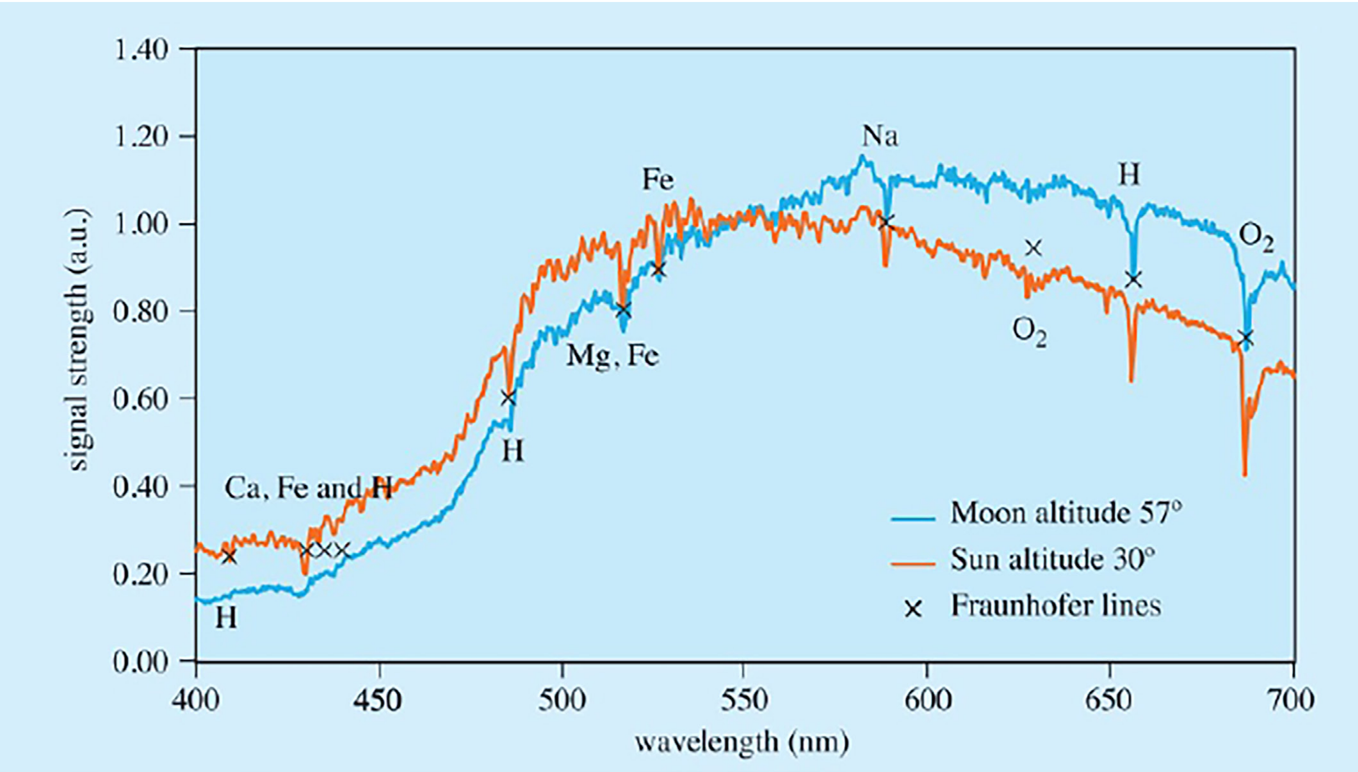
AUTHORS

Susanne Klein
Susanne Klein is an EPSRC Manufacturing Fellow and an associate professor at the Centre for Print Research at the University of the West of England in Bristol, UK. In 1995 she joined the University of Bristol where she worked on 19th century optics. In 1998 she joined Hewlett Packard Labs and specialised in liquid crystal display technology and new materials for 3D printing. Her research interests now are 19th century photomechanical processes, especially Woodburytype, Woodbury gravure, Lippmann photography and colour photography based on Maxwell's three colour theory. She is also interested in alternative ways of colour recording and reproduction.

Ben Goodman
Ben Goodman is an artist and wood engraver. He is an elected member of The Society of Wood Engravers and has exhibited extensively throughout the UK and internationally. His work is part of the national collections at The V&A, MMU and CAFA.

