New Scientist

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WHAT DOES SPACE LOOK LIKE?

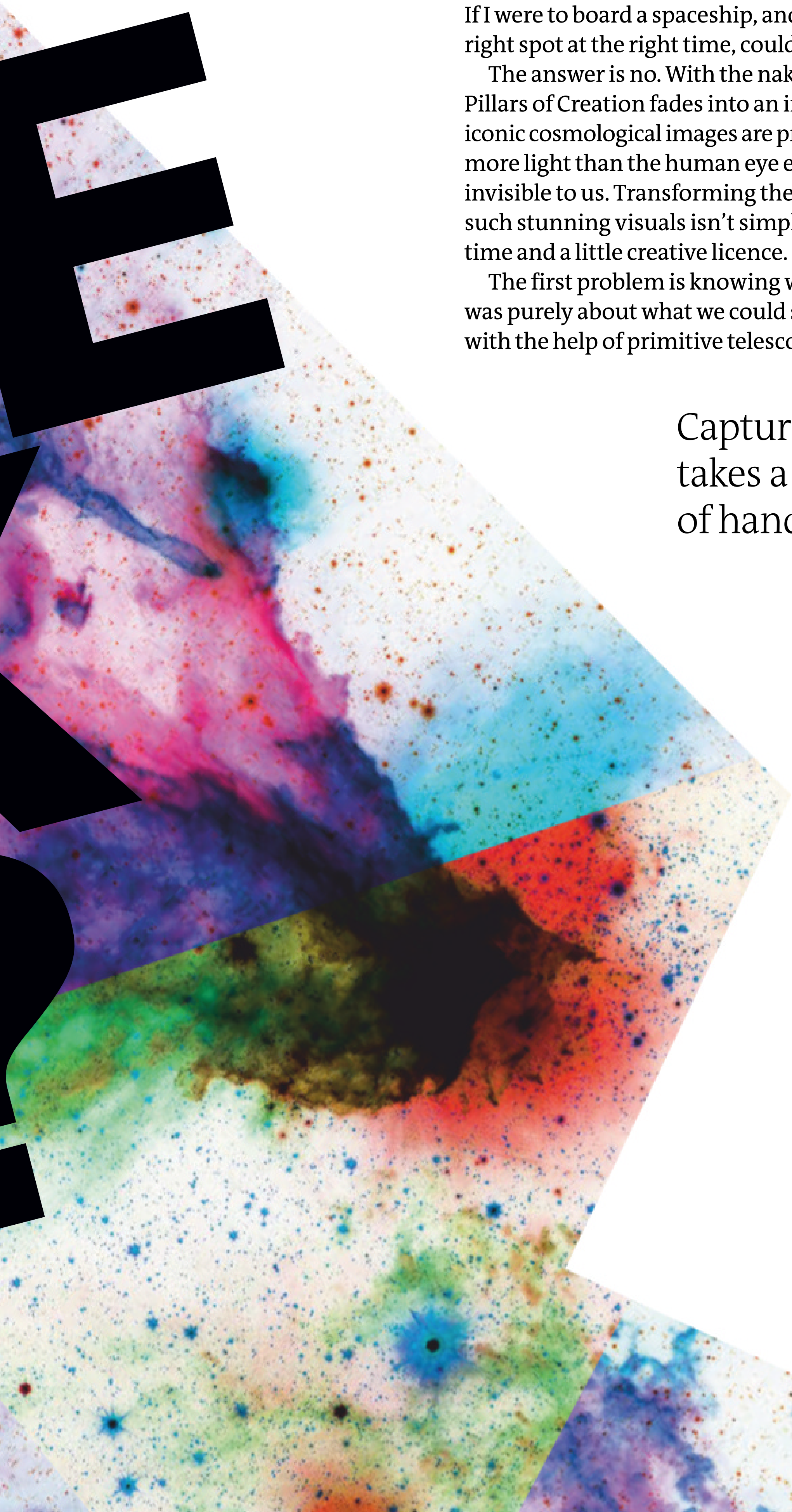
Capturing the beauty of the cosmos takes a little photographic sleight of hand, reveals **Leah Crane**

