REVIEWED

Dwarflab's DWARF II smart telescope

At a glance

Size: 204mm × 62mm × 130mm (excluding tripod)
Weight: 1kg
Battery life: Approximately 3 hours from a swappable internal rechargeable battery or user-supplied external power pack
Aperture (telephoto): 24mm
Focal length: 100mm
Focal ratio: f/4.2
Optical design: four-element refractor with one ED glass component
Field of view: 3.2° × 1.6°
Image sensor: colour CMOS Sony IMX415
Sensor matrix: 3,840 × 2,160 pixels (1 × 1 binning), 1,920 × 1,080 pixels (2 × 2)
Pixel size: 1.45 µm
Sensor resolution: 3 arcseconds/pixel (1 × 1 binning)
Optical resolution: 4.8 arcseconds
Dew heater: integral
Tripod: tabletop, supplied
Mount: alt-azimuth (but can be polar aligned on a user-supplied sturdy photo tripod with a ball head)
Alignment: automatic star recognition and plate solving
Price: Classic: £369; Deluxe: £479
Website: dwarflab.com

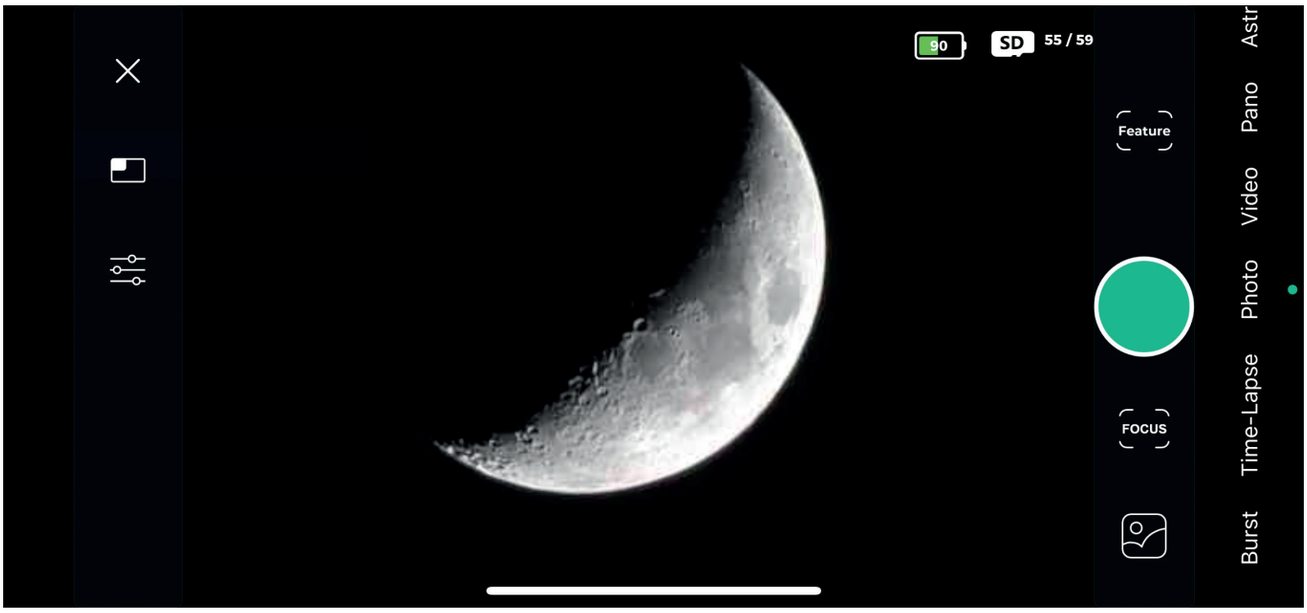
DWARF II: a towering achievement in smart telescope technology

At a quarter of the competition's price, and equally at home videoing nature or sporting events by day as it is imaging nebulae and galaxies at night, is the diminutive DWARF II the smartest robotic telescope yet? **Ade Ashford** checks it out.

▼ Dwarflab's DWARF II (D2) smart telescope. You can see the two lenses belonging to its telephoto and wide-angle cameras. All images: Ade Ashford.

Dwarflab are a Chinese optoelectronic start-up about to turn the smart telescope industry on its head. Run by a group of young PhD entrepreneurs who describe themselves as "a technology-driven optical team obsessed with innovation," their first electronically-enhanced telescope was the Kickstarter crowdfunded TinyScope (aka DWARF I) in November 2020. Such was the demand for a follow-up to their debut product that a Kickstarter campaign for the DWARF II (hereafter referred to as the D2) in December 2021 raised its funding goal in just 40 minutes! By the middle of January 2022, more than 2,500 backers had raised over $1 million for D2 development and manufacture.

