# A History of the Universe in 100 Stars

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Quercus

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# Foreword

## A History of the Universe in 100 Stars

Are a hundred stars enough for a history of the entire universe? No: the cosmos is far larger than we can possibly imagine, and contains an equally unimaginable number of stars. Their true number is the subject of one of the hundred stories in this book, which, taken together, tell just one of many possible stories about the universe.

This book is not a mere inventory of the cosmos. Of course, you'll find out everything about the stars, galaxies, planets and all the other celestial bodies and phenomena you may encounter in the universe. You'll meet stars that tell of galactic collisions and reveal how black holes work; stars orbited by planets stranger than anything science fiction has to offer. Some stars allow us a glimpse of the beginning of the universe, others reveal what its future holds.

But a history of the universe is always also a history of mankind. Ever since we appeared on the scene, the universe has exerted a never-ending fascination on us. The stars have influenced our culture and our thinking, and have made us what we are today – which is why the scientists who have expanded our knowledge of the universe matter, too. The stars in this book tell stories about famous people such as Isaac Newton and Albert Einstein, as well as about people you may not have heard of before: Dorrit Hoffleit, who first counted them; Henrietta Swan Leavitt, thanks to whom we know how big the universe is; Amina Helmi and her research into galactic fossils; Cecilia Payne, who discovered what stars are made of; Georg von Peuerbach, who paved the way for the heliocentric world view; and James Bradley, who proved once and for all that the Earth revolves around the Sun. They, and the many others who show up in this book, have enabled us not only to admire the night sky, but also to understand it.

By the light of the stars, we can see how everything started 13.8 billion years ago, and how the Sun and the planet on which we live came into being. Their light has inspired us to invent myths and tell stories, spurred us to perform great technological feats and encouraged us to think deeply about what makes us who we are. Nowadays, it compels us to wonder whether we're alone in the universe and what our cosmic future might look like.

The hundred stars I have chosen for this book have little in common. Some are bright, and have for thousands of years been part of the stories we tell ourselves about the heavens. Some shine so feebly that we can only discern them with the help of immense telescopes. Some have famous names, others merely bear catalogue designations consisting of lots of digits and letters. There are large stars, small stars, nearby stars, remote stars. Some of the stories are about stars that haven't formed yet, others about ones that are long gone.

The stars are as variegated as the universe itself; each has its very own story to tell, and collectively they have shaped the history of the whole world. And that's exactly how this book works. You can open it at any chapter you like and immerse yourself in a partial story of the universe – each chapter has been conceived such that it can be read independently of the others. Or you can start at the beginning and read through to the end, and with each story delve deeper into the secrets of the universe.

The history of the universe is too complex to be encompassed by a single person in a single book. But the version told here with the help of the chosen hundred stars is one of the greatest stories ever told about the universe. It's the story of all those people who, over the course of millennia, have tried to understand the world in which they live – and the story of the fascinating discoveries made along the way.

Enjoy your journey through the cosmos.

# 1

## Hikoboshi

### The Cowherd and the Heavenly Weaver Girl

It's hard to miss the brightest star in the Aquila constellation. Just sixteen light years from Earth, it is eleven times brighter than the Sun and the twelfth brightest star in our night sky. Its official name is Altair, which, like so many other stars' names, comes from Arabic.

During the eighth and ninth centuries, Arab astronomers expanded on ancient Greek knowledge and published translations of the classical texts. When medieval European scholars translated these Arabic works in turn, they also adopted their designations for the stars. Thus *al-nesr al-tā'ir* ('the flying eagle') became the star we know as Altair today. Nearly every bright star in the sky has a name that stems from Arabic, including Ras Algethi, Algol, Dschubba, Fomalhaut, Mizar, Zubenelgenubi and many others. A handful bear Latin appellations, such as Polaris, Regulus and Capella. But even if Western culture very much rests on the foundations of Graeco-Roman antiquity and its Arab reception, we mustn't forget that the sky has been studied at all times by all people.