LIKE the crumbling turrets of a fairy-tale castle, three spires emerge from a greenish haze, their tops spraying out blue streamers of light. Bright stars shine through the gaseous crenellations, outlines framed in stark yellow. The image in which they feature may seem like a work of pure fantasy, but this misty fortress is very real. It is an area of the Eagle Nebula called the Pillars of Creation, a massive stellar nursery 4 light years across and 7000 light years away.

It is a photograph that shows us hundreds of stars being born from clouds of dust and gas produced in the final explosions of a previous stellar generation. It certainly puts our own puny solar system into perspective. Small wonder, then, that today you can find it adorning everything from shower curtains to phone cases, astronomy's equivalent of Van Gogh's *Sunflowers*. But it prompts a vexing question. If I were to board a spaceship, and travel for long enough to be at the right spot at the right time, could I see its beauty with my own eyes?

The answer is no. With the naked eye, the technicolour majesty of the Pillars of Creation fades into an indistinct red blur. Many of our most iconic cosmological images are produced by telescopes that can capture more light than the human eye ever could, and at wavelengths that are invisible to us. Transforming the hidden wonders of the night sky into such stunning visuals isn't simple. It takes a lot of technology, a lot of time and a little creative licence.

The first problem is knowing where to look. For millennia, astronomy was purely about what we could see. First with the naked eye and then with the help of primitive telescopes, astronomers observed moons, spotted planets and catalogued stars. These distant objects gave off light, and we were able to pick out these tiny pinpricks in the darkness. Then, in the early 20th century, we realised the darkness wasn't actually dark at all. It was awash with light, only in forms we couldn't see.



We now know that astronomical objects give off light with a vast range of wavelengths spanning the electromagnetic spectrum. Black holes burn with gamma rays, whose wavelengths are billionths of a millimetre long, while stars give off microwave radiation, whose wavelengths can stretch up to a metre. Almost of all this richness is hidden from us. Our limited eyes can see wavelengths of between about 380 and 740 nanometres, a pitifully narrow window onto the cosmos.

It isn't only our natural insensitivity to the wider spectrum that holds us back. Much of what happens in the universe takes place on timescales or at distances that eyes could never deal with, or behind clouds that visible light can't penetrate. With the help of telescopes that extend our vision deep through time and space and across many different kinds of light, we have made the invisible visible (see diagram, page 36).

The instrument that transformed how this was done was the Hubble Space Telescope. If you have ever gazed slack-jawed at a picture of deep space, chances are it was taken by Hubble. Launched in April 1990, it was perhaps the most transformative instrument astronomy had seen.

Thirty years later, it is still there. About the size of a lorry, it orbits some 540 kilometres from Earth. Four main cameras take images in ultraviolet, visible and near-infrared wavelengths, allowing us to peer at objects billions of light years away in previously unimaginable ›

> “AT THE BEGINNING, EVERY SINGLE PICTURE WE TOOK WITH HUBBLE WAS THE CLEAREST VIEW HUMANITY HAD SEEN OF THAT OBJECT TO DATE”

detail. “At the beginning, every single picture we took with Hubble was the clearest view humanity had seen of that object to date,” says Paul Scowen at Arizona State University. “So every time we took a picture with Hubble, it was jaw-dropping.”

