TRANSIT

The January 2014 Newsletter of

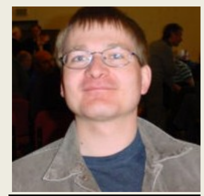
Cleveland & Darlington Astronomical Society

<u>NEXT TWO MEETINGS, each at 7.15 pm at Wynyard Planetarium</u>

Friday 10 January 2014

Your first telescope

Dr Jürgen Schmoll, *Chairman of CaDAS*



o – o – o – o – o

Friday 14 February 2014

A year with a large-aperture Dobsonian

Ian Morris, *CaDAS*

Content

Editorial

Rod Cuff

To all, a Happy New Year and perihelion (4 January – thank you, Neil …). The first *Transit* issue of 2014 continues Ray Brown's series on gravity with an article on Lagrangian points, explaining why there are so many telescopes bunched up at a couple of places near Earth's orbit. There's also a new piece from the AAVSO store of articles, examining how astronomers can now distinguish the smallest 'proper' stars from failed 'stars' known as brown dwarfs.

Before you get to those, I've written what I hope/intend will be the first of a series of half histories, half observing guides. Both as author and as editor, I'd be very interested to know what you think of the general idea of the series, the background to which is explained in an introduction to this first article.

Many thanks to Ray, the only other CaDAS contributor this time – more articles from others, please! The copy date for material for February's *Transit* is Wednesday 29 January.

Best wishes –

Rod Cuff, info@cadas-astro.org.uk *1 Farndale Drive, Guisborough TS14 8JD*
(01287 638154, mobile 07775 527530)

Letter

The BBC are still at it

from Ray Brown

BBC4 recently re-ran a programme *The Secret Life of Ice*, first shown two years ago. Discussing ice core data, an expert, Dr Robert Mulvaney of the British Antarctic Survey, correctly stated, 'As we go into an ice age, the levels of carbon dioxide (the greenhouse gas in the atmosphere) decrease. As we come back out of an ice age, they start to increase again.'

Then the programme's presenter, Dr Gabrielle Walker, followed with the nuanced paraphrase, 'As carbon dioxide levels rise, as they are doing today, temperature will also rise.'

Wow, probably unnoticed by most viewers, an effect had been conjured into the cause. Al Gore was discredited for using the same sleight of hand in his film *An Inconvenient Truth*.

In fact, ice core data show that carbon dioxide changes *lagged centuries behind* the temperature changes. Yet BBC science editors allow this sort of thing to pass.

Ray Brown

OBSERVATION REPORTS AND PLANNING

Websites – January 2014

Here are some suggestions for websites that will highlight some of what to look out for in the night sky in January. The **Telescope House** site is particularly good this month, and elsewhere on it has a preview of astronomical happenings in the whole of 2014.

Also, I've added a video to the usual list: the **Sky Notes** given by Nick James at the meeting of the **British Astronomical Association** shortly before Christmas, covering the anticipated sky in December through January. Much of the material that the BAA posts on its website (http://britastro.org) is available to anyone, not only to its members. It also has a public YouTube channel, which is where the regular Sky Notes appear in video/audio form, recorded live at its meeting. I'll make sure the latest video is listed here each month. A PDF of the Notes is also always available from the website.

- **BAA Sky Notes** for December 2013 and January 2014:

  http://tinyurl.com/os4ytwu

- **HubbleSite**: another **video** of things to see each month:

  http://hubblesite.org/explore_astronomy/tonights_sky

- **Night Sky Info's** comprehensive coverage of the current night sky:

  www.nightskyinfo.com

- **Jodrell Bank Centre for Astrophysics** – The night sky:

  www.jodrellbank.manchester.ac.uk/astronomy/nightsky

- **Telescope House** monthly sky guide:

  http://tinyurl.com/pzzpmsx

- **Orion's** What's in the Sky – January:
  www.telescope.com/content.jsp?pageName=In-the-Sky-this-Month

- **Society for Popular Astronomy's** monthly Sky Diary:

  www.popastro.com/documents/SkyDiary.pdf

A life in the sky: an introduction

Rod Cuff

For several years now, I've been musing over an idea for a book, e-book or series of articles about astronomers whose names appear in the sky and may be familiar to many amateurs. Anyone who's been actively interested in astronomy for more than a short time will know something about [Charles] Messier and the Messier (M) objects, about [Sir William] Herschel and his *Catalogue of Nebulae and Clusters of Stars* and the modern observing challenge of the Herschel 400 subset from it, and about [Sir Patrick] Caldwell-Moore and the Caldwell catalogue of some of the sky's glories that Messier left out.

But there are other, often well-known, objects in the heavens that are associated with a named individual about whom you may know little or nothing. Who was Kemble of Kemble's Cascade? Or Hind of Hind's Crimson Star? Or Encke of Encke's Comet?

You may not care a jot – horses for courses, etc – but I've always been interested in the history of astronomical discoveries and progress, and also curious about some of the names that I keep coming across when planning which objects to observe. It occurred to me that there was no single source that brought these object/people pairings together, so I started thinking about filling the gap.

I remember talking about the idea with Keith Johnson in a pub in Thornton-le-Dale at the start of a Dalby Forest Star Party weekend several years ago, when my working title ('working' being purely imaginary at the time) was *A Century of Astronomers*, because I'd been thinking of concentrating on 20th-century astronomers and trying to gather information on 100 of them. Behind that lay the idea that Sir Patrick Moore might have met and perhaps interviewed many of them, and I could propose to him that I use whatever notes/transcripts/memories he'd had for those interviews, and/or his own current thoughts, as part of the write-up for a goodly number of entries in a book that would carry both our names. It's not such a batty idea as it might at first sound, since I had a couple of potential entry-points into Patrick's world: Keith was one, of course, but my ex-brother-in-law is Dr Peter Cattermole, who was a long-time collaborator and friend of Patrick.

However, I went away from that idea for various reasons, including a realisation that a lot of work would be involved for a very uncertain outcome. But the basic idea never went away.

So I've decided to write individual articles – for fun and for *Transit* – and see how it goes. The format I have in mind is to cover the main aspects of the subject astronomer's professional and personal life, and then look at how and where aspects of that life are represented in objects that an amateur observer can view today. Each article then becomes part history and part a suggested observational tour, particularly of objects that bear the person's name.