Every culture thus has its own name for the stars, and tells its own stories. In Japan, for example, Altair is known as Hikoboshi, and every year on 7 July a celebration is held in its honour. Or rather, in honour of Hikoboshi and Orihime – the cowherd and the weaver girl. Their story harks back to a 2,600-year-old Chinese folk tale: Orihime, daughter of Tentei, god of the sky, spends her days weaving garments for the gods. To provide his daughter with a little distraction, Tentei arranges her engagement to the cowherd Hikoboshi; but, like other young people in love, they consequently forget all about their work: the cows are running around unsupervised and the gods are waiting in vain for the cloth for their new robes. Tentei is forced to intervene and separate the lovers. He sends them into exile on opposite banks of the Amanogawa, the great heavenly river; yet there, too, their work remains undone, because Orihime and Hikoboshi are far too unhappy to concentrate on their duties. They are therefore granted permission to meet once a year, on the seventh day of the seventh month. However, when the time comes for their first visit, they find that there is no bridge across the heavenly river. Orihime cries so bitterly that a large flock of magpies takes pity on her and forms a bridge across the Amanogawa with its wings; they promise the couple that they will from now on do this for them every year on the seventh day of the seventh month – as long as there's no rain to make the heavenly river swell too much.

This sad love story and its happy ending are displayed in the sky to this day. Hikoboshi is, as I've said, the star Altair, and the heavenly weaver girl Orihime is represented by the bright star Vega; and just like in the tale, you can see the Milky Way – the heavenly river Amanogawa – stretch out between them. If you look very carefully, you can even make out the kind-hearted magpies: the region of the Milky Way visible between Vega and Altair is partly filled with large interstellar dust clouds stretching in a dark band across the 'heavenly river'.

You can see Orihime and Hikoboshi high up in the sky in the summer, and particularly clearly at precisely the time that Japan celebrates the Tanabata. On that day, people commemorate the story of the cowherd and the weaver girl by erecting bamboo trees, to which they attach little pieces of paper containing their most ardent wishes.

The stars have inspired stories since long before we knew what they were all about. The sky is full of them, and we mustn't forget a single one: for, just as the stars tell us about the universe, the stories we tell about them reveal to us something of ourselves.

# 2

## 2MASS J18082002-5104378 B

### Catching Sight of the Big Bang

The star 2MASS J18082002-5104378 B is much more exciting than its rather unwieldy designation suggests. It's a small red dwarf just under 2,000 light years from Earth, and allows us a brief glimpse of the beginning of the universe.

When the universe emerged 13.8 billion years ago, there was only nothingness. Or not quite: everything was potentially there, but not in its current form. Today, the universe is full of complicated things made from matter: large, hot spheres of gas orbited by smaller, cooler spheres, on which in turn (in one instance at least) even smaller beings have made themselves comfortable – beings that can, on rare occasions, also be spherically symmetrical. However, at the beginning of the universe there was no matter, and none of the many different kinds of atoms of which it's made.

Although we can't make any definitive statements about the moment of the Big Bang itself, we do have a fairly precise conception of the time immediately after. In the beginning it was enormously hot, and all that existed was energy and elementary particles. These had yet to arrange themselves into atoms as we know them today, which wasn't an easy thing to do: an atom is composed of one or more shells and an atomic nucleus consisting of positively charged protons and uncharged neutrons, which in turn consist of quarks. To the best of our knowledge, quarks are elementary particles, i.e. subatomic particles that cannot be divided into further particles.

The number of protons in an atomic nucleus determines which chemical element we're dealing with: one proton forms the nucleus of a hydrogen atom, helium needs two, lithium three, and so on. On the other hand, the number of neutrons in an atomic nucleus can vary, and doesn't change an element's fundamental chemical qualities. For a complete atom you also need a shell around the nucleus, which contains the elementary and negatively charged electrons.

