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# Visions of Heaven

an exhibition of

**David Malin's**

pioneering astrophotography

## 14 – 23 October 2011

The Bristol Gallery,
Millennium Promenade, Harbourside, Bristol, BS1 5TY

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University of BRISTOL

Prifysgol Cymru Y Drindod Dewi Sant University of Wales Trinity Saint David

HEAVENLY DISCOURSES
MYTH, ASTRONOMY AND CULTURE

Friday 14 - Sunday 16
October 2011




# Visions of Heaven

an exhibition of
## David Malin's
pioneering astrophotography

held in conjunction with
*Heavenly Discourses: Myth,Astronomy and Culture*
an interdisciplinary conference organised jointly by
Nicholas Campion
School of Archeology, History and Anthropology, Sophia Centre for the Study of Cosmology in Culture, University of Wales Trinity Saint David and
Darrelyn Gunzburg
Department of History of Art, University of Bristol.

## 14 - 23 October 2011
Exhibition curated by Darrelyn Gunzburg

We would like to thank the Australian Astronomical Observatory and The Brsitol Gallery for their support in the organisation of this exhibition.

Australian Government
Department of Innovation, Industry, Science and Research

AAO

FINE ART SHOP ART

The Bristol Gallery

*Front cover:* The Great Nebula in Orion which appears as a misty patch around the central star of the line of three which form Orion's sword. Three-colour image made from plates taken at the UK Schmidt Telescope. *Creator:* David Malin. ©Anglo-Australian Observatory/ David Malin images.

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# *Visions of Heaven*

14 – 23 October 2011

Exhibitions bring images together in a complex gathering of perspectives, like a many-faceted conversation that flows endlessly, allowing new insights to be gained.

The verb we commonly use with photographs is 'taken'. However, these are no ordinary photographs. David Malin prefers the verb 'made' and the method he used illustrates that careful and painstaking process of making something distinctive. The works in this exhibition and which are illustrated in this catalogue have been selected from a wider but closed set of images created by David Malin from glass plates when he worked as photographic scientist-astronomer at the Anglo-Australian Observatory from 1975 to 2001.

These images illustrate other worlds that, due to Malin's work, now form part of our world, the known and the unknown, the deep black velvet sky of stars that we see if we are gifted with a clear night, yet images that reveal such an extraordinary jewel-like nature that we can only gasp in wonder.

The images were selected to express the diversity of the sky through David Malin's art but they also show us the diversity of David Malin, the man who first 'coloured' stars and gave us our view of deep space in ways that we now take for granted. In this regard it is my particular pleasure and honour to be presenting his work in Bristol.

Darrelyn Gunzburg

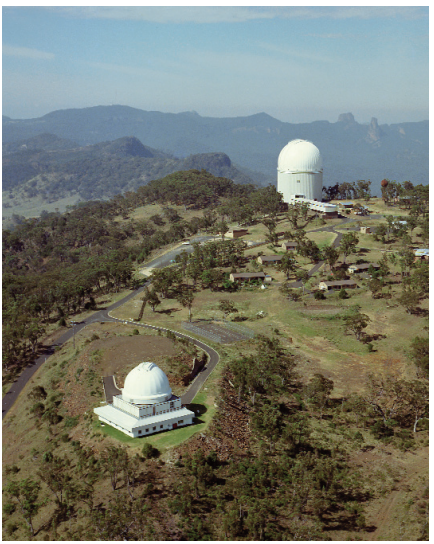
**Printing – print laboratory and framing**

These superb images have been printed using Giclée Printing through specialist Bristol print laboratory Hello Blue. A Giclée is a very high-resolution ink-jet print onto an acid and bleach free, 100% cotton archival paper. The highest quality light-fast, UV stable inks are used. The print is then coated in a protective spray, which gives it an added level of UV and moisture protection and an extremely high tolerance to environmental factors. Every colour print is light-fast for at least 75 - 100 years. If kept in suitable conditions there is almost no limit as to how long they could last. Giclée Printing is able to reproduce the images so as not to lose shadow detail in the prints. As David Malin explains, the sky should be anything but solid black, as this effectively undermines the enormous amount of time and effort he put into revealing all the faint structures.

The prints are framed using non-reflective glass that maintains the luminosity of the images. Normal framing glass dulls the prints and actually adds a layer of green. Non-reflective glass allows the images to explode with life. The prints have been framed by Framing Bristol. Damien da Costa, the director, is an artist who understands the necessity of quality framing and has developed specialist framing techniques so the image appears to float behind the thin edged frames. His specialty is lacquer frames and the 92 x 73.6 images are all framed using his unique lacquer frames.

# The telescopes of the Australian Astronomical Observatory

The two telescopes of the Australian Astronomical Observatory (AAO) are on Siding Spring Mountain in outback northwestern New South Wales, Australia overlooking the Warrumbungle National Park, one of Australia's finest. Both these instruments are constantly updated to exploit their natural advantage of being located beneath some of the world's darkest skies.





*Above right*:In the foreground is the dome of the Anglo-Australian Telescope (AAT) itself, and around its base is the red packing case that carried its 4 meter mirror from its final polishing in England. Alongside it is the concrete dummy mirror used as a test weight to balance the telescope during construction.

*Above left:* In the foreground is the small dome of the UK Schmidt Telescope (UKST), constructed in 1974, but since 1988 a vital part of the AAO. Despite its diminutive size the UKST has exquisite optics and a field of view much greater than the AAT. It has been used to make surveys of the largely unexplored southern sky, discovering new objects that are studied in more detail with the AAT.

Both images and text © 1977 -2002 Astralian Astronomical Observatory. Photograph by Davd Malin.

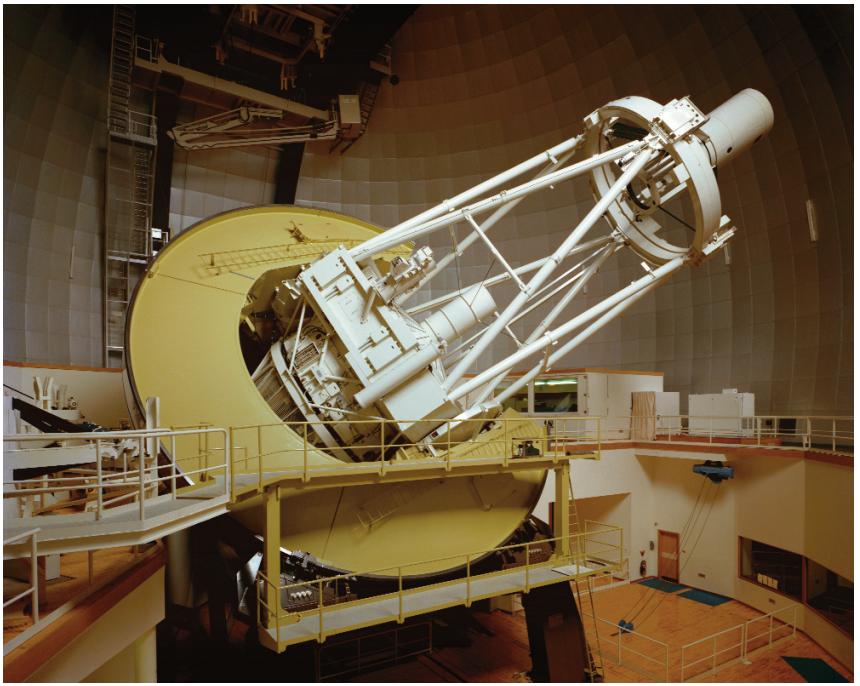


*Left:* AAT Dome and facilities building, the last of a series of 4m telescopes constructed in the mid-1970s. Of all the telescopes operated on this mountain, the dome of the AAT is the most imposing, rising nearly 50 metres from the ground. The lower, cylindrical portion houses offices, darkrooms, small workshops and the many pieces of equipment required for the efficient operation of a large optical telescope and its complex instruments. The upper, rotating hemispherical portion is the dome itself, within which the telescope resides protected from the elements. When the telescope is in use a small opening in the dome is positioned directly in front of it.

Image © 1977 text ©2010 Astralian Astronomical Observatory . Photograph by Davd Malin.

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Image © 1980 text © 2010 Astralian Astronomical Observatory. Photograph by David Malin.



The Anglo-Australian Telescope (AAT) was the last of a series of several 4m-class equatorial telescopes of similar design that were built in the mid 1970s, and it is one of three that were constructed in the southern hemisphere. The AAT, along with its companion telescope, the 1.2m UK Schmidt Telescope, and offices and laboratories in the Sydney suburb of Epping, comprise the Australian Astronomical Observatory, successor organisation to the Anglo-Australian Observatory. Regularly scheduled observations began with the AAT in July, 1975, and operates every clear night of the year except for a few nights in the southern summer when the mirror is removed for re-aluminising.

Seen here pointing low in the east, the telescope is capable of looking anywhere in the southern sky more than 20 degrees above the horizon. It does so by swivelling on two axes. The motion which follows stars from east to west across the sky is defined by the yellow horseshoe bearing. This rotates resting on pads supported by pressurised oil. The second motion is around an axis between the arms of the horseshoe that permits the white structure holding the large mirror to tip north and south. At the end of the telescope is the tube-like prime focus 'cage' where light from the primary mirror is brought to a focus. It is from this focus that all the AAT colour photographs in this exhibition were made between 1978 and 2000, mostly using glass photographic plates. These were mostly intended for scientific purposes, but many of them were suitable for making 3-colour images using an additive process described in this catalogue. Some care has been taken to ensure that the colour in the images derived from these plates is realistic.

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# Photography and the Telescope, a Heavenly Marriage

When Galileo first turned his telescope to the sky in 1609, he discovered a universe more varied and more mysterious than anyone had imagined. It was not so much the magnification of the telescope that led to this leap in understanding, though this helped, rather it was the detection of faint light. As human vision was extended by ever more powerful telescopes, increasingly fainter objects were seen.

The first astronomical object to be photographed was the Moon, probably by Daguerre in 1839. As it became easier to use, photography was gradually adopted by astronomers, and by 1882 it was demonstrated that it could reveal stars fainter than could be seen by the keenest eye using the same telescope. This transformed it from a mere recorder of what was visible to a detector of the unseen. For a hundred years thereafter it played a key role in advancing our knowledge of the nature of stars and of the distances of the galaxies and ultimately of the age and size of the Universe itself. The application of photography to astronomy was as influential as the invention of the telescope itself.

In the digital age the revolution continues apace, and while the materials and techniques are quite different from those of the photographic era, the idea of extracting as much information as possible from the feeble light of the distant stars and galaxies remains central. A similar series of steps can be seen in the evolution of the microscope, another instrument that completely changed our understanding of the world around and within us.

I have been fortunate to use both types of instruments in my scientific career and found it is possible to use a telescope or a microscope to record some normally invisible aspect of nature in a way that is both scientifically useful and aesthetically pleasing. Indeed several of the techniques I had used in my microscopy work in England were even more useful in astronomy, where there is no possibility of manipulating the position, lighting or environment of the objects of interest, which can only be seen at night, under dark skies, and with an enormous telescope. These techniques involve optical methods applied to the images themselves, to extract more detail — and more information — from the processed files or plates, while respecting and preserving the integrity of the data.

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## A Universe of Colour

In the mid-1970s, few colour images of astronomical objects apart from the Moon and planets existed. In part this was because those astronomers who still looked through telescopes saw very little colour; the eye is insensitive to colour at low light levels. When colour photography was tried, exposures were extremely long and the colours revealed were unsatisfactory. This was because photographic materials were intended for snapshot exposure times. 'Everyday' film becomes very inefficient as exposure times increase, and the three layers in colour film respond differently. They also require lots of valuable telescope time for an activity that is difficult to justify scientifically in a professional observatory. Thus most successful colour photography was done initially by persistent amateurs, usually with relatively small telescopes.

When I joined the Anglo-Australian Observatory (now the Australian Astronomical Observatory) in the mid 1970s I found that astronomers had long been accustomed to taking separate black and white images in blue and green light as a way of measuring the temperatures of the stars. Very hot stars appear bright on blue-sensitive plates, while cooler, reddish stars seem relatively brighter on green-sensitive plates. Unlike colour film, these special plates were designed to record faint light, and could be made even more sensitive with special hypersensitising processes. All that was need to make a true-colour picture from the blue– and green–light plates was an image of the same object taken in red light. The UK Schmidt Telescope (UKST), alongside the Anglo-Australian Telescope (AAT) at Siding Spring, already had such plates in their archive.

While it was initially difficult to align the separate colour images in register using conventional processes in the darkroom, I realised the James Clarke Maxwell had done this using beams of light from three 'magic lanterns' in 1861, so I adopted his additive colour approach. This used projected red, green and blue (RGB) light images overlapped to recreate the colour images rather than yellow, magenta and cyan pigments or dyes of the subtractive process used by printers and painters. This same method of combining many projected images of the same field in register also improves the signal-to-noise ratio of the final composite. Exploiting this led to several interesting astronomical discoveries unrelated to colour imaging. The first additive three-color images were made from UKST plates in 1978, and I found that the other image manipulation processes I had used to extract information from the plates could be incorporated into the process to make colour images of objects that had never been seen in colour before. These techniques included unsharp masking

(to explore dense negatives of bright objects)(Figs. 1 and 2) and photographic amplification (sometimes referred to as 'malinisation'), a data 'stretching' process which revealed the faintest objects on glass plates.

## The End of an Era

Traditional photography is no longer used to detect light in astronomy, but making colour pictures using red, green and blue (RGB) colour separations is now universal in digital imaging in professional and most amateur observatories. It is the only way that a telescope like the Hubble Space Telescope could operate. Nowadays, most digital imaging software includes tools for combining separate images in register, for unsharp masking and for stretching images to emphasise faint detail — and much else that could not be done in the darkroom.

All the images in this exhibition were made from data derived from glass photographic plates using the UK Schmidt or Anglo-Australian Telescopes. These data have been digitally remastered to make the prints and other derivatives seen here.