Dwarflab possess a refreshingly unconventional approach to optical innovation, design and marketing. They were particularly savvy in providing YouTube influencers and online equipment reviewers with gratis pre-production versions of the D2, which ensured that they received valuable feedback about any hardware issues to fix and software enhancements to implement before the finished product landed in consumers' hands,



as well as generating enormous online interest and commercial demand.

▲ A screen capture of the waxing crescent Moon on 25 April 2023 obtained from the Photo menu within the DWARFLAB app.

Key features

Measuring just 204 by 62mm by 130mm and tipping the scales at one kilogram, D2's radical design is unique in form and function. Its optical tube is reduced to a stubby cylinder with an axis of rotation coincident with both the instrument's optical and altitude axes. Light enters the telescope in the same way as a periscope, via a mirror inclined at 45 degrees, affording the D2 stability, compactness and an unvarying centre of gravity. In a nod to convention, the D2 still rotates in azimuth about its base.

The other design feature that sets the D2 apart is its tandem f/4.2 telephoto and f/2.4 wide-angle imaging systems. The two megapixel wide-angle camera has a field of view of approximately 50 degrees and is capable of capturing images and videos. It also acts as as a finder for the primary eight-megapixel telephoto camera. The refracting optics of the latter consist of a four-element objective (one lens is composed of extra low-dispersion glass) of 24mm aperture and 100mm focal length. At its focus lies a Sony STARVIS™ IMX415 CMOS sensor with 1.45 micron pixels in a 3,840 × 2,160 matrix (1 × 1 binning), delivering a 3.19 by 1.79 degree field of view.

To put this into context, D2's telephoto imaging system is equivalent to a 400mm lens on an APS-C format DSLR camera, or a whopping 650mm lens on a full-frame DSLR. The telephoto camera's focal length of 100mm means its IMX415 sensor has a resolution of three arcseconds per pixel. However, a 24mm objective has a resolution of about 4.8 arcseconds at visual wavelengths, so D2's telephoto images are somewhat oversampled in its high-resolution 1 × 1 binning mode, which is a good thing. Its engineers chose the 2 × 2 binning mode for deep-sky imaging because of the increased sensitivity it affords, delivering

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▼ The Deluxe D2 package reviewed here includes a soft carry case, tabletop tripod, two 5600 mAh rechargeable Li-Ion batteries, a 64GB microSD data storage card, a dual 31.75mm (1.25-inch) magnetic filter holder, two ND solar filters and a UHC filter for deep-sky imaging.

a resolution of six arcseconds per pixel over a 1,920 × 1,080 matrix. However, Dwarflab promises full-resolution, 1 × 1 binning for astro-imagers in a future firmware update that may be available by the time you read this.

Other innovative features that set the D2 apart from the competition are its ability to capture 4K video at 30 frames per second, and a built-in neural-network processing unit (NPU) giving it the ability to automatically recognise and track movement. The latter is cutting-edge electronics for a budget device. Aside from imaging the night sky, D2 has great daytime potential for videoing birds and animals, cars at a race meet, or aircraft at a show. The D2 has a phenomenal slew rate of up to 30 degrees per second, an azimuth range of 340 degrees, and can pitch in altitude up to 120 degrees either side of vertical. The D2's 20-degree 'blind spot' in azimuth is caused by a hard stop preventing internal cable wrap, but with thoughtful positioning during initial setup, it's not an issue.

Dwarflabs sell the D2 in two flavours: the Classic and the Deluxe. The Classic comes with a soft carry bag, a tabletop tripod, a 5600 mAh rechargeable Li-Ion battery and a 64 GB microSD card to store your pictures and movies (microSD cards up to 512 GB are supported). The Deluxe package is the Classic plus an extra battery, a dual 31.75mm (1.25-inch) filter holder, two ND solar filters (to protect both the wide-angle and telephoto lenses while imaging the Sun), and a UHC filter for deep-sky imaging with the telephoto lens. The D2 is in stock to order from dwarflab.com, quoting a 15-day delivery to the USA, Canada, UK and Europe, and Australia.

D2's telephoto imaging system is equivalent to a 400mm lens on an APS-C format DSLR camera, or a whopping 650mm lens on a full-frame DSLR.

▼ When the D2 is powered-up the status ring glows green or red in a variety of patterns according to the instrument's operational mode.

Operating DWARF II with the DWARFLAB app

My D2 Deluxe order arrived on time in a sturdy double-boxed shipping carton containing a beautiful white 25cm by 15.5cm by 20cm presentation box. The positive first impression didn't end with the unboxing: D2 feels solid in-hand and well-finished, with a high standard of construction in quality materials throughout. The main case has a matte light-grey and slightly rubberised finish with dark grey end accents. The tabletop tripod is an all-plastic affair with a built-in ball head best described as adequate that fits in the carry case, but the D2 can be used on your own sturdy full-height photo tripod. The base plate of the instrument has a 1¼-20 thread for the purpose.