For atoms to be stable they require certain external conditions, which have only appeared in our universe over time. When the universe was in its infancy, it was still much too hot, and the enormous temperatures caused the quarks and electrons to move far too quickly for stable atoms to form. Fortunately, though, space cooled down very rapidly, and after just a hundredth of a second the newborn universe's temperature had decreased to a pleasant ten billion degrees Celsius – enough to enable the quarks to cluster into protons and neutrons. A little while later, they in turn were able to form the first atomic nuclei, and thus the first chemical elements.

Hydrogen is a very straightforward element; nothing else has to happen for it to form, because a single proton already makes up the nucleus of a complete hydrogen atom. For helium, however, two protons and two neutrons have to find each other in the particle chaos of the young universe, and then connect. There's just one problem: unlike a proton, a neutron flying solo through the universe is unstable, and destroyed by radioactive forces within a few minutes. After the Big Bang, then, the protons and neutrons only had a few minutes to find each other and fuse into nuclei, which is too little time for a complex nucleus to form. In the early universe there was thus an abundance of hydrogen nuclei (c. 75 per cent), somewhat less helium (c. 25 per cent), and here and there individual lithium and beryllium nuclei in vanishingly small numbers.

At least, this is what current cosmological theories about the Big Bang tell us about the ratio of chemical elements. We can only verify this through observation – for example by examining very old stars: the ones that were formed first in the universe can obviously only consist of the elements around at the time, i.e. hydrogen and helium, and in the aforementioned ratio. All the other chemical elements were created only later by the nuclear fusion that occurs in stars, so the older the star the more closely its composition has to match the ratio of masses present after the Big Bang.

And that is precisely what we have been able to observe: 2MASS J18082002-5104378 B is one of the oldest known stars – perhaps even the oldest. It was born just a few hundred million years after the Big Bang, and as predicted consists almost exclusively of hydrogen and helium, in exactly the expected ratio.

It's hard to believe that we can actually make concrete statements about the beginning of the universe, given how unbelievably long ago it all happened. But thanks to stars like this one such statements aren't science fiction – they can help us to confirm our theories and allow us to catch a brief glimpse of the moment when our cosmos began.

# 3

## 34 Tauri

### The Planet That Was Once a Star

The star 34 Tauri doesn't exist. Nevertheless, when the British astronomer John Flamsteed observed it in the sky he might have won great renown, if only he'd realized what it was he was looking at.

At the beginning of the eighteenth century, the Astronomer Royal was working on a large sky atlas at the observatory in Greenwich, which required him to systematically scour the sky and enter all the stars and their positions into a catalogue. Theoretically, it was the ideal starting point for making new discoveries. He named one of those stars 34 Tauri – only it wasn't a star, but the planet Uranus. No one yet knew of its existence at the time. Uranus revolves around the Sun far beyond Saturn's path; it's as good as invisible to the naked eye, and even through a telescope barely distinguishable from a star. In contrast to real stars, however, it noticeably changes position over the course of several days.

The fact that the true nature of this spot of light eluded Flamsteed during his first surveys is understandable. They were separated by an interval of several years, and it's easy to see how he may not have worked out that it was always the same object, only in a different place in the sky. Moreover, his telescope wasn't quite good enough to show the planet as a small disc. All he saw was a dot, which looked just like all the other dots in the sky.

However, when Uranus came into his telescope's sights three times in the space of a single week in March 1715, he really should have noticed that there was something moving there, against the backdrop of stars. Yet he didn't – and because he failed to analyse his data closely enough, he was deprived of becoming the first person to have discovered a new planet. He shares this tragic fate with a few other near-discoverers of Uranus, including the German astronomer Tobias Mayer, who also registered the planet but didn't recognize it for what it was.

Nobody did, until sixty-six years later, when the British astronomer William Herschel spent 13 March 1781 in his garden monitoring the area around the Taurus constellation and noticed a spot of light that didn't quite belong there. Herschel built his own telescopes, and he built them better than anyone else, which is why he quickly saw that he wasn't dealing with a star. At first, he thought that the object was a comet; but his colleagues' calculations in due course confirmed that it was actually a planet, orbiting the Sun at nineteen times the Earth's distance.

