

The building of *Fossil Light* – a 46cm lightweight Dobsonian reflector

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The design and construction of a 46cm lightweight telescope that can be easily transported in a small family car is described.

Introduction

For many years I had wanted a telescope that would be large enough to help me satisfy my hunger to see detail in deep-sky objects, but would not be an ordeal to transport to dark country skies. In October 1993 I started to build such an instrument, spurred on by inspiration from a book called *Lightweight Giants*, by Steve Overholt.¹ The author of this book designed a unique 56cm ultra-lightweight Dobsonian, using composite materials and many novel constructional methods.

After reading this book I felt challenged to build a 46cm (18") reflector which I could easily transport, partly disassembled, in the back of my Vauxhall Astra hatchback. I wanted the telescope to be quick and easy to set up and dismantle single-handedly in the dark, be a pleasure to use, look good, and above all, give excellent images of planets and detail in deep-sky objects. In addition, because I had only very limited access to a lathe and no access at all to a milling machine, almost everything would have to be built using the main workshop tools of a drill press, a bench mounted disc sander, and a bandsaw.

Nearly three years later, after spending almost 3,000 hours on construction and design, and approximately £3,000 on optics and materials, an f/4.4, 46cm Dobsonian reflecting telescope which met these requirements was finished (Figure 1). I have named the telescope *Fossil Light*, after the light from distant galaxies which started its journey to us many aeons ago.²

In this paper I have tried to avoid presenting a dry step-wise account of the building of the telescope. Instead I thought it would be better to pick out parts of the design which might appeal to others interested in telescopes and their construction.

Overall design

There are five main parts to be joined together to use *Fossil Light*, all of which must be remembered when packing the car before driving to a dark sky site. At the top of the telescope, seen in the general view in Figure 1, is the upper tube assembly (UTA) or head assembly, to which the focuser, secondary mirror and finder scope are fixed. The next part

is the system of truss poles which join the UTA to the third sub-assembly, the bearing box. The bearing box (better seen in Figure 4), as well as acting as a frame for attachment of the truss poles, also holds the big semicircular altitude bearings and the bottom end of the light shroud. The mirror box, the fourth main part of *Fossil Light*, is attached to the underside of the bearing box. The mirror box holds the 46cm diameter primary mirror in an adjustable flotation system, and also houses

the mirror cooling fan. These four components, the UTA, the truss poles, the bearing box and the mirror box, when assembled together, make up the so-called tube assembly. The weight of this tube assembly is taken on its altitude bearings, which rest on the fifth sub-assembly, the rocker box. The rocker box, as in all Dobsonians, forms the lower half of the altitude bearings and swivels on its base to give full 360° azimuthal movement.

As indicated above, rather than using a large solid tube for the middle part of the telescope, *Fossil Light* utilises a system of truss poles, resulting in an open-tube design. This arrangement follows the Serrurier Truss method of construction, which has been successfully employed on many large aperture portable Newtonian telescopes in recent years. This innovation, first introduced by Mark Serrurier on the 200-inch Hale telescope, uses eight poles to link the head assembly, containing the focuser and diagonal mirror, to the bottom end, where the primary mirror is

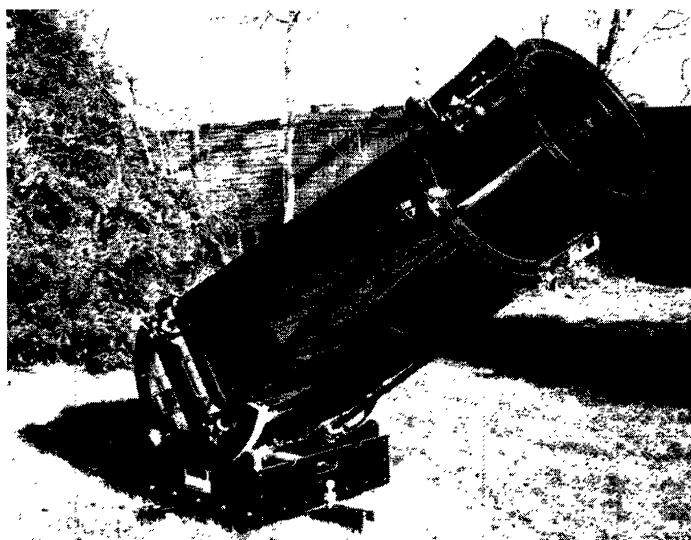


Figure 1. General view of *Fossil Light*.

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housed. The truss poles are arranged in a pattern of triangles which provides great structural rigidity for relatively little weight.

Sky Designs first introduced Serrurier trusses into the amateur telescope market in the mid-1980s. They saw the significant benefits of using the method to enable large aperture Dobsonian telescopes to be readily dismantled and transported in the rear of a car, to observe faint deep-sky objects from dark sky sites. The use of trusses to replace the traditional solid tube, and the housing of the mirror in a separate box, saved weight and lowered the centre of mass of the tube assembly. This lowered the altitude axis and allowed squatter and more stable altazimuth mounts to be employed, saving further total weight. David Kriege of *Obsession Telescopes*³ added further innovations and refinements, including increasing the diameter of the altitude bearings so that the frictional forces in both altitude and azimuth movements were more closely matched. This move also further improved scope stability, saved weight and improved portability. Steve Overholt has taken the design ideas of Kriege a stage further by the clever use of composites and lightweight materials, which allowed him to make a 56cm reflector weighing only 43kgs, as well as an incredible 76cm telescope which fits in the back of a Fiesta-sized hatchback car.