David Malin

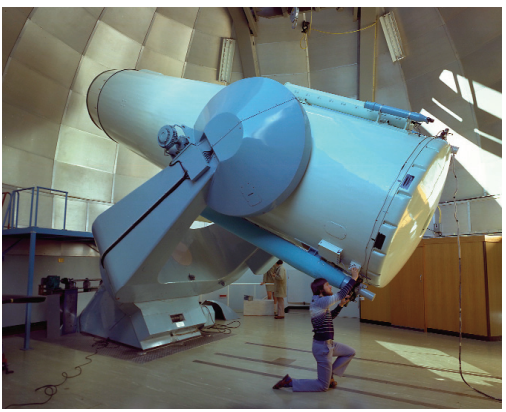


Image and text © 1977 - 2002 Astralian Astronomical Observatory. Photograph by David Malin.

The UK Schmidt is a specialised telescope that was designed primarily for photography. It combines a wide field of view over 6 degrees across with superb optics and a very wide aperture of 1.2m. Imagine having a camera lens with a focal length of over 3 meters, working at F/2.5. It was intended to make a very deep photographic survey of the largely unexplored southern sky in a number of colours. The dark skies of Siding Spring and photographic expertise developed at the telescope ensured that this survey was a revelation to astronomers from around the world. This task is now completed and the survey images are publicly available in digital form, a development not forseen when the telescope was constructed in 1974.

The telescope no longer takes photographs, but much of its effort is now devoted to spectroscopy, using optical fibres to collect the light from numerous individual galaxies and stars. The wide field, large aperture and clear, dark skies over the Warrumbungles remain a priceless advantage, and the telescope continues to make a significant contribution to international astronomy.

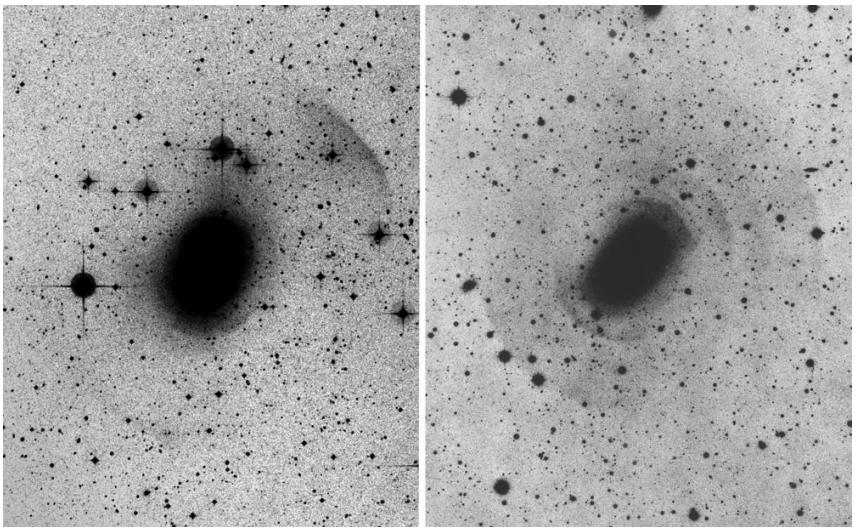


Figure 1.Combining several images of a normally featureless elliptical galaxy such as NGC 1344 *(above left)* can reveal very faint external shell-like features that hint at earlier encounters. At right is NGC 3923, whose internal shells, normally hidden in the brightest parts of the galaxy, are revealed by unsharp masking.



Figure 2. Images of the Orion nebula made from the same set of three,5-minute exposure plates taken with the Anglo-Australian Telescope in red, green and blue light. The image on the left shows the result of combining these plates directly into a colour image. On the right the separate plates were copied using photographic unsharp masks before combination.

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# Sources of Colour in Astronomy

We are inclined to think the colourful world around is all there is to see, and even a large telescope used at night does little to dispel that perception. The stars seem more numerous and brighter with a telescope, but there is little obvious colour. That is partly because the eye is blind to colour when light levels are low — moonlight shows us the shape of the nocturnal landscape but not its colour. Also, the eye has trouble perceiving the colour of very small images (small field tritanopia) along with the fact that the astronomical objects that are colourful are almost always extremely faint.

So how do we know that colour exists if we cannot see it? It is an interesting philosophical point: can colour exist if it is invisible? The answer is certainly yes, but the light-gathering properties of photography are needed to make it visible.

Even before photography, astronomers knew that the light from stars was similar to sunlight because it could be split by prism into a continuous rainbow colours (continuum spectrum). But some objects in the sky had spectra that consisted of narrow lines of colour (line spectrum), quite unlike stars or rainbows. We now know these lines are mostly from glowing gas and the physical processes involved are similar to those that create the light in advertising signs such as 'neon' lights. These narrow lines are essentially monochromatic (single colour) and so are as strongly coloured as they can be. But if they are faint they do not seem so when seen by eye in a spectroscope, a device for viewing spectra. When the spectroscope was made into a spectrograph by the addition of a black and white photographic plate to record the pattern of light, it immediately became clear that some 'extended' (i.e. non-stellar) astronomical objects must be strongly coloured, because the light from them was confined to a few, narrow parts of the spectrum, often in the blue-green and deep red regions. But how is a black and white negative turned into a colour picture?

## Colour Separation Photography, an Outline

Three separate exposures of the object are made in red, green and blue light, in our case on special black and white photographic emulsions coated on glass plates which can be up to 356 mm (14 inches) square for the UK Schmidt Telescope, or 256 mm (10 inches) square for the AAT. The telescopes were designed in inches and those were the units used by the plate suppliers. The plates were always hypersensitized by baking in nitrogen and hydrogen just before use. This increases their long-exposure speed dramatically, and was an essential part of photographic observing. Preparing the plates just before the observing run often took many more hours that the observing itself. The exposures are made sequentially, but, since the objects of the night sky that we were usually interested in hardly change in millenia, the images can be taken years apart.

RGB photography on the AAT and UK Schmidt was done with a series of three different photographic emulsions, all made by Eastman Kodak, and each with a mysterious code name. These photographic plates went out of production in about 1997, but they had been introduced in the 1930s, initially as special products (Eastman Spectroscopic Plates) from Kodak's famous Research Laboratory. They were further developed in conjunction with astronomers and other scientists, and by 1937, no fewer than 20 different spectral sensitivities were offered with six different types of photographic emulsion.

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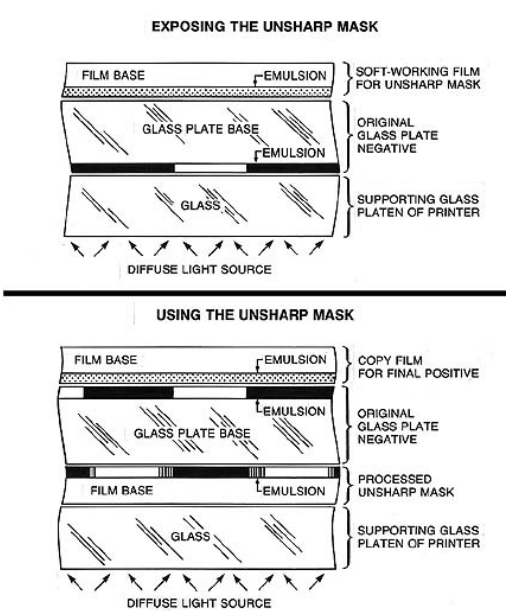
Nowadays it is much simpler to combine the three images using software such as Adobe Photoshop, but before image processing software was invented, many of the image enhancement techniques that are now routine on a computer were performed photographically in the darkroom. Three techniques in particular were important for astronomical photography:

## Unsharp Masking

The photographic negatives used for astronomy were special high contrast, fine grained materials designed to capture the faintest cosmic light behind the uniform glow of the night sky. They were also processed in energetic developers for maximum sensitivity, so astronomical negatives are usually contrasty and very dense (black) where any light at all was captured. Technically speaking, their Dmax was about 5, which means that in the darkest parts of the processed negative transmitted only 0.00001 percent of the light (from an enlarger, for instance) incident upon it. These negatives could not be printed like 'everyday' negatives, where the Dmax is 1.5, and they transmitted a few percent or so of light, making photographic printing easy.

My solution was to this to make a contact copy of the negative on a sheet of low contrast film, but with the back side of the glass in contact with the film. If this light source was diffuse, the resulting positive would be unsharp — blurred — and the amount of blurring could be controlled by adding extra layers of glass. The density and contrast of the mask could also be controlled by varying the exposure and processing of the mask film.

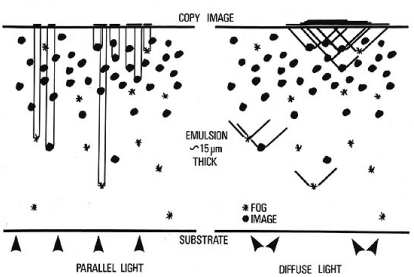
Once processed and dried, the mask was replaced in position on the back of the original plate and a contact copy was made in the normal emulsion-to-emulsion manner, again using the diffuse light copier. The unsharp positive had the effect of canceling unsharp information in the negative and reducing its dynamic range, so the resulting positive appeared sharper and was much easier to print.




This process is closely analogous to the Adobe Photoshop unsharp masking tool. The variation in glass thickness controls the area over which the mask works, equivalent to radius in digital unsharp masking, and the density and contrast of the photographic mask control the amount of unsharp masking that is applied.

## Photographic Amplification ('Malinisation')

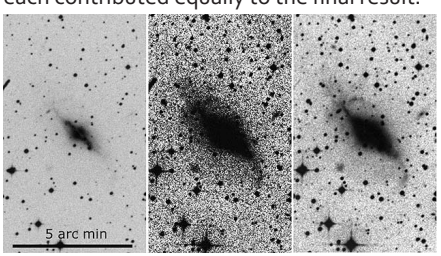
Although the negatives were already contrasty, for many science purposes it was desirable to extract as much faint information from the images as possible, even at the cost of sacrificing the image highlight tones. This was done by making a high contrast copy of the original plate (without unsharp masking), using a lith-type film with extremely high contrast and a diffuse-light copier. The exposure is controlled so that the sky background of the resulting positive had a low density, thus the highest density on the copy film was between 0.4 and 0.5. This requires the copy exposure to be controlled with great precision, but has the effect of exaggerating the near-surface image grains that carry much of the faint detail hidden in the emulsion layer, as shown on this diagram.




The resulting thin, but very contrasty positive was then printed on high contrast photographic paper. This analogue process is similar to selecting a small section of the levels histogram in Photoshop. All highlight detail is lost and minute variations in photographic density (corresponding to faint astronomical objects) are revealed. However, photographic grain is also exaggerated, so, while the signal is increased, so is the noise. But there is a cure for this.

## Multi-image addition

In astronomy, it is not uncommon to make many long-exposure photographs of the same part of the sky for survey purposes. In each of these separate photographs, the stars, galaxies and faint detail are the same, but the grain structure of the image is different. The image can be considered as signal (stars and galaxies) and noise (the grain structure). By combining many separate, photographically-amplified images in register, it is possible to dramatically decrease the amount of noise, rendering the signal more obvious. This method of increasing the signal-to-noise ratio has been very useful for detecting the faintest features of bright galaxies amongst other things. This was done manually in the darkroom by sequentially projecting many identical, photographically amplified positive images on to a sheet of paper or film, using a simple home-made device. However, each image had to be carefully aligned before the exposure was made, and the exposure equally divided among the several (or many) separate images available, so that each contributed equally to the final result.




Original appearance *(left)*, after photographic amplification *(centre)* and seven images combined *(right)*, all at the same scale.
Plates taken in blue light with the UK Schmidt Telescope.

Exactly the same can now be achieved digitally, using the 'layers' transparency control in Adobe Photoshop, and alignment is achieved using the 'transform' and 'rotate' options. Especially useful in Photoshop are the skew and distort possibilities for precisely aligning images that had unavoidable distortions from chromatic or other optical aberrations. This was always difficult and sometimes impossible in the darkroom.

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# Microscope to Telescope

Though a chemist by training, I have had a lifelong interest in the interplay of optics, colour, light and the use of the photographic process as a way of recording these phenomena, often in scientific context. These interests were fostered by working for many years for a large international chemical company with extensive laboratories in the north of England. I used optical and electron microscopes and X-ray diffraction techniques to explore problems in pure and applied chemistry, often on coloured, crystalline products such as pigments and dyestuffs. In the 1960s and 70s the major enabling technology for these analytical techniques was photography, where it functioned as a detector of unseen radiation, as a recording medium and almost incidentally as a way communicate complex findings to a wider audience.

I also soon learned that my photographs were more likely to be looked at if they were attractive to the eye while remaining faithful to the science. In the course of my work I also developed an interest in the remarkable chemistry and physics of the photographic process itself, which records an astonishing amount of information entrained in a tiny amount of energy.

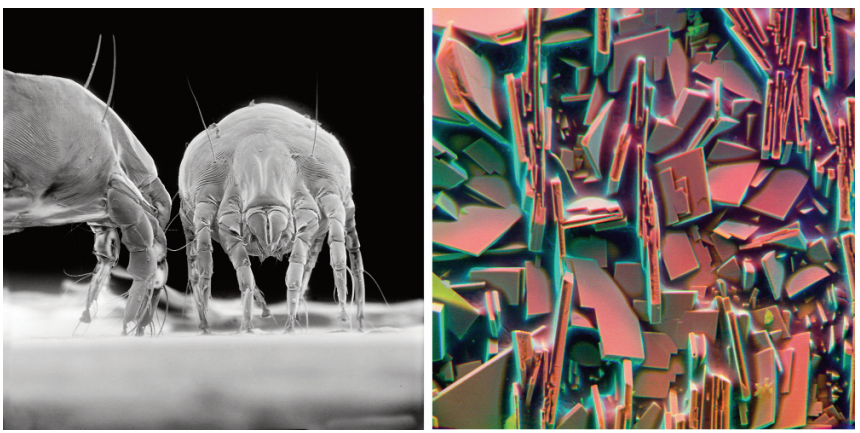


Figure 3. Scanning electron micrographs of house dust mites out to lunch *(left)* and a 3-colour image showing a tungsten-aluminium alloy seen at at different accelerating voltages (*right*).

