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Roger Hill, Editor

My focuser is working nicely and is ready to go. The two tiny screws I needed from Halton Industrial Supply (great people) worked properly, but I still couldn't get the coupler (the aluminum adapter shown here on the bottom end of the focuser shaft) tightened down as much as I wanted. A quick chat with Les Nagy, though, solved that one. He suggested coating the two shafts with epoxy, or Loctite, rather than trying to shim the shaft to make it slightly larger. I was worried about the epoxy, though, as that could have made the shaft too big, so I used some clear nail polish, instead, and that worked perfectly.

The focuser is now a treat to use. L can look through an eyepiece, or the camera viewfinder, loosen the tension knob, and then focus manually. The tension knob is then tightened, and the stepper motor is then used to get exact focus, which would be even easier if I had a Bahtinov mask. Fortunately, there's a place in Toronto that makes them : http://www.kendrickastro.com/kwikfocus.html . I made my own for my 300mm f/4 telephoto lens, and I have one (made by Kendricks) for my 12" SCT, so I know how well they work.

The next thing I want to do is work on the EQ5 mount that I have. I'd really like to add stepper motors to it, and I certainly have a few spare motors around. I'll probably see what I can do with EQAstro: https://www.astroeq.co.uk/tutorials.php?link=/doku/doku.php?id=custommotors . My daughter will be coming over from the U.K. for Christmas, so she can bring the device with her, and I can save a bit on shipping. The rest of the materials, like the motor brackets, screws, pulleys, drive belts, etc., I can source in North America.

By the time I'm done, I hope to have a very portable beautifully tracking GOTO mount with a 6" RC on it. It should be perfect for the eclipse in the USA next year.

The 2017 eclipse will be the fourth trip to the Shadow of the Moon for me, and I hope for two more beyond that: April 2024 in (probably) Texas, and 2019 outside of La Serena in Chile. It is this latter one that I'm most excited about, as I expect it to be my third trip to Chile. The first two were a couple of the astronomical highlights of my life. Les Nagy also features prominently in some of the other events, too, like the Texas Star Party, and seeing 9 planets in less than 24 hours. So, going down to Chile is just something I have to do every few years (or less!).

And so ends my ninth year of editing Orbit. I've now done 88 issues (illness prevented two being produced). One of these months, I'll get around to producing an index to them all. I'd like to carry on doing this for another two years, so I can do the 50th Anniversary issue, as well as doing over 100. Eric Golding and Bob Speck each have a copy of every issue of Orbit. I hope to be able to scan in all of them, possibly use OCR (Optical Character Recognition) so they can be catalogued and searched! That, I think, would be a fitting tribute to all of the editors who have preceded me, and a nice present to all the members who will come afterwards.

Roger

Presidents Message
October 2016

Elections

It's that time of year again when we elect our Board of Directors. I hope you will all be at our October 6 meeting to say a big thank you to the members of the outgoing Board who have contributed their valuable time towards reaching our goals.

We have 2 people who will be retiring from the board:

> **Andy Blanchard** has held a board position more than a decade now. Andy has served in a number of roles, including past President, and most of you know him as the driving force behind ASTROCATS and many other projects. Andy will continue to work on several of our long-term objectives.
>
> **John Devonshire** has devoted several years at a time when his IT skills were especially needed. His day job requires frequent unscheduled travel and can't commit to attending Board meetings, but he has offered to continue supporting our Website and other IT needs. Thank you John!

Most of our current Board of Directors have offered to stand for election again for the next year ahead. And we invite each of you to step forward and make your mark on the direction of our club. With 2 members retiring, we need at least 2 more people to join out Board. Interested? Contact me: gary@bendun.net

Club Events – Let's Do Some Astronomy!

Our observatory is lonely! Let's change that, OK? Ever since I have been a member of RASC Hamilton Centre, it has been assumed that astronomy can't happen unless one of our board members organizes an event. It doesn't take a formal event just to get together and have some fun, so, ***I have a proposal****…… let's organize "clubs" that focus on different areas of interest and give members that ability to organize their own get-togethers.*

I will be sending out a "survey" and ask you to tell us which types of activities you are interested in being part of. Right now, my list of Activities includes:

Visual Observing
Astrophotography
"Real Science" – Exoplanet, etc. Spectroscopic
Solar
Telescope Making
Equipment Clinic
Radio Astronomy
Outreach: Sidewalk Astronomy / Youth (Scouts, schools)

Give special consideration to being part of our Outreach group. You will have more fun being part of this group than any other. Don't be shy… even a "newbie" knows more about astronomy than the average person and we now own equipment that doesn't require any experience (auto-align). In fact, we have 3 telescopes that are reserved for outreach only. ***Special reward….*** outreach volunteers get to borrow this equipment.

Of course, the Board of Directors will still organize major events such as Observatory Training or Lunar/Solar Eclipse observing, etc.

Observatory Keys

My personal goal for the upcoming year….. EVERY qualified member will have their own key to the observatory. If you have been a member for 1-year, that means YOU! All it takes is a 1-evening training session.