I decided that I wanted to build a telescope with all the features shown by David Kriege's *Obsession* telescopes together with some of the weight reducing methods used by Steve Overholt. In addition, I would add some design features of my own. Apart from attempting to optimise optical performance and ease of use, the design areas I spent most time on were concerned with ease of assembly and disassembly, and how readily the parts of the telescope could be loaded into the car. A lot of this latter design work was concerned with trade-off between structural rigidity and lightness.

Upper tube assembly (UTA)

General

Achieving the optimum balance between structural rigidity and lightness was especially difficult in the case of the UTA, which is the cylindrical cage which holds the focuser, diagonal mirror and finder (see Figure 2). This had to be light, to keep the centre of gravity of the telescope low, but had also to be sufficiently rigid to maintain the optical components in proper alignment. *Fossil Light's* UTA cage consists of two structural rings of 51cm internal and 59cm outside diameter, held apart by four 36cm long spacer tubes and a focuser mounting board. The spider is stretched between the four spacer tubes, and the focuser mounting board is also used to mount the finder.

The whole telescope project was started by designing and building the UTA. As long as one knows the diameter and f-ratio of the mirror that will eventually be used (which affects the choice of diagonal size and the UTA internal diameter) it is possible to design and build the UTA without worrying too much about how the rest of the scope will turn out. The actual weight of the UTA, however, has a

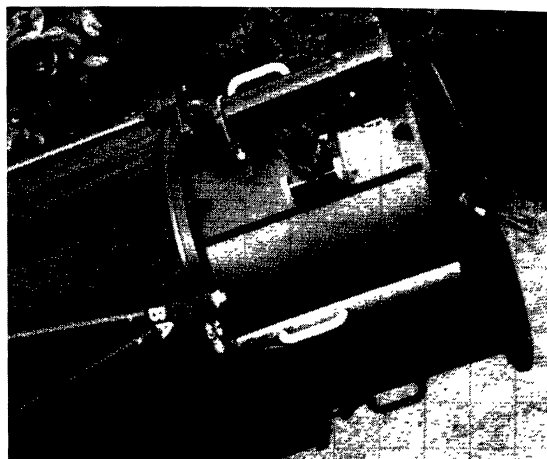


Figure 2. Detail of Upper Tube Assembly (UTA) showing general construction as well as finder and truss pole attachment methods.

strong bearing on the rest of the telescope design, and the greatest freedom in the design of the rest of the scope, together with benefits in scope stability, is afforded by minimising the weight of the UTA. *Fossil Light's* UTA weighed in at only 3.7kgs, without the finder.

Use of composite materials

Clearly the weight of the UTA needs to be minimised without unduly compromising its rigidity. To achieve this, it was an obvious decision to make use of composite materials to help optimise the stiffness-to-weight ratio. Because all the Serrurier truss poles attach to it, the lower UTA ring must be the primary structural member of the head. The ring is of a composite construction, composed of a core of balsa wood with a thin skin of fibreglass PCB material bonded onto the outside with epoxy resin. The PCB material, which I bought with the normal copper coating stripped off by the supplier, was 0.4mm thick on the top and inside edge of the ring and 0.8mm thick on the more vulnerable bottom and outside edge. The balsa wood was arranged as a ring of 24 equally-sized, tapered blocks glued together with the wood grain running from inside to out. Four 7cm long blocks of less compressible lightweight mahogany were incorporated into the ring at 90° intervals. These became the attachment points for the eight truss poles as well as for four oval spacer tubes which connect the top and bottom rings of the UTA.

The top ring of the UTA and the focuser board are made of a 10mm thick composite aircraft board, which is composed of glass fibre outer skin and a varnish impregnated paper matrix core. Although the material is strong and very light, it is rather unpleasant to use, because the glass fibres which are released when cutting it easily get under one's skin. In addition, the raw cut edge has to be filled in and then sanded back to get a clean edge. Even so, I believe the extra effort was worth it. The focuser board, which is 36cm long and 12cm wide, weighs only 170g.

The main skin of the UTA is also strong and light, being made of 3mm thick black corrugated plastic, of the type often used for estate agent signs and obtainable (by using a little charm!) in free, 'handy' 2.4×1.2m sample sheets from

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packaging material suppliers. The skin is bent along the line of the flutes and pinned to the two structural rings with plastic push-in ribbed pins. I tried to use lightweight fasteners all over the UTA. Using aluminium alloy screws instead of steel wherever possible probably saved a total of about 150g.

The spider and secondary holder

Although lighter aluminium blades could have been used for the four vanes of the spider I decided to use thinner stainless steel to minimise diffraction effects. Although the thickness of the tapered blades was only 0.7mm, I used a design suggested in J. B. Sidgwick's *The Amateur Astronomer's Handbook*,⁴ where the rigidity of the secondary mounting is maximised by offsetting the blades' attachment point at the centre. This method is seen in Figure 3.

To keep its weight down, the body of the secondary holder is constructed from 76mm diameter plastic drainpipe and its fittings are made of aluminium and Tufnol (a very useful resin-based material which is light, easy to machine, and very strong). Adjustment of the secondary is achieved with adjustable thumbnuts and small, powerful, compression springs which hold the set alignment. This method is simple to use and works better than the standard system which uses opposing screws to lock everything in place. I have never known the secondary alignment to change during transportation of the telescope and adjustment, when required, only takes seconds.