This was a sensational discovery. Until then, the only known planets were the six that are visible to the naked eye: Mercury, Venus, Earth, Mars, Jupiter and Saturn. It hadn't occurred to anybody that there might be more such large heavenly bodies revolving around the Sun. At a single stroke, Herschel's discovery of Uranus doubled the size of the known solar system, and opened our eyes to the many things astronomy still held in store for us.

Out there were numerous new worlds waiting to be discovered, and Herschel's planet was just the start. Since then we have discovered asteroids, found Neptune and Pluto, and eventually even identified planets belonging to stars outside the solar system. And if John Flamsteed had been just a tiny bit more meticulous in his work, we could have begun our voyage of discovery sixty-six years earlier.

# 4

## Alcyone

### Georg von Peuerbach and the Start of a Revolution

Nowadays, we tend to trace the switch from a geocentric to a heliocentric world view back to the first decades of the seventeenth century, when Galileo Galilei and Johannes Kepler's new findings made it clear that the Earth isn't at the centre of the universe, but moves around the Sun. But every revolution has a past.

Aristarchus of Samos already suspected in the third century BC that the Earth doesn't repose idly at the centre of the cosmos. Our history, however, begins on 3 September 1457, when Georg von Peuerbach and his student Regiomontanus were standing together in the town of Melk in Lower Austria regarding the star Alcyone. There was a reason why the two astronomers' attention wasn't focused exclusively on the lunar eclipse that happened to be taking place at that moment: they weren't merely interested in watching the Earth's shadow darken the full moon, but wanted to find out exactly *when* it would happen. Yet fifteenth-century clocks weren't the most precise of instruments, so they resorted to the big clock in the sky. To do that, you need to know a thing or two about stars.

Georg von Peuerbach took up his university studies rather late, at the age of twenty-three, but was already lecturing at Italian universities three years later. He eventually became the first dedicated astronomy professor at the University of Vienna, where he busied himself with the creation of astronomical tables: this is what they called those long tables consisting of formulas and digits which they used to calculate the position of the Sun, the Moon and the planets in the sky.

To verify the data in his tables he needed to take concrete measurements, which in turn required the occurrence of clearly definable and predictable events in the sky – for example the occultation of a planet by the Moon, or indeed a lunar eclipse, like the one due on 3 September 1457. To check that the formulas were correct, you had to know the precise time at which that event took place.

Georg von Peuerbach took advantage of the fact that the Earth rotates on its axis once a day; or, as they still thought in those days, of the fact that the firmament revolves around the Earth once a day, while the Earth sits motionless at the centre of the universe. Regardless of how you look at it, though, in the course of the night you can see the stars climb higher and higher in the sky, and then, once they have reached the highest point, start to descend again. A star does this at a constant speed, equal to the speed at which the Earth rotates on its axis. When you measure the height of a star above the horizon, you can therefore simultaneously determine the passage of time – and that's exactly why Georg von Peuerbach and Regiomontanus were watching Alcyone. This bright star belongs to the distinctive Pleiades star cluster, which you can see clearly even without a telescope. This was rather useful, of course, because the two researchers didn't have an optical instrument like that at their disposal; it was only invented 150 years later.

Even without one, though, Peuerbach was able to ascertain that the predictions made by the classical tables were not as accurate as they could have been. He began making corrections to the astronomical tables, developed mathematical methods for their improvement and built instruments with which you could determine the position of the stars more accurately than ever before. His early death in 1461 meant that his work was left unfinished; it was later completed by Regiomontanus, who was really called Johannes Müller (he owed his nickname to the Latin translation of his birthplace, Königsberg, meaning 'king's mountain'). He continued his mentor's work, producing even more precise calculations and developing even better mathematical techniques. He too died young – he was only forty when he died in Rome in 1476.