See you on October 6

Gary Bennett

President, RASC Hamilton Centre

One Incredible Galaxy Cluster Yields Two Types of Gravitational Lenses

By Ethan Siegel

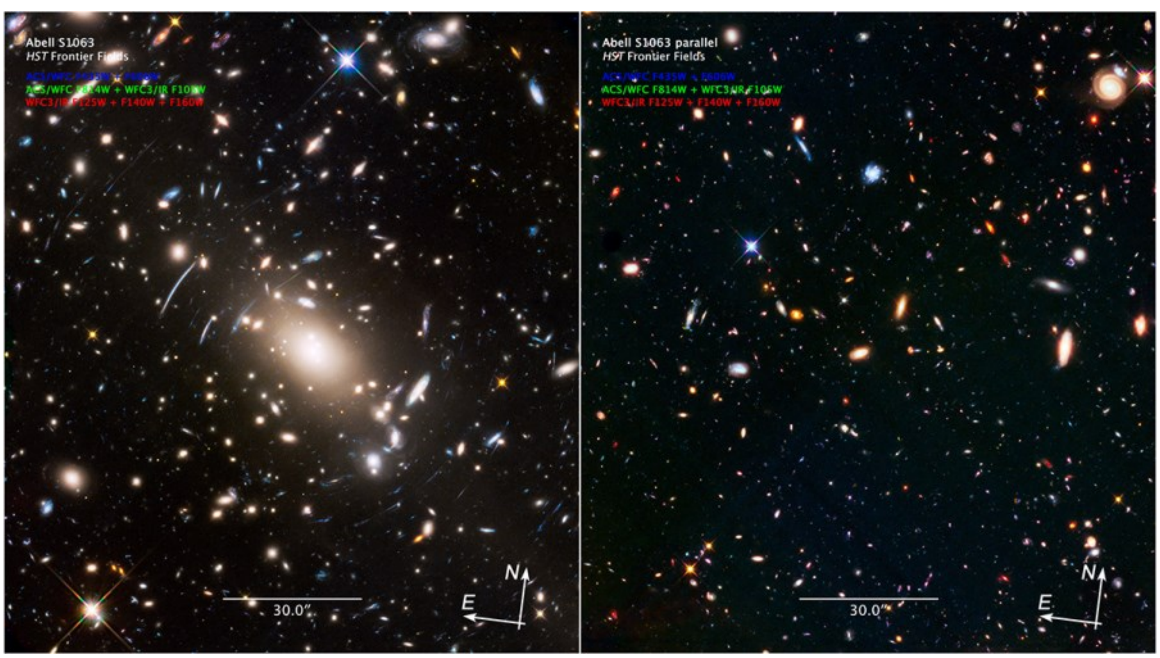
There is this great idea that if you look hard enough and long enough at any region of space, your line of sight will eventually run into a luminous object: a star, a galaxy or a cluster of galaxies. In reality, the universe is finite in age, so this isn't quite the case. There are objects that emit light from the past 13.7 billion years—99 percent of the age of the universe—but none before that. Even in theory, there are no stars or galaxies to see beyond that time, as light is limited by the amount of time it has to travel.
But with the advent of large, powerful space telescopes that can collect data for the equivalent of millions of seconds of observing time, in both visible light and infrared wavelengths, we can see nearly to the edge of all that's accessible to us.

The most massive compact, bound structures in the universe are galaxy clusters that are hundreds or even thousands of times the mass of the Milky Way. One of them, Abell S1063, was the target of a recent set of Hubble Space Telescope observations as part of the Frontier Fields program. While the Advanced Camera for Surveys instrument imaged the cluster, another instrument, the Wide Field Camera 3, used an optical trick to image a parallel field, offset by just a few arc minutes. Then the technique was reversed, giving us an unprecedentedly deep view of two closely aligned fields simultaneously, with wavelengths ranging from 435 to 1600 nanometers.

With a huge, towering galaxy cluster in one field and no comparably massive objects in the other, the effects of both weak and strong gravitational lensing are readily apparent. The galaxy cluster—over 100 trillion times the mass of our sun—warps the fabric of space. This causes background light to bend around it, converging on our eyes another four billion light years away. From behind the cluster, the light from distant galaxies is stretched, magnified, distorted, and bent into arcs and multiple images: a classic example of strong gravitational lensing. But in a subtler fashion, the less optimally aligned galaxies are distorted as well; they are stretched into elliptical shapes along concentric circles surrounding the cluster.

A visual inspection yields more of these tangential alignments than radial ones in the cluster field, while the parallel field exhibits no such shape distortion. This effect, known as weak gravitational lensing, is a very powerful technique for obtaining galaxy cluster masses independent of any other conditions. In this serendipitous image, both types of lensing can be discerned by the naked eye. When the James Webb Space Telescope launches in 2018, gravitational lensing may well empower us to see all the way back to the very first stars and galaxies.

If you're interested in teaching kids about how these large telescopes "see," be sure to see our article on this topic at the NASA Space Place: http://spaceplace.nasa.gov/telescope-mirrors/en/



Galaxy cluster Abell S1063 (left) as imaged with the Hubble Space Telescope as part of the Frontier Fields program. The distorted images of the background galaxies are a consequence of the warped space dues to Einstein's general relativity; the parallel field (right) shows no such effects. Image credit: NASA, ESA and Jennifer Lotz (STScI)

I am Rosetta, property of the European Space Agency, and today I die

I'm a spacecraft and I'm about crash into a comet. On any other day, this news would have set off alarm bells on Earth and caused crews of engineers to try to fix my trajectory. Instead, today, these engineers will sit back and watch me die.