In 1975, this notion became much more relevant when I applied for the position of photographic scientist at Anglo-Australian Observatory (now the Australian Astronomical Observatory), where the Anglo-Australian Telescope (AAT) had recently been commissioned. I was based in Sydney, but with regular visits to the telescope itself, which was located far from the city, under the dark skies of the Australian outback. I soon found that the methods of handling photographic data I had developed ina completely different field were very useful in astronomy. Indeed there were many parallels, including the idea of the photographic material

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as a detector, rather than simply a recorder of radiation, and that what was being recorded were scientific data from which images can be made, rather than merely pictures.

However, unlike the work in the laboratory with microscopes and X-rays, observing with a large optical telescope offered an entirely new experience. For a start, it is obviously not a job with regular daylight hours, working with colleagues in a convivial laboratory atmosphere. Indeed the most important and challenging aspect of the work takes place at night, on a remote mountain-top far away from city lights with one or two highly specialised technicians for company. Unlike a microscope or other laboratory equipment, a large telescope is not free to use when the need arises. Instead, time on such an instrument is applied for months in advance, and subject to rigorous peer review by a committee faced with a heavily over-subscribed telescope. In a good year an allocation of 10 nights is considered generous, and on average two or three of those would be cloudy.

## Capturing faint light

The once-familiar business of loading a roll or cassette of film into a lab microscope camera was replaced with what seemed like a step backwards in time. The photographic materials used at a professional telescope were large glass plates coated with special emulsions, made to order by the Eastman Kodak Company in the USA. Rather than being old-fashioned, these emulsions were among the most sensitive ever produced, so sensitive that the plates had to stored and shipped around the world in refrigerated containers. Coated on film and kept on a shelf in a retail store these products would rapidly fog and be useless in a week or so.

Before use the plates had to be hypersensitized to make them even more sensitive to faint light. This usually involved baking them in nitrogen in a moderate oven, and then exposing them to hydrogen gas for a few hours at room temperature, all of it in light-tight containers. This reduced their shelf life even further, so they had to be prepared a few hours before use, and my photography-chemistry background was very useful in understanding and exploiting these mysterious processes.

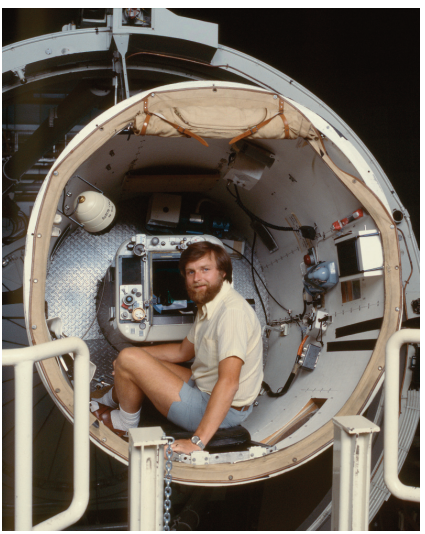
With a large telescope like the AAT, the photographic observer sat at the top end the 600 tonne telescope, at its prime focus, which at the AAT is 12.7 meters above the 4-m diameter primary mirror and 25 meters or so above the floor of the cavernous dome. Exposed to the cold night air, in total darkness and with one's back to the stars there were long periods of inactivity as feeble, ancient light was turned into a latent image on the photographic plate in the plate-holder between your knees. Exposures were typically 30 to 90 minutes, occasionally

longer, which gave plenty of time to gaze at the stars overhead and listen to music piped up from the control room far below. In between each exposure there was a brief period of intense activity as the telescope slewed to the next object, the top end of the telescope rotated, a new plate and filter was inserted and a suitable guide star found. If all went well, 90 seconds or so later a new exposure was begun, and so on, throughout the night. Before going to bed the plates had to be processed, one at a time, again in total darkness. Only then could the lights be turned on and the night's work assessed.

The past tense here is deliberate, for astronomical imaging has changed completely since I joined the AAO in 1975. Light is now detected using a solid-state charge-coupled detector (CCD) mounted at the prime focus, and controlled remotely from the control room. Observing now involves watching a bank of electronic monitors, exposures are much shorter and the image readout is almost instantaneous. Image processing is done digitally, often on the fly. The light sensors are much more sensitive than the photographic plate ever was, and it is electronics, not chemistry that makes the image visible.

Much has been gained with electronic imaging in astronomy, but at a big telescope something has been lost as well. It is much more efficient and versatile than photography ever was, but it is now neither convenient nor necessary to sit at the end of the telescope beneath the stars, contemplating origins and destiny.

David Malin

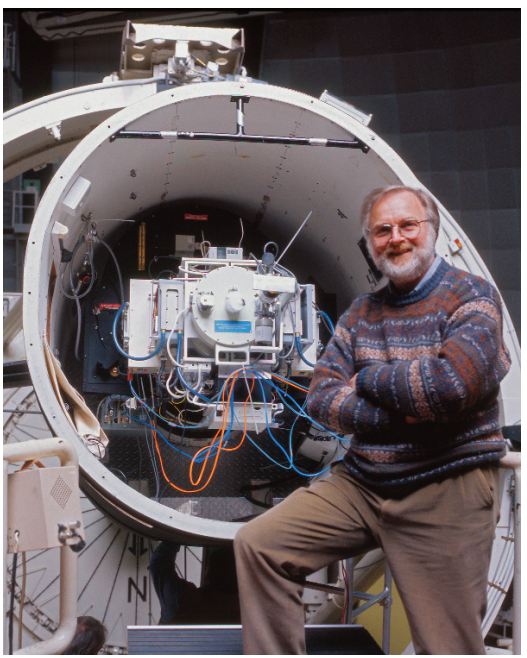


David Malin at the prime focus of the Anglo-Australian Telescope in 1976. Behind his head is the camera back, designed to take 250 mm (10-inch square) photographic plates.





*Above left:* David Malin at the prime focus of the Anglo-Australian Telescope in 1991. In the mid 1990s astronomical images began to be acquired with increasingly sophisticated electronic detectors known as CCDs (charge-coupled devices), and these have now completely replaced traditional photography. These are larger and much more elaborate versions of the light detectors used in most digital cameras. In practice they are now operated remotely from the telescope control room, or even from another location



entirely, but as they were being developed the observer was required to change the filter and to make other adjustments necessary for observing. The picture made in 1997 *(above right)* shows the observer holding a filter wheel.

However, now there is now no need for the observer to ride inside the 'cage' at all, as the image made in 2000 *(left)* shows. Not only is there no need — there is no room! Indeed for ease of access to the much more elaborate devices produced after this photograph was made, the prime focus cage is a hinderance and has been removed.

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# CATALOGUE

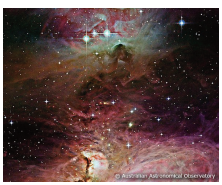
1 **A spiral galaxy in the constellation Hydra** NGC 5236, (Messier 83) Landscape 92 cm x 73.6 cm
Top left is NE. Image width is about 17 arc min.



M83 is in the huge constellation of Hydra, and is thought to be very like our own Galaxy, the Milky Way, but seen from above one of its poles and at a distance of about 15 million light years. Composed of billions of stars and huge clouds of dust and gas, this object is one of the finest examples of a spiral galaxy. It shows a concentration of older, yellow stars in its central nucleus with younger, blue stars and patchy red clouds of glowing gas and dark dust lanes in the trailing spiral arms. The massive blue stars occasionally explode as supernovae; at least eight have been seen in Messier 83 in the last 70 years.

Image and text © 1985-2010, Australian Astronomical Observatory, photograph by David Malin.

2 **Reflections of the Orion Nebula** Landscape 92 cm x 73.6 cm
Top left is NE. Image width is about 27 arc min.



A little over a degree north of the Orion nebula is a loose grouping of bright stars NGC 1973-75-77, seen at the top of this picture. Light from these stars is scattered by the dust, producing a reflection nebula that should be bluish. However, the plates that were used to make this image picture have been photographically enhanced and the colour balance distorted so that they appear greenish. Nonetheless, this photograph is the first to show a new kind of nebula, whose light is not starlight reflected by dust, but the reflected glow of another nebula, seen as the yellowish fronds cross the centre of the image. They are the reflection of light from the Orion nebula itself, which is off the lower part of the picture. All these objects are about 1350 light years distant, in the distinctive constellation of Orion.

Image and text © 1989-2010, Australian Astronomical Observatory. Photograph from UK Schmidt plates by David Malin.

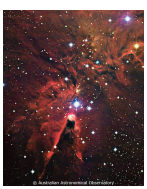
3 **The tail of the Corona Australis reflection nebula, the southern crown** (CrA) Landscape 92 cm x 73.6 cm
Top left is NE. Image width is 4.5 degrees.



Corona Australis is in the far southern sky but visible from the southern states of the USA. The constellation is small but distinctive. The conspicuous globular cluster NGC 6723 is at the western (right) edge of the photograph, but it is in Sagittarius, and is about 30,000 light years distant. Our picture is about 4.5 degrees across and the extremely faint Corona Australis nebula meanders along the Sagittarius-Corona Australis border, and in the same E-W direction. Almost all the nebulosity here is starlight, reflected from minute grains of dust, some of which gather into darker condensations ('molecular clouds'), blotting out the background stars. By far the largest and densest of the molecular clouds is at the western end of the picture, seen in more detail here. It is about a degree long, corresponding to 8 light years at the 500ly distance of the nebula and is extremely opaque so background stars are dimmed by an astonishing 35 magnitudes. However, not all is darkness, and the dusty cloud appears to be tipped by a pair of bright stars, embedded in bright reflection nebulae. The brightest of these is NGC 6726-27 and it contains both a visual binary and a variable star. Other wispy nebulae in the western part of the dark cloud betray the presence of young, hidden stars.

Image and text © 2001-2010, Australian Astronomical Observatory. Photograph from UK Schmidt plates by David Malin.

4 **The Cone Nebula in Monoceros** Portrait 92 cm x 73.6 cm
Top left is NE. Image width is about 16.5 arc min.



The Cone nebula is part of an enormous cloud of hydrogen and tiny solid particles associated with the loose open cluster, NGC 2264 in the equatorial constellation of Monoceros. More of this region is seen in Cat. No. 29. Within and around this cloud are many recently formed stars, some completely hidden within the dense interstellar matter. They can be detected by special infra-red techniques which are able to penetrate the obscuration. The largest of the dust clouds is the curious straight-sided feature which gives this object its name.

Image and text © 1981-2010, Australian Astronomical Observatory, photograph by David Malin.

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5 **The Great Nebula in Orion** (Messier 42) Portrait 92 cm x 73.6 cm

Top left is NE. Image width is about 58 arc min.



Many other, much larger nebulae than M42 in Orion are known, but none offers us so intimate a view of a nearby stellar nursery. To the eye, the nebula appears as a misty patch around the central star of the line of three which form Orion's sword. Binoculars or a modest telescope will show that these three 'stars' are loose groups of several individuals, but in this long exposure photograph they are lost in the central brightness. The central group of stars, the Trapezium cluster, is responsible for producing the nebula. It is the high concentration of dust and gas in this part of the sky which has resulted in the formation of the stars, so the Orion nebula is no random association of bright stars and dusty gas. At a distance of about 1500 light years, the Orion nebula is one the nearest and by far the brightest star-forming region.

Image and text © 1982-2010, Australian Astronomical Observatory.Photograph from UK Schmidt plates by David Malin.

6 **The Sombrero galaxy, on Virgo's southern border**, NGC 4594 (Messier 104 ) Landscape 60 cm x 48 cm

Top left is NE. Image width is about 9 arc min.



The Sombrero, named after the broad-brimmed Mexican hat it superficially resembles, is probably the most famous galaxy in the sky. The light from this remarkable spiral system is dominated by the billions of old, faint stars that form the vast 'bulge' around its tiny hidden nucleus. Most spirals, including the Milky Way, have clouds of old, faint stars around their nuclei, but in M104 the galaxy's light is dominated by them. This effect is enhanced because disk of the galaxy is seen nearly edge-on and dust in its outer parts is in silhouette as it crosses the picture. Within the dusty disk are low contrast structures that show this galaxy to be a genuine spiral, immersed in an unusually large central bulge. The bulge is seen best on a deep image and is much bigger than it appears here. It also shows some extremely faint features that are suggestive of tidal tails — merger remnants. The galaxy is about 65 million light years distant, on Virgo's southern border.

Image and text © 1993-2010, Australian Astronomical Observatory, photograph by David Malin.

7 **The Helix Nebula ('The Sunflower Nebula') in Aquarius,** NGC 7293 Landscape 60 cm x 48 cm

Top left is NE. Image width is about 25 arc min.

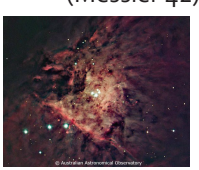


This faint object is the nearest planetary nebula to the Sun and on deep photographs has a diameter of about half a degree — the same apparent size as the Sun in the sky. Planetary nebulae are the ejected surface layers of a dying star, and advertise an end point in the evolution of stars around the mass of the Sun. The AAT colour picture shows the brighter parts of the nebula, revealing various ionisation levels within the shell of matter ejected from the central star. The greenish middle portion is evidence of excited oxygen atoms; the outer red is predominantly light from nitrogen and hydrogen. The smallest of the radial blobs inside the red shell are about 150 astronomical units across (150 times the Earth-Sun distance) and they give this beautiful object its alternative name, the Sunflower Nebula. These fine features are emphasised here by using an unsharp mask during the copying stage of the original plates. The Helix is about 700 light years away in Aquarius, and is almost 200 times more distant than the nearest stars.

Image and text © 1990-2010, Australian Astronomical Observatory, photograph by David Malin.