To maximise the size of the field of full illumination, the secondary has to be offset equal distances away from the eyepiece and towards the primary mirror.⁵ The design of the spider automatically holds the secondary at the calculated 4.3mm offset from the eyepiece, whilst the offset distance towards the primary is set during initial collimation.

Secondary mirror size

The secondary mirror is secured on its holding plate using three pads of silicone rubber adhesive, each about 1cm in diameter and about 1.5mm thick (the transparent silicone is the strongest). The mirror has a minor axis of 83mm giving a primary obstruction of 18% (by diameter). This is quite a low figure for an f/4.4 reflector and is well below the 20–25% limit where secondary diffraction starts to significantly affect image contrast.⁶ With this size of secondary, achieving a decent field of full illumination for visual work of 14mm, required the focus of the primary to be as close in to the body of the scope as practically possible. This necessitated the use of a low-profile focuser.

Low-profile focuser

Although there are several well-engineered and very low-profile focusers of the helical type on the market, I have never really found these satisfactory. Refocusing is frustratingly slow, especially after changing eyepieces. Instead, I opted to buy a Meade low-profile rack-and-pinion focuser and modify it, managing to reduce its effective height from 80mm to a squat 40mm (see Figure 3). The modifications involved the judicious removal of metal from the focuser

casting, together with eliminating some unnecessary parts, such as the 2" drawtube locking ring. In addition, a friend machined for me a new rebated 1¼" to 2" eyepiece adaptor. This new adaptor allows both eyepiece sizes to be inserted by the same amount into the chrome drawtube (in the original, 1¼" eyepieces were held 8mm further out than 2" eyepieces). The focuser modifications reduced the distance between the secondary mirror and the focal plane from 36cm to 32cm. Without such a reduction a significantly heavier and more expensive 93mm secondary would have been required for the same size fully illuminated field.

The focuser has additional features that readers might find interesting. To improve the smoothness of the drawtube travel and eliminate the need for grease on the barrel, two strips of ultra-thin PTFE 'plumbers tape' were gently burnished onto the roughened inner surface of the focuser casting opposite the drawtube rack. The PTFE has a low coefficient of friction and gives the focuser movement a beautifully smooth feel to it, allowing very small changes in focus to be made easily. Another noteworthy feature incorporated in the focuser is a blackened, circular, brass weight fixed to the back of the 1¼" to 2" eyepiece adaptor. The magnitude of this weight is carefully chosen, so that the weight of an average 2" eyepiece is similar to the combined weight of the modified adaptor holding an average 1¼" eyepiece. With this design feature there is little change to the scope balance when swapping between the two different eyepiece sizes. This is important when 2" eyepieces weighing over a kilogram could be used in the scope and this weight is similar to the force on the UTA required to move the telescope on its bearings.

The finder

As I usually do a lot of star-hopping to find deep-sky objects, fitting a good finder was essential (Figure 2). The choice of aperture was a difficult balance between light gathering power and weight. In the end I settled for a finder that uses a secondhand 60mm binocular objective.

An Amici (roof) prism is incorporated into the body of the finder which allows right-angle operation, so reducing

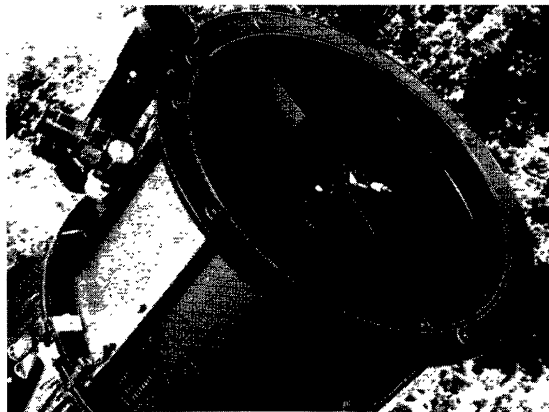


Figure 3. Another view of the UTA showing attachment of top end of finder, secondary spider with blade offset, and low profile focuser.

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neck strain. The prism gives views which have the same field orientation as the naked eye, which is a tremendous advantage when using charts to star-hop to deep-sky objects. I built such a finder for a previous 10" reflector and was so pleased with it that I now regard it as an essential feature on any Newtonian telescope.

The finder is fixed to the UTA using a simple lightweight method which allows it to be detached in seconds and eliminates the need to loosen adjusting screws before tightening others, a frustrating operation with the standard 3-screw finder mounting. The method, seen in Figures 2 and 3, uses two plastic adjusting screws at the bottom end, set at 90° to each other, in combination with a long spring from a china plate-hanger to provide the opposing force. The top of the finder is held in position by a long screw which is fixed to the inner edge of the finder's dew cap. This screw passes through an oversize hole in the side of the upper UTA ring. Screwing a thumb nut onto the end of this screw pulls the plastic dew cap against a vee-shaped notch in the UTA ring. This arrangement allows limited rotation at the top end when the finder is being aligned using the two bottom screws. The finder mounting method allows for very quick adjustment in two perpendicular directions and the eyepiece position has been chosen so that it is very easy to swap viewing between finder and main scope.

The finder, together with the mountings, weighs in at 570g. This low weight has been achieved by use of the simple mountings as well as a prism holder and lens cell made of Tufnol. In addition, the main tube is made of cardboard to which has been epoxied a layer of the same 0.4mm glass fibre sheet used to coat parts of the lower UTA ring.