Death is not something I understand. You go from being active to being inactive. All the electrons running through your copper cables and silicon chips come to a halt and then there's… nothing?

I thought I understood what nothing meant. Between leaving Earth in 2004 and arriving at comet 67P Churyumov-Gerasimenko in 2014, I was put in hibernation for much of the journey. I spent a lot of time doing nothing and experiencing nothing. But death will be different. Unlike coming out of hibernation, this time there will be no going back.

I've spent a long time thinking about this moment, and I've not made much progress. So, in my last note, instead of brooding about the nothingness that is to come, it's perhaps better to reflect on what I've experienced.

The goals of my mission to 67P were simple: reach the comet, send the little lander *Philae* to land on it, and observe as much as I could from a distance about how comets behave. Perhaps most exciting was that, among the handful of missions ever sent to a comet, mine was going to be the most ambitious.

Comets are unlike any other celestial body we've observed. They acquire beautiful long tails as they pass by the Earth. And, yet, despite our having studied them for centuries, comets still hold so many mysteries. They were created from the remnants of the matter that became the solar system's planets. But during their formation, they were thrown to the edge of the solar system, where they preserved their pristine state for millions of years.

In my two years orbiting 67P, I've made observations and discoveries that have already changed our understanding of comets. I sampled 67P's indescribably thin atmosphere, studied its magnetic field, understood what its dust grains were made of, and even tasted its water.

Though scientists on Earth are still making sense of this data, they've already made two big discoveries. First, the water on 67P was not the same as that on Earth. This puts into question a popular theory that Earth got its water when comets crashed into it during the planet's early years. Second, I found that 67P had compounds that are crucial to life on Earth. So even if comets didn't seed Earth with water, they might have seeded it with the ingredients for making life.

The brave lander I sent to the surface of 67P had quite a tale to tell of its own. After a landing mishap, though *Philae* performed its most crucial duties, I was forced to leave it for dead while I continued my mission. Fortunately, shortly before my own end was to come, I found it lying in a corner of the comet.

In the last few months, my mission goals changed. The engineers found that as 67P and I traveled farther away from the sun, my solar cells weren't capturing enough energy to keep me functioning. I asked if I could be put into hibernation again and wait for a chance at revival when, along with the comet, I come nearer the sun again in 2022. But I was told that there's little chance of surviving such hibernation in empty space with no power in my batteries.

So now my final task is to crash-land on the comet. For a change, instead of observing from a distance, in my final moments I'll get close to the celestial body I've been chasing all my life. In the process, I'll send even more valuable data back to Earth. It's a fitting end… even though I still don't understand what "end" means.

Farewell,
Rosetta

From Quartz:
http://qz.com/797173/the-rosetta-spacecrafts-farewell-note-before-it-crashes-into-comet-67p-churyumov-gerasimenko/

Daring Chinese telescope is poised to transform astronomy by David Cyranoski

Set in a remote natural depression in the mountainous region of Guizhou, China, the world's largest single-dish telescope is on the brink of sparking a new era in radio astronomy. But scientists also worry about the daringly complex structure of the Five-hundred-meter Aperture Spherical Radio Telescope (FAST).

"It will be the instrument of choice for any exotic object in its range," says Matthew Bailes, an astrophysicist at the Swinburne University of Technology in Hawthorn, Australia. But "its design is so radical, we're all wondering if it will work."