8 **The Great Orion Nebula Trapezium Stars** (Messier 42) Landscape 60 cm x 48 cm

Top left is NE. Image width is about 8 arc min.



The central 'star' of the three groups forming the asterism of Orion's Sword is in reality a nebula, and is clearly nebulous to the unaided eye when seen under a dark sky. At the heart of the most luminous nebulosity shimmer a handful of stars known as the Trapezium cluster, visible in binoculars. These are the brightest members of a substantial cluster of stars, most of which are still hidden in the dusty recesses of the Orion nebula against which they are seen. The stars of the Trapezium provide much of the energy which makes the brilliant Orion Nebula visible and are at a distance of about 1350 light years. This image was made with three, 30-second exposures at the prime focus of the the Anglo-Australian Telescope, using a process that involved an unsharp mask.

Image and text © 1979-2010, Australian Astronomical Observatory, photograph by David Malin.

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9 **The Lagoon and Hourglass Nebulae in Sagittarius** (Messier 8) Landscape 60 cm x 48 cm

Top left is NE. Image width is about 19 arc min.



At the heart of the Lagoon Nebula in Sagittarius lies the diminutive Hourglass Nebula. This extremely bright object is associated with the blue star alongside it, named Herschel 36 after its discoverer. Herschel described M8 as 'A noble nebula' and 'a fine and complicated nebula', but he was clearly intrigued by the Hourglass which he compared to the nucleus of the Andromeda nebula, M31 as 'decidedly not stellar'. Surrounding the Hourglass is an extensive emission nebula, popularly known as the 'Lagoon' nebula in allusion to the sinuous dark lane winding through it. The dusty division seems to separate the Hourglass nebula from a scattered open cluster, NGC 6530, at left of the picture here. It seems likely that the cluster is evidence of an earlier bout of star formation here, which has now spread westwards, into the Hourglass region. The cluster formed about 10 million years ago and is 5000 light years distant.

Image and text © 2003, Australian Astronomical Observatory, photograph by David Malin.

10 **The northernmost 'star' in the sword of Orion,** NGC 1973-75-77 Landscape 60 cm x 48 cm

Top left is NE. Image width is about 38 arc min.

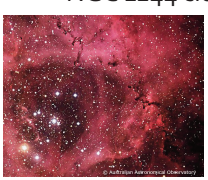


This group of nebulous stars is just half a degree north of the much brighter Orion Nebula and has largely been ignored because of it. The group of stars here appear as a single star to the unaided eye, the northernmost 'star' in the sword of Orion. Most of the blue nebulosity is starlight scattered by dust, while some of the stars are sufficiently hot to excite the wisps of hydrogen that linger here and create a distinctive red glow. To the south of the nebula (at the bottom of the picture) faint traces of the yellow reflected light of the Orion nebula can just be detected. Together, the stars and nebula seen here create an impression of quiet beauty quite unlike the maelstrom of the adjacent Orion Nebula. All these objects are about 1350 light years distant.

Image and text © 1983-2010, Australian Astronomical Observatory, photograph by David Malin.

11 **The Rosette Nebula,** NGC 2244 cluster (off-centred view) Landscape 60 cm x 48 cm

Top left is NE. Image width is about 38.5 arc min.

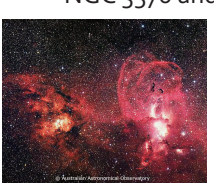


In the hollowed-out centre of the Rosette nebula lies NGC 2244, the cluster of young stars recently formed there. The cluster has itself created the cavity, radiation pressure and stellar winds from the stars blowing the gas and dust away from the young cluster. The hottest (and brightest) members of the group are seen as distinctly blue on this photograph, a colour corresponding to a surface temperature around 20,000K which may be compared with the Sun's 5500K. The nebula and its cluster is at a distance of about 4500 light years in Monoceros, the modern constellation of The Unicorn, which sits astride both the Milky Way (and thus the Galactic equator) and the celestial equator. It shows many streaks and globules of dust, remnants of the cloud from which the stars formed.

Image and text © 1984-2010, Australian Astronomical Observatory, photograph by David Malin.

12 **Carina, the keel of Argo Navis,** NGC 3576 and 3603 Landscape 60 cm x 48 cm

Top left is NE. Image width is about 41 arc min.



These two star-formation regions appear side by side in Carina, the keel of Argo Navis, the giant mythical sailing vessel afloat on the southern Milky Way, and seem to be linked as parts of an extensive nebula. However, the apparent intimacy is a line-of-sight effect because these two objects are at quite different distances from the Sun. The curious looped nebula NGC 3576 is about 7000 light years from us while its neighbour NGC 3603 is more than twice as far away. That NGC 3603 is the more distant is confirmed by its colour, which is a ruddier red than the pinkish hue of NGC 3576. The change in colour is due to absorption of the blue-light component of the nebulosity by dust particles in the much longer line of sight. This effect is known as interstellar reddening, though it would be better described as 'de-blueing' and is also seen in the Horsehead nebula (Cat. Nos. 21 and 34).

Image and text © 1984-2010, Australian Astronomical Observatory, photograph by David Malin.

13 **The Seyfert Galaxy in Dorado, the Goldfish or Swordfish,** NGC 1566

Landscape 60 cm x 48 cm

Top left is NE. Image width is about 11 arc min.



NGC 1566 is the brightest member of a nearby galaxy group in Dorado, the Goldfish or Swordfish (Xiphias), a constellation introduced by Johann Bayer, best known for his 1603 star atlas *Uranometria,* which was the first to cover the entire sky. Dorado is notable mainly for containing most of the Large Magellanic Cloud, the nearest galaxy to the Milky Way. NGC 1566 is at a distance of about 50 million light years. It has beautifully symmetrical, tightly-wound spiral arms, which on deep images appear to almost encircle the galaxy. This striking object is also of interest because it has a highly luminous nucleus which has many of the characteristics of a quasar, though it is much less energetic. Galaxies of this type are known as Seyfert galaxies, after Carl Seyfert who first recognised their peculiar nature in 1943. The active region at the centre of NGC 1566 has recently been found to vary on a timescale of less than a month, which indicates that it is extremely compact. Spectra show that hot gas near the tiny nucleus is moving at an abnormally high velocity, usually an indication that it may be in orbit around a massive black hole at the heart of NGC 1566.

Image and text © 1984-2010, Australian Astronomical Observatory, photograph by David Malin.

14 **Sculptor group galaxy,** NGC 300

Landscape 60 cm x 48 cm

Top left is NE. Image width is about 38 arc min.



NGC 300 is among the least conspicuous members of a sparse cluster of galaxies that are scattered across the south galactic pole, ideally placed for study with the AAT. The three photographic plates from which this picture was made have been specially enhanced to emphasise the delicate structure of the galaxy, revealing that the light of the spiral arms is dominated by young, blue stars. Here and there along the arms, indeed largely responsible for defining them, are denser clumps of stars, some still associated with the gas from which they formed. Many stars are clearly visible as individuals, for the Sculptor Group is relatively nearby, about 8 million light years away.

Image and text © 1991-2010, Australian Astronomical Observatory, photograph by David Malin.

15 **Ara the Altar,** NGC 6188 nebula and NGC 6193

Landscape 60 cm x 48 cm

Top left is NE. Image width is about 19 arc min.



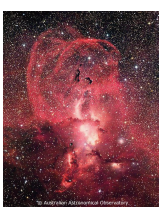
Here we see two bright stars whose radiant energy is beating down on to the surface of a dark cloud, similar to the Horsehead in Orion. The cloud itself is opaque and because of that, extremely cold inside. These conditions are ideal for the formation of organic molecules on the surfaces of the chilled dust particles. The opacity of the cloud protects the fragile molecules within from the energetic radiation of nearby stars, but as its surface is gradually warmed and eroded, the delicate organic molecules are destroyed and the hydrogen released glows as a distinctive red emission nebula. The constellation of Ara was recognised by the Greeks and Romans and was visualised as the altar on which the Centaur, Centaurus, was to sacrifice Lupus, the Wolf. This is reflected in its Latin name, Ara Centauri.

Image and text © 1991-2010, Australian Astronomical Observatory, photograph by David Malin.

16 **Carina, the keel of Argo Navis, t**he loops of nebula NGC 3576

Portrait 60 cm x 48 cm

Top left is NE. Image width is about 24 arc min.



The stars that excite this unusual nebula in Carina, the keel of Argo Navis, the giant mythical sailing vessel afloat on the southern Milky Way, are not visible on this photograph. They are hidden in the dusty cloud at the 'base' (south) of the huge loops of nebulosity. This is material that has been blown out by radiation pressure and stellar winds from the concealed stars. Silhouetted against the tenuous loops are dark clouds of dust with bright rims which indicate the direction of the stars which excite the nebula. This large complex of gas and dust is at about the same distance as the much brighter Eta Carinae nebula, about 7000 light years away.

Image and text © 1984-2010, Australian Astronomical Observatory, photograph by David Malin.





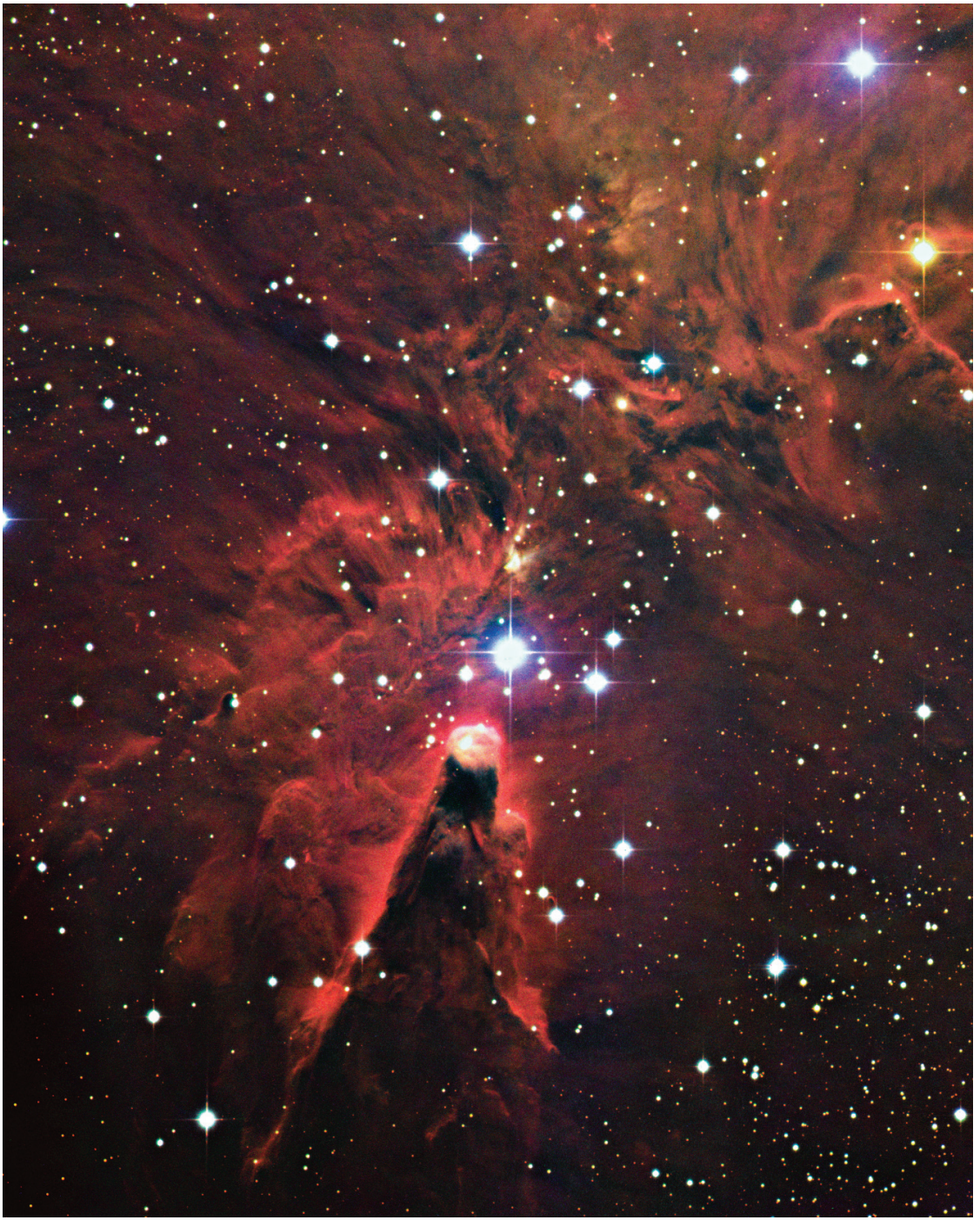


**Cloths of Heaven**

Had I the heavens' embroidered cloths,
Enwrought with golden and silver light,
The blue and the dim and the dark cloths
Of night and light and the half-light,
I would spread the cloths under your feet:
But I, being poor, have only my dreams;
I have spread my dreams under your feet;
Tread softly because you tread on my dreams.

William Butler Yeats (1865-1939)

*Above*: Cat.No. 23 — The Pleides in Taurus.
*Right*: Cat. No. 4 — The Cone Nebula in Monoceros.
*Over:* Cat. No. 3 —The Tail of Corona Australis, the southern crown.





'Mortal as I am, I know that I am born for a day. But when I follow at my pleasure the serried multitude of the stars in their circular course, my feet no longer touch the earth.'

Claudius Ptolemy (c.90-168)

*Above*: Cat.No. 21 — The Horsehead Nebula.
*Right*: Cat. No. 37 — The interacting galaxies of the Antennae in Corvus the Raven.