Three years before his death, in the far north a boy named Niclas Koppernigk was born. He naturally knew nothing about Regiomontanus or Peuerbach yet, but when he grew older and began to preoccupy himself with astronomy, he based his work on their theories and on their data relating to the movements of planets. Today, Koppernigk is better known as Nicolaus Copernicus, the man who demonstrated that the Sun, and not the Earth, is at the centre of things, and orbited by the planets. This fact only became public in 1543, the year of his death, and it was another half a century before Galileo Galilei, Johannes Kepler and Isaac Newton established that a geocentric world view does not, in fact, correspond to reality. The 'Copernican Revolution' thus happened long after Copernicus's time, and had started long before it.

# 5

## Freistetter's Star

### Can You Buy a Star's Name?

There is no 'Freistetter's Star'. Not a single one of the countless stars in the sky is named after me, and I'm quite sure that this won't change. I don't mind, though. I enjoy finding out about celestial bodies much more than the idea of having my name immortalized in the sky. Which, by the way, is not as easy as various online companies would like you to think.

These are the companies that offer you the opportunity to 'Name a Star – Includes Registry and Certificate'. For a small sum, you can pick any one of the many stars in the sky and call it whatever you like. You can name it after yourself, or after someone else, as a present. Once you've paid the required amount – and the brighter the star, the higher the amount – the name is entered into a 'globally recognized star name register' or an 'international star register'. You receive an official-looking certificate and can then sit back and rejoice in the knowledge that a piece of the universe now bears a very special name.

Most of the rejoicing, though, is done by the companies that sell these certificates, for they're offering a product that doesn't really exist. The stars don't belong to anyone, and therefore nobody has the right to sell their names. Or, to look at it another way: each one of us has the right to name them.

What we think of as the 'official' names of stars are merely designations agreed by scientists, who consider them binding in their field. Aside from a few hundred stars that received their

Greek, Arabic and Latin epithets in antiquity or the Middle Ages, most only have a catalogue designation consisting of digits and letters. For the scientific community, it is far more important and practical to have an orderly, unified nomenclature for the stars than to lend them poetic names.

Only in 2016 did the International Astronomical Union (IAU) – the global association for the promotion of astronomical research and collaboration – set up a working group for the naming of stars. The group's task is to standardize their names and, if necessary, assign new ones. So far, the official catalogue has 336 entries, and only 6 are named after people: there are a Cervantes and a Copernicus, named after the Spanish author and the famous astronomer; Barnard's Star, after the astronomer Edward Emerson Barnard, who discovered that particular star's immense speed in the early twentieth century; Cor Caroli ('Charles's heart'), the brightest star in the Canes Venatici ('hunting dogs') constellation, after King Charles II; and then there are Sualocin and Rotanev, in the Dolphin constellation, named after the Italian astronomer Nicolaus Venator – they are his first and last names written backwards, and have been called this since 1814, though nobody quite knows why.

These names were given to those six stars a long time ago, and had became so commonplace that the IAU simply carried them over into their official catalogue. There are a few other stars whose unofficial nicknames were inspired by real people, specifically the astronomers who discovered them: Tabby's Star, for instance (named after the astronomer Tabetha Boyajian), refers to the object with the catalogue designation KIC 8462852, which created much excitement in 2015, when astronomers observed strange variations in its luminosity, which some put down to alien activity. Once these nicknames have been used for a sufficiently long time by a sufficient number of members of the scientific community, it's possible that they, too, will at some point be recognized by the IAU. But the commercial purveyors' 'star registers' have nothing to do with the naming of stars. All you get for your money is an entry into some company database or other – which is neither binding nor unequivocal, because nobody can stop these firms from selling several names for the same star. Instead of spending money on the non-binding baptism of a star, therefore, you could do what people have done for ever: enjoy the view of the night sky, and make up your own stories and names for the stars and constellations. Nobody can stop us from doing that. The sky belongs to us all.

# 6

## HR0001

## Mrs Hoffleit Counts the Stars

‘Do you know how many stars there are?’ asks a well-known children’s song written in 1837 by the Protestant pastor Wilhelm Hey from the village of Leina in Thuringia. Hey immediately provides the answer – or at least, something like an answer: ‘the Lord God has counted them,’ the lyrics continue; but sadly the Creator doesn’t reveal the result of his cosmic stocktake.