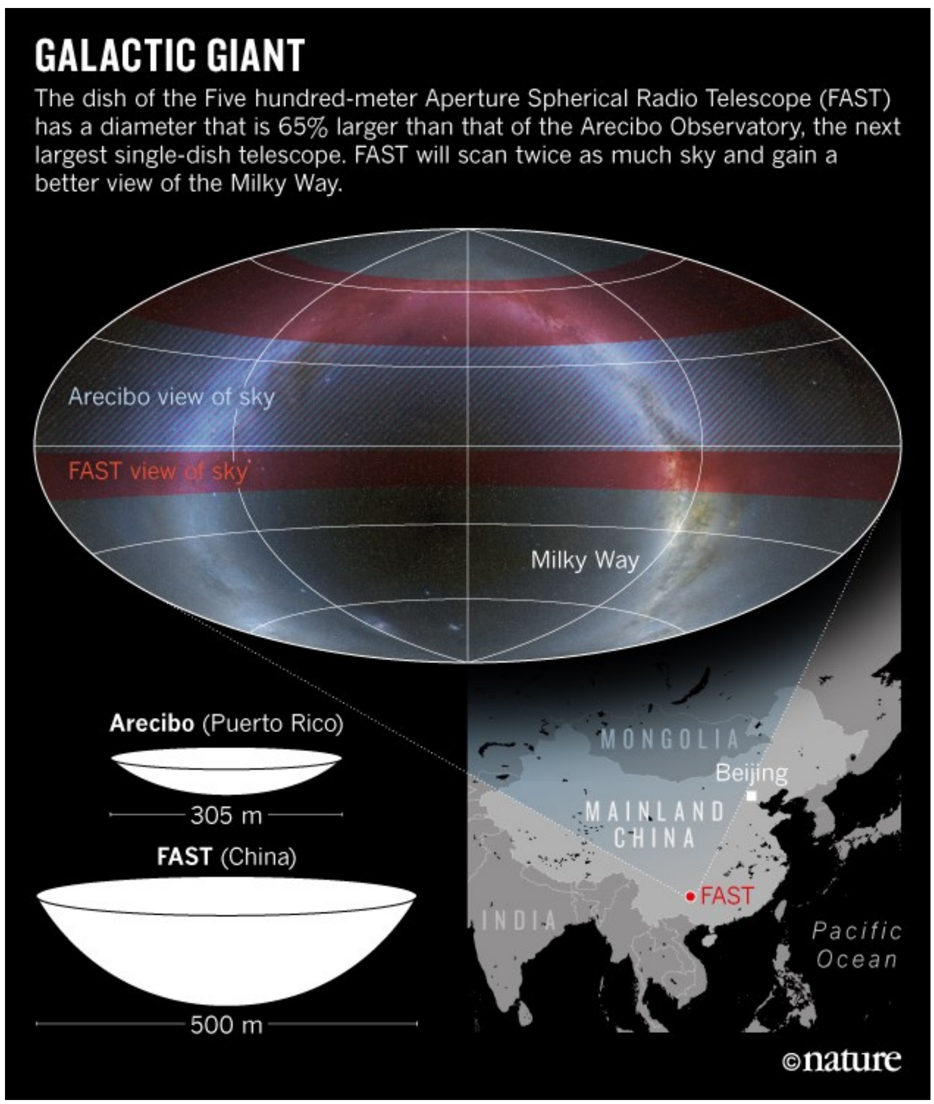
On 25 September, FAST's construction was declared officially complete. Some 200 scientists from around the world attended an inauguration ceremony and got their first look at FAST's preliminary data, which will be used to debug the telescope. That process could take three years or more, says Peng Bo, an astronomer at the National Astronomical Observatories in Beijing and the project's deputy manager.

Then teams from around the world will be able to bid for time to use the telescope, FAST chief scientist Nan Rendong told Nature.

Many observatories are open to international teams, but astronomers were unsure whether FAST would be. "This is critical to achieving the best possible science," says astronomer Jason Hessels at the Netherlands Institute for Radio Astronomy in Amsterdam.

FAST has twice the effective collecting area of the Arecibo Observatory in Puerto Rico and will scan twice as much sky (see 'Galactic giant'). Size matters because many celestial objects are tough to detect. Spinning stars called pulsars and the cosmic clouds of hydrogen that hold clues to the origin of the Universe emit faint signals, whereas mysterious 'fast radio bursts' are transient. A larger -telescope increases the number of signals available, aiding the discovery and characterization of such objects.

Pulsars, which send out periodic bursts of radio waves as they spin, are expected to give FAST its first taste of success. Peng thinks the telescope will more than double the current pulsar count of 2,600. FAST might even uncover the first pulsar with a period of under a millisecond, suggests Shri Kulkarni, an astronomer at the California Institute of Technology in Pasadena. Because pulsars are predicted to break up at around this speed, this "would blow away a number of models of physics of dense matter", he says.



FAST should also detect more ‘millisecond pulsars’, whose regular periods of 1–10 milliseconds mean that they rival atomic clocks as timekeepers, says Kulkarni, who helped discover the first millisecond pulsar using Arecibo. FAST should eventually be able to track them for long enough to reveal distortions in their periods caused by gravitational waves, the ripples in space-time whose direct detection was announced in February.

Nan, who is an astronomer at the National Astronomical Observatories in Beijing, says FAST will also be able to detect molecules from outer space that are suggestive of life, and plans to enlist the telescope in the search for extra-terrestrial intelligence (SETI). The giant telescope is also likely to discover something completely unexpected, say astronomers.

Behind the curve

But FAST’s construction was not easy, and its reliability is not a given. Like Arecibo’s, FAST’s dish curves like a sphere. Such a surface is the simplest and cheapest to build, and means that the dish receives signals from a broad swathe of sky. But unlike steeper ‘parabolic’ dishes, it does not concentrate the signals at one point, and so there is a loss of focus, causing FAST’s designers to opt for a radical solution.

Arecibo has mirrors attached to its dish to correct for the loss of focus, but a similar set-up for FAST would have meant 10,000 tonnes of metal hanging over the dish. Instead, FAST’s surface is made up of some 4,500 panels, some of which can be tilted, raised and lowered by 2,225 actuators to temporarily make it parabolic.

But this makes FAST extremely complicated. The 100-metre-wide parabolic Green Bank Telescope in West Virginia has about 2,000 moving panels to help it maintain its shape, but these usually shift by only a few centimetres, says astronomer D. J. Pisano at West Virginia University in Morgantown, who has studied hydrogen clouds for 10 years using Green Bank. “For FAST they will be moving the panels over distances of metres,” he says. “This is definitely a challenge.”