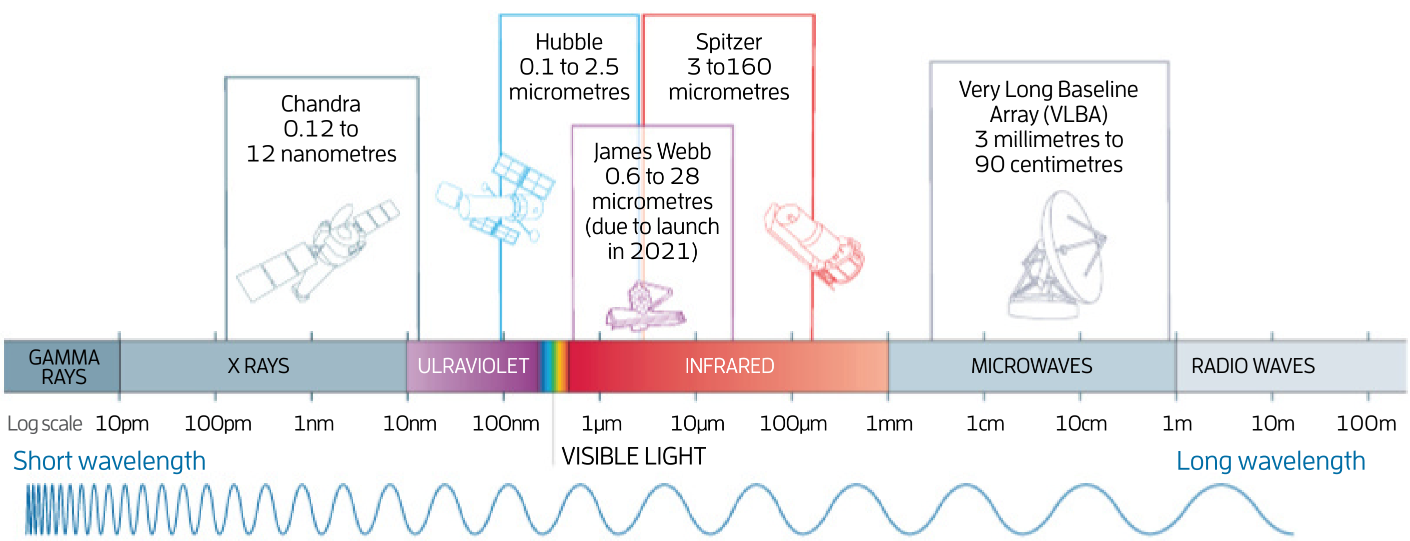
Many of its images are justly iconic – like those inset on these pages. But taking beautiful pictures was never Hubble’s core remit. Most of its images were captured to answer scientific questions. The original Pillars of Creation image, for example, was taken in 1995 to examine how newborn stars interact with their hazy environment. “The colour picture is a nice afterthought, but the science is really done on the statistics and the photon counts and intensities from the actual data,” says Lisa Frattare, who processed Hubble images for 20 years.

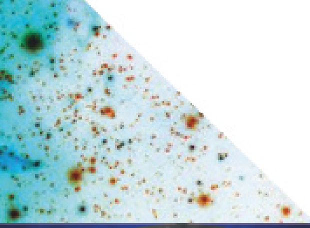
For one thing, all its pictures start in black and white, regardless of what colours a human eye might be able to see in the object itself. “Hubble’s cameras are black and white detectors,” says Zolt Levay, who developed some of the first programs to translate Hubble data into images while at the US Space Telescope Science Institute in Baltimore, Maryland, which manages Hubble. That isn’t an aesthetic choice. “Producing [...] colour in the detector actually increases the noise and lowers the resolution,” he says.

Astronomers can choose what filters they want to be placed in front of Hubble’s detectors before they take their images. These act like

Seeing the invisible

The ability of telescopes to see light from across the electromagnetic spectrum enables them to expand our horizons





This iconic image of the Eagle Nebula was taken by the Hubble Space Telescope 20 years after first capturing it in 1995. The three visible structures are known as the Pillars of Creation, showing dust accumulating into stars 7000 light years away. Molecules of hydrogen, oxygen and sulphur are present, all of which can emit distinct wavelengths of light.