In Figure 2 a second viewing position at the bottom end of the finder can be seen. This consists of a black plastic film canister with a 3mm hole punched in the bottom and a rubber eyecup pushed on the end. Together with an 8mm plastic bead mounted on top of a short screw protruding from the top of the finder's dew cap, these parts act as a zero-power 'peep sight', for initial line-up on objects. This sight is extremely light, has no power requirements and will never dew up. I use it all the time, and it is particularly useful when viewing near the zenith because I can use it to roughly point the telescope without need to step foot on a ladder.

A 25mm focal length, 1 1/4" diameter eyepiece, with cross-wires and a low-weight Tufnol barrel, is used with the finder and gives $\times 10$ power and a 4.5° field. I recently made up two more eyepieces for the finder; a 12.5mm one for higher power, and another 25mm one to use when the first dews up and is warming in my pocket. This eyepiece dewing problem is particularly troublesome on finders like this, where the eyepiece eye lens normally faces skywards and I considered all sorts of more complicated remedies before arriving at this rather pragmatic solution.

Truss poles

Whilst building the UTA I had to consider how the truss poles would be attached at this end and also at the bearing box end. The attachment method had to be lightweight and preferably require no tools or fittings that could be lost at

night. In addition, the design had to ensure that there was minimal loss in collimation when dismantling and reassembling the scope. Also the method had to enable the delicate UTA to be easily attached and detached from the eight poles single-handed, without risk of damage to any of the parts, at night, in the cold, and when I might be very tired. The design I came up with has worked very successfully but did require quite a lot of difficult manufacturing steps, especially in making the truss poles.

The first step in attaching the UTA to the rest of the scope involves inserting the eight poles into clamp blocks which are fixed to the corners of the bearing box. Each pole is inserted and twisted clockwise so that a metal pin in its bottom end contacts a rotation stop. All the clamps are then tightened to securely grip the poles. The UTA lower ring has four 6mm pins, spaced at 90° intervals, which stick out of the side of the ring. These pins are designed to be inserted through reinforced holes in flat Tufnol blades which protrude from the tops of each of the poles (Figure 2). Once the pins are inserted through the holes in the truss pole blade pairs, small toggle clamps then squeeze each of the four pairs hard up against the edge of the ring.

The reader may have spotted that the problem with such an attachment method is that getting all the pins located in the holes is not an easy one-person operation. You need to be an octopus to splay all the pole pairs apart, then locate the pins, one at a time, into the holes in the truss blades, whilst holding the UTA at the same time. The solution I came up with was to make two of the pins retractable and to make one of the pins with a flexible 5mm plastic 'nose' to it. Inserting all the pins is now easy. The UTA is held just above the pole ends and the plastic nose is inserted into the holes in the first blade pairing. This is the trickiest part. Next, holding the rear UTA handle with one hand, the back end of the UTA is dropped down slightly and the pin at the back is inserted in the pole pair. The toggle clamp here is then applied. The method now is to go round to both sides and slide out the remaining two pins and apply the rest of the toggle clamps. Removal of the UTA at the end of an observing session is essentially the reverse of this but with

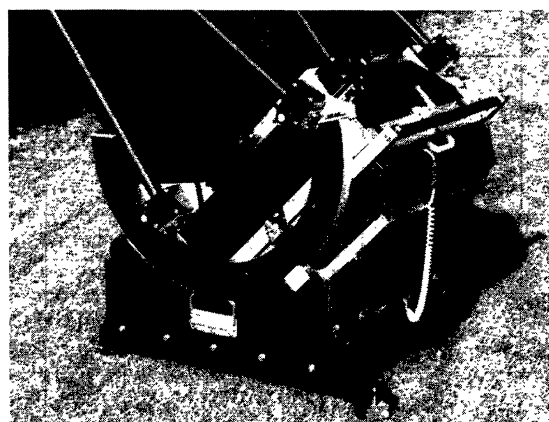


Figure 4. Bottom end of telescope showing large semicircular altitude bearings and lower truss tube attachment blocks on side of bearing box, mirror box clamped to bearing box underside, and supporting rocker box with three-legged pedestal base.

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the use of a little 'springer block' to act as a 'third hand' to disengage the blades from the pin with the plastic nose.

Six of the truss poles are 25mm diameter, 18 gauge (1.22mm thick), black anodised aluminium tubing. The remaining poles are stronger, being 16 gauge (1.63mm thick), and 32mm diameter. These two poles are used in the lower side position where the greatest mechanical demands are placed on them. If I ever built another similar sized telescope with Serrurier poles I would use 25mm poles all round, because on reflection I do not think the extra effort of making two different pole sizes is warranted.

The mirror box and the bearing box

Early in the building of *Fossil Light* I realised that there would be some parts of the scope which would be heavy and some parts which would be large. In order to reduce difficulties in transporting and assembling the scope, I resolved not to have any parts which were both heavy *and* large. It was an obvious choice, therefore, to build the lower part of the telescope tube assembly in two parts. There would be a smaller and heavier mirror box containing the 14.5kg primary, and a larger but not so heavy bearing box, to which the trusses and the big altitude bearings would be attached. This split has worked very well and allows easy access to the mirror if required. If I had not separated the two parts like this then the huge 42kg combination would have been impossible for me to manage on my own.

The 25kg mirror box attaches with medium size pull clamps to the underside of the 17kg bearing box (see Figure 4), and is held in alignment with two pairs of pins and sockets.

Mirror box

The mirror box cartridge is designed to be just thick enough to hold the 39mm thick Suprax primary on its 18 pt. flotation system. The box is made up from 25mm square section aluminium framing and shaped 3mm thick aluminium side panels which have been polyester powder coated to give a pleasing black textured finish. To give the box the necessary rigidity, the pieces have all been screwed together with aluminium bracing pieces in the corners.