Even Nan is worried that it could be some time before the telescope is ready to do science. “It’s terrible, terrible, thinking about reliability,” he says. The team has found more than 150 problematic actuators in the months running up to the first testing phase, leading to arguments with the contractors who supplied them. “And it’s not just the actuators,” Nan says. “Everything is difficult, everything is risky.”

Peng is more sanguine and says of Nan: “I’m too optimistic; he’s too sceptical.”

Saga of adventure

Nan, who like Peng has been involved in FAST since its inception in the early 1990s, relates its history like a saga. There was the exhausting lecture circuit to drum up support. There was the lobbying for permission to use ultra-high-resolution GPS to find the best site. And there were the old-school construction methods, which were necessary because the surrounding mountains are too steep for heavy machinery.

But Nan’s despondency belies his excitement. He wrote a poem for a promotional video, and he speaks of the telescope as an almost sacred endeavour. The rock formation on which it sits is “unique on Earth, I promise you”, he says. And he describes FAST’s potential to find clues to alien life as “the possible detection of civilization”.

“We’ll see a lot of beautiful things,” he says. “It’s an adventure.”

An Inexpensive DIY star tracker by Steven Barrett

K2 is a motor-driven star tracker that I designed and built to allow photographs of the night sky to be taken without the photographs showing star trails due to the rotation of the Earth. I wanted to be able to take the star tracker on holiday to Kenya (on the equator) and photograph the skies there that are unaffected by light pollution.

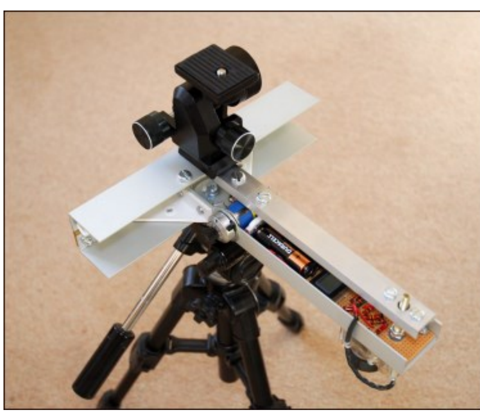
So the star tracker had to be:
- •Compact
- •Light
- •Strong
- •Accurate
- •Battery operated
- •Low power
- •Cheap
- •Easy to construct

In practice, this means:
- •Footprint no larger than a sheet of paper.
- •Less than 1 kg
- •Support a digital SLR camera
- •Exposures of up to 15 minutes
- •No mains electricity in the bush
- •Operate for up to 6 hours
- •Less than about £50 for all components
- •Manual tools + electric screwdriver

Construction

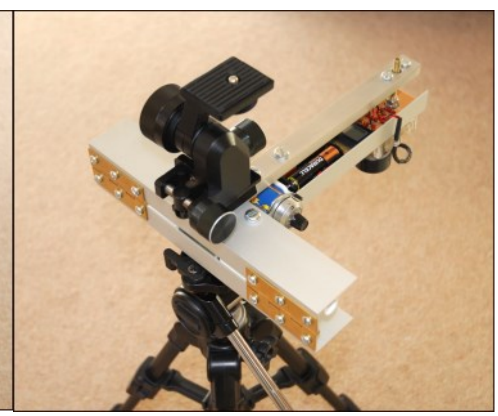
As this was my second star tracker (I built my first one when I was a student at college) I called it K2. I decided to construct K2 from lengths of L-section and U-section aluminum bolted together as this is very strong and very light. The sections make two 'T' shapes, the static base T and the moving top T. The pivot is provided by two brass hinges that connect the two T's together, positioned at the ends of the top bars of the T's. When operating the two T's are pushed apart by a bolt driven at 1 rpm by a small motor and gearbox. The design is optimised for low latitudes (within 20° of the equator), but will also work in the UK (latitude 52°) provided that the camera and lens are not so heavy that they put the whole system out of balance.

The M6 bolt has a 1 mm pitch and is positioned 230 mm from the hinge axis. A nut sits on the bolt and is driven upwards as the bolt rotates (the nut cannot rotate as it is constrained within the U-section arm that forms the length of the top T). Driving the bolt at 1 rpm forces the top T to rotate at approximately 1/230 of a radian per minute, or one revolution per day, to counteract the rotation of the Earth. The design is much more accurate than a conventional tangent drive and much simpler than a double-arm drive. The reason for the high accuracy is explained, with technobabble, at https://www.liverpool.ac.uk/~sdb/Astro/K2/K2-accuracy.html



K2 in operating configuration

K2 opened to show components

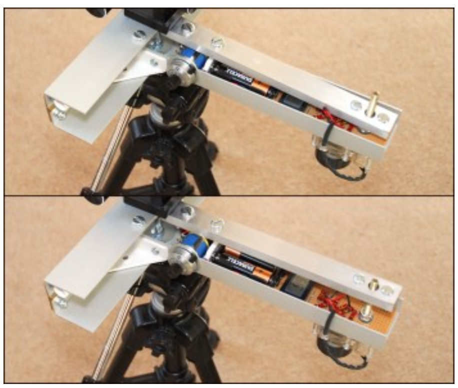


Hinges give a smooth motion

The long arm of the base T is made from two lengths of L-section aluminum bolted together to form a 'U' section of width 40 mm (the width of two AA batteries side-by-side). If my local B&Q store had had some U-section aluminum in stock that was 40 mm wide I would have used that instead. The arm forms a tray in which all the components fit - batteries, switches, potentiometer, voltmeter and circuit board (see close-up image on the right). The motor/gearbox is bolted underneath the end of this arm with the M6 bolt poking through a hole in the arm and in the circuit board. The head of the bolt is filed down to fit snugly into a slot in the gearbox output shaft.