His work focuses primarily on portraiture and the human body, and uses the reduction method to produce intricate wood engravings that resemble miniature paintings. The human figure is a constant inspiration for his work and Ben uses engraving to explore the variety and beauty of the human form. From the subtle shadows running across a person's back, to the complex structure of the human face.

IMAGE GALLERY



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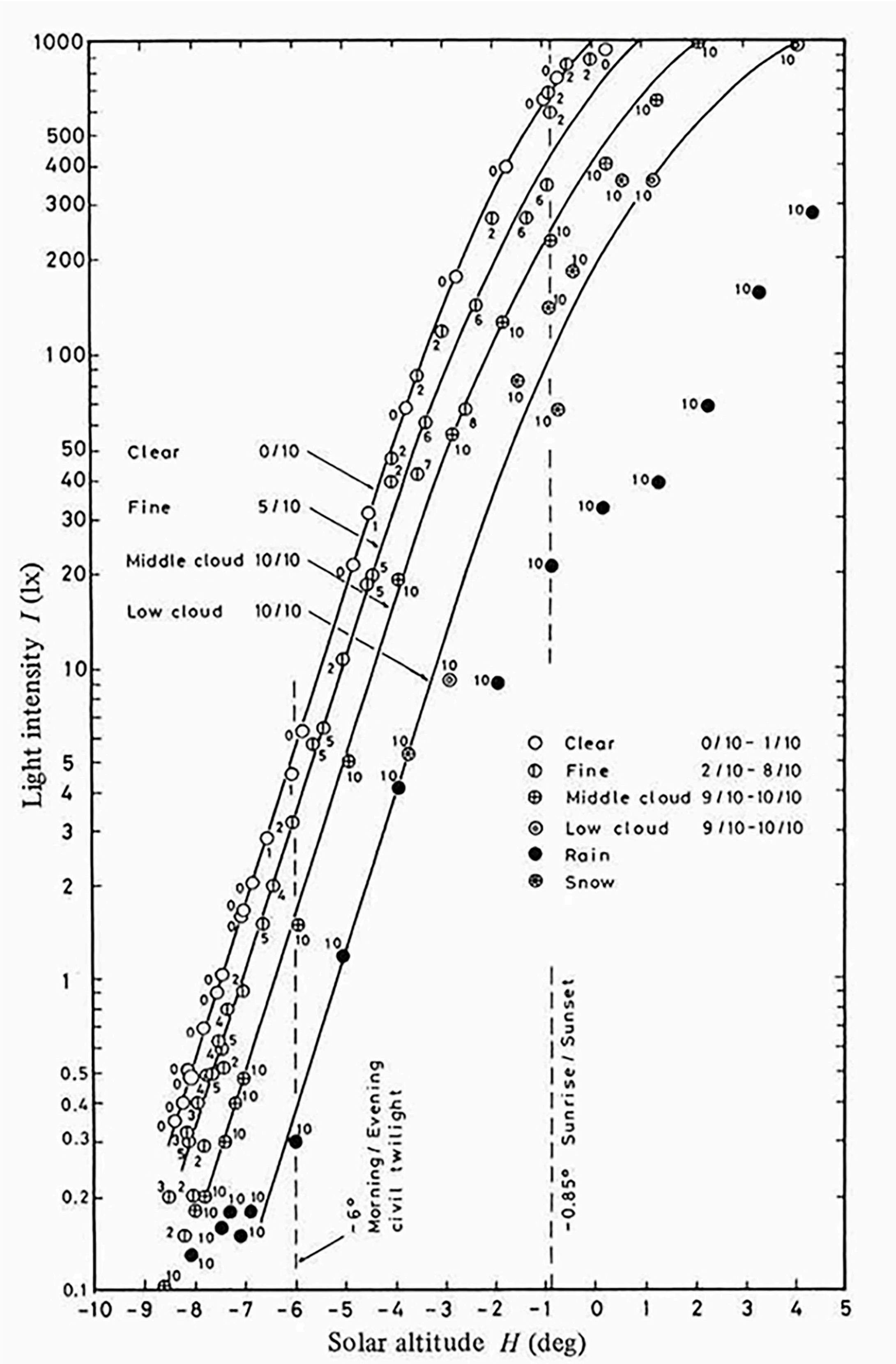