Figure 5 shows a rear view of the mirror box clipped to the bottom of the bearing box. The photo shows the two collimating knobs on the cross-member which also double up as feet (the third, lower, adjuster is preset, and is not touched in normal use). Also shown is the flexible plastic ring which holds all the components of the 18 pt. flotation system in alignment and which eliminates the need for anti-rotation pins for the bars and triangles. This system is used in David Kriege's *Obsession* telescopes and is a very elegant solution to a traditionally difficult problem in mirror cell design.³

Not shown in the photo is the sling which evenly supports the bottom half of the mirror when the scope is pointing at low altitudes or when the mirror box is being carried. The sling is made of a 10mm wide strip of packing case strapping. This is made of glass fibre reinforced polyester and hence is very strong with negligible stretch in it. It is a

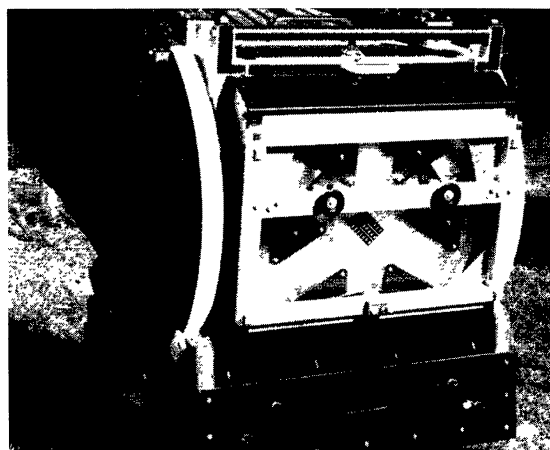


Figure 5. View of bottom of mirror box (before fan added) showing collimation knobs and 18-point support system for primary, including the plastic ring for holding support components in alignment.

superb material for this application. Other parts of the mirror cell not seen in the photo include the small PTFE covered cork pads that the mirror rests on, and the mushroom-shaped posts on either side of the mirror which restrict its side-to-side movement and prevent it toppling forward during transportation.

The split mirror box/bearing box design obviously begs for some sort of mirror protection whilst the mirror box is detached, and also to protect it from dust during storage of the scope. Such protection is achieved by use of a large sliding shutter which is removed after the two are clipped together. The shutter is made of clear polycarbonate (a very tough material used for items such as riot shields and helmet visors), and has the advantage that one can assess the state of the mirror and whether or not it is dewed without removing the shield and exposing the cold mirror to warm moist air – which would definitely cause it to dew over.

Bearing box

The bearing box acts as a frame for attaching the mirror box, the eight truss poles, and the big semicircular altitude bearings. Again it has to be rigid and light, and uses the same 25mm square section aluminium tubing used for the mirror box. The side panels are two layers of the same lightweight plastic corrugated material used as the skin of the UTA. To reduce tube currents during use, the inside of the sub-assembly is clad with 1cm thick foam insulation. In addition to this, a 50cm inside diameter baffle is fixed inside the bearing box to improve image contrast.

Bearing design

The design of the telescope's bearings was crucial in determining how easy it would be to use the telescope to locate and follow objects at night. Good Dobsonian bearings have to be correct in many areas and I spent a lot of time trying to ensure that the design was optimised. All the effort eventually paid off and I now feel that both sets of bearings are close to being as good as Dobsonian bearings can be. The mount and bearings are very stable. They work extremely

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well in all modes of operation, including fast sweep, slower scan and the very demanding stop-start mode generally used to follow objects in a manually driven telescope. With a little concentration, the bearings even allow objects to be kept centred in the field at magnifications of over $\times 680$.

The key to good Dobsonian bearings is the exact choice of bearing materials.⁷ Both the altitude and azimuth bearings on *Fossil Light* use the same combination of materials. Matching these materials is important to ensure that the force versus velocity characteristics are similar for both axes throughout their whole operating range, from high speed sweeps to slow tracking nudges.

One face of the bearings consists of thin sheets of a special Teflon based material stuck onto shaped pads with double-sided tape. Running against this surface is a carefully chosen laminate which has a glossy fine pebble texture finish. This laminate was bought at a large DIY warehouse and its original intended use was to cover bathroom or kitchen surfaces. Textured laminate prevents the formation of 'vacuum pockets' that can occur with a smooth gloss surface and which can cause the bearing surfaces to stick. Creases and pits in the textured laminate also trap particles of dust and dirt that could interfere with the smooth operation of the bearings.

After first assembling the whole telescope, and before I found a better Teflon based material for the pebbled laminate to run against, both the altitude and the azimuth bearings ran on plain PTFE pads, whose area had been calculated to give a surface pressure of 15 psi. These worked reasonably well, but tended to stick a bit, especially when trying to track objects using a stop/nudge movement. This stickiness was dramatically improved by shaping the pads to closely follow the profile of the opposing laminate surface. This was done by sticking fine emery paper onto the laminate with double-sided tape and working the bearings back and forth for a short while to sand the PTFE to shape. I would recommend this approach to all those wishing to optimise the performance of their PTFE scope bearings as the improvement can be quite dramatic. Do, however, ensure that all traces of the abrasive are removed from the PTFE surfaces afterwards!

The azimuth bearing diameter is 56cm, virtually the full width of the mount, whilst the altitude bearings are 66cm in diameter and 4cm thick. These sizes give superb stability and have been chosen so that the force required to move the scope in altitude is about the same as that required to move the scope in azimuth (when the scope is at angle of 45°), making diagonal sweeps and scans easier to execute.