At least initially, I'll be avoiding the Messiers and the Herschels and the Caldwells, who are well covered elsewhere, and looking instead at the people who aren't astronomical-household names. I'll illustrate the objects wherever I can, and want to favour images created by amateurs – and preferably by CaDAS members, naturally. So please, if you've taken images or made drawings of *any* object I mention, please send it to me and I'll publish it in the next available issue. It's fine if the article in question was several issues back, and also fine even if I illustrated it at the time with another image of the object you've imaged – I don't care, I just want to encourage more activity out with the telescope! If this became a CaDAS 'project', I'd be delighted.

It goes without saying, too, that I welcome any letter or notes or articles that add to, correct, or go off at a tangent from anything that I write. And criticism of the format is perfectly OK, too – I'm working it out as I go along. This month's first subject, E.E. Barnard, turned out to deserve much more time than I'd expected to devote to him, and most articles are likely to be a lot shorter than this one. Anyway, do please settle back and read …:

A life in the sky – 1: E.E. Barnard

Rod Cuff

Things to observe

Barnard's Star … Barnard's Loop … satellites of Jupiter … dark nebulae.

Who was Barnard?

Edward Emerson Barnard (1857–1923) was a gifted and largely self-taught observational astronomer and pioneering astrophotographer.

Born into a poor family in Nashville, Tennessee, he received only a few months' regular education before beginning work at nine years old as a photographer's assistant. He became interested in astronomy in his teens and later acquired a 5-inch reflector and started observing the heavens. Starting in 1881, he discovered three comets in quick succession, although rather oddly didn't announce the very first of them.

For most observers, the fact of discovery would be reward enough in itself, but later in the same decade Barnard was able to make his hobby a profitable one. The philanthropist Hulbert Harrington Warner announced that he would give a $200 award (equivalent to over $4500 today) to the discoverer of each new comet. Barnard discovered a further five, which nicely funded the building of a house for himself and his wife.

-This recognition of Barnard's observational diligence and quality led to a rather touching development – one that is unlikely to be matched these days, but that would have a major impact on the astronomical world. His admirers among Nashville's amateur astronomers raised enough money to give him a scholarship to Vanderbilt University. He never graduated (although later was awarded an honorary degree there – the only one in the university's history), but was placed in charge of Vanderbilt's observatory, which turned out to be a stepping-stone to his joining the staff of the Lick Observatory, near San Jose, California, in 1892, soon after it began operations.

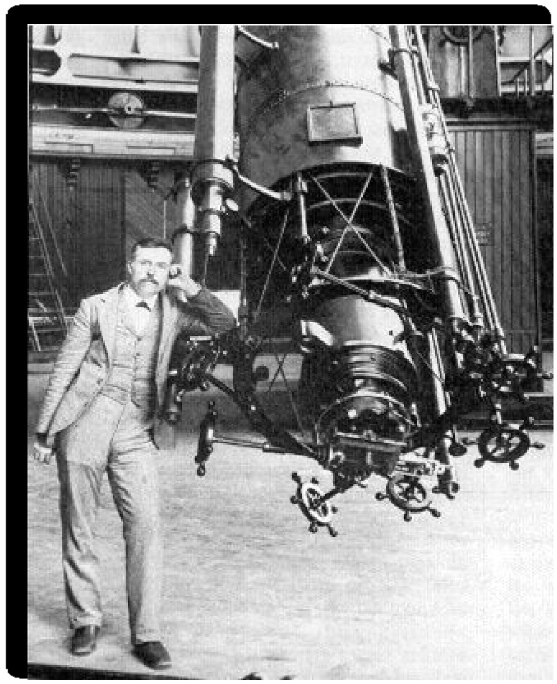


Figure 1. Barnard with the 36-inch reflector at the Lick Observatory.

Three years later be became Professor of Practical Astronomy at the Yerkes Observatory, part of the University of Chicago but situated in Wisconsin, and the home of the famous 40-inch refractor, the largest ever built. He remained there, hugely productive, for the remaining 28 years of his life. An obituary characterised him as 'easily the foremost observational astronomer of his age'.

Barnard for today's observer

- **AMALTHEA ('Barnard's moon')**, Jupiter's fifth satellite, was discovered visually by Barnard in 1892 using the 36-inch refractor at Lick – the first discovery of a new satellite of Jupiter since Galileo turned his telescope on the planet in 1610, and the last one to be discovered purely by visual means. It was photographed in detail by the Voyager 1 & 2 and Galileo spacecraft. It's the reddest object in the Solar System.

  Observing notes: Its apparent magnitude of 14.1 and its relative closeness to Jupiter makes it a challenging visual target for anything smaller than a 16–18-inch telescope. The Project Pluto website from 2000 states without further reference: *'I understand that some people have since [Barnard's discovery] observed it with much smaller instruments, all the way down to 12-inch (30-cm) reflectors. An occulting bar would obviously help.*' It should be a more readily achievable, if tricky, target for CCD photography, and details of its current position are obtainable in various desktop planetarium programs, such as Stellarium or Starry Night. There are hardly any amateur images of Amalthea on the web, but Daniele Gaspari's website has one taken in 2005 with a 235mm Celestron and a webcam, so it's quite feasible!

- **BARNARD'S STAR** (v2500 Oph) remains probably the best-known object associated with Barnard's name (remarkably, there's no mention of it in the 1400-word obituary mentioned above).

Although it was later traced on Harvard plates dating back to 1888, Barnard was the first to notice and measure its **proper motion** (apparent speed across our sky) in 1916. It's the largest of any known star: 10.3 arcsec per year, about half the angular diameter of the Moon in a human lifetime.

Some data on Barnard's Star	
RA	$17^h\ 57^m\ 49^s$
Declination	+04° 41' 36"
Apparent mag.	9.54
Distance	6 LY
Variable type	BY Draconis
Mass	0.144 × Sun's mass

It is also the closest star to Earth that can be seen by observers at our latitude. The star is a low-mass red dwarf, and its age of around 10 billion years probably makes it one of the oldest stars in our galaxy. Red dwarfs have very long lifetimes; Barnard's Star may have 40 billion years to go before it becomes a black dwarf. Such old stars are usually assumed to be stable and quiescent, so it was a surprise when an intense stellar flare from its surface was detected in 1998.

There is a dynamic GIF at http://en.wikipedia.org/wiki/File:Barnard2005.gif showing the relative position of Barnard's Star and its surroundings every 5 years from 1985 to 2005.

Observing notes: Its **midnight culmination** (when it appears due south and at its highest for the year) is on 21 June, the summer solstice. Although it's not **astronomically dark** in our region then, the star will have an altitude of about 40° above the southern horizon and should be just about visible in 10 × 50 binoculars, though not easy to identify with certainty. It will be an easy target with a small telescope, especially a go-to type. For a binocular search, make sure you use a chart showing stars down to at least 10th magnitude, such as Figure 22, which is about 8° across.