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17 **The Bubble Nebula, toward the northern boundary of Cassiopeia,** NGC 7635 — Landscape 60 cm x 48 cm
Top left is NE. Image width is about 13 arc min




Although it looks delicate, the 10 light-year diameter Bubble Nebula, NGC 7635, offers evidence of violent processes at work. To the right of the Bubble's centre is a hot, O-type star, several hundred thousand times more luminous and approximately 45 times more massive than the Sun. A fierce stellar wind and intense radiation from that star has blasted out the structure of glowing gas against denser material in a surrounding molecular cloud. Seen toward the northern boundary of Cassiopeia, a northern sky constellation shaped in a distinctive 'W' by five bright stars, distance estimates for the Bubble Nebula and associated cloud complex are around 11,000 light-years.

© 1992-2002, Malin/IAC/RGO. Photograph from Isaac Newton Telescope plates by David Malin. Text © R.Nemiroff & J. Bonnell (APOD)

18 **The nucleus of the Andromeda galaxy,** M31. — Landscape 60 cm x 48 cm
Top left is NE. Image width is about 15.5 arc min.




The nearest comparable spiral galaxy to the Milky Way is M31 (NGC 224), the great galaxy in Andromeda. Visible to the unaided eye, it has been known as a curious hazy patch since ancient times. Only in the last 75 years has its nature as a distant city of stars like the Milky Way become apparent. This picture covers almost half a degree of sky (about the size of the full moon), but wide angle telescopes show the galaxy to be over 3 degrees long at its widest. Here we see only the central part of M31, the huge mass of stars that are in orbit around its nucleus. Silhouetted against this starry background are tangled sheets and curtains of dust, highly reminiscent of dust clouds we see in our own galaxy. M31 and the Milky Way are gravitationally bound to each other and do not share in the general expansion of the universe. They are approaching each other at a velocity of about 300 km per second, a modest speed on the cosmic scale.

Image and text © 1991-2002, Malin/IAC/RGO. Photograph from Isaac Newton Telescope plates by David Malin.

19 **The southern arm of the Andromeda galaxy,** (Messier 31) — Landscape 60 cm x 48 cm
Top left is NE. Image width is about 38 arc min.




M31 is the finest and nearest large spiral galaxy in the sky, about 2 million light years away. Despite its distance it can be seen as an elongated streak with the unaided eye in northern skies and in a large telescope under good conditions it is clearly resolved into stars and star-forming regions. This picture shows less than half the galaxy but the spiral structure, star clouds and dust lanes are evident. Also here is one of M31's close companions, the compact elliptical galaxy M32 (NGC 221), at upper left (NE). M31 and its companions belong to the Local Group of about 30 galaxies that includes the Milky Way and M31 as its most massive members as well as the Magellanic Clouds. This picture is about half a degree across and is of the same region as the frontispiece in Hubble's famous book *The Realm of the Nebulae* (Harvard UP, 1936).

Image and text © 1991-2002, Malin/IAC/RGO. Photograph from Isaac Newton Telescope plates by David Malin.

20 **The Crab nebula,** NGC 1952, (Messier 1) — Portrait 60 cm x 48 cm
Top left is NE. Image width is about 11 arc min




The Crab nebula is the expanding remains of a star that was seen to explode by Chinese astronomers in 1054 CE. It is one of the strongest radio sources in the sky and was first identified with the optical nebula seen here by Australian astronomers in 1947. At the heart of the nebula is a rapidly-spinning neutron star, a pulsar, and it powers the diffuse, strongly polarised bluish 'synchrotron' nebula from which the red emission-line filaments seem to emerge. The photograph was made from plates taken on the Palomar 5m telescope in February, 1956. The plates were taken in several colours for scientific analysis, but are sufficiently well matched in exposure to allow three, taken in red, green and blue light, to be re-constructed into a three-colour image using conventional photographic techniques. Other plates in this series were used to reconstruct a false-colour polarisation map of the nebula.

Image and text © 1990-2002, Malin/Pasachoff/Caltech. Photograph from Hale 5m plates by David Malin.

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21 **The Horsehead Nebula in Orion,** NGC 2024 and IC 434

Landscape 60 cm x 48 cm
Top is W, left is N. Image width is about 100 arc min.



This distinctive red emission nebula (IC 434) is the result of radiation from sigma Orionis interacting with the surface of a dusty cloud of gas from which projects the dark shape of the head of a horse. Sigma is the second brightest star in the picture and is at about the same distance from the Sun as the nebula. The brightest star here is zeta Orionis, easily visible to the unaided eye as the easternmost star in the line of three which form Orion's Belt. Partly obscured by the glare of zeta is the curious yellowish nebula NGC 2024, whose energy comes from stars hidden in the dark lane, while other nebulae simply reflect the light of embedded hot stars and appear blue. All the nebulous objects and the dark cloud of dust that hides distant stars are about 1350 light years away.

Image and text © 1980-2010, Australian Astronomical Observatory. Photo from UK Schmidt plates by David Malin.

22 **Reflection nebula in Ara, the Altar,** NGC 6188

Landscape 60 cm x 48 cm
Top left is NE. Image width is about 37 arc min.



Ara the Altar is a small constellation in the southern Milky Way, and devoid of bright stars. The fainter stars here are cool, like those that orbit the inner 'bulge' of the Milky Way and appear slightly yellow on colour pictures. The foreground patch of dust that crosses this photograph must be illuminated by energetic radiation from stars that are much hotter than those in the background because hydrogen, which is associated with the dust, has been excited into a vivid red fluorescence by absorbing the invisible ultraviolet light. Here and there a few bright but cooler stars are caught up in the outskirts of dust clouds and some of their light is scattered to produce the blue reflection nebulae. Ara was recognised by the Greeks and Romans and was visualised as the altar on which the Centaur, Centaurus, was to sacrifice Lupus, the Wolf. This is reflected in its Latin name, Ara Centauri.

Image and text © 1987-2010, Australian Astronomical Observatory, photograph by David Malin.

23 **The Pleiades in Taurus,** (Messier 45)

Landscape 60 cm x 48 cm
Top left is NE. Image width is about 3.5 arc min.



The Pleiades are one of the finest and nearest examples of a reflection nebula associated with a cluster of young stars. The cluster itself is a group of many hundreds of stars about 400 light years away in the direction of the northern constellation of Taurus. A handful of the brightest stars cluster together in space and have been recognised as a group since ancient times. However, even the brightest of the Pleiades stars (Alcyone, apparent visual mag +2.9) is relatively faint and would be inconspicuous (and nameless) if it were not a member of the cluster. The faintest named star is Asterope, (V = +5.8), close to the threshold of naked eye visibility. All the visible stars of the Pleiades are in reality much more luminous than the Sun. The nebulosity seen here is light reflected from the particles in a cloud of cold gas and dust into which the cluster has drifted. It appears blue because these tiny motes of interstellar dust scatter blue light more efficiently than the longer wavelengths of red light, and it is streaky because of the distribution of dust particles in space.

In western literature and legend the stars bear the names of the Seven Sisters, the daughters of Atlas and Pleone. They were also half-sisters to the goddesses of the of the nearby Hyades stars. Most other peoples who have turned their eyes to the sky have stories about them. The delicate beauty of the stars has them identified as a group of women in many cultures, from Australian Aborigine to Native American. To the Japanese they are 'Subaru', a conglomerate or collection (i.e. cluster), while some Chinese legends refer to a swarm of bees. Maori and some Pacific Islands people call the Pleiades 'Matariki', the star cluster that heralds the start of the Aotearoa Pacific New Year.

Image and text © 2000-2010, Australian Astronomical Observatory. Photograph from UK Schmidt plates by David Malin.

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## 24 Antares in Scorpius, (Messier 4), NCG 6144

Landscape 60 cm x 48 cm
Top left is NE. Image width is about 2 degrees.



Antares is a giant among stars, and like giants in general, extremely rare. Antares is about 600 light years away in the direction of Scorpius. It is a first magnitude star 15 times more massive than the Sun and tens of thousands of time more luminous. It has spent most of its short life as a blue supergiant star, its mass obliging it to consume its vast store of nuclear fuel (hydrogen) very rapidly. This nuclear fusion process supplied the energy that prevented the star collapsing in on itself — all stars support themselves against gravity in this way. Now, the supply of fuel in the core of the star is close to exhaustion and the star has undergone a major internal re-arrangement to cope with the changed circumstances, both cooling and swelling in the process. It has become a red supergiant. This star is big, about 700 times the diameter of the Sun. If Antares were to replace the Sun in the solar system, both the Earth and Mars would be inside the distended atmosphere of the star. At its cool surface, tiny solid particles begin to appear, made from traces of heavier elements formed inside the star. In this photograph the tiny dust grains drift away, reflecting Antares' yellowish light and making the wispy nebula that seems to envelop the moribund star, soon to be a supernova. In the background, seen through the nebula is a globular cluster, NGC 6144, over 30,000 light years away, while much brighter and closer is the globular cluster M4, NGC 6121, about 7,200 light years distant.

Image and text © 2001-2010, Australian Astronomical Observatory. Photograph from UK Schmidt plates by David Malin.

## 25 The head of the Corona Australis reflection nebula

Landscape 60 cm x 48 cm
Top left is NE. Image width is 3 degrees.



Corona Australis is in the far southern sky but visible from the southern states of the USA. The constellation is small but distinctive. The conspicuous globular cluster NGC 6723 is at the western (right) edge of the photograph, but it is in Sagittarius, and is about 30,000 light years distant, while the wispy dust cloud that dominates the picture is about 500 light years away. Our picture is about 3 degrees across and the faint Corona Australis nebula meanders along the Sagittarius-Corona Australis border, and in the same E-W direction. Almost all the nebulosity here is starlight, reflected from minute grains of dust, some of which gather into darker condensations ('molecular clouds'), blotting out the background stars. By far the largest and densest of the molecular clouds is at the western end of the picture. It is about a degree long, corresponding to 8 light years at the distance of the nebula and is extremely opaque — background stars are dimmed by an astonishing 35 magnitudes. However, not all is darkness, and the dusty cloud appears to be tipped by a pair of bright stars, embedded in bright reflection nebulae. The brightest of these is NGC 6726-27 and it contains both a visual binary and a variable star. Other wispy nebulae in the western part of the dark cloud betray the presence of young, hidden stars.

Image and text © 2001-2010, Australian Astronomical Observatory. Photograph from UK Schmidt plates by David Malin.

## 26 The Orion Nebula, M42 and M43

Landscape 60 cm x 48 cm
Top left is NE. Image width is about 32 arc min.



The Orion Nebula is famous for a number of reasons. It is the nearest bright nebula to us and can be seen with the naked eye. Its brightness led to it being the first nebula ever photographed (in 1882) and its proximity (1350 light years) means that we know more about it than any other star-forming region. It is also in a highly active stage of star formation and it is perfectly placed for us to explore the intimate details of the birth of stars. The inner regions are glowing mainly in the red light of excited hydrogen, which together with some green emission from oxygen give the centre of the nebula a yellowish colour. The energy for this spectacular display comes from the small cluster of stars in the brightest part of the nebula. Three, five-minute exposures were used to make this picture using plates from the Anglo-Australian Telescope, and an unsharp mask was used during the copying stage.

Image and text © 1979-2010, Australian Astronomical Observatory, photograph by David Malin.

27 **The dusty southern spiral galaxy Centuarus** Portrait 60 cm x 48 cm
NGC 4945
Top left is NE. Image width is about 16 arc min



This is one of many peculiar galaxies that populate the large southern constellation of Centaurus, one of the richest parts of the southern sky. At over 1000 square degrees it is the ninth largest constellation. Along with Sagittarius, it represents a centaur in Greek mythology, a half-man half-horse creature. This learned centaur is the legendary inventor of the main constellations. This remarkable spiral galaxy seen almost edge-on, and the spiral structure is chaotic and difficult to discern. In part this is because the galaxy is itself extremely dusty, and it is seen through dust in the Milky Way. These effects together account for its yellowish hue, though patches of bluish stars can be seen. The dust in NGC 4945 absorbs most of the visible light, especially the blue light from the numerous bright stars present within the galaxy. This energy is re-radiated at infrared wavelengths, which penetrate dust more readily, hence the galaxy is unusually bright in the infrared.
Image and text © 1993-2010, Australian Astronomical Observatory, photograph by David Malin.

28 **The Hydra cluster of galaxies** Portrait 60 cm x 48 cm
(Abell 1060)
Top left is NE. Image width is about 25 arc min.



This splendid cluster of galaxies in Hydra is framed by two nearby, cool stars in our own Milky Way. The brightest is about 5th magnitude, visible to the unaided eye only under a dark sky; the second brightest is below naked-eye visibility. In contrast the galaxies appear featureless in all but the largest telescopes. The bluish, elongated galaxy is an edge-on spiral, NGC 3312. It has been distorted by interactions with its neighbours. They in turn have been affected, and the brightest of the two adjacent yellow elliptical galaxies (NGC 3311) has an assymetrical envelope, perhaps as a result of this encounter. It's hard to tell who is jostling who in a crowded group of galaxies such as this. Among the most interesting galaxies in the group are two faint spirals (NGC 3314) that are by chance aligned along the line of sight, seen a little to the left of the fainter star and directly below the brighter. It is clear we are seeing one galaxy in front of another. Such chance alignments are rare and allow astronomers to study the contents of the foreground galaxy in great detail, thus addressing a controversial topic in astronomy: are galaxies transparent?
Image and text © 2000-2010, Australian Astronomical Observatory, photograph by David Malin.

29 **The Fox-fur nebula and S Monocerotis** Portrait 60 cm x 48 cm
Top left is NE. Image width is about 24 arc min.



The region around the 4.7 magnitude star S Mon is a fascinating mixture of red fluorescent hydrogen and dark, obscuring dust lanes. Some dust patches are close enough to bright stars to reflect light from them; these appear blue for the same reason that the day-time sky is blue — because some of the interstellar particles preferentially scatter blue light. The dust is mixed with gas and this affects the appearance of the emission nebulae, giving some of the faintest a curious 'fox fur' texture in this enhanced photograph. About 250 stars have been recognised as members of NGC 2264 which is at a distance of about 2700 light years.
Image and text © 2001-2010, Australian Astronomical Observatory, photograph by David Malin.