Altitude bearings

The semicircular altitude bearings have a core consisting of three layers of 12mm marine ply and have been clad on the non-bearing faces with black laminate to protect them and to improve their appearance. Two strips of the special textured laminate which is used as the bearing faces, have been stuck onto the outer face of the plywood semicircles with a 'weak' contact adhesive (water-based) which allows them to be fairly easily replaced should the bearing surface ever be damaged.

For the instrument to balance properly, the centre of

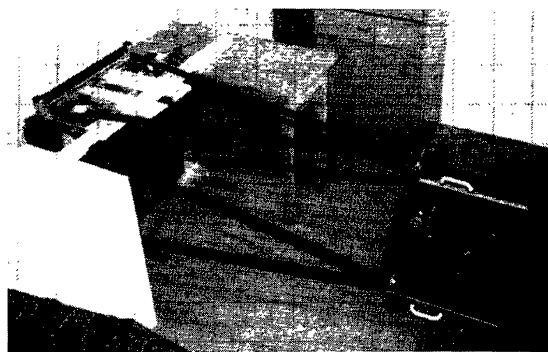


Figure 6. Finding the balance axis of tube assembly with dummy mirror in place.

gravity of the whole telescope minus the base has to coincide with the centre of curvature of the altitude bearings. Accomplishing this was great fun! First I had to make a dummy mirror which was the same size and weight as the real one. Its purpose was to enable the telescope centre of gravity to be found without risking damage to the precious primary. The dummy was made of a 46cm plywood disk to which was screwed a 14.5kg lead disk which I cast in the back garden in an old pie dish. The next step was to put the dummy in the mirror box and assemble this with the UTA, bearing box, and truss poles for the first time. A large wooden jig was then made to hold the whole tube assembly and enable the balance axis to be found (Figure 6). The centre of gravity of the altitude bearings was then found and a rather large calculation done to combine all the measurements and account for any items which would later be added to the telescope. The centre of gravity of the tube assembly ended up being only about 2.5cm above my target location (level with the top of the bearing box).

The top half of the rocker box forms the lower half of the altitude bearing and holds the four bearing pads 80° apart on each side. As it is important to keep the bearing surfaces clean, I have stuck short strips of fuzzy Velcro next to the pads to act as dust wipers for the laminate runners. I also fixed PTFE pads either side of the rocker box to restrict lateral movement of the altitude bearings and prevent the mirror box fouling the inner side of the rocker box.

Azimuth bearings

The azimuth bearing has several parts, all of which are incorporated into the rocker box. A large sheet of textured laminate is glued to the underside of the main box and rests on three Teflon coated pads fixed at 120° intervals to the top of a three-legged pedestal base. At the centre of this arrangement is a 12.5mm diameter pin and bearing race, which together act as the azimuth axis. The bearing pads are arranged on a smaller radius than for the altitude bearings (56cm compared to 66cm). This on its own would tend to make it easier to move the telescope in azimuth than altitude, however, in reality this effect is offset by the fact that the total force pressing down on the altitude pads is greater by the weight of the top of the rocker box (47kg compared to 63kg), which tends to balance the frictional resistances in the two axes.

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Dust can easily adversely affect the relatively open bearings found on Dobsonians and so, as with the altitude bearings, I fixed strips of fuzzy Velcro either side of each bearing pad to act as dust wipers. Because the azimuth bearing is so close to the ground I took further precautions and also made up a large diameter, thin plastic disc which shields the surface of the laminate sheet from contamination.

The rocker box

As already mentioned, the rocker box has two main parts. The lower part comprises a three-legged pedestal base which sits on the ground. On top of this sits an open-topped box, which pivots in azimuth and upon which the telescope is able to swing in altitude. The rocker box supports the weight of the whole of the telescope tube assembly, as well as incorporating the altitude bearing pads and the whole of the azimuth bearings into its construction. Because of this it is very important that the rocker box is very rigid and stable. This stability has been achieved by the use of a squat design, solid construction, and a pedestal base with widely separated adjustable feet.

As discussed in the section on overall design, the squat design actually springs from using large diameter altitude bearings together with a low centre of gravity to the tube assembly. To a large degree, a good squat rocker box can only be built if sufficient thought and design has gone into the rest of the scope. One could compensate for too high a centre of balance for the tube assembly by enlarging the altitude bearings, enabling one to still have low sides to the rocker box. This would cause problems, however, if one wanted to retain the previously discussed advantages in using the same combination of materials in both bearings. One would then have problems with the force required for movement in altitude being significantly greater than the force required for azimuthal movement, due to the disparity in bearing radii. As an aside, I do think that on many commercial Dobsonian designs the altitude bearing is undersized. To balance up the frictional resistances in the two axes *in slew*, which is the mode generally tried in the simple 'shop test', differing materials are used for the altitude and azimuth bearings. This then gives differing characteristics for the two axes when the telescope is used in other modes of movement such as slow scan and nudge-to-follow. Often the altitude bearing radius could be significantly increased, leading to a better match between the forces required for movement in altitude and azimuth and significant improvements in stability, as well as immunity from problems due to minor tube assembly imbalances.