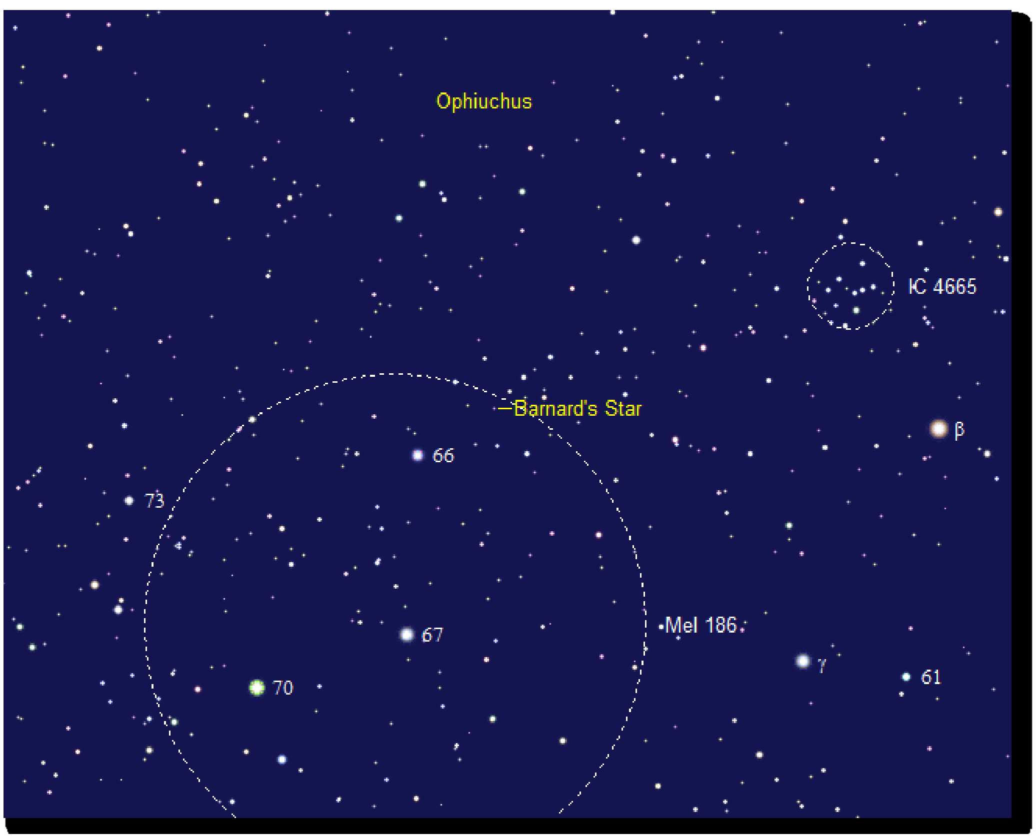


Figure 2. A chart to help find Barnard's Star using binoculars

A CCD exposure of 10 seconds or more will show stars down to a considerably fainter level, and something like Figure 3 (a screen-grab from SkyTools 2 with data on position, magnitude and field of view) will be useful. Remember that Barnard's Star has almost certainly moved since the data your sky map is using was supplied – look for the surrounding patterns and find the star that doesn't fit properly!