30 **The globular cluster 47 Tucanae** Landscape 60 cm x 48 cm
(NGC 104)
Top left is NE. Image width is about 24 arc min.



Among the many spectacular objects in the southern skies are two magnificent naked-eye globular clusters, omega Centauri and 47 Tucanae. Both these common names imply that they are stars, yet both are clearly non stellar, even to the casual naked-eye observer. In binoculars or a small telescope they resolve into vast numbers of tiny stars. These clusters are ancient cities of stars and are captives of the Milky Way. They were formed long before our Galaxy assumed its present shape, and contain some of the oldest known stars. 47 Tuc is about 15,000 light years distant and contains several million stars. The crowded central region leads to occasional stellar encounters and it is in 47 Tuc that numerous, rapidly-spinning (milli-second) pulsars have been discovered by radio astronomers. Though the light of globular clusters is dominated by so-called 'red' giant stars, their colour is no redder than a domestic tungsten lamp, so the true colour of 47 Tuc is close to the pale pink-yellow reproduced here.
Image and text © 1981-2010, Australian Astronomical Observatory, photograph by David Malin.

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## 31 The Trifid Nebula in Sagittarius

Portrait 60 cm x 48 cm

Top left is NE. Image width is about 6 arc min.



Vast clouds of hydrogen mixed with tiny dust grains are distributed throughout the Milky Way. The hydrogen only becomes visible when it is illuminated by ultraviolet light very hot stars, which causes the gas to glow (fluoresce) with its characteristic red colour. In most cases, such as here, the hot stars formed recently from the hydrogen cloud. The stars found at the heart of the Trifid Nebula are here seen associated with dust lanes which are silhouetted against the glowing background. This nebula, Messier 20 (NGC 6514) is in the constellation of Sagittarius at a distance of about 3000 light years.

Image and text © 1986-2010, Australian Astronomical Observatory, photograph by David Malin.

## 32 The Hourglass Nebula in Sagittarius

Portrait 60 cm x 48 cm

Top left is NE. Image width is about 3 arc min.



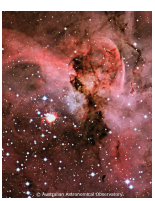
At the heart of the Lagoon Nebula in Sagittarius lies the tiny Hourglass Nebula, M8, NGC 6523. This extremely bright object is associated with the blue star immediately to the right (west) of the Hourglass. This star is named Herschel 36 after its discoverer. John Herschel described M8 as 'A noble nebula' and 'a fine and complicated nebula', but he was clearly intrigued by the Hourglass which he compared to the nucleus of the Andromeda nebula, M31 as 'decidedly not stellar'. The tiny bright nebula that captured Herschel's attention is energised partly by the bright star H36 and partly by a star which, for the present, remains hidden in the pinched waist of the Hourglass. The obscured star is only visible in infrared light which can penetrate the thick clouds of dust seen over much of the Lagoon Nebula and clearly evident in a recent Hubble Space Telescope photograph. These stars are probably less than 10,000 years old, about as old as the Hourglass itself, and are evidence of recent star-formation in this very dusty and active region.

Image and text © 1994-2010, Australian Astronomical Observatory, photograph by David Malin.

## 33 Eta Carinae and the Keyhole Nebula in The Argo

Portrait 60 cm x 48 cm

Top left is NE. Image width is about 6 arc min.



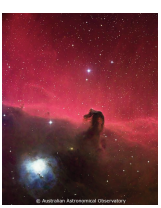
This wonderfully complex region at the heart of the NGC 3372 nebula was first described in detail by Sir John Herschel in 1838. He saw the bright circular shell visible in the upper part of the picture extending to the south to form a keyhole-shaped nebula. This luminous outline is no longer seen and the southern extension appears only as a dark dust cloud. It seems that the curious, explosively variable star Eta Carinae has enveloped itself in a cocoon of obscuring matter in the years since Herschel's observations and light from the star is no longer able to illuminate the rim of the dust cloud. The nebula thrown off by eta Carinae in Herschel's time has grown to the tiny orange nebula seen to the left of the dust cloud and is known as the Homunculus nebula. It has also ejected some rapidly moving spikes seen on a black and white photograph made some years ago at the f/8 focus of the AAT. The whole nebula complex is in Carina, the Keel, a remnant of Argo Navis, a giant mythical sailing vessel afloat on the southern Milky Way, at a distance of about 7000 light years.

Image and text © 1985-2010, Australian Astronomical Observatory, photograph by David Malin.

## 34 The Horsehead Nebula in Orion

Portrait 60 cm x 48 cm

Top is W, left is N. Image width is about 31 arc min.



This curious dark nebula is one of the best-known images in astronomy, probably because of its chance likeness to a recognisable form. The horse-head shape is an extension of a large cloud of dust which fills the lower part (east) of the picture and hides the light of stars beyond. The outer surface of the dusty gas (IC 434) runs roughly north-south and is illuminated by sigma Orionis (off the top of the picture) which causes the hydrogen there to fluoresce, outlining the horse-head shape. Though conspicuous here, the Horsehead is very difficult to see visually, even with a large telescope. A bright star is partially enveloped in the dust cloud and its scattered light is seen as the large, irregular blue reflection nebula, NGC 2023. All these objects are about 1350 light years distant.

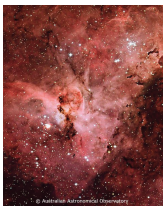
Image and text © 1984-2010, Australian Astronomical Observatory, photograph by David Malin.

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## 35 The Eta Carinae Nebula and Trumpler 14

Portrait 60 cm x 48 cm

Top left is NE. Image width is about 15 arc min.



In the small region pictured here are some of the brightest stars known in our Galaxy, each a million times more luminous than the Sun. To the left of the picture is an even more extreme star, Eta Carinae, shrouded in a small bright irregular nebula of its own making. In the upper right of the photograph is Trumpler 14, a cluster of very young stars which appears to be associated with a number of bright-edged 'elephant trunk' dust lanes, typical of star-forming regions. All these objects and most of the bright stars scattered across the face of the nebula are together in space in Carina, the Keel, a remnant of Argo Navis, a giant mythical sailing vessel afloat on the southern Milky Way, at a distance of about 7000 light years. Despite this distance, the Carina nebula is clearly visible to the unaided eye to those who live in the southern hemisphere.

Image and text © 1985-2010, Australian Astronomical Observatory, photograph by David Malin.

## 36 A barred spiral galaxy in Fornax in the southern part of Eridanus, the River

Portrait 60 cm x 48 cm

Top left is NE. Image width is about 12 arc min.



Galaxies occur in a variety of shapes, but among the most eye-catching are the spirals, especially barred spirals. One of the finest in the sky is NGC 1365, the largest spiral in the southern constellation of Fornax, at a distance of about 60 million light years. This beautiful galaxy is about as massive as the Milky Way, itself a substantial galaxy. Not much is known about how galaxies take on their beautiful forms, but a good deal is known about their internal organisation. The obvious 'bar' has the nucleus of the galaxy at its hub and is surrounded by masses of cooler stars that appear yellow on colour photographs. The bar itself is also yellowish, and has distinct dust lanes but it terminates abruptly in slender, curved arms that are lit by blue stars and the pink star-forming regions from which they spring. This galaxy is a member of the nearby Fornax cluster of galaxies that includes NGC 1316-17, the radio source Fornax A. Fornax was created out of several faint stars in the southern part of Eridanus by Nicolas Louis de Lacaille, who originally named this obscure grouping *le Fourneau* (the Furnace) in the 1750s. The name was later Latinised (by Bode) to *Fornax Chimiae*, the Chemical Furnace, in honor of the famous French chemist Antoine Lavoisier, who was guillotined in 1794 during the French Revolution.

Image and text © 1991-2010, Australian Astronomical Observatory, photograph by David Malin.

## 37 The interacting galaxies of the Antennae in Corvus the Raven

Portrait 60 cm x 48 cm

Top left is NE. Image width is about 5.5 arc min.



NGC 4038 and 4039 are the well-known pair of interacting galaxies in Corvus, the Raven or Crow, an ancient constellation recognised by Ptolemy almost 2000 years ago. They show two broadly curved tails of stars, the 'antennae', extending a considerable distance from the action. This distinctive display is seen in Cat. No. 38 and gives the structure its popular name: it seems to have distracted attention from the interacting galaxies themselves. It is possible that one of the two disc galaxies involved was a 'gas-less spiral' (S0), because the most southerly of the pair is distinctly yellow, while the outer parts, its companion, are bluer. The colour picture reveals the burst of star formation triggered by the encounter, the large numbers of pink emission nebulae in the inter-galaxy region and the location of the numerous dark, brownish-yellow clouds of dust. The yellow nuclei of the two galaxies are also still visible as separate entities. The galaxies are at a distance of about 45 million light years.

Image and text © 1991-2010, Australian Astronomical Observatory, photograph by David Malin.

## 38 The tails of the Antennae in Corvus the Raven

Portrait 60 cm x 48 cm

Top left is NE. Image width is about 5.5 arc min.

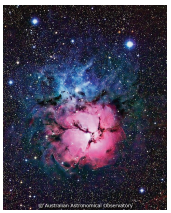


The description of Cat.No. 37 applies here. The faint tails seen here were derived from a plate taken on the Kitt Peak 4m telescope, by Al Millikan in May, 1973. Millikan was from the Eastman Kodak Company, and he was testing the then-new IIIa-J photographic emulsion.

Image and text © 1991-2010, Australian Astronomical Observatory, photograph by David Malin.

39 **Reflection nebulosity around the Trifid Nebula in Sagittarius, the Archer** Portrait 60 cm x 48 cm

Top left is NE. Image width is about 29 arc min.



The spectacular Trifid nebula (Messier 20) is one of the best known in the sky and it is in a rich star-field in Sagittarius. It is a striking mixture of brilliant red light emitted from excited hydrogen gas and the soft blue glow of a reflection nebula. The blue arises from starlight, scattered by dust particles between the stars. The size of the particles is minute, similar to those of smoke, which also has a bluish hue. However, the scattered light is not a pure blue, and if we see it through a medium that is yellow (i.e. absorbs blue light) some green colouration remains. This effect can be seen in some of the darker parts of the faint reflection nebula that surrounds the Trifid, where partial absorption of light by foreground dust provides a yellow 'filter', producing shades of green. This image has been photographically enhanced using an unsharp mask.

Image and text © 1991-2010, Australian Astronomical Observatory, photograph by David Malin.

40 **Part of the Vela supernova remnant** Portrait 60 cm x 48 cm

Top left is NE. Image width is about 28 arc min.



A supernova event marks the catastrophic end-point in the life of a massive star. The self-destruction of the star releases a huge amount of energy as radiation of all kinds, but a substantial fraction of the force of the explosion blasts the outer part of the supernova into an expanding shell of matter that travels through the almost empty space between the stars. As the rapidly moving blast wave encounters the relatively stationary interstellar medium it creates a very narrow, luminous shock front that appears as a faint nebula. Because the shock front is very convoluted the nebulosity appears to be highly structured and the various colours define different energy levels within the interaction. Though the star responsible for the Vela supernova remnant exploded 12,000 years ago, it is still affecting its environment. Vela forms the sails of the constellation Argo, the giant mythical sailing vessel afloat on the southern Milky Way

Image and text © 1992-2010, Australian Astronomical Observatory, photograph by David Malin.

41 **The 'Pencil nebula' in Vela, the sails of the constellation Argo,** NGC 2736 Portrait 60 cm x 48 cm

Top left is NE. Image width is about 13 arc min.



This is an outlying wisp of the Vela supernova remnant (SNR), almost the only sign of the eastern part of this vast bubble of expanding shock wave from a stellar explosion 12,000 years ago. Though clearly detected with radio and X-ray telescopes, the Vela SNR is partially hidden to optical observers. Many fine, tangled filaments are seen in the western part of the nebula, but in the east, most of it is hidden in dust. This is one of the brighter eastern fragments, and its unusual linear appearance in the telescope was remarked on by Sir John Herschel who discovered to nebula in the 1840s. This spindly shape is the source of its popular name.

Image and text © 1994-2010, Australian Astronomical Observatory, photograph by David Malin.

42 **The annulus of Shapley 1, a planetary nebula next to the constellation Lupus** Portrait 60 cm x 48 cm

Top left is NE. Image width is about 2.5 arc min.



This is an unusual annular planetary nebula in Norma, (originally Norma et Regula, the builder's level and set square), an insignificant scattering of stars compared to the neighbouring constellations of Lupus and Centaurus. Like Circinus (the Drawing Compasses), it was invented by Nicolas de Lacaille, who charted the southern sky from South Africa in 1751-2 and felt obliged to fill vacant spaces in the sky with Enlightenment-inspired instruments of science. The nebula itself appears quite small at a little over an arc minute in diameter, while its central star is a magnitude 14 white dwarf. This object is unusual because those planetaries that are not bipolar are more or less spherical shells of material thrown off by the central star as it undergoes an internal rearrangement. We often see them as thick annuli because we look through a greater thickness at the edge of the shell. However, Shapley 1 seems to be a true torus, a doughnut-shaped ring of material that we happen to see face-on around the central star. Sp-1 is about 1000 light years distant.

Image and text © 1995-2010, Australian Astronomical Observatory, photograph by David Malin.

## 43 Hubble's variable nebula, NGC 2261

Portrait 60 cm x 48 cm

Top left is NE. Image width is about 6 arc min.



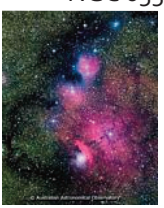
Hubble's variable nebula is in the modern constellation Monoceros, the Unicorn, a mythical creature with the forelegs and (horned) head of a horse, the hindquarters of a stag and the tail of a lion that sits astride both the Milky Way (and thus the Galactic equator) and the celestial equator. NGC 2261 was the first object to be photographed with the famous 200 inch Hale Telescope at Palomar in 1948. This curious object is a reflection nebula in which is embedded the star R Monocerotis. Variations in the appearance of the nebula were noted by the American astronomer Edwin Hubble in 1916. They are probably caused by opaque clouds of dust passing between the hidden star and the outskirts of the nebula we see, the moving shadows changing the apparent form of the glowing dust in an irregular way. This picture was made from three AAT plates taken over several years and subtle colour changes around the edge of the nebula are indications of the variability, not of any change in the colour of the nebula.