Available in both Android and iOS flavours, it's fair to say that Dwarflab's support for Apple devices is somewhat behind the curve. That said, the iOS feature-set is growing and should soon be on a par with the Android offering. At the time of writing, current versions of the DWARFLAB app are 1.1.9 for Android 5.0 and higher, and 1.1.2B6 for iOS 12.0 or later.

The app initially establishes a connection with the instrument over Bluetooth, then via Wi-Fi over a hotspot that D2 generates, so your smartphone or tablet needs to be Bluetooth 4.0 compliant. Recent firmware updates have enabled the longer range (but slower data transmission) of 2.4Ghz Wi-Fi in addition to the device's native 5 GHz communication. You can also establish Station Mode (STA) connections between D2 and a wireless router, meaning you can control it over your home wireless network.

A short press of D2's power button turns it on (a long press turns it off) indicated by the instrument's status light spinning and 'breathing' green when it's ready. The status ring glows green or red in a variety of patterns according to the D2 operational mode. The battery indicator also glows green in one (low) to four (full) lights. The Android app (and hopefully soon the iOS) thoughtfully allows you to turn off the status and battery lights in the field so as not to affect the dark adaption of nearby observers.

Expect to get a maximum of three hours use out of a D2 on full charge. If its Li-Ion battery is depleted then it may take 90 minutes to fully charge it. You do this by connecting a powered

USB-C data cable (not supplied) to the socket on the base. It's quite permissible to use the D2 while it's charging (although not in freezing conditions).

I tested the DWARFLAB app on both a 4.5-year-old Lenovo tablet with 1GB RAM running Android 7, and a 7.5-year-old iPhone 6S Plus with 2GB RAM running iOS 15.7.5. Both the Android and iOS apps present a similar user interface on their opening screen with a prominent connection button that invokes the 'Camera Searching' process. Once connected, the live screen of the telephoto camera is the default, with the wide-angle camera preview as a pop-up in the upper-left of the screen. You can toggle between the two views and pan around using an on-screen joystick, setting the slew speed with a pop-up slider. There are options to manually set the shutter speed, gain (think ISO, or sensitivity on a DSLR), white balance and more for each camera should you wish, and either manual or auto-focus before pressing a green button to capture a picture.

The DWARFLAB app is largely intuitive to use and any sluggishness I experienced under Android with my Lenovo tablet I attributed to its small complement of RAM. The iOS version of the app was a little less stable but far more responsive on my iPhone 6S Plus. It's good that you don't have to use the latest smart devices. You can have more than one device connected to the D2 simultaneously although you may get some conflict over which is in control.

Solar and lunar observing

With the magnetic filter holder clicked into place and the supplied ND filters covering the telephoto and wide-angle cameras, you can observe and track the Sun from the Photo menu on the DWARFLAB app. Given that the instrument's main camera has just a 24mm aperture lens, you can still capture pleasing full-disc solar images and video that will show prominent sunspots, limb darkening and hints of photosphere granulation, or the progress of a solar eclipse. At night or in twilight you can also track and capture pleasing Moon images from the DWARFLAB app's Photo menu. Don't expect super-fine resolution, but in my images craters as small as 10 kilometres across are discernible.

For daytime terrestrial and solar imaging, or capturing the Moon after dark, D2 possesses an internal infrared-cut filter to preserve colour balance. This infrared filter has a bandpass similar to that found in DSLR cameras, meaning that a lot of the hydrogen-alpha light in the red end of the spectrum given out by emission nebulae is heavily attenuated. Fortunately, D2's infrared-cut filter can be switched in or out of the optical train electronically. When passing infrared light some red stars will appear bloated, but the UHC filter supplied with the Deluxe model largely corrects for this.

▲ The Omega Centauri globular cluster captured in just 51 six-second exposures with D2's telephoto camera and a UHC filter under heavy light pollution.

Nighttime imaging

And now the moment most of you have all been waiting for: how well can a 24mm, f/4.2 refractor capture views of nebulae and galaxies?

D2 uses a process of light accumulation, or stacking, to produce images of faint objects. By capturing hundreds of short exposures of a few seconds duration and digitally superimposing them, it dramatically improves the signal-to-noise ratio – meaning that accumulated light from actual features in the subject gradually overwhelms spurious, electronically-generated noise manifesting as randomly coloured pixels.

▼ The D2 shown solar observing with two 31.75mm (1.25-inch) ND filters screwed into the magnetic holder protecting both the telephoto and wide-angle cameras.

▲ Using the UHC light-pollution filter on the D2's telephoto camera, 274 six-second exposures were captured for the Eta Carinae Nebula. The result is amazing considering the light-polluted sky it was taken in.