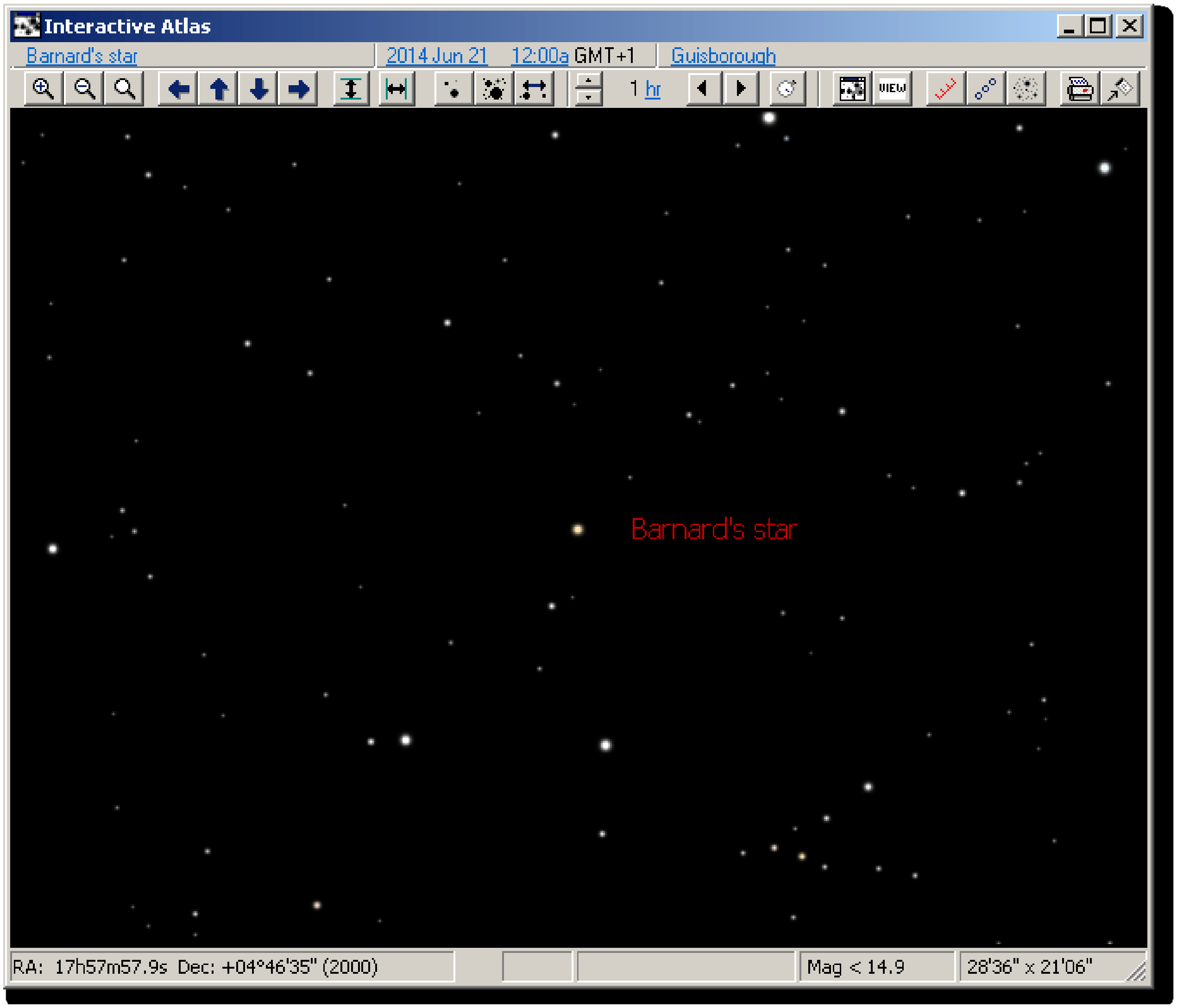


Figure 3. A chart to help find Barnard's Star from a CCD image

If you have a CCD camera, there is a fairly easy and rewarding, if rather long-term, project that you might consider: determining your own estimate for the star's proper motion (and perhaps **parallax**) by taking images of the region around it over a period of a few years. This needs a careful approach, of course, but Robert Vanderbei at Princeton tried it recently with a series of 8-second unguided exposures on three nights over a 15-month span using a 10-inch 'scope, and arrived at a very respectable 'ballpark' figure of 10.49 arcsec per year, only a couple of percentage points out.

- **BARNARD'S LOOP** (Sharpless 2-276) is an **emission nebula** (one that we view by its own radiation rather than by reflection of light from another celestial body) that curls around much of the area of sky marked out by the major stars of Orion (Figure 4). It's thought that William Herschel (who else?!) may have discovered it in 1786, but it was at least re-discovered by Barnard around 1900 using long-exposure photography and now bears his name. Its origin and its relationship with the Orion stars are still uncertain, but it may be a supernova remnant excited by very hot and young O- and B-type stars in the constellation and re-emitting radiation at a lower wavelength. It's about 1600 light-years away and 300 light-years across.

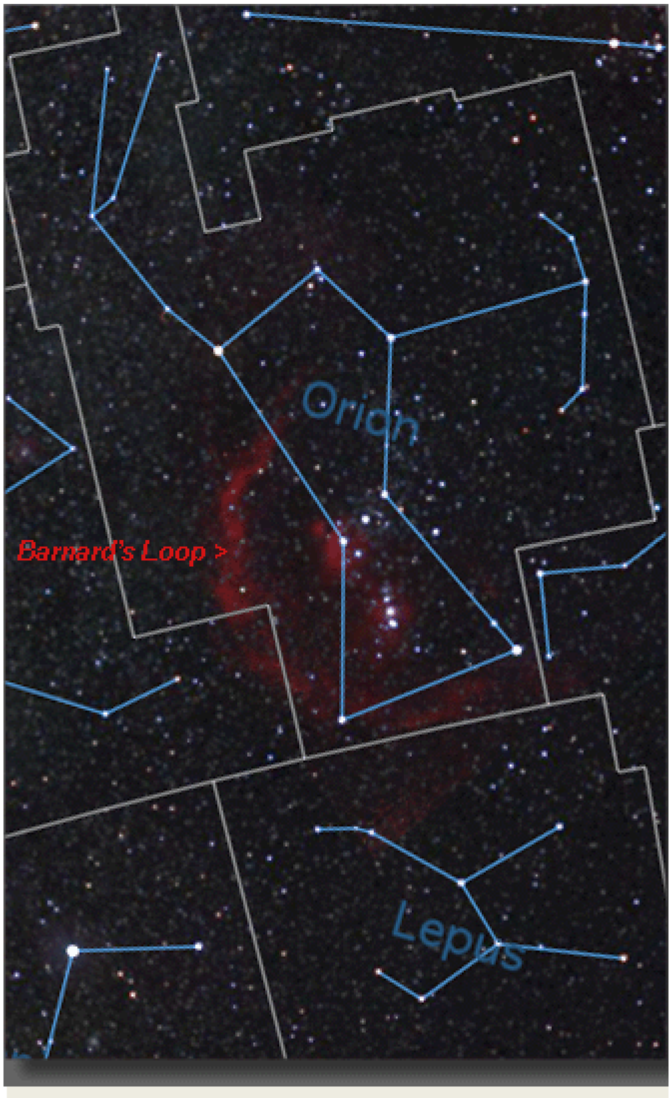


Figure 4. Where to find Barnard's Loop

Figure 5. Barnard's Loop: 10 × 3-minute exposures with a modified Canon 300D

Many thanks to Rich Richins (www.enchantedskies.net) for permission to use his images.

Observing notes: There are many reports on the web from amateur observers who have seen and traced much of Barnard's Loop visually using instruments as small as a 3-inch refractor, with a **hydrogen-alpha or –beta filter** giving greater clarity. Dark skies very definitely help, as do low magnification, good dark adaptation, averted vision and patience. If you don't have a Hα or Hβ filter, a **UHC** (ultra-high contrast) filter is well worth trying and is usually much cheaper.

One observer commented that very good, starfield-filled views can be had with 10 × 50 binoculars with appropriate material across either the eyepieces or the objective lenses. If that's too messy to contemplate but you have one of the filters mentioned above, try to get to a dark site and put the filter up to your naked eye. This has worked for some observers.

Note that the Loop is not of consistent brightness and density, so you may be able to detect some parts but not others.

A DSLR seems the ideal camera for the wide-field photography necessary to capture a sizeable part of the Loop. For instance, Figure 5 was formed from 10 × 3-minute exposures using a modified Canon 300D (further technical details are on Rich Richins's website – see the link below the figure).

- **The BARNARD CATALOGUE**, more properly known as the *Barnard Catalogue of Dark Markings in the Sky*, was the triumphant realisation of Barnard's skills as a relatively early astrophotographer. Barnard took many long (2–5-hour) exposures of the Milky Way, which revealed what he at first thought were dark holes and lanes but later came to realise were clouds of interstellar gas and dust that obscured the stars behind them in line of sight. Following an eight-month working visit to Mount Wilson Observatory in California, he selected some of the best of these for publication in *A Photographic Atlas of Selected Regions of the Milky Way* – by all accounts a beautiful book, not least because the obsessively perfectionist Barnard personally inspected each print in every one of the 700 copies distributed. The searchable plates of this and a later augmented edition of the catalogue, along with Barnard's introduction, can be found reproduced in the Georgia Tech Collection. Clicking on 'Intro' there, you can also find a typically appreciative and well-written account of Barnard, and in particular his dark-nebulae work, by one of my personal astronomical heroes, Alan Sandage, who calls the *Atlas* 'one of the gems of astronomical literature'.