Where theology is at a loss, astronomy can help. However, astronomers do a lot more than just count the stars in the sky: they want to understand them in all their particulars. Yet to do that, they first have to catalogue them. That’s why any astronomical endeavour begins with a catalogue listing as many characteristics as possible about as many stars as possible. For example, if you want to work out a star’s mass or determine its age, you first need to know where it is, how bright it is and how quickly it moves. Catalogues seem boring, but they are the foundation on which our knowledge of the universe rests.

On 25 April 2018, this foundation was significantly extended when the space telescope Gaia published the Gaia DR2 catalogue, which lists no fewer than 1,692,919,135 stars. An impressive number, and a distinct improvement on the ‘mere’ 2.5 million stars previously recorded in what was then the most comprehensive star catalogue (Tycho-2). But our Milky Way alone consists of a few hundred billion stars, which means that the enormous Gaia catalogue contains only around 1 per cent of all the stars out there

– even less, when we consider all the other galaxies in the universe. There are up to a quadrillion of these star systems in the visible cosmos, and each of them, too, consists of hundreds of billions of stars.

This means that there are a total of a few hundred septillion stars in the sky. At least in theory, for in practice we can't see most of them. Our telescopes are too weak and small to make them out. The most we can aspire to for the foreseeable future is to deepen our knowledge of the stars in our own galaxy – and even then it's highly unlikely that we'll one day have listed and counted all the billions of stars in the Milky Way.

For now, then, let's stay with the stars we can see without a telescope. Our eyes may be weak, but on a clear night they're eminently capable of observing an impressive firmament – as long as the artificial illumination from our cities doesn't outshine those natural sources of light. In a typical European city, 'the Lord God' would be quickly done with the counting: in densely populated and highly illuminated areas you can see no more than three dozen stars.

A glance at the Yale Catalogue of Bright Stars shows us what things might look like under ideal conditions. It was compiled by the American astronomer Dorrit Hoffleit in 1956. In it, she listed all the stars that can theoretically be seen with the naked eye. Her extensive catalogue begins with the star HR0001, which is about 530 light years from Earth, and glows so weakly that you can only see it if your eyes are very good indeed. All in all, the catalogue comprises 9,095 stars, and all the relevant data known about them at the time.

Scientifically speaking, the correct answer to the question 'Do you know how many stars there are?' is 'no'. Nobody knows. Lots and lots, that much is certain. But only 9,095 of them can be seen with the naked eye – and those weren't counted by the Lord God, either, but by Dorrit Hoffleit of Yale University.

Until 1984, nobody knew for sure whether planets could form near stars other than the Sun; the dust surrounding Vega was the first confirmation we had that what happened in our corner of the universe also happens elsewhere, and that the search for the planets of other stars isn't futile.

# 8

## Rasalhague

### Confounded Astrologers

Rasalhague (Arabic for 'serpent's head') is the brightest star in the Ophiuchus ('serpent-bearer') constellation that regularly causes much excitement in the tabloid press and among astrology buffs. They claim that NASA has reclassified the star signs, and that there is now a thirteenth: 'Don't freak out, but your star sign may have changed', reads one headline from September 2016; 'Daily horoscope BOMBSHELL: Your zodiac is WRONG says NASA – HERE is your REAL star sign', reads another, from October 2018. According to these reports, anyone born between 30 November and 18 December is no longer a Sagittarius, but a Serpent-Bearer.

The reason for these regular bouts of media frenzy – aside from the tabloids' thirst for clickbait – is that many people are stumped by the difference between constellations and star signs as much as by the difference between astronomy and astrology.

We haven't always distinguished between them. In the old days, we used to watch the skies not only to study the movements and characteristics of all those dots of light we saw there, but also because we believed that heavenly bodies had mythological and religious significance. Comets, for instance, were for centuries thought to be portents of doom, or celestial accompaniments to momentous events (such as the birth of Christ). People thought that whatever happened in the sky had a material effect on human life, and that if we studied and understood the stars and planets well enough we'd be able to extract from them crucial information about the future.