We get even better results by digitally subtracting dark frames – images taken in total darkness so they contain just the inherent electronic noise of the camera – to produce cleaner pre-processed images before stacking them. The DWARFLAB app has an Astro Dark tab where you can create a library of dark frames for different exposure and gain settings: just pop D2 in its zipped-up carry case away from any light source and the process is done automatically in about ten minutes.

With a dark frame library created, D2 automatically takes each newly captured light frame, subtracts the dark frame noise, and superimposes the processed frame with all those that precede it, using star images as reference points. The image of a deep-sky object starts out grainy and ill-defined, gradually growing in clarity, contrast and colour with time. We call this process electronically-assisted astronomy.

While watching the live-stacking of an image on your tablet or smartphone, you can also request that D2 stores the raw files in FIT or TIF format. After the imaging session you can connect the instrument to your PC via a USB-C cable and copy the data across in MTP mode, or take the microSD card out of the D2 to copy the files via a card reader.

◀ Dwarflab designed the D2 for alt-azimuth use, but the Calibration (alignment) process of plate-solving three starfield images works equally well if the azimuth axis is polar aligned using a sturdy photo tripod and ball head. The D2 is shown here solar observing.

Aligning D2 on the sky

Before it can locate objects and capture any images, the D2 must know its location, the date and the time. The app automatically transfers GPS data to the instrument, but the D2 must go through an alignment process by taking three separate images of the stars to establish where it's pointed. Dwarflab call this process Calibration, and you invoke it from the app's Astro tab. Implementation of this process is impressively fast, capturing and plate-solving the three star-fields in a minute or less. However, the way that Dwarflab implemented their Calibration algorithm has some interesting consequences.

D2 is intended to be used in an alt-azimuth configuration, so stacked images composed of hundreds of frames compiled over several tens of minutes will show artefacts at the corners where the instrument has had to automatically rotate the images before stacking them – something called field rotation. But if you use a sturdy photo tripod and ball head to tilt the instrument's azimuth axis towards the celestial pole, Calibration still works, but you've effectively polar aligned the D2. You don't need to achieve perfect polar alignment

I consider the results to be amazing given the instrument's small aperture and the challenging conditions.

either, but the better you do it the smaller any field rotation will be. It's a very clever and unique feature of this instrument.

Test results

Coincidentally, this review overlapped with my most recent work-related trip to New Zealand's South Island, so I relished the prospect of capturing some of my favourite far southern deep-sky objects under exceptionally dark antipodean skies. D2's tiny 25cm by 15cm by 18cm soft case is capable of carrying everything you need for an imaging trip near or far, including the tabletop tripod and my Lenovo tablet. Placed inside my aircraft carry-on luggage, I still had plenty of room for everything else I needed on the plane.

New Zealand is renowned for its pristine skies, but in order to make it a more stringent test of the D2 (and because I was impatient) I chose to image under the most light-polluted conditions I could find: beside the Christchurch International Airport hotel where I was staying on 4 April 2023. Furthermore, the Bortle 8 sky was compounded by an almost full Moon in the north. Using the supplied tabletop tripod in an alt-azimuth configuration, I placed the D2 on the grass surrounded by white light LED streetlights, floodlighting for the airport buildings and a constant stream of car headlights along State Highway 1 nearby.

At 9.30pm NZST, the Southern Cross and Pointer Stars alpha and beta Centauri were comfortably visible high in the south-eastern sky, but not a lot else to the naked eye. Using the UHC light-pollution filter on D2's telephoto camera, I took 274 six-second-frames (amounting to 27.4 minutes) of the Eta Carinae Nebula, one of the largest diffuse nebulae in the sky. I also captured 51 six-second-frames (5.1 minutes) of data for Omega Centauri, the Milky Way's largest-known globular cluster.

I consider the results, processed with the freeware *ASIStudio* and *Siril*, to be amazing given the instrument's small aperture and the very unfavourable conditions.

The D2 is one of the best conceived and implemented imaging devices I've encountered in a long while. Yes, there are still issues with the software, but Dwarflab are very responsive to user requests and regularly issue app and firmware updates. The tiny GoTo database is shortly to receive a 500-object upgrade and target selection from a digital star map, although it's currently possible to target any object from its J2000 equatorial coordinates as a workaround.

Ade Ashford has travelled the globe writing about astronomy and telescopes, serving on the staff of astronomy magazines on both sides of the Atlantic.

▼ Dwarflab have included a UHC filter with Dwarf II Deluxe package that screws into the magnetic filter holder over the telephoto camera's lens.

■ Markarian's Chain is an attractive curving line of galaxies in the Virgo Cluster. This is a 50-minute integration of 200 15-second frames captured with the D2.