  Observing notes: There are many **Barnard objects** from the catalogue that are accessible to (and often well-known by) amateur astronomers. Perhaps the most famous is Barnard 33 – the Horsehead Nebula in Orion, shown in Figure 6…

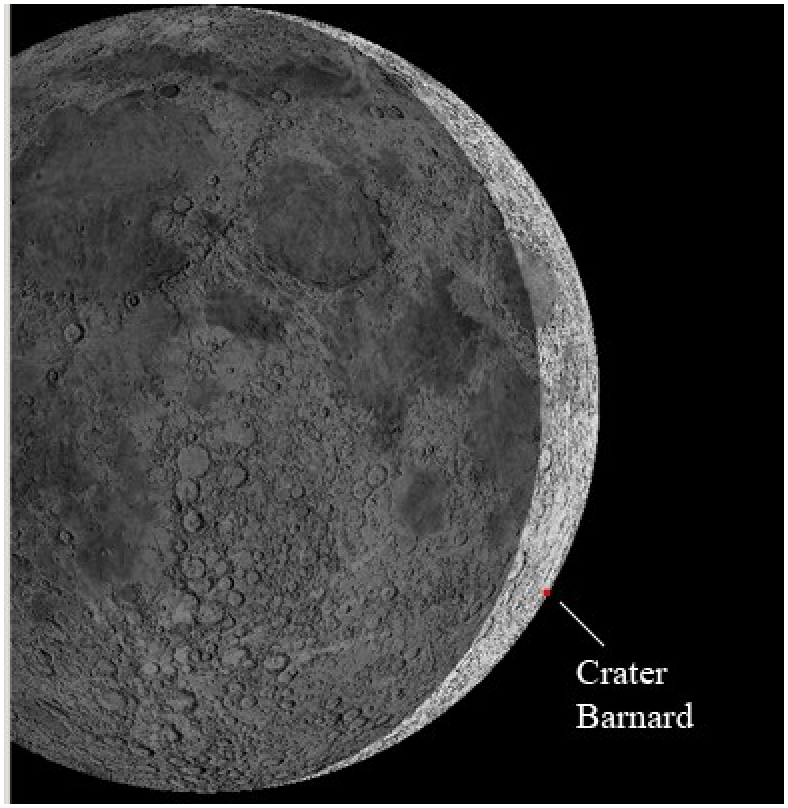
Figure 6. Barnard 33 – the Horsehead Nebula (another image from Rich Richins) RA 05^{h}40^{m}59^s, Dec –02°27'30"

Figure 7. Barnard 68 in Ophiuchus (Astro. Picture of the Day, 11 May 1999 – NASA). RA 17^{h}22^{m}38^s, Dec –23°49'34"

… but there are many others worth looking up and trying to see or photograph – such as the eerie-looking Barnard 68 (Figure 7), so close to us (500 light-years) that not a single star comes between us and it. Observations indicate that it should start collapsing under its own gravitation within about 100,000 years, on its way to becoming a new star.

The first edition of the catalogue in 1919 listed 182 dark nebulae. Barnard died before he could complete the second edition, but his work was completed in 1927 by a relative, Mary Calvert, and the Director of Yerkes Observatory, Edwin Frost, when a total of 369 objects were listed.

- **CRATER BARNARD** on the Moon. Although 105 km wide, it's on the extreme south-east rim of the Moon (longitude 86.4° East) and thus a tricky spot. The easiest approach is to find the much larger crater Humboldt, about which Wikipedia says, *'Due to foreshortening this formation has an extremely oblong appearance. The actual shape of the crater is an irregular circle, with a significant indentation along the southeastern rim where the prominent crater Barnard intrudes*.' Both craters are best seen either two days after New Moon or one day after Full Moon. Virtual Moon Atlas (from which this screen grab is taken) says endearingly that Crater Barnard has a 'very tormented floor'.



Other Barnard achievements

Barnard discovered or co-discovered many comets – the exact number seems to depend on which reference you read, but there were at least 17 and probably getting on for 30. D/1892 T1 (Barnard) was the first comet ever to be discovered by photography; it was subsequently lost (which is what the 'D' prefix means) but twenty orbital revolutions later was rediscovered in 2008, so it is now more properly called 206P/Barnard–Boattini (the 'P' meaning 'periodic'). It will next reach **perihelion** on 27 August this year – the BAA Handbook predicts that it will peak at 19th magnitude, so don't get your hopes up for another Great Comet.

The webpage at www.klima-luft.de/steinicke/ngcic/persons/barnard.htm contains a full and impressive list of Barnard's deep-space discoveries. They include 66 galaxies, 25 emission nebulae, 15 reflection nebulae, 8 open clusters and 7 planetary nebulae, the great majority being visual discoveries.

As you might expect, subsequent generations have honoured Edward Emerson Barnard by naming a few solar system objects after him. In addition to the lunar crater that bears his name, Mars has another one, and there's an asteroid 819 Barnardiana and a Barnard Regio on Ganymede. Not bad for someone with only a few months' formal education.

Further reading

There are delightful anecdotes in a warm obituary in *The Observatory* from 1923 by his friend and colleague Samuel Mitchell. One story in particular will touch the heart of anyone who has struggled to set up well-adjusted observing kit on a cold night, only to look up at the end of the process and realise the clouds have come in. If I have space, I might include it in next month's *Transit.*

Please send in images or drawings you have for any of the objects listed above, including any of the 367 other dark nebulae in Barnard's catalogue. What other Barnard objects have you found out about that could interest other readers?

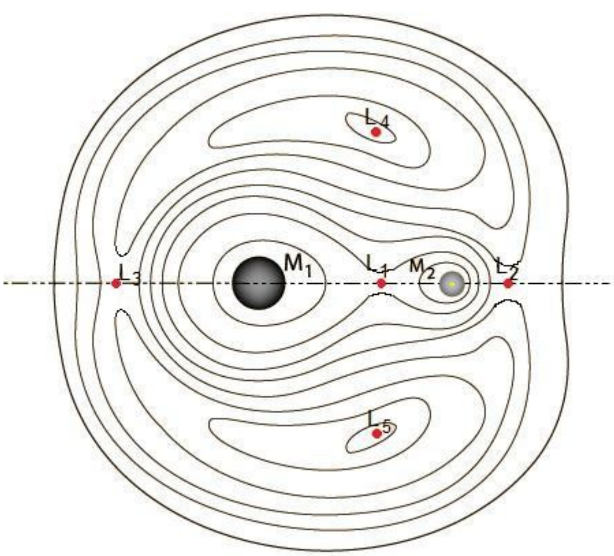
GENERAL ARTICLES

Some thoughts on gravity and tides
Part 4: Lagrangian points

Ray Brown

Where two large masses M_1 and M_2, such as Earth and the Moon, are in circular orbits around a **barycentre** (centre of mass) B, there are a total of five **Lagrangian points**: special positions in the orbital plane where a third body of relatively negligible mass m can be located so that its combined gravitational attractions to M_1 and M_2 enable it to orbit around the barycentre while maintaining a constant position relative to the heavy bodies. Thus if the angular velocities of masses M_1 and M_2 are ω then the angular velocity of mass m at a Lagrangian point must also be ω. Some of the Lagrangian points are of importance and interest as residence sites for man-made satellites in the Earth–Moon system or in the Sun–Earth system and as possible staging posts for manned space missions. Some moons and asteroids within the Solar System occupy other Lagrangian points.