Figure 2. Ambient light intensity as a function of solar altitude, from (Kishida 1989)

Figure 3. Moon printed with two layers of Hawthorn Stiff Opaque Letterpress White, Ben Goodman

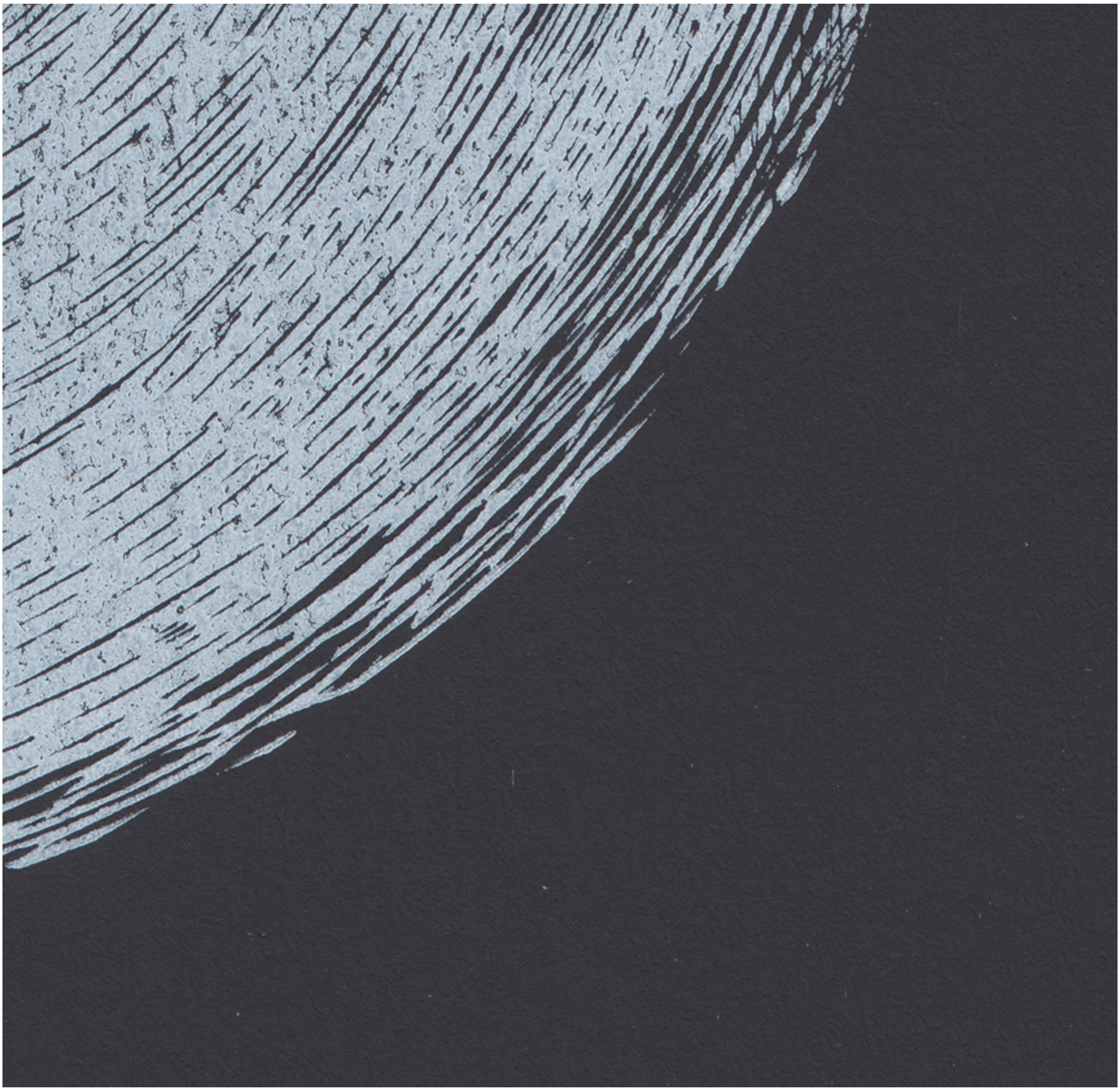