The three smaller images show the emission at three of these distinct wavelengths. It was these that Hubble actually captured, but only in black and white. To form the dramatic main picture, each of these monochrome scenes was assigned a colour to match their relative positions on the electromagnetic spectrum and then combined.

The top one shows only the light emitted by an ionised form of oxygen at a wavelength of about 502 nanometres. Because this is the shortest wavelength of the three, it was coloured blue. The middle picture shows emission from hydrogen and nitrogen atoms at a wavelength of about 657 nanometres – it was coloured green. The bottom of the three small images shows light from an ionised form of sulphur at about 673 nanometres. Being the longest of the wavelengths, this was assigned the colour red.

With the naked eye, you wouldn't see anything like the final picture. Instead, it would appear a much less interesting blurry red. That is because two of the three main wavelengths of light that it emits fall in the red part of the spectrum.

EAGLE NEBULA

NASA, ESA/HUBBLE AND THE HUBBLE HERITAGE TEAM

stained glass, allowing only certain colours of light through. Sometimes they are fairly broad, allowing all red, green or blue light in. At other times, they are very specific, letting small sections of the spectrum pass, so that only light emitted by particular elements gets through.

Which filters you use depends on what you're trying to learn about the object. For example, if looking for young, hot stars, you might want to use a filter that captures their distinctive blue light. Or, if you want to see clouds of hydrogen gas, you would use a very narrow-band filter that lets through only the particular red wavelength of the light they emit.

That means that the people processing the image from the raw data don't usually have any choice as to what filters have been used. "Those filters don't necessarily correspond to what the colours would look like to our eye," says Levay. Because the human eye combines all the colours, we never see light one wavelength at a time. And because Hubble can see colours we can't, it might take images in a range of ultraviolet wavelengths that would be invisible to our eyes.

Generally, though, regardless of the filters, the people doing image processing use the same mapping that our eyes and brains do: visible light with the highest wavelength is red, green is in the middle and blue has the shortest wavelength. As an RGB computer screen shows, superposing images in those three colours is enough to produce any shade. That is why, after the output from each filter is coloured red, green or blue, combining them can produce a dazzling final image.

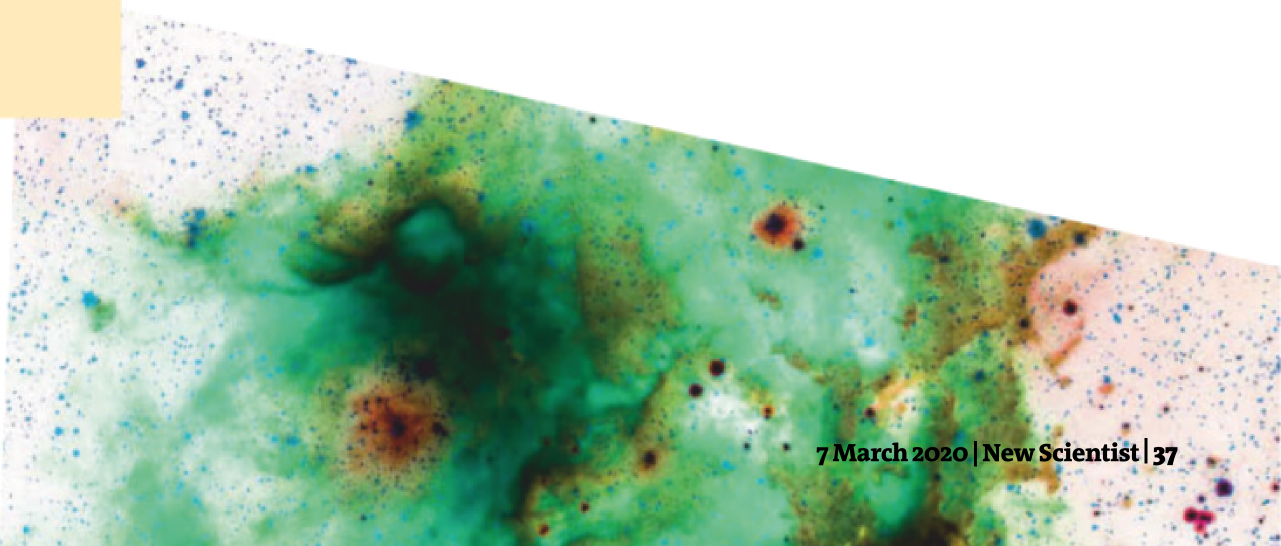
"There's this misconception that we're making things up, or we're just 'photoshopping' the image and creating data where there isn't data and assigning colours however we want to," says Joseph DePasquale, senior science visuals developer at the Space Telescope Science Institute. "But almost always, the longest wavelengths in the image are coloured red and the shortest are coloured blue. Those colours have a physical meaning."