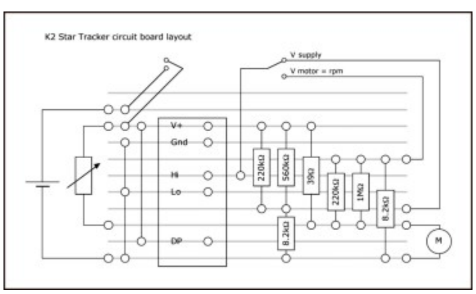
The camera is mounted onto an adjustable mount bolted to the top T, close to the hinge axis. If the hinge axis of K2 is aligned with the Earth's axis, then the camera should follow the stars as they appear to rotate around the sky and hence the stars will not trail when a long-exposure photograph is taken. A plastic tube is fitted to the underside of the top T, parallel to the hinge axis, visible in the image above in which K2 is opened up. This can be used as a sighting tube to align on Polaris when operating in the UK. It does not work in Kenya as Polaris is on the northern horizon and is usually hidden by trees, hills, lions or elephants.

In practise, the tracking accuracy of K2 is determined by the degree of alignment between the hinge axis and the Earth's axis. A polar scope, used in some commercial star trackers, is useless if Polaris is on the horizon. An alternative method of alignment is to use an inclinometer and a compass to set the altitude and azimuth, respectively. A digital inclinometer is accurate to 0.1°, but even a digital compass is only accurate to about 1° and you have to know the offset between magnetic North and true North for your location. Inaccurate polar alignment is the biggest factor that affects the overall tracking accuracy of K2 and I am thinking about ways to improve it.

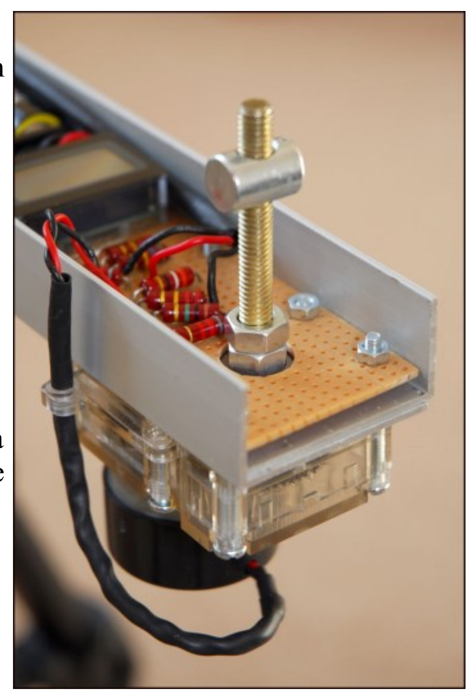


The image on the left shows K2 at the start (top) and end (bottom) of a 15-minute run. The motor has turned the bolt 15 revolutions, pushing the nut 15 mm upwards along the bolt and rotating the top T by about 4° from its starting position. At this point the top T can be lifted off the nut and the nut spun back down the bolt by hand, ready to start another 15-minute run.

Note that the direction of the bolt moves slightly as the top T moves relative to the base T. The nut moving on the bolt is cylindrical (see close-up image below right) and so the contact point on the underside of the top T 'rolls' over the cylinder. Small strips of teflon on the underside of the top T ensure that the contact between the nut and top T is smooth.



The layout of the components inside the base T is shown in the circuit diagram on the left. The potentiometer is in parallel with one of the resistors in the potential divider that drops the battery supply voltage down from 3 V to 2.3 V. This allows the voltage across the motor, and hence the speed of the drive, to be adjusted to compensate for the slow drop in voltage of the batteries as they gradually run down. When starting a photography session, the potentiometer is adjusted until the voltmeter, set to read the voltage across the motor (divided by 2.3), reads 1.000 rpm. Over a 15-minute period, the battery voltage will hardly change at all, but it can be checked at the end of each 15-minute session when the top T is lifted to spin the nut back to its starting position. The voltage supplied by a battery changes with temperature, so it's worth keeping an eye on it over the course of a night as the temperature drops.



As K2 was built with hand tools, I could not guarantee that the dimensions were exactly as per theoretical design. This is not a problem. For instance, if when constructed it turns out that the distance from the drive bolt to the hinge axis is 231 mm, rather than 230 mm, then the motor can be set to drive at 231/230 = 1.004 rpm.

Performance

So, does it work? I have tried it with a Nikon D200 digital SLR and a Sigma 100-300 mm f/4 zoom lens. The combined mass of camera plus lens was about 2 kg, so this was a good test of the rigidity of the system. I took 30 sec exposures rather than anything longer as I was not sure about the alignment of the hinge axis with respect to the Earth's axis.