Figure 4. No ink spread [two layers of Hawthorn Stiff Opaque White] Ben Goodman

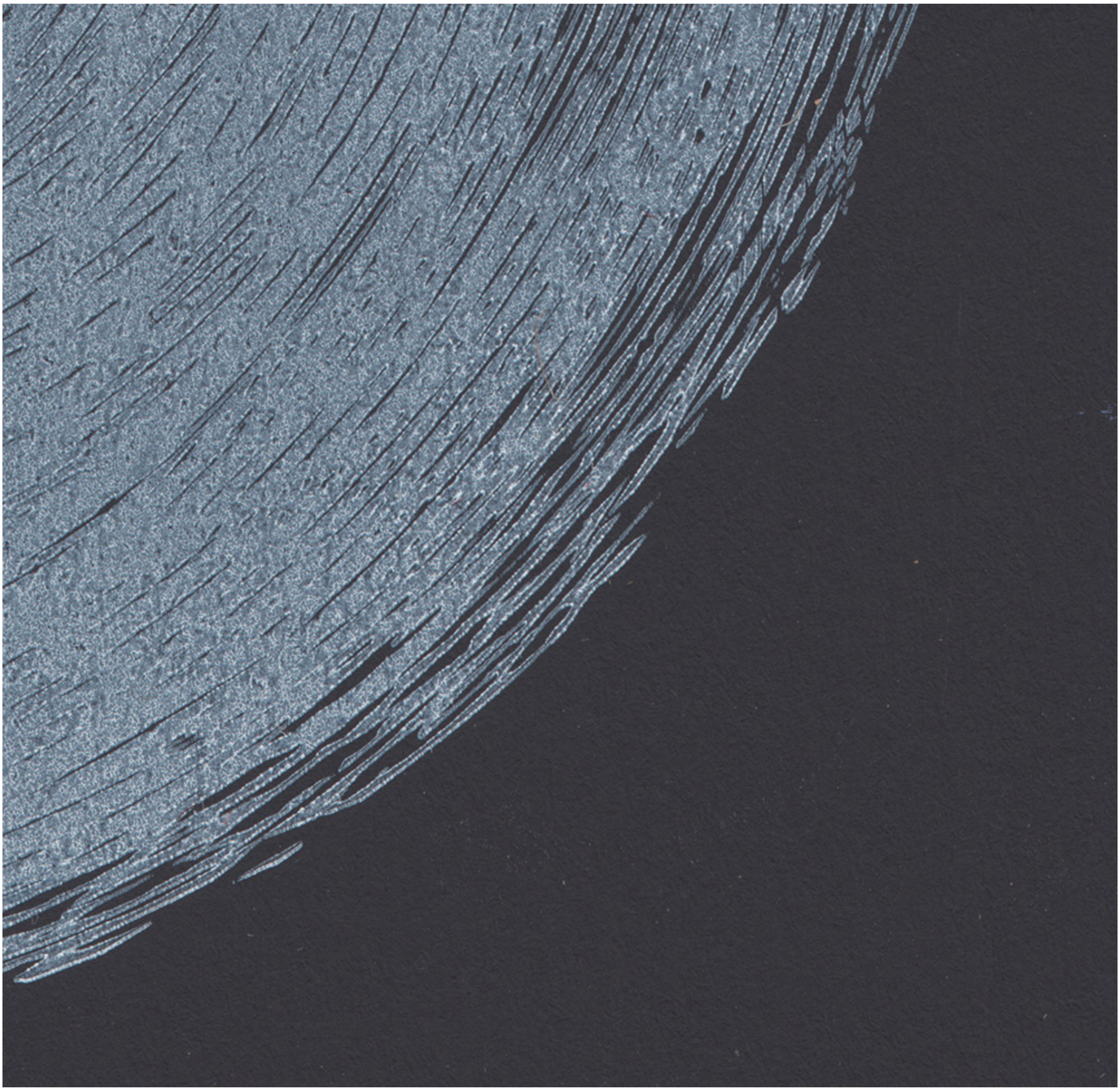

Figure 5. Ink Spread [two layers of 50% Titanium dioxide + 50% 200 poise copper plate oil, Ben Goodman