Image and text © 1993-2010, Australian Astronomical Observatory, photograph by David Malin.

## 44 The dusty region in Sagittarius, NGC 6559 and IC 1274-75

Portrait 60 cm x 48 cm

Top left is NE. Image width is about 47 arc min.



This dusty region in Sagittarius is probably associated with the brighter and better-known Lagoon (Cat.No. 9) and Trifid (Cat. No. 31) Nebulae which are nearby in the sky and part of the same molecular cloud. The soft red glow of fluorescent hydrogen is evidence that there are young hot stars associated with the dusty clouds. These bright stars also illuminate the tiny solid particles, producing blue reflection nebulae bordering some of the emission regions. The dust is also evident in silhouette, both as sinuous dark lanes winding through the luminous gas and as the dark patches obscuring the ancient, yellow stars that populate the central parts of the Milky Way.

Image and text © 1979-2010, Australian Astronomical Observatory. Photograph from UK Schmidt plates by David Malin.

## 45 Antares, the heart of the Scorpion, and the Rho Ophiuchi Dark Cloud

Portrait 60 cm x 48 cm

Top left is NE. Image width is about 3.5 arc min.



The dusty region between Ophiuchus and Scorpius contains some of the most colourful and spectacular nebulae ever photographed. The upper part of the picture is filled with the bluish glow of light from hot stars reflected by a huge, cool cloud of dust and gas where such stars are born. This dust is also seen as a dark nebula, a molecular cloud, hiding the light of background stars, especially on middle left (east) of the picture. Dominating the lower half of this cosmic landscape is the over-exposed image of the red supergiant star Antares, the heart of the Scorpion (Cat. No. 24), a star that it is steadily shedding material from its distended surface as it nears the end of its life. These tiny, smoke-like solid particles reflect Antares' light and hide it in a nebula of its own making about 600 light years away. Partly surrounding Sigma Scorpii (735 light years distant) at the right of the picture is a red emission nebula, completing the most comprehensive collection of nebular types ever seen in one photograph. There's also two globular clusters, one of the nearest to the sun, M4 (NGC 6121, 4500 light years away) at lower centre right and NGC 6144, 28,000 light years away, buried behind Antares' haze.

Image and text © 1979-2010, Australian Astronomical Observatory. Photograph from UK Schmidt plates by David Malin.

## 46 The constellation Scorpius OB association, NGC 6231 cluster

Landscape 60 cm x 48 cm

Top left is NE. Image width is about 13 arc min.



The constellation of Scorpius is scattered through with spectacular individual stars forming loose groups. If such groups contain many hot, extremely luminous OB-type stars they are known as OB associations, an identification of the site of recent star formation, usually a broadly spread group of stars that has a strong influence on its surroundings. The stars in such groups are mostly expanding away from some common center, which presumably marks their birthplace. Close to the center of the Scorpius OB association is the cluster NGC 6231, gravitationally bound and very young, with an age of about 3.5 million years. The cluster is also highly luminous and its radiation, and that of the ultra-luminous star zeta-1 Scorpii (about 1 degree to the south of this image) affects a vast volume of space, turning dark and dusty clouds into vivid nebulae such as that seen in Cat. No. 55. It is not surprising therefore to find the names of OB associations linked to the most spectacular regions in the sky, in Orion, (the nearest and richest), in Carina, in Cygnus and Perseus.

Image and text © 1992-2010, Australian Astronomical Observatory, photograph by David Malin.

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47 **An edge-on galaxy in the Sculptor Group,** NGC 55 Landscape 60 cm x 48 cm

Top left is NE. Image width is about 26 arc min.



The nearest galaxy to the Milky Way is the Large Magellanic Cloud (LMC), which we see from a distance of 170,000 light years. It is inclined to our line of sight by about 40 degrees. Magellanic-type galaxies are quite rare, as are edge-on galaxies, so we are lucky to have such a close view of such an unusual specimen which is also nearby. NGC 55 is at a distance of about 5 million light years, and a member of the Sculptor group, where the galaxies are few in number and well separated in space. It is probably for this reason that NGC 55 is not rich in star forming regions, because it is not interacting with any nearby companion galaxy, unlike the LMC, which is stirred up by interactions with both the Milky Way and the Small Magellanic Cloud. It and is close enough for us to see it resolved into individual stars. Sculptor was originally named *L'Atelier du Sculpteur* (the Sculptor's Studio) by Abbé Nicolas Louis de Lacaille during his sojourn at the Cape of Good Hope between 1751 and 1752, later Latinised to *Apparatus Sculptoris*, and then shortened. It was made from stars that were originally between Cetus and Phoenix.

Image and text © 1993-2010, Australian Astronomical Observatory, photograph by David Malin.

48 **A spiral galaxy in Antlia,** NGC 2997 Landscape 60 cm x 48 cm

Top left is NE. Image width is about 12 arc min.



NGC 2997 is a fine southern spiral galaxy seen from a distance of about 45 million light years and is inclined at about 45 degrees to our line of sight, revealing its internal structure and giving the galaxy an oval appearance. It is in Antlia (originally *Antlia Pneumatica*, the Air Pump), an unremarkable constellation invented by Lacaille in the 1750s. It is hemmed in by the meandering body of Hydra to the north and the sparkling constellations of the Milky Way to the south. Seen face-on, NGC 2997 would look rather like Cat.No.1. Like most spirals, the galaxy has two prominent spiral arms, which appear to originate in the yellow nucleus, and are peppered with bright red blobs of ionised hydrogen similar to regions of star formation in our own Milky Way. Within these gas clouds are produced the hot blue stars which generate most of the light in the arms of the galaxy. A much older population of yellowish stars are concentrated around the nucleus. The galaxy is much bigger than it appears.

Image and text © 1980-2010, Australian Astronomical Observatory, photograph by David Malin.

49 **Nebulosity in Sagittarius,** NGC 6589-90 Landscape 60 cm x 48 cm

Top left is NE. Image width is about 29 arc min.



Our view towards the centre of the Galaxy is obscured by extensive clouds of interstellar dust in the direction of the constellation of Sagittarius. The large-scale, patchy nature of the obscuration can be seen with the unaided eye. Light from bright stars within the dust produces the two blue reflection nebulae (NGC 6589 and 6590), and these stars are members of a loose open cluster of stars, NGC 6595 (Sharpless 37) at a distance of about 5,900 light years. A large, almost transparent cloud of hydrogen, mixed with traces of dust, glows with a characteristic magenta hue over most of the field of view. This is known as IC 1283, 1284 and 4700 and is likely at a similar distance to NCC 6595.

Image and text © 1994-2010, Australian Astronomical Observatory, photograph by David Malin.

50 **Dust cloud Barnard 86 and open cluster NGC 6520** Landscape 60 cm x 48 cm

Top left is NE. Image width is about 17 arc min.



The majority of old stars in our Galaxy, as in most others, appear yellowish on photographs. This is because the hotter, bright blue stars have relatively short but spectacular lives. We see these old stars in vast numbers as the brightest patches of the Milky Way and a powerful telescope like the AAT reveals them to be as numerous and crowded as grains of sand, especially in Sagittarius. Superimposed on this distant background in the photograph is a small cluster of young blue stars, NGC 6520. In the same region as the cluster is a dark cloud, Barnard 86. The cluster is at a distance of about 7000 light years and is probably associated with the dark cloud. The dust is visible only because it blocks out light from the myriads of stars beyond.

Image and text © 1980-2010, Australian Astronomical Observatory, photograph by David Malin.

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51 **The Toby Jug Nebula,** IC 2220

Landscape 60 cm x 48 cm
Top left is NE. Image width is about 8 arc min.



The bright, supergiant star at the centre of this nebula is in Carina, the Keel of Argo Navis, a giant mythical sailing vessel afloat on the southern Milky Way. It is known only by its catalogue designation, HD 65750. The nebulosity around the star is the result of light reflected by dust surrounding it. The dust is thought to consist mainly of particles of silica condensed from material which the star is losing from its distended surface at a fairly steady rate. The rate of mass loss is much higher than in normal stars and is sufficient to produce the reflection nebula IC 2220. The stellar nature of the central object is revealed by the four diffraction spikes extending from it. These are artefacts due to structures within the telescope. The light from the star has also produced the annular halation ring (a photographic artefact) that ornaments the nebula. These features, real or otherwise, have provoked the name 'Toby Jug' for this nebula, after the ornamental English drinking vessel or beer mug.

Image and text © 1980-2010, Australian Astronomical Observatory, photograph by David Malin.

52 **Around the compact nucleus of the Galactic pole,** NGC 300

Landscape 60 cm x 48 cm
Top left is NE. Image width is about 8.5 arc min.



At the centre of the spiral arms of NGC 300 is an unusually compact, star-like nucleus. It is surrounded by a faint but extensive yellow haze, consisting of millions of faint, cool stars. This is the older population, or 'bulge' of NGC 300, a distant equivalent to the (much more numerous) stars that we see in our own galaxy as the brightest part of the Milky Way in Sagittarius. This picture was made from the same set of three plates that were used for Cat.No.14 and shows that the inner parts of the galaxy contain many compact clusters of bright stars and their associated nebulae. The galaxy is in the constellation of Sculptor, which in turn is the direction of the Galactic pole, where we look out from the Milky Way at right angles to the Galactic centre. This is why the image contains very few bright Milky Way stars.

Image and text © 1991-2010, Australian Astronomical Observatory, photograph by David Malin.

53 **Coma Berenices** (Messier 100) NGC 4321

Landscape 60 cm x 48 cm
Top left is NE. Image width is about 22 arc min.



The Virgo cluster spills over into the adjoining constellation of Coma Berenices and is the nearest moderately rich cluster of galaxies. It contains examples of almost every known kind of galaxy and two quite different types are represented here. The dominant galaxy is the face-on spiral M100, one of the finest spirals in this diverse group. As might be expected in a galaxy-rich environment, the lack of perfect symmetry in its brightest spiral arms suggests that M100 has been disturbed by gravitational interaction with its neighbours. The somewhat distorted shape of the so-called 'nucleated dwarf' elliptical galaxy above M100 and the first colour picture of it, suggests it could be both influencing and being influenced by M100, and may be the cause of the asymmetry in the spiral arms. Dwarf galaxies are by far the commonest kind in rich clusters such as this, but nucleated examples are quite rare.

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54 **A cometary globule in Puppis, the stern of the Argo,** CG 4

Landscape 60 cm x 48 cm
Top left is NE. Image width is about 22 arc min.



Cometary globules are isolated, faint, relatively small clouds of gas and dust within the Milky Way, many of them in Puppis, the Stern of the Argo. Cometary globules were first recognised in 1976 and their faintness makes these objects particularly challenging objects for colour photography. This example is about 1300 light years distant, so the head is some 1.5 light years in diameter, and the tail, which fades away off the picture, appears to be about 8 light years long. The dusty cloud contains enough material to make several sun-sized stars. The head of the nebula is itself opaque, but glows because it is illuminated by light from very hot stars nearby, of the left of the photograph. Their energy is gradually destroying the dusty head of the globule, sweeping away tiny particles that scatter the starlight as a faint, bluish reflection nebula. This particular globule also shows a faint red glow, probably from excited hydrogen, and seems about to devour an edge-on spiral galaxy, which in reality is hundreds of millions of light years away, far beyond CG 4.

Image and text © 1991-2010, Australian Astronomical Observatory, photograph by David Malin.

## 55 A dark cloud in Scorpius

Landscape 60 cm x 48 cm

Top left is NE. Image width is about 32 arc min.



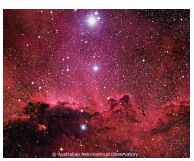
This curious collection of un-named bright and dark nebulae is similar to the cometary globule seen in Cat.No.54, but is much more massive. Its swept-back shape is moulded by radiation from very luminous stars (notably Scorpii zeta-1) in the open cluster NGC 6231, (Cat.No. 46), the Scorpius OB association of very hot, young stars. The cluster is over a degree to the SE and is not seen here. If the dark nebula pictured is at the same distance from the sun as NGC 6321 (about 6000 light years), the open cluster and the dark cloud it is eroding are at least 100 light years apart. The direction of the radiation source can be seen from the flow pattern in the dark cloud and the extensive bright red rims (emission nebulae) where the gassy dust is exposed to radiation from the hot stars in NGC 6231. This part of the nebula is reminiscent of the famous Horsehead nebula in Orion (Cat. No.21) which is also the consequence of starlight destroying a dark cloud. It even contains small blue reflection nebula, like NGC 2024 near the Horsehead (Cat. No. 34).

Image and text © 1991-2010, Australian Astronomical Observatory, photograph by David Malin.

## 56 Ara, the Altar,
NGC 6188 nebula and NGC 6193 (wide field)

Landscape 60 cm x 48 cm

Top left is NE. Image width is about 41 arc min.



The molecular cloud of dusty gas and starlight in Ara, the Altar, in the far southern sky mixes to produce vivid reds and gentle blues, set against a curtain of faint stars that are more distant than the dust. There is enough interest in this little-known region to justify a more detailed look and the two adjoining images, Cat.No.15 and Cat. No.22, show two quite different parts that appear together here in a field of view that is about three-quarters of the AAT's full prime focus field when used photographically. Ara was once considered part of Centaurus and Lupus but became separated when the 'modern' constellation Norma was created by Lacaille in the 1750s. It was recognised by the Greeks and Romans and was visualised as the altar on which the Centaur, Centaurus, was to sacrifice Lupus, the Wolf.

Image and text © 2000-2010, Australian Astronomical Observatory, photograph by David Malin.

## 57 The Toby Jug Nebula,
IC 2220, deep image

Landscape 60 cm x 48 cm

Top left is NE. Image width is about 9 arc min.