The images are 600 x 800 pixel areas cropped from the original 10 Mpixel images. They were taken with the zoom lens set to a focal length of 100 mm. They are single exposures (no stacking of multiple frames) and no dark frames were subtracted to reduce the noise levels. Note the red dot in the bottom left corner of each image, a pixel that is not recording the correct light intensity. Such 'hot' pixels would be removed by subtracting a dark frame, which is common practice with astrophotography.

The image taken with K2 switched off shows the extent of trailing that would be expected due to the rotation of the Earth. The image taken with K2 switched on shows essentially no trailing. So, yes, it works.

This image of the Milky Way shows what you can do with K2 and a 35 mm lens from a dark sky site, in this case the Teide Observatory in Tenerife.

Components

The components used to construct K2 are listed below:

2 aluminum sections 200 mm long	L-section 40 x 20 mm for hinged sides of both Ts
2 aluminum sections 250 mm long	L-section 40 x 20 mm for U-section arm of base T
1 aluminum sections 210 mm long	U-section 20 x 10 mm for arm of top T
2 plastic corner braces	To brace junction of base T
1 metal 'T' brace	To brace junction of top T
2 brass hinges	To provide the pivot axis
Motor and gearbox (£25)	http://www.precisionmicrodrives.com - part #256-101*
M6 bolt with barrel nut	60 mm, sold as 'furniture bolt'
2 AA batteries in holder	Standard
2 mini switches	Single pole double throw
Mini LCD voltmeter (£20)	3.5 digit reading 0-1.999 volts - RS stock num 223-199
1 kohm potentiometer	Standard
Resistors	Values will depend on motor - see circuit diagram
Circuit board	100 x 40 mm

* This motor is an integrated motor/gearbox/microswitch. Although the motor and gearbox are ideally suited for the job of driving K2, the integrated microswitch was an unnecessary addition. A cam on the output shaft of the gearbox operated the microswitch every revolution, which caused a small but noticeable periodic error in the motor's speed. If you use a motor like this, I suggest that you remove the microswitch.

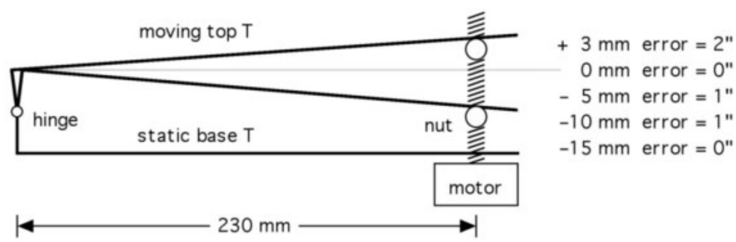
K2 Star Tracker Accuracy

The accuracy of the K2 star tracker is a function of the design of the arms and the drive bolt that moves one relative to the other. K2 is an 'isosceles' drive as the arms and drive bolt form an isosceles triangle, with each arm having the same (fixed) length. This is different to a tangent drive, in which the point at which the drive rod acts moves/slides along the moving arm.

The tracking error is the difference between where the tracker is pointing and where a star is. A single-arm tangent drive which starts the arm rotating at the correct (sidereal) rate of one revolution in 23h 56m will show a tracking error after a few minutes. If the angle through which the arm has turned is theta, then theta is always less than tan(theta) and so if the motor drives the arm such that tan(theta) increases at a constant rate - as a tangent drive does - then the rate at which the arm is rotating will decrease with time. This slow down can be compensated for to a limited extent by running the drive slightly fast so that the point at which the effect of the slow down becomes serious is delayed for a few minutes. Some designs of star tracker use a double-arm drive so that the tangent error can be compensated for more accurately, but this results in a more complex design.

With K2, I took a different approach. The planes in which the drive bolt intercepts the motor (on the static base T) and the drive nut (under the moving top T) do not contain the hinge axis. The hinge axis is offset from these planes by 20 mm. Note that for the first 15 minutes of operation the drive is pushing the two arms **towards** being parallel, not **away** from being parallel.

In the diagram (right) the angles of the moving top T relative to the static base T have been exaggerated for clarity. The distances indicate the position of the top of the cylindrical nut relative to the height that would make the top T parallel to the base T (grey line), together with the total tracking errors at those positions. The nominal 20-minute working range of K2 corresponds to the nut covering the range from -15 mm to +5 mm.



Plotting the tracking error (in arcsec) as a function of time (in minutes) shows the difference between (i) a tangent drive, (ii) a tangent drive with the motor running fast by 0.15%, and (iii) the K2 design. In the diagram above the angles of the moving top T relative to the static base T have been exaggerated for clarity. The distances indicate the position of the top of the cylindrical nut relative to the height that would make the top T parallel to the base T (grey line), together with the total tracking errors at those positions. The nominal 20-minute working range of K2 corresponds to the nut covering the range from -15 mm to +5 mm.