Figure 6. Yellow Moon in shadow, Ben Goodman

Figure 7. Yellow Moon with reflection, Ben Goodman

Figure 8. Blue Moon in shadow, Ben Goodman

Figure 9. Blue Moon with reflection, Ben Goodman

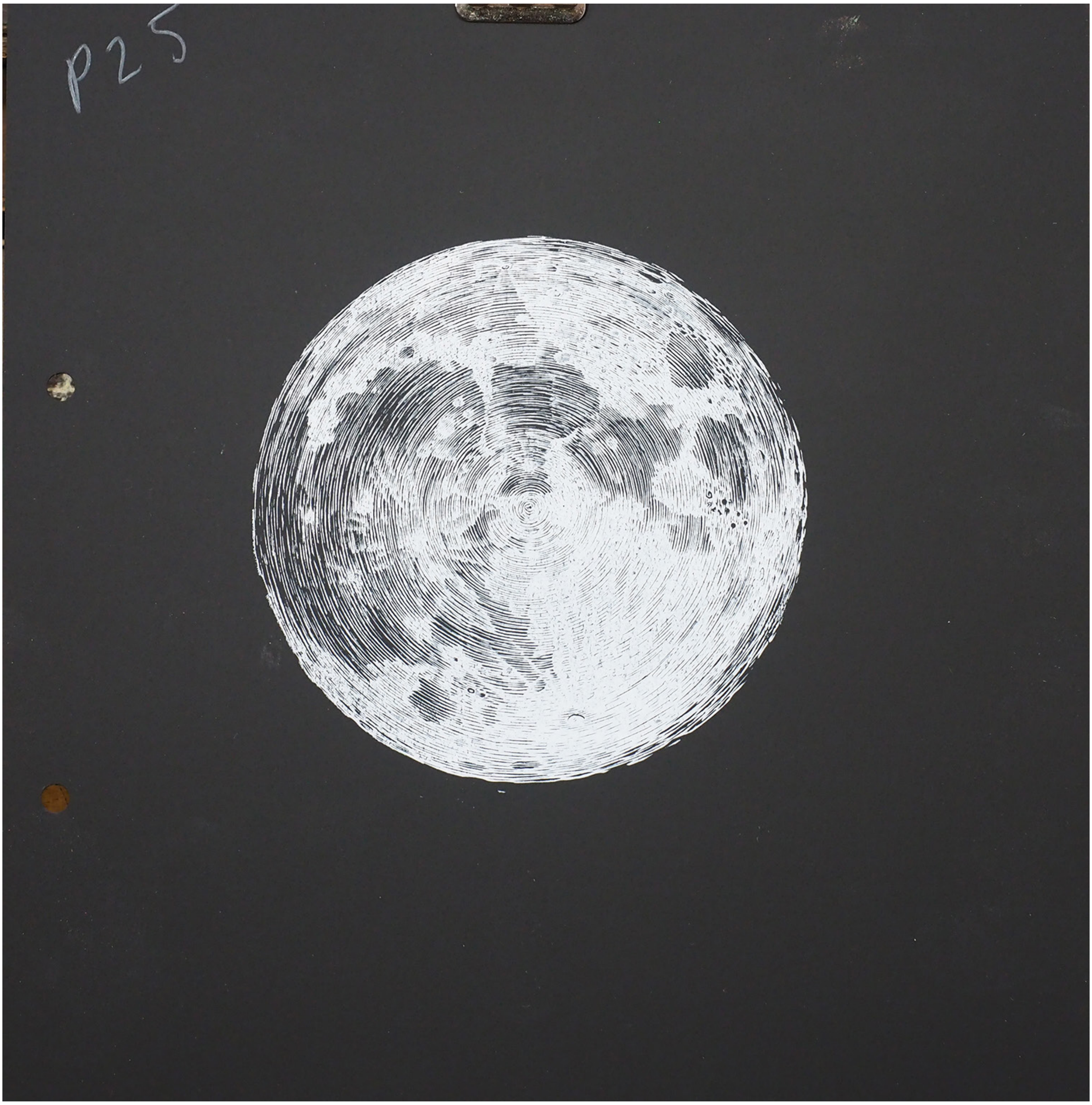

Figure 10. Two layers of Hawthorn Stiff Opaque Letterpress White with one layer of Sepctraval White on top (with torch shining at the print to show it’s reflection) Ben Goodman