That makes processed images easier to interpret: the areas emitting high-energy light are bluer, both in nature and in the picture. For example, in images of galaxies, star-forming regions tend to be shown in blue, whereas dusty areas are more reddish.

"You can think about a weather map on the nightly news – there's a red temperature for the hotter temperatures and blue for the cooler temperatures, and the viewer will get an immediate snapshot of what's going on," says astronomer Kim Kowal Arcand, who makes images with data from NASA's Chandra X-ray Observatory, another space telescope. "We're trying to recreate some of that with astronomical data."

In order for that cosmic weather map to mean anything, the colours have to be well separated – a temperature map where everything is in similar shades of orange doesn't convey a lot. Sometimes that means that using the light's true colour just doesn't work.

The Pillars of Creation, for example, contain molecules of hydrogen, oxygen, nitrogen and sulphur, all emitting light in the visible part of the spectrum. But these wavelengths, while distinct, are too close together for our eyes to tell apart. "If you make a colour composite image ›



where you stick to what colour those things actually are, you get a muddy image that's mostly red," says DePasquale. "But if you take that image and change the colours a little bit you get a really beautiful image, and it also reveals a lot of information that you lose if you colour it according to the actual wavelengths."

In the pillars image, blue was assigned to oxygen, red to sulphur and green to hydrogen and nitrogen. That allows the viewer to understand the scale and depth of the towering clouds of gas and dust while drawing out scientifically interesting features that might not otherwise be visible. For example, the way that high-energy light hitting the clouds causes delicate streams of gas to evaporate at the top of the pillars.