In reality, natural orbits are elliptical, not perfectly circular, so **Lagrangian regions**, or local orbits, should supplement our concept of Lagrangian points.



This diagram shows a contour plot of the effective potential arising from the net effect of combined gravitational attractions of masses M_1 and M_2 and the centripetal force on a particle co-orbiting with them around their barycentre.

Does mass m placed at a Lagrangian point have any tendency to drift away from it?

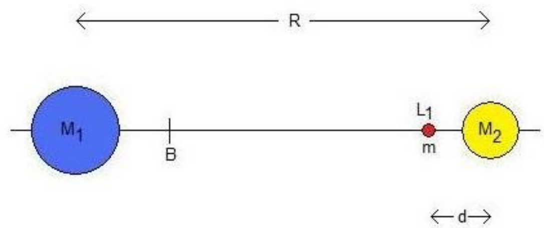
In the cases of L_1, L_2 and L_3, those three of the five points that are co-linear with M_1 and M_2, the mass m does tend to move away along that line in one direction or the other. Maintaining any of these three **metastable** Lagrangian positions is like balancing a ball on a saddle.

So any satellite located there must have the means actively to stay there. The power of its rocket motors needs only be small, but constant correction must always be available.

By contrast, the 'triangular' Lagrangian points L_4 and L_5 correspond to maxima of the local potential and so the metastability applies in *all* directions. Yet paradoxically, as a result of the **Coriolis effect**[1], they do provide regional stability in local orbits – i.e., any drift in position is self-correcting by causing m always to veer sideways from its instant direction. The actual behaviour of mass m placed at L_4 or L_5 is analogous to a ball put in the shallow bowl of an extinct volcano. A satellite put at L_4 or L_5 can be expected to orbit around the point. It has been shown that this 'stability' is conditional upon the mass ratio $M_2/(M_1+M_2) < 0.0385$.

Consider the five Lagrangian points in turn.

Point L_1 lies between masses M_1 and M_2.



Following from an earlier part, the centripetal field required by m is $\omega^2\ [RM_1/(M_1+M_2) - d]$, which must be supplied exactly by the net gravitational field due to M_1 and M_2:

$$G\ [M_1/(R-d)^2 - M_2/d^2]$$

But in that earlier part we showed that

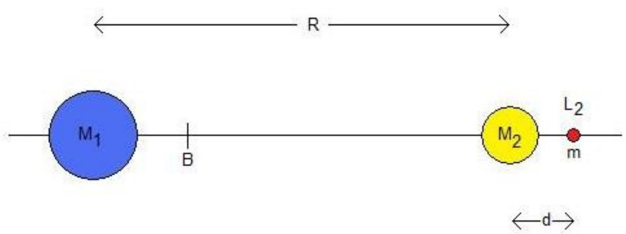
$$R^3\omega^2 = G\ (M_1 + M_2) \qquad (4)$$

So $$G/\omega^2 = R^3/ M_1 + M_2) = [RM_1/(M_1+M_2) - d] / [M_1/(R-d)^2 - M_2/d^2] \qquad (5)$$

Eqn. 5 shows how d depends on R, M_1 and M_2. If masses M_1 and M_2 differ greatly in size (as in the examples of the Earth being 81 times heavier than the Moon and of the Sun being 3×10^5 times the mass of Earth) then $M_1 >> M_2$ and eqn. 5 can be approximated to

$$d \approx R\ (M_2/3M_1)^{1/3} \qquad (6)$$

The **second Lagrangian point L_2** lies outside the orbit of M_2.



Now the centripetal field required by m is $\omega^2\ [RM_1/(M_1+M_2) + d]$, which must be supplied exactly by the net gravitational field due to M_1 and M_2.

$$= G\ [M_1/(R+d)^2 + M_2/d^2]$$

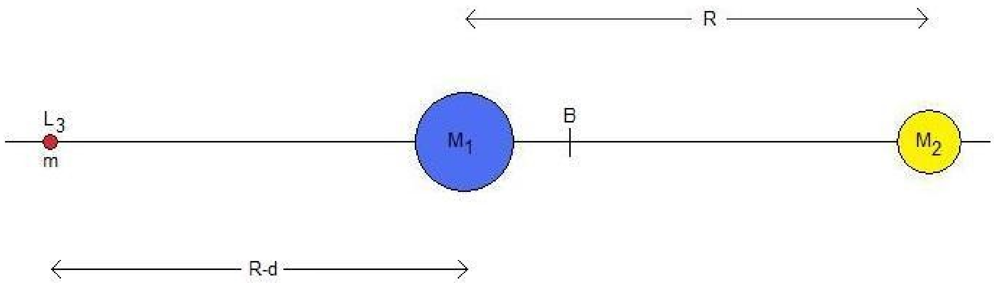
---

[1] *If m drifts radially outwards towards a larger orbit its angular velocity ω necessarily falls so that it moves backwards in the rotating frame of reference. The consequent drop in the centripetal force in relation to the net gravitational attraction by M_1 and M_2 cause* m *to turn back to a smaller orbit. Should* m *drift radially towards a smaller orbit then* ω *increases, so throwing* m *outwards. The net effect is a stable local orbit around the L_4 or L_5 point*.

Again using eqn. 4 and eliminating G/ω^2, we obtain an expression for d in terms of R, M_1 and M_2. As in the case of L_1, if $M_1 >> M_2$ the same approximate result is obtained:

$$d \approx R\,(M_2/3M_1)^{1/3} \qquad (6)$$

Using eqn. 6, we calculate that the L_1 and L_2 points of the Sun–Earth system lie 1.5×10^6 km from Earth and those for the Earth–Moon system lie 6×10^4 km from the Moon.