Although the rocker box is large and very rigid it is not unmanageably heavy, weighing in at about 21kg. The weight has been kept down by using 63×50mm 'U'-section aluminium alloy for the pedestal base and a composite construction for the swivelling upper box. This upper box is made of panels of 12mm marine ply, epoxied to the outsides of a light but rigid polyester foam. At the bottom of this box is the base board which forms the top half of the azimuth bearing and whose rigidity is key to the rigidity of the whole mount. This board is also of a composite

construction. After much deliberation I decided to make this board 63mm thick with a 40mm thick polyester foam core. Even though this is a substantial thickness, the whole 51×51cm board only weighed about 8kg and I have no regrets as the scope in use exhibits virtually no shake or wobbliness, even at magnifications of over ×600 in light breezy conditions.

Light shroud

To improve image contrast and significantly reduce the problems of air currents from the observer's body disturbing the image, most truss pole Dobsonians have a separate light-blocking shroud. This is usually made of a dark material which wraps around the outside of the poles like a cape, and is zipped up like a coat or attached with straps or Velcro. *Fossil Light* uses a shroud made of a black 'rip-stop' nylon fabric, bought off the roll from a kite shop. This fabric has low weight, very high strength, and good resistance to dewing, and because it is thin and breathable it readily dissipates internal tube currents. Although the use of this material is not novel, I believe the overall design and the way in which the shroud is erected is quite different from most other Dobsonians.

Fossil Light's shroud consists of a fabric tube whose bottom end is permanently attached to the top of the bearing box. Once the scope has been assembled, the shroud is simply pulled up on the *inside* of the poles and is hooked to the four carrying handles on the UTA. To keep the tube circular and prevent it sagging into the scope's light path, it is pulled taut with elasticated attachments at top and bottom. In addition, at intervals along the length, the shroud uses open-ended hoops of thin carbon fibre kite rods which, because they are trying to spring outwards all the time, keep the walls of the shroud hard up against the inside of the truss poles. With this design, the shroud only takes about 15 seconds to put up and it can never be forgotten when packing the car for an observing session. In addition, because it is on the inside of the truss poles, the effects of any thermal currents from the cooling metal poles are lessened.

Improving thermal characteristics

When the telescope was set up for observing shortly after 'first light', it would take 2 to 2½ hours for the instrument to cool to near ambient temperature and for internal convection currents to die down to reasonable levels. This was mainly because I kept the scope indoors, combined with the large thermal mass of the primary mirror sitting at the bottom of the telescope. To speed up the cooling rate of the primary and reduce tube currents I spent a good deal of time experimenting with a 12 volt DC brushless fan sited behind the primary. I tried an arrangement with the fan blowing on its back and a soft air dam around the mirror to prevent air being blown up the tube. I also tried no air dam and the fan rotation reversed, with the area around the fan at the bottom of the mirror box sealed with a plastic sheet. With this setup, air was sucked down the tube and past the primary to cool

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it. The slimline fan, which incidentally gives no discernible vibration even at maximum speed and observing powers over $\times 700$, has a resistive control box giving several possible speeds. Best results seem to be obtained by giving the mirror a fast blast for about half an hour and then turning the speed down to a more gentle level. The cool-down of the mirror is dramatically improved compared to setting up without the fan; decent seeing is achieved in about 45 minutes now. In addition, keeping the fan on at a low level eliminates any slow moving residual heat currents and seems to improve seeing all night.

With the whole scope cooling down more quickly due to the addition of the fan, dewing of the secondary became more of a problem. To combat this, I was able to exploit the heating potential of the small sealed lead-acid battery which I now had on board to power the fan. I removed the secondary and bonded a 0.7mm thick and 63mm diameter heating mat to the back face of the mirror. This mat, available as part of a range of self-adhesive heating mats from RS Components, was rated at 3W when run at 12 volts and I calculated that it would raise the temperature of the secondary by about 1°C per minute. In practice it works extremely well, driving off the dew after about four or five minutes and requiring only another five minutes or so for the resulting astigmatism to fully disappear.

Finishing touches

To improve image contrast as much as possible, I lined many of the internal surfaces of the telescope with black flocked 'sticky-backed-plastic', which I bought from a local hardware shop. I have used this material on other telescopes with very good results. It is quick to apply and very black, even at shallow angles of incidence where paints such as the very matt 'blackboard black' look decidedly reflective. I

lined the inside of the bearing box as well as the UTA with the material, including the secondary holder and the inside of the focuser tube. This latter item is responsible for significant contrast loss in many telescopes, because of its location just in front of the eyepiece, and because it is often left with a silvered or even chromed finish.

I knew that given the British weather I would probably spend more time looking at my telescope than looking through it. Because of this I wanted the telescope finish to be good. Most of the parts that were not inherently black or that I couldn't anodise or powder coat black, I painted. Smaller items I sprayed with car paint, but for larger items like the rocker box I used gloss marine paint applied using a small sponge roller. The marine gloss came up like a mirror without having to polish back the surface after it was dry. I was very pleased with its look, although there was a lot of sanding down between coats which I found very laborious and messy.

Previous experience with telescopes that are carried to observing locations had taught me that there are usually never enough carrying handles on the body of the telescope. I had four handles on the bearing box, four on the rocker box, four on the UTA (also used to steer the scope) and one very large one on the heavy mirror box. This number was just about right!

With a scope of this size it is not possible for one person to drag the assembled instrument a few yards to change the observing location. To get away from an unshielded light or to see past a close tree I designed a system using 15cm diameter soft pram wheels to roll the scope in the desired direction (Figure 7). The wheels are on short shafts which plug into bores in the ends of the pedestal legs when needed. Each pedestal leg end has a choice of three bores at 30° , 0° and -30° ; by choosing the appropriate combination of shafts in holes, the scope has three main preferred directions. This is a simple system which does not add any height to the scope, keeps the weight down and maintains maximum stability in normal use, when the spongy wheels are removed.