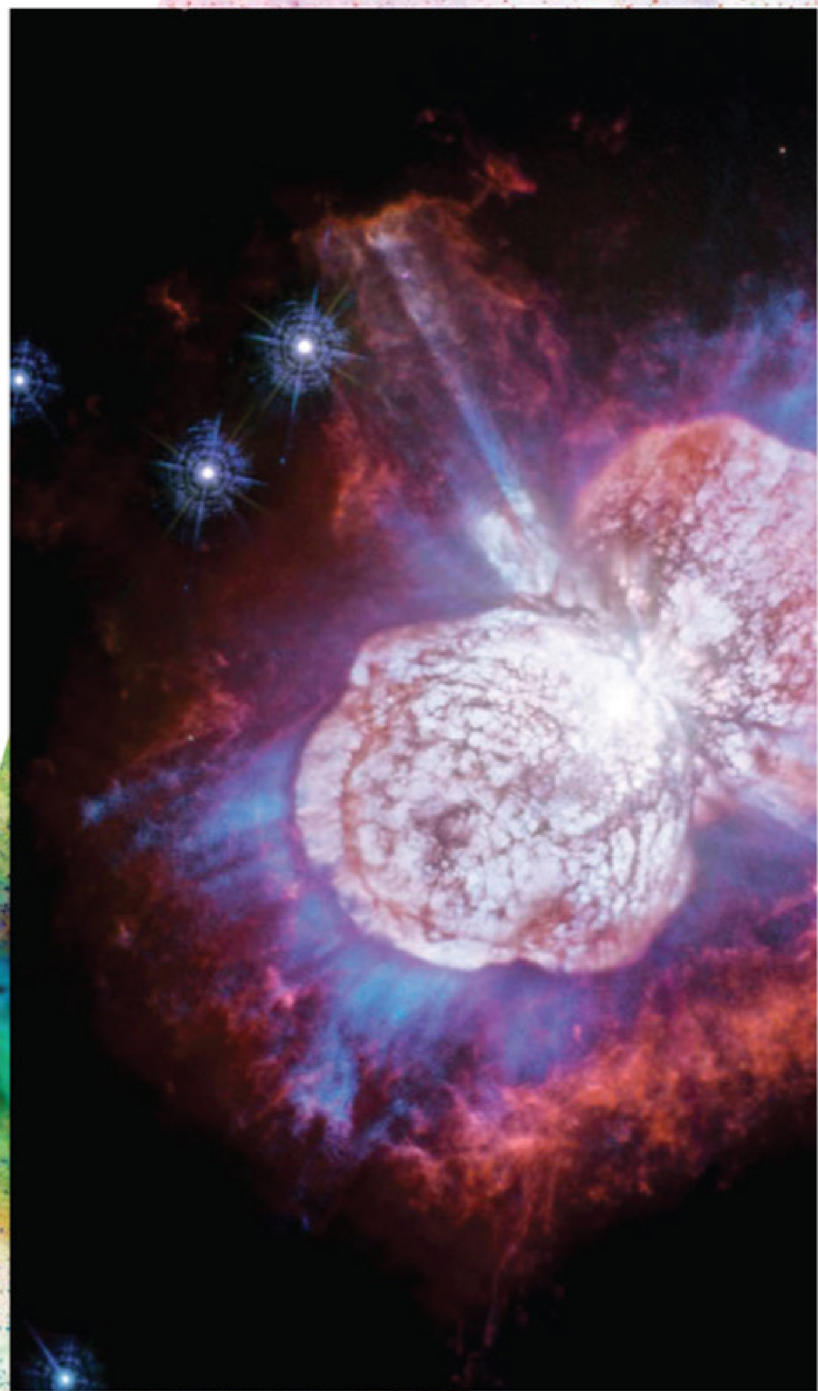
Most of the time, colour decisions are made for the sake of science and clarity. Sometimes, though, tweaks have to be made in the name of aesthetics too. "We're trying to straddle the line and make something that's pleasing and still totally scientifically accurate," says Arcand.

She cites the example of an image of the area surrounding a black hole as it devoured the dust and gas around it. The image only had a single filter, so her team presented two versions to a focus group: one in blue, and one in red. Before they knew what the image depicted, the group liked each image equally, but once they knew that it was hot material falling into a black hole the vast majority preferred the red one – in everyday life, red means hot, so the subject of the image was more intuitive. "There are already connotations of what colour means here on Earth, so we try to keep those in mind," Arcand says.

The Event Horizon Telescope (EHT) team used a similar tenet when putting together the famous image of the black hole at the centre of the galaxy M87, the first ever direct image of a black hole's shadow. "There is nothing in our data that has to do with colour," says Michael Johnson at the Harvard-Smithsonian Center for Astrophysics in Massachusetts, who coordinated the EHT's imaging efforts. "All that we do measure is how much light is coming from each part of the image."