Many stars lose a substantial part of their mass as they age. The more massive the star, the greater the fraction of their substance is lost. Much material is ejected by intense stellar winds driven from the surface of extremely hot stars and the mass loss is often only detectable in the stellar spectrum. In cooler stars temperatures may be low enough for elements or simple compounds to form solid grains in the star's outer atmosphere. This is seen as dust, and sometimes there is enough to reflect the light of the star within. As is often the case with stellar outflows, the IC 2220 reflection nebula is bipolar, hinting at conditions near the surface of the central star. See also Cat.No.51.

Image and text © 1991-2010, Australian Astronomical Observatory, photograph by David Malin.

## 58 The Dumbell Nebula,
(Messier 27) NGC 6853

Landscape 60 cm x 48 cm

Top left is NE. Image width is about 13 arc min.



Discovered on July 12th 1764 while searching the skies above 18th century France for comets, astronomer Charles Messier diligently recorded this object as number 27 on his list of things which are definitely not comets: 'Nebula without star. Seen well in 3-foot telescope. Appears oval and contains no star.' Now classified as a Planetary Nebula, it is, however, not a planet, even though it appears round and planet-like in a small telescope. It is now known to be an excellent example of a gaseous emission nebula created as a sun-like star runs out of nuclear fuel in its core. The nebula forms as the star's outer layers are expelled into space, with a visible glow generated by atoms excited by the dying star's intense but invisible ultraviolet light. The beautifully symmetric interstellar gas cloud is about 1,200 light-years away in the constellation Vulpecula, Latin for 'little fox', or simply The Fox, created in the late 17th century by astronomer Johannes Hevelius and located in the middle of the Summer Triangle (an asterism consisting of the bright stars Deneb Adige, Vega and Altair).

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59 **The Veil Nebula in Cygnus the Swan,** IC 1340 Landscape 60 cm x 48 cm

Top left is NE. Image width is about 31 arc min.




The Milky Way galaxy contains many traces of ancient supernova explosions, not least of which are the heavy metals we find in the earth's crust. There are few directly visible supernova remnants but the Veil nebula in Cygnus, the Swan, is one of the finest. This image shows a small portion of the eastern side of what is a large, almost spherical glowing shell of gas, about 3 degrees across, the expanding remains of a star that exploded between 5,000 and 8,000 years ago. The nebula (and thus its precursor star) is about 1900 light years distant and about 100 light years across. It is the result of the shockwave from the explosion exciting the tenuous interstellar medium and making it glow.

Image and text © 1992-2002, Malin/IAC/RGO. Photograph from Isaac Newton Telescope plates by David Malin.

60 **The Lagoon Nebula in Sagittarius,** (Messier 8), NGC 6523 Landscape 60 cm x 48 cm

Top left is NE. Image width is about 72 arc min.




The irregular distribution of light in this beautiful part of the sky is due mainly to clouds of dust that dim the light of vast clouds of stars that make Sagittarius one of the brightest parts of the Milky Way. The Lagoon nebula is an illuminated part of such a dark ('molecular') cloud and it reveals the dust as dark lanes and globules silhouetted against the luminous gas. Within the nebula is the scattered young star cluster NGC 6530, recently formed from this material, though the centre of star-forming activity has now shifted westwards from the cluster to the brightest part of the nebula, around the tiny Hourglass Nebula (Cat.No.32). The Lagoon nebula is clearly visible to the unaided eye on southern winter nights, in a dark part of the Milky Way close to the great star clouds in Sagittarius.

Image and text © 1979-2010, Australian Astronomical Observatory. Photograph from UK Schmidt plates by David Malin.

61 **A globular cluster in Pavo, the Peacock,** NGC 6752 Portrait 60 cm x 48 cm

Top left is NE. Image width is about 16 arc min.

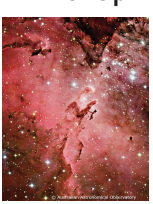



Globular clusters are among the oldest objects known. The stars within them seem to contain much less of the 'metals' found in other stars, and since the universe was almost completely metal-free in the beginning, containing only hydrogen and helium, it seems that globular cluster stars were among the first stellar objects to form. However, it is certain these beautiful, compact cities of stars did not look like this in their youth, when they would have been much brighter, their light dominated by hot massive stars that have vanished. This particular globular cluster is in the deep southern sky in Pavo at a distance of about 14,000 light years. It is just visible to the unaided eye in a particularly obscuration-free part of the sky, so, despite its distance we see the colours almost unaffected by interstellar dust. The colours of the stars are subtle but this picture clearly shows the cool but bright red giant stars whose light dominates the cluster. Pavo, the Peacock, lies south of Sagittarius and Corona Australis, and is one of Johann Bayer's twelve constellations, introduced in 1603. It is one of several birds in the southern sky. Hera, goddess of the heavens, ordered a 100-eyed giant, Argos Panoptes, to keep his eyes on her errant husband, Zeus. When Zeus slayed Argos, Hera transformed the 100 eyes into the Peacock's tail. They are also meant to represent the starry sky.

Image and text © 1987-2010, Australian Astronomical Observatory, photograph by David Malin.

62 **The dust lanes of Serpens, the Serpent of Ophiucius,** (Messier 16), NGC 6611 Landscape 60 cm x 48 cm

Top left is NE. Image width is about 11.5 arc min.




There are few clearer examples anywhere of the intimate relationship between dust, gas and young stars than M16 in Serpens. We see a young cluster of stars (NGC 6611) which formed about 2 million years ago, illuminating a cloud of hydrogen gas. The gas is also dusty, and in places the dust is dense enough to prevent starlight from reaching the gas, making it glow with its distinctive red hue. The luminous hydrogen provides a vivid background against which are seen numerous dark lanes and discrete globules of dust. Many of the dusty clouds are edged with bright rims which indicate the direction of the exciting stars and point to the cluster as the energising source. Serpens the Serpent of Ophiuchus, the serpent holder, is an ancient constellation and is unique as it is formed from two separate sections, Serpens Caput (the head of the snake) to the west and Serpens Cauda (the tail) to the east.

Image and text © 1986-2010, Australian Astronomical Observatory, photograph by David Malin.

63 **The spiral galaxy in Leo the Lion** (Messier 66), NGC 3627

Portrait 60 cm x 48 cm
Top left is NE. Image width is about 10 arc min.



M66 in the constellation Leo the Lion is a dusty spiral galaxy, and is a member of the same compact group of galaxies as M65 and NGC 3628. The striking symmetry of M65 is lacking, and the central bulge, though large, is less well defined. The spiral arms are very easy to see, but seem distorted and displaced above the plane of the galaxy, probably a result of interactions with its neighbours. Much more dust is visible here as well as a few pink nebulae, signs of star formation, near the end of one of the arms. Leo the Lion was the creature whose skin was so impenetrable that the only way Hercules could kill it as the first of his 12 labours was to wrap his arms around it and crush it. The constellation is of great antiquity; Pliny wrote that the ancient Egyptians worshiped these stars, and that the lion also represented in the Sphinx.

Image and text © 1989-2010, Australian Astronomical Observatory, photograph by David Malin.

64 **The Tarantula nebula around 30 Doradus in the Large Magellanic Cloud**, NGC 2070

Portrait 60 cm x 48 cm
Top left is NE. Image width is about 4 arc min.



The brightest cluster of stars in this picture was believed until recently to contain a single, uniquely massive object with the mass equivalent to 1000 suns, and was named as a star, 30 Doradus. Sophisticated image analysis techniques have been used to show that this is a very compact group of stars, many of which are massive, but not unimaginably so. The radiation from this star cluster is sufficient to excite a huge cloud of hydrogen gas in its vicinity so that it glows with its distinctive red colour. This picture is essentially a one minute exposure. A longer exposure would show that the curving tendrils of nebulosity are the brightest parts of the huge Tarantula nebula, one of the largest star-forming regions known anywhere. It is in the Large Magellanic Cloud, the nearest galaxy to the Milky Way, in the constellation of Dorado, the Goldfish or Swordfish (Xiphias), a constellation introduced by Johann Bayer, best known for his 1603 star atlas *Uranometria*, which was the first to cover the entire sky. Image and text © 1991-2010, Australian Astronomical Observatory, photograph by David Malin.

65 **The Corona Australis nebula,** NGC 6726-27-29

Portrait 60 cm x 48 cm
Top left is NE. Image width is about 23 arc min.



This spectacular reflection nebula lies in Corona Australis (the Southern Crown), recognised by Ptolemy and adjacent to Sagittarius the Archer. One legend suggests it represents the coronet worn by Sagittarius. The nebula is the result of a few bright stars caught up in a large, dusty cloud. If that is all there was here, this region would be considered to be like the Pleiades(Cat.No.23), an accidental association of dust and stars. However, there are features here that show the dark cloud to be an active star forming nebula, though most of the action is hidden from view. The peculiar yellowish curved streak near the two bright reflection nebulae surrounds an intriguing object best seen in infrared light. It is R CrA, a young star still accreting interstellar material on to its surface. It seems to be the source of two compact but distinctly red patches, roughly equidistant from the yellow curlicue. These are are Herbig-Haro objects, often the first visible signs of star formation occurring deep inside dark clouds. These compact nebulae are ejected from proto-stars during the later stages of star formation and sometimes appear in pairs, moving in opposite directions from the hidden star-forming region. The R CrA complex is about 500 light years distant, one of the nearest star-forming regions. The two bright blue nebulae are reflections of the light from embedded stars, not hot enough to excite an emission nebula, which would be red, but bright enough so that a small amount of light is scattered by surrounding dust grains. The grains are minute, more like smoke than dust. The star in the southernmost nebula (IC 4812) shows two distinct diffraction spikes, artefacts of the optical system used to photograph it. This implies that there are two stars here, and this is a the well known double star BrsO 14, discovered and catalogued at Governor Brisbane's observatory in Parramatta, near Sydney, in the 1820s. The brighter reflection nebula also contains a widely spaced pair of double stars.

Image and text © 1991-2010, Australian Astronomical Observatory, photograph by David Malin.

## 66 **The diffuse planetary nebula in Eridanus the River,** NGC 1360

Portrait 60 cm x 48 cm
Top left is NE. Image width is about 11 arc min.



Planetary nebula mark the demise of sun-like stars, many of which have been burning for thousands of millions of years. Although the nebulae themselves last only a few tens of thousands of year, a brief moment on the cosmic time-scale, planetary nebulae are plentiful because sun-like stars are numerous. The astonishing variety of forms is partly the result of the random orientation of (mostly) hollow shapes in the sky. These shapes are themselves complex and represent a range of ways a star can eject its outer layers. Most planetary nebulae show a distinctive and well marked symmetry and have well-defined boundaries. For reasons that are not understood, NGC 1360 in Fornax, in the southern part of Eridanus the River, defies all these conventions, yet its colour still clearly identifies it as a planetary nebula. The green hue is oxygen, excited by the hot central star, and to the north-east of the nebula is a faint red smudge, probably traces of material ejected before the star became a true planetary nebula.

Image and text © 1993-2010, Australian Astronomical Observatory, photograph by David Malin.

## 67 **A barred spiral galaxy in Volans the Flying Fish,** NGC 2442

Portrait 60 cm x 48 cm
Top left is NE. Image width is about 9 arc min.



This unusual barred spiral galaxy is in the far southern constellation of Volans and was discovered by Sir John Herschel who described one of its spiral arms as hook-like. Volans was introduced by Johann Bayer in 1603 as Piscis Volans, the Flying Fish and in old star atlases is seen flying alongside the ancient sailing ship Argo Navis. However, the fish has flown and only the adjective Volans (flying) remains. The stars form a distinctive pattern but at magnitudes between 3.7 and 4.0 they are not bright. Although not seen here, (but evident on very deep images) NGC 2442 appears to have a less massive, distant companion that is also distorted, and it seems likely that the two have had a close encounter in the recent past. If there are no further meetings, the forces that hold NGC 2442 together will restore the galaxy to a more symmetrical spiral form. However, much more likely is that the companion has been captured by the distorted spiral and will eventually be devoured by it, triggering a dramatic bout of star formation. NGC 2442 is about 50 million light years distant.

Image and text © 1995-2010, Australian Astronomical Observatory, photograph by David Malin.

## 68 **Cygnus the Swan and a group of reflection nebulae,** NGC 6914

Portrait 60 cm x 48 cm
Top left is NE. Image width is about 26 arc min.




A dramatic study in contrasts, this colorful skyscape features stars, dust, and glowing gas in NGC 6914. The complex of nebulae lies some 6,000 light-years away, toward the high-flying northern constellation Cygnus the Swan and the plane of our Milky Way Galaxy. With foreground dust clouds in silhouette, both reddish hydrogen emission nebulae and dusty blue reflection nebulae fill the 1/2 degree wide field. The view spans nearly 50 light-years at the estimated distance of NGC 6914. Ultraviolet radiation from the massive, hot, young stars of the extensive Cygnus OB2 association ionize the region's atomic hydrogen gas, producing the characteristic red glow as protons and electrons recombine. Embedded Cygnus OB2 stars also provide the blue starlight strongly reflected by the dusty clouds.

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## 69 **The Horsehead and Orion nebulae,** NGC 2024 and IC 434

Portrait 60 cm x 48 cm
Top left is NE. Image width is about 2.2 arc min.



This wide-angle picture of the Orion region has been made to reveal the extensive network of very faint filaments which are traceable over most of the constellation. These faint features are optical evidence of a substantial dark cloud of molecular gas and dust which are detectable at radio wavelengths. Where hot stars are closely associated with the molecular cloud such as this, a bright nebula appears. By far the most conspicuous of these is the Orion Nebula, M42. This spectacular object is so bright that its light is reflected from filaments of the dark cloud some distance away. In contrast, the wisps of the Horsehead Nebula are much fainter but even here faint tendrils of nebulosity show that the nebula is much more extensive than is generally realised. All these objects are about 1350 light years distant.

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