Lagrangian point L_3 is shown above. Now the centripetal field required by m is

$$\omega^2\,[RM_2/(M_1+M_2) + R - d]$$

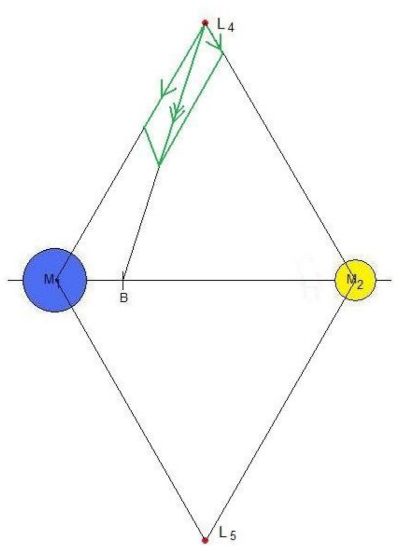
which must be supplied exactly by the net gravitational field due to M_1 and M_2

$$= G\,[M_1/(R-d)^2 + M_2/(2R-d)^2]$$

Again eliminating G/ω^2, we obtain an expression for d in terms of R, M_1 and M_2 that in cases when $M_1 >> M_2$ can be simplified to give the approximate result

$$d \approx 7RM_2/12M_1$$

Although the net force fields at points L_1, L_2 and L_3 are zero, we can show by differential calculus that the field *gradients* along the line of centres of mass are *not* zero, so these three co-linear points, despite being stable against displacement in the direction of rotation (tangential to the orbit), are only metastable along the line of centres of mass; the smallest perturbation from any of these positions will prompt a runaway from equilibrium.



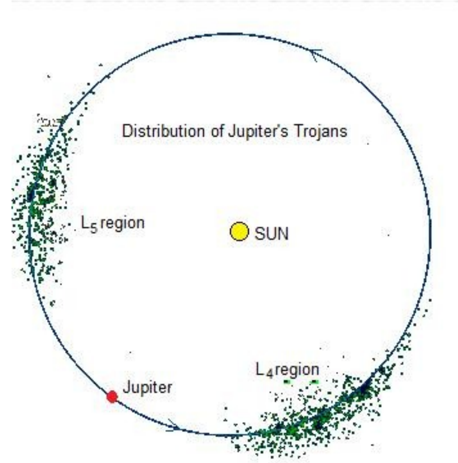
L_4 and L_5 are each located at the third corner of an equilateral triangle, with M_1 and M_2 being at the other corners.

As L_4 is equidistant from M_1 and M_2, the gravitational attractive forces that they exert on m are directly proportional to their respective masses, M_1 and M_2. But the distances of M_1 and M_2 from the barycentre B are inversely proportional to their respective masses. So the resultant force on m due to M_1 and M_2 acts towards B, causing m to orbit around B.

Furthermore, geometry also requires that, for each of the three masses, the ratio of the resultant force field it experiences to its distance from B is the same for all, so they all have a common orbital period.

As is the case with the co-linear Lagrangian regions, multiple occupancy of L_4 and L_5 regions by bodies in local orbits is common.

As moons, asteroids etc have no motors and technology to keep them on station, they cannot hold to the co-linear Lagrangian regions, so in the natural world only L_4 and L_5 are important. Best known are the almost 5000 Trojan asteroids that inhabit the L_4 and L_5 regions of Jupiter. Likewise, the Sun–Mars system has four Trojans, the Sun–Neptune system has nine and the Sun–Uranus system has one.



The L_4 region of the Sun–Earth system hosts the 300-metre-diameter Trojan 2010 TK_7.

Some minor moons of Saturn sit at triangular Lagrangian points of the planet and its major moons; thus Helene is at the L_4 point of Dione, and Polydeuces at its L_5 point. Likewise, Telesto occupies the L_4 point of Tethys, and Calypso its L_5 point.

Man-made satellites make use of L_1 and L_2. The L_2 region is ideal for astronomical studies and so has been or will be home to WMAP, Herschel, Planck, Gaia and James Webb. Here the Sun is 85% occulted by Earth, allowing just enough sunlight to power the solar cells while shielding the equipment to provide dark sky and to avoid overheating. The L_1 region conveniently accommodates the space-weather satellites SOHO, ACE and WIND, all of which have local orbits that circle L_1 but do not intersect the Earth–Sun line, so that equipment on Earth is free from direct solar glare.

With the exception of science fiction authors, neither man nor nature has so far shown much interest in L_3 positions. Indeed, for the Sun–Earth system it is likely to be an unsuitable station because of interference by other planets, notably Venus.

For simple animations, see www.esa.int/Our_Activities/Operations/What_are_Lagrange_points

For further reading, see www.physics.montana.edu/faculty/cornish/lagrange.pdf or www.merlyn.demon.co.uk/gravity4.htm

Next month: Part 5, the last in this series, will discuss ***how Einstein changed the scene****.*

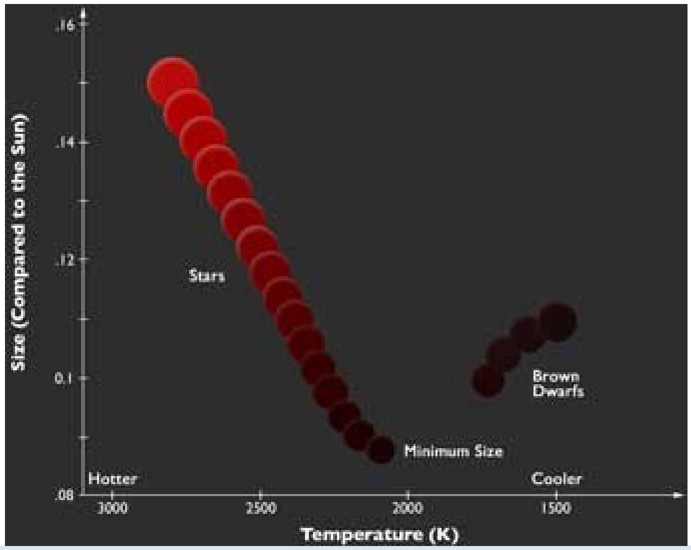
New cutoff for star sizes

John Bochanski, Sky & Telescope

Astronomers have found a gap between 'real' and 'failed' stars.