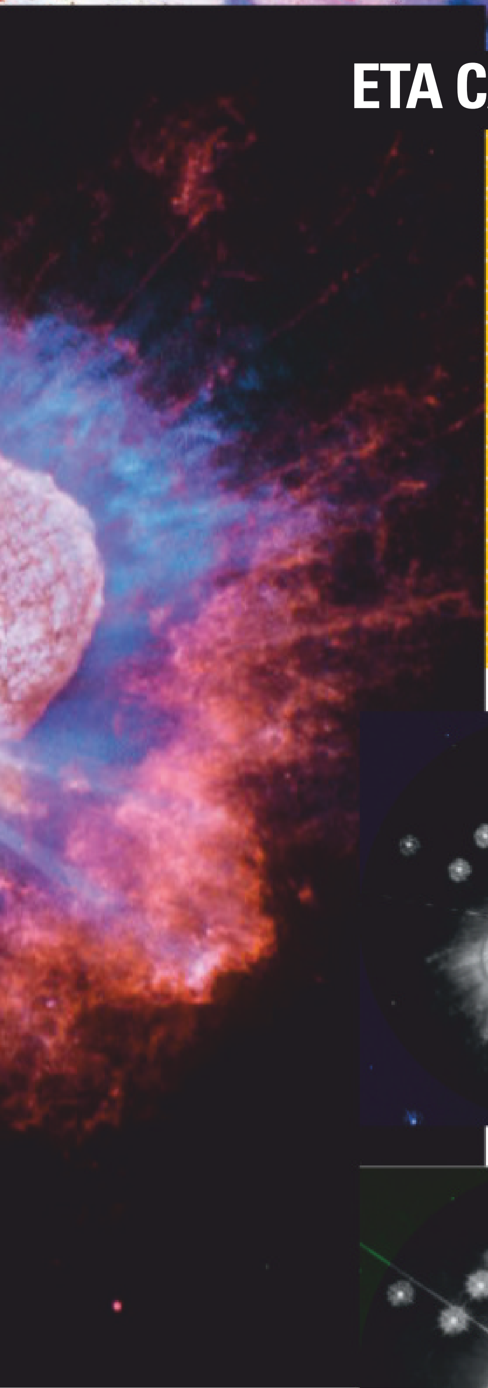
The image could have been green and purple instead of orange, but that version was confusing and unpleasant to look at, Johnson says. "It is kind of jarring to pick colour schemes that don't correspond to intuitive notions of heat." When straying away from a simple red-green-blue colour scheme, the most important

NASA, ESA, N. SMITH (UNIVERSITY OF ARIZONA) AND J. MORSE (BOLDLYGO INSTITUTE)



"FOR A LOT OF THESE OBJECTS, EVEN IF YOU WERE IN A SPACESHIP GOING BY THEM, YOU JUST COULDN'T SEE THEM BECAUSE THEY'RE IMPOSSIBLY DIM OR THEY ONLY EMIT IN THE INFRARED"