It was only in the seventeenth century that the science of astronomy as we know it today began to diverge from the old superstition of astrology. These days, all those mythological figures and stories that people used to project onto the heavens in the form of constellations are only of historical relevance. Astronomy may still recognize the constellations, but they no longer have anything much to do with astrology's star signs.

The twelve 'signs of the zodiac', to give them their proper name, which are drafted into the service of newspaper horoscope columns to this day, are constellations situated in a very specific place in the sky. They are ranged along the ecliptic, i.e. lined up along the Sun's apparent annual route through the sky. The ecliptic is simply the Earth's orbit around the Sun, projected against the sky; and the rest of the solar planets also move in, or close to, this plane. This is the reason why the twelve signs of the zodiac used to play such an important role in ancient surveys of the skies: people were able to observe when and how the planets passed through the individual constellations, and draw astrological conclusions from this.

Just like the constellations of Scorpius, Sagittarius, Aries, etc., the Ophiuchus constellation also stems from antiquity, and it too is traversed by the ecliptic. But for some reason it was never included among the official signs of the zodiac – perhaps because they thought twelve a more auspicious number than thirteen.

For a long time, there was no binding regulation governing the constellations. There was no written record of which constellations existed, or a list of the stars in each constellation. It took until 1928 for scientists to put things right, when the International Astronomical Union divided the sky into eighty-eight discrete areas and thus created the eighty-eight constellations still officially recognized today. The twelve constellations along the ecliptic whose names correspond to the twelve star signs have remained; and so has Rasalhague, in the Ophiuchus constellation.

Which isn't to say that Ophiuchus is an astrological star sign, too. Astrology frequently ignores the insights gained by astronomy, and Ophiuchus is no exception. While the constellations occupy areas of different sizes in the sky, the astrologers' star signs are all the same size. This results in substantial discrepancies: for example, someone whose star sign is Aquarius will assume that, astrologically speaking, the Sun was in Aquarius's part of the sky at the time of their birth; from an astronomical perspective, however, the Sun was in Pisces.

Astrology isn't a science, and star signs have nothing to do with the official constellations, or with the Sun's actual position in the sky. Nevertheless, the star signs have their own part of the cosmic story to tell – they are testament to the human urge to put our lives in some kind of celestial context. But there's no need to worry that you might have been living under the wrong star sign; though you might well ask why we still place such value on an ancient superstition.

# 9

## TXS 0506+056

### Ice Cube Astronomy

At the Earth's South Pole there is what must be the world's strangest telescope. Or, to be more precise, it's more than a kilometre underneath the South Pole, frozen into the Antarctic ice. It's searching for a very special type of light down there. What it's trying to find is neutrinos – something that requires a considerable effort.

A neutrino is an elementary particle. It has almost no mass, and hardly interacts with other matter. Around a hundred million of them are racing unnoticed across each square centimetre of the surface of our bodies at any given second. The entire Earth, in fact, is exposed to a steady stream of neutrinos, but without being in any way influenced by it. As far as these elementary particles are concerned, the Earth isn't merely transparent – it's as if it didn't exist at all.

Neutrinos are created by nuclear reactions, and in especially vast numbers by the nuclear fusion that occurs inside stars: the Sun produces not only the light it radiates into space, but also a continuous flow of neutrinos, which are much harder to see. The numerous neutrinos that continously hit our planet only rarely interact with normal matter; but when they do, these collisions form new particles, which then briefly emit energy in the form of a bright light. However, for us to witness an event like that a number of other factors have to coincide: there has to be a lot of matter around for the neutrinos to encounter something in the

# 10

## π1 Gruis

### A Simmering Giant

There's a giant star bubbling away in the Grus constellation, 530 light years from Earth. Its name is π1 Gruis, and if it was in our solar system it would have swallowed Earth long ago. It has almost reached the end of its life, but not without first showing us something we've never observed before in this form.