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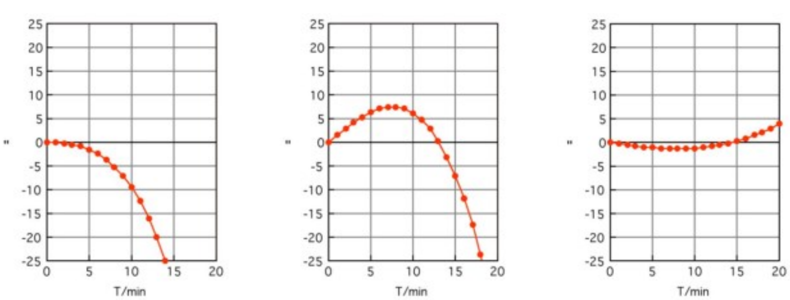
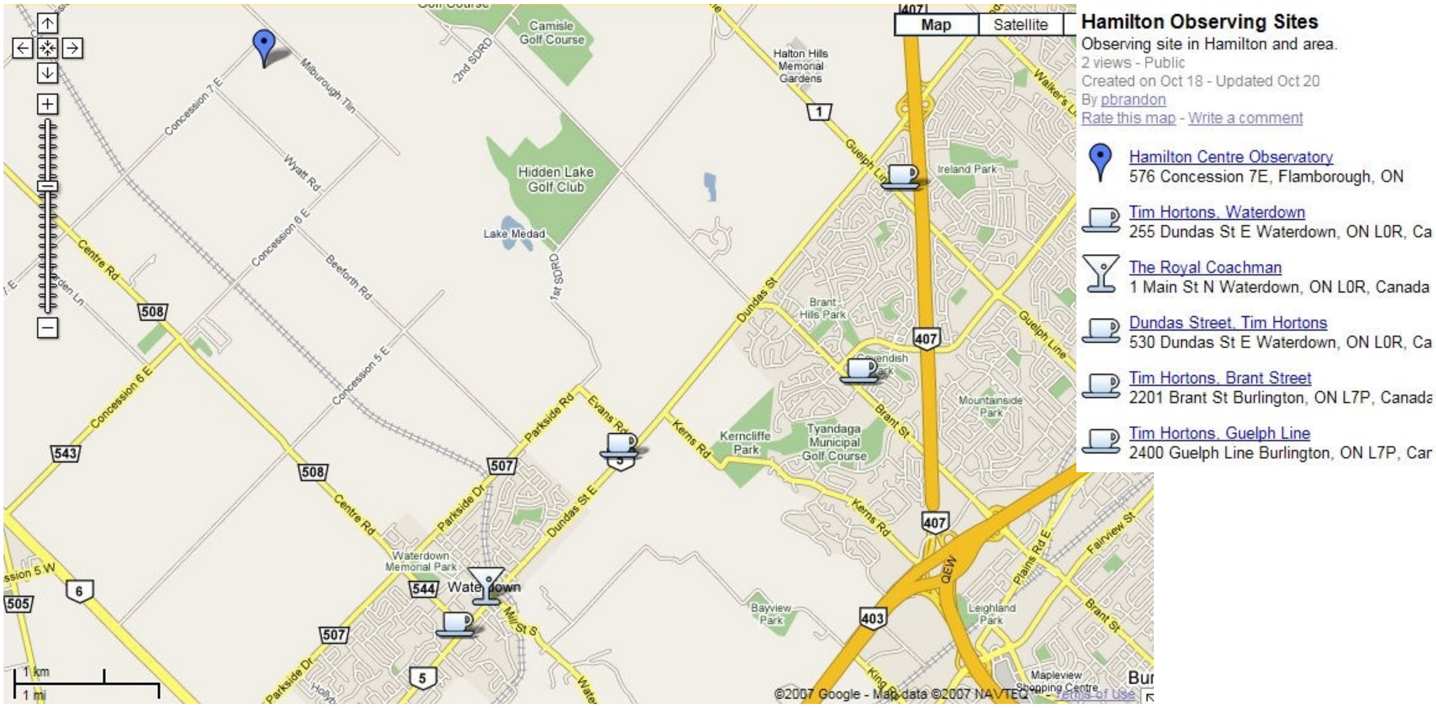


Tangent drive < 10" over 10 minutes

Tangent drive running fast < 8" over 15 minutes

K2 design < 2" over 18 minutes

For a tangent drive (left) the tracking error starts small, but just grows with time. Running the drive fast by 0.15% (middle) produces an initial tracking error of a few arcsec in the first few minutes, but then the tangent error kicks in and the tracking error goes through zero and then grows rapidly. With the K2 design (right) the tracking error can be kept within the range of +/- 2 arcsec over 18 minutes.



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Special Projects	Bob Prociuk
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Youth Outreach	Ed Mizzi

I understand that Andy Blanchard and John Devonshire will be stepping down from the Board at the Annual General Meeting.

I'd like to extend a very grateful "Thanks" for all the work they've done for the Hamilton Centre in the past year.

A volunteer organization such as ours thrives on the active participation of volunteers like Andy and John.

No doubt that both of these fine gentlemen will contribute to the Hamilton Centre in the future, but for now they deserving of our thanks.

Above: Zodiacal light in the Atacama: March 14, 2016, a stack of 10 30-second exposures using 8mm fisheye on modded Canon T1i