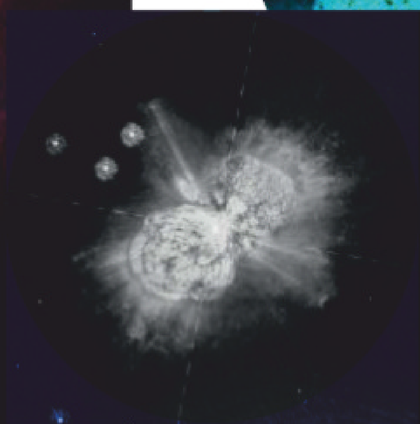
ETA CARINAE

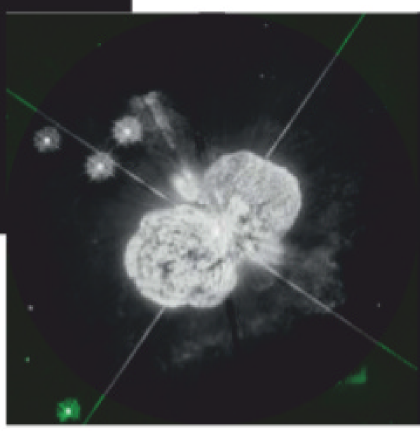


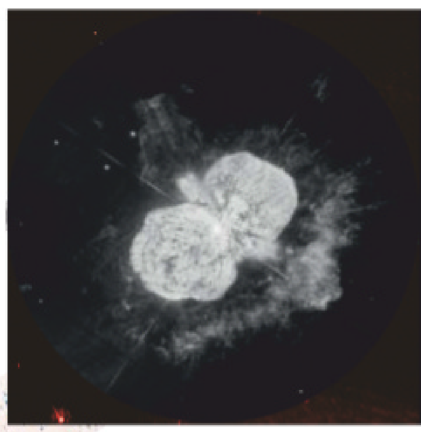
Eta Carinae, shown here in a picture from the Hubble Space Telescope, is one of the biggest stars in our galaxy. In the 1840s, it was seen erupting, blasting out what we now know are two enormous lobes of hot gas and dust. Even now, nearly two centuries later, there is still a lot of energy bouncing around, so Hubble used filters chosen for their ability to catch higher-energy ultraviolet light.

The three smaller images below the main one show the different wavelengths of light that Hubble collected. To create the main image, these were allotted visible colours and combined. The top one used a filter to capture light from a form of magnesium emitted at a wavelength of about 280 nanometres. For image processing purposes this was coloured blue. In the middle is a filter that allowed in a wider range of ultraviolet light with slightly higher wavelengths, which was coloured green for the combined final image. At the bottom is light from nitrogen at about 658 nanometres. This was given a red tinge.

Combining these for the dramatic final image produces a picture that allows our eyes to see what would be invisible – warm magnesium gas between Eta Carinae's bright bubbles of material and the filaments of nitrogen that surrounds them.


BLUE CHANNEL


GREEN CHANNEL


RED CHANNEL

thing is to make sure the viewers can still tell what's going on.

After all, that is the beauty of the enormous observatories used for this type of work: they show us things in the cosmos that we could never otherwise see. "For a lot of these objects, even if you were in a spaceship going by them, you just couldn't see them because they're impossibly dim or they only emit in the infrared," says amateur image processor Judy Schmidt. "It's not fake, it's absolutely real, but your eyes can't see it."

That's especially true for pictures that incorporate data from beyond the visible spectrum of light. Many of the famous space images you might see today combine shots from Hubble and other orbiting observatories like Chandra or Spitzer. These cram as much data as possible into a single image, adding up X-ray or infrared light that we would never otherwise be able to see, or providing extra information about colour that can't be captured in a single frame.

"If you flew to the Crab Nebula and looked at it with your human eyes, it would never look as good as it does through Hubble or the other great observatories," says Arcand. "Our eyes are kind of sad and puny – our imagination and technological inventiveness go far beyond what our eyes can do."

That is true in terms of filters applied to the whole image, but also on a smaller scale. Sometimes, bringing an image to its full potential means making certain areas of the picture brighter or darker – dodging and burning, as darkroom photographers call these processes.

"By doing those local adjustments, we're actually making information visible in the data that's not otherwise visible," says Levay. "To my mind, it's a more honest representation of the data." For example, in an image of a spiral galaxy, the centre is often far brighter than the arms, so it needs to be darkened in order to show details of both in the same image.

Almost all images get some level of manipulation simply because of the mechanics of the telescope. "The universe speaks to you in whispers, but there are also these loud bits that you don't want," says Schmidt. Those bits can be cosmic rays or other charged particles, which hit the telescope's detectors and fill them with unwanted light, or satellites flying between a telescope and the target object, and they are edited out so they don't distract from the actual science.

All these adjustments turn the zeroes and ones that come down from the space telescopes into images that are legible not just to scientists and computer programs, but to anyone who looks at them. "If you think of it as a language that you can't understand, we translate it into something that we can understand and see," says DePasquale.

"I think of all this as a kind of nature photography," says Levay. "Why is it important to do this stuff? Because it shows us what the universe is." ∎

Leah Crane is a space reporter at *New Scientist*. She tweets @downhereonearth