What does the smallest star look like? This question is deceptively difficult to answer. Stars spend most of their lives fusing hydrogen in their cores, a prime time of life called the **main sequence**. As you go down the scale of stellar sizes on this sequence, stars become dimmer, cooler and less massive. But determining the absolute properties of the smallest stars — their mass, radius, temperature and overall light output — is challenging for at least three big reasons.

First, these stars are extraordinarily dim: even the brightest low-mass stars produce only a few percent of the light seen from the Sun. Second, their atmospheres are very cool, meaning many types of molecules can survive there. Those molecular species make the stars' spectra much more difficult to understand than those of their high-mass counterparts. And last but not least, the smallest stars have colours and brightnesses similar to the largest 'failed stars', which astronomers call **brown dwarfs**.



This diagram shows the relation between size (compared with the Sun) and temperature (kelvin) for stars and brown dwarfs. As astronomers suspected, there's a clear gap between where stars end and brown dwarfs begin. Click here for zoom.

P. Marenfeld & NOAO / AURA / NSF

Brown dwarfs are lightweight objects, generally not more than eight percent of the Sun's mass. They do not have enough mass to create the high internal temperatures and pressures needed to sustain nuclear fusion in their cores.

For objects with surface temperatures near 2000 K (or about one-third that of the Sun), discriminating between stars and brown dwarfs has been extraordinarily difficult. Now, new results accepted for publication in the *Astronomical Journal* point to a clear demarcation between 'successful' and failed stars.

Sergio Dieterich (Georgia State University) and colleagues assembled a wealth of data on 63 nearby low-mass stars and brown dwarfs. The team meticulously measured distances to each of the objects, along with their colours in multiple optical and infrared wavelengths. Combining the distances, colours and brightnesses in each wavelength filter, they were able to estimate each object's temperature, radius and luminosity by comparing it with expectations from cutting-edge models of what stars look like on the main sequence. The astronomers verified their method by comparing their computed sizes with a handful of radii measured directly using **very-long-baseline interferometry**, a technique that allows astronomers to link telescopic observations together to achieve high-resolution measurements.

A star's (or a brown dwarf's) radius is related to its brightness and its surface temperature. Dieterich's team examined the radius–luminosity and radius–temperature distributions, searching for a gap in sizes that would mark a break between the smallest stars and the largest brown dwarfs. Astronomers expect this gap to exist because, although stars' and brown dwarfs' radii are related to their luminosities and temperatures, they're related in opposite ways: if you increased the mass of a star, it would respond by growing in size; a brown dwarf would shrink.

And the search turned up a gap. 'We see that radius decreases with decreasing temperature, as expected for stars, until we reach a temperature of about 2100 K', says Dieterich. 'There we see a gap with no objects, and then the radius starts to increase with decreasing temperature, as we expect for brown dwarfs.'

'We can now point to a temperature (2100 K), radius (8.7% that of our Sun) and luminosity (1/8000th of the Sun) and say, "The main sequence ends there"', co-author Todd Henry (Georgia State University) adds. 'And we can identify a particular star (with the designation 2MASS J0513–1403) as a representative of the smallest stars.'

Determining the boundary between brown dwarfs and stars is not only interesting to those who study these objects, but it is also important in searches for new exoplanets. Low-mass stars have become increasingly attractive targets for planet searches for many reasons. They are common, are long-lived and have habitable zones nestled closer around them than more massive stars do, often making any planets within those zones easier to detect. But brown dwarfs cool with age, so they would make poor hosts to planets — just imagine what would happen on Earth if the Sun became 20% cooler every 100 million years! Planet hunters can use these new results to ignore any brown dwarfs masquerading as small host stars, limiting their searches to systems with planets that could actually be habitable for several billion years.

Reference:

S.B. Dieterich *et al*. The Solar Neighborhood XXXII. The Hydrogen Burning Limit. *Astronomical Journal*, in press.

[Ed: This content distributed by the AAVSO Writer's Bureau. Dr Bochanski is Visiting Assistant Professor at Haverford College in the Greater Philadelphia Area, Pennsylvania.]

THE TRANSIT QUIZ

Answers to December's quiz

Every answer starts with the letter K. The questions are in very rough order of increasing difficulty.

1. He proposed what might have been the Thomson scale. **Lord Kelvin (1824–1907), born William Thomson.**
2. The distance at which a star would subtend a parallax of 0.001 arcsec. **Kiloparsec.**
3. Tycho Brahe's even more famous assistant. **Johannes Kepler (1571–1630).**
4. Popular type of eyepiece with large eye relief – essentially, a modified Ramsden design. **Kellner, after its inventor Carl Kellner (1826–55).**
5. Popular name for the shape marked out by ε, ζ, η and π Herculis. **Keystone.**
6. A group of comets with similar orbits and a perihelion distance within 0.01 AU (about a million miles). **Kreutz sungrazers, first recognised by Heinrich Carl Friedrich Kreutz (1854–1907) in 1888.**
7. Essentially empty regions of the asteroid belt at 2.5, 2.95 and 3.3 AU, caused by resonances due to Jupiter's gravity. **Kirkwood gaps, first recognised by Daniel Kirkwood (1814–95).**

8. The US national research facility for ground-based optical astronomy. It has the most diverse collection on Earth of telescopes for optical and infrared astronomy and daytime solar studies. **Kitt Peak National Observatory, in Arizona.**
9. German physicist who, with Robert Bunsen (1811–99), developed the principles and techniques of astronomical spectroscopy. **Gustav Robert Kirchhoff (1824–87).**
10. Inventor of the term 'contact binary', director of Yerkes Observatory, discoverer of Titan's atmosphere, carbon dioxide in Mars' atmosphere, and methane in the atmospheres of Uranus and Neptune. But you'll probably know his name for another reason … **Gerard Peter Kuiper (1905–73), co-proposer of the existence (later proved) of the Edgeworth–Kuiper belt, the planetary debris belt beyond Neptune (30 AU) and out to around 1000 AU.**

January's quiz

Every answer starts with the letter L. The questions are in very rough order of increasing difficulty.

1. An oscillation of a celestial object around some mean position.
2. Celestial body containing the Tarantula Nebula.
3. A period of intense cratering during the final stages of Solar System planetary formation about 3.8–4 billion years ago.
4. A galaxy with a central bulge and disk, but no spiral arms.
5. Generally accepted as the inventor of the telescope.
6. M76.
7. The two Soviet Moon vehicles that were the first automated rovers to operate on another world.
8. The first site occupied by the European Southern Observatory (ESO).
9. Discoverer of the period–luminosity relation for Cepheid variable stars.
10. Constellation whose 'alpha' star is Zuben el Genubi.