The only star we can examine in proper detail is the Sun. It may look like a simple white disc, but when you consider it a bit more closely through a telescope you'll recognize it for what it really is: an enormous, hot, simmering mass of gas. What you see happening on its surface is the same thing that happens when you boil a saucepan full of water. Think of the Sun's centre as the 'stove', where hydrogen nuclei are fusing into helium nuclei; that's where the Sun produces all its energy. First, this energy spreads out in the form of high-energy light particles, in a 'radiation zone' extending to around 500,000 kilometres; this far from the centre, the temperature has already decreased from about 15 million degrees to 1.5 million degrees Celsius. The energy is then transported by the heat across the remaining 200,000 kilometres to the Sun's surface. The radiation heats up the gas in the Sun, which starts to rise. As it does so it cools down, until it reaches the Sun's surface at a temperature of just 5,500 degrees Celsius. Now that it has cooled down, the gas sinks back towards the centre until it once again grows hotter, and the process is repeated.

This cycle is called 'convection', and is exactly what happens when we heat water in a saucepan. The Sun's individual convection cells – that is, the zones in which its material rises to the surface – measure about 1,000 kilometres across and are called 'granules'. When you look at a time-lapse video of the surface of the Sun, you can watch it literally bubbling away.

What is comparatively straightforward in the case of the Sun proves to be almost impossible in the case of other stars. They are too far away for us to perceive them as anything other than spots of light, even through large telescopes. Their surface structures and the convection processes that occur there usually remain invisible to us. But in 2018, we managed to observe them on π1 Gruis. Not only is it a huge star, but it's a thousand times brighter than the Sun – so luminous that, when the European Southern Observatory in Chile combined the data from four different telescopes to create a virtual telescope of much greater dimensions, Claudia Paladini from the University of Brussels and her colleagues were able to 'resolve' the star's surface and make its convection cells visible.

The cells on π1 Gruis are as colossal as the star itself: the granules measure close to 120 million kilometres across, which is almost the same as the distance between Earth and the Sun. The reason for this is the star's low density: it may have one and a half times the Sun's mass, but it's much bigger than the Sun – and therefore less dense. This is also why the gravitational force is weaker on its surface than on the Sun's, which results in larger granules.

This behaviour had already been predicted by theoretical star models, but was definitively observed for the first time on the surface of π1 Gruis. Some of it was down to sheer luck: the phase in which the giant star currently finds itself lasts just tens of thousands of years, a hundred thousand at most. π1 Gruis has already shed a substantial part of its atmosphere into outer space; in a few tens of thousands of years it will have disappeared completely, leaving behind only a small, dead star-remnant. We caught it just in the nick of time to watch it bubbling away.

# 11

## B Cassiopeiae

### A Dogma Blows Up

The star B Cassiopeiae no longer exists. Even while it was alive, nobody knew of its existence. We were only able to see it when it disappeared – and took an old dogma with it in the process.

It's actually wrong to describe B Cassiopeiae as a 'star'. However, the Danish astronomer Tycho Brahe didn't know that when, on 11 November 1572, he saw a brightly shining object he'd never observed before in the Cassiopeia constellation. But there it was, almost as bright as Venus, and impossible to miss. It was a 'new star', and he wrote an eponymous book about it which made him one of the most renowned astronomers of his time. In *De Stella Nova*, he proved that the bright object wasn't – as many of his contemporaries thought – merely a mysterious light phenomenon in the Earth's atmosphere, but had to be located somewhere among the stars.

After all, if the light were somewhere in our atmosphere, close to Earth, it would have to move against the backdrop of stars in the sky as the Earth rotates around its axis once a day. (Or rather, according to the generally accepted view at the time, the light would have to be standing still along with Earth, while the rest of the universe revolves around it once a day.) But this wasn't the case: the light was moving in unison with the stars. Tycho Brahe was therefore convinced that it was a new star.

Tycho Brahe was not the first, or the only one, to see it, but no one else at the time examined it as closely as he did. With his