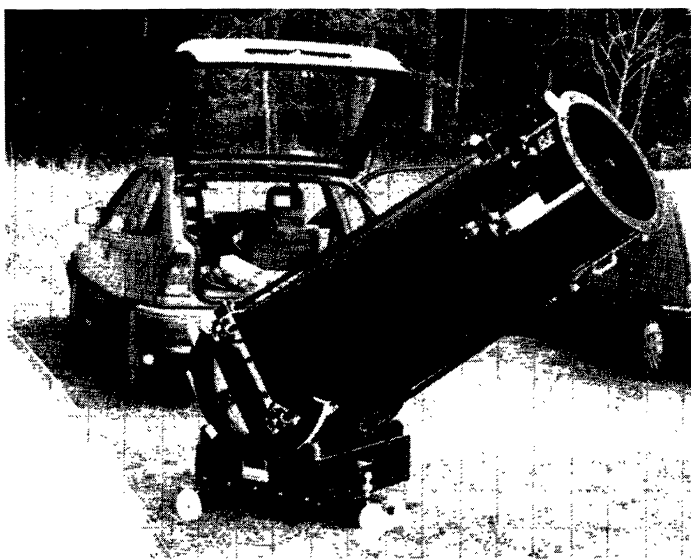


Figure 7. General view of assembled scope prior to loading car after Equinox Star Party 1996. Note the wheels fitted to the pedestal base to enable the scope location to be changed.

Mechanical performance and maintenance

I am very pleased with the telescope, but am still looking for ways to improve its performance and ease of use.

After much planning and experimentation, the performance of the bearings is now just what I had hoped for. The scope moves smoothly, does not stick when moving at the very slow speeds needed to manually track objects, and does not suddenly jump forward when I try to nudge it forward slightly. 'Dobson's Hole', the zenith area, which is traditionally a difficult area for Dobsonians to observe objects in,⁸ presents no real difficulties, apart from leg-ache from standing two steps up a ladder for prolonged periods (the eyepiece is 1.98m high when pointing at the zenith).

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Figure 8. Loading of Astra hatchback after Equinox Star Party in 1996.

- A. Back seats folded down and UTA in position.
 B. As photo A but rocker box and mirror box loaded in.
 C. As photo B but bearing box and truss poles also loaded.

Fossil Light is extremely stable in use and I am pleased that all the effort on this aspect of the design has paid off. When I stop pushing it stops moving, with no visible after-shake. I can even observe in a light breeze, at high magnification, with no problems of image vibration.

The desired objective of being able to pack *Fossil Light* into the back of my Astra for travels to dark sky sites, has been successfully achieved. With the back seats folded flat,

it fits in with relative ease and there is also room for my observing ladder, a small folding table, two large boxes of accessories, a bag of star charts, a pair of moon-boots and other warm clothing, as well as having plenty of room for a fellow observer. Figure 8 shows how the parts of the scope fit into the back of the car. The set of photos was taken at the 1996 Equinox Star Party in Thetford Forest. On that expedition the car also swallowed up two tents, cooking gear and food, as well as clothes, sleeping bags and all the other bits and pieces that two people need on a three-day camping and astronomy holiday.

The assembly and break-down procedure for the scope is now well-practised and on my own it takes about 5 to 8 minutes. The exact time depends on the distance between the car and where I am setting up to observe. On top of this assembly time, I also need about a minute or two of collimation using a Cheshire eyepiece. The amount of collimation required is usually very small, frequently only requiring a tweak of the primary. Quite often it is unchanged since the scope was last used. I am very pleased about this aspect of the performance as it is an indication both of the stability of the mechanics and of the tolerances in the build of the mating parts. I take no drastic measures to protect *Fossil Light* from shock or damage during transportation to a dark sky site. The only precautions I normally take are to put cushions between the UTA and the neighbouring bearing box and between the bearing box and the back end of the car, and to put two small blocks of 25mm thick heavy-duty sponge rubber under each of the rear two pedestal feet of the rocker box. On long daytime journeys in the summer, I also use a white nylon sheet draped over the telescope parts to protect them from excessive warming by the sun.

Although *Fossil Light* has picked up a few inevitable but annoying scratches and nicks in the past few years, the mechanics have not deteriorated to any perceptible degree and there has been no noticeable wear in the mating parts of the sub-assemblies. There are occasional minor running repairs to be done, however, and each summer during 'the-time-of-no-night' (mid-May to mid-July) I spend a few hours servicing the telescope. This service involves a general check over, followed by thorough cleaning of all the bearing surfaces and lubrication of moving parts such as the toggle clamps and the sliding pins in the UTA. I use an excellent new bicycle lubricant for this purpose which dries to leave a non-sticky, Teflon based, low friction film.

Optical performance

The views through the eyepiece have been worth all the toil and money. Memorable sights have been: M101 with scores of knots and arms from Exmoor one spring; M13 blazing to the core with pinpoint stars on the same night; the central star of the Ring Nebula at the Equinox star party; the central 'shield' of the Eskimo Nebula from my garden in St Albans; easy dust lanes in NGC 4565 and NGC 891; faint galaxy clusters such as Hickson 97, as well as divisions in ring A of Saturn from the WOLAS observing location in the Chilterns. My favourite objects at present are edge-on galaxies, and I have plenty of these and other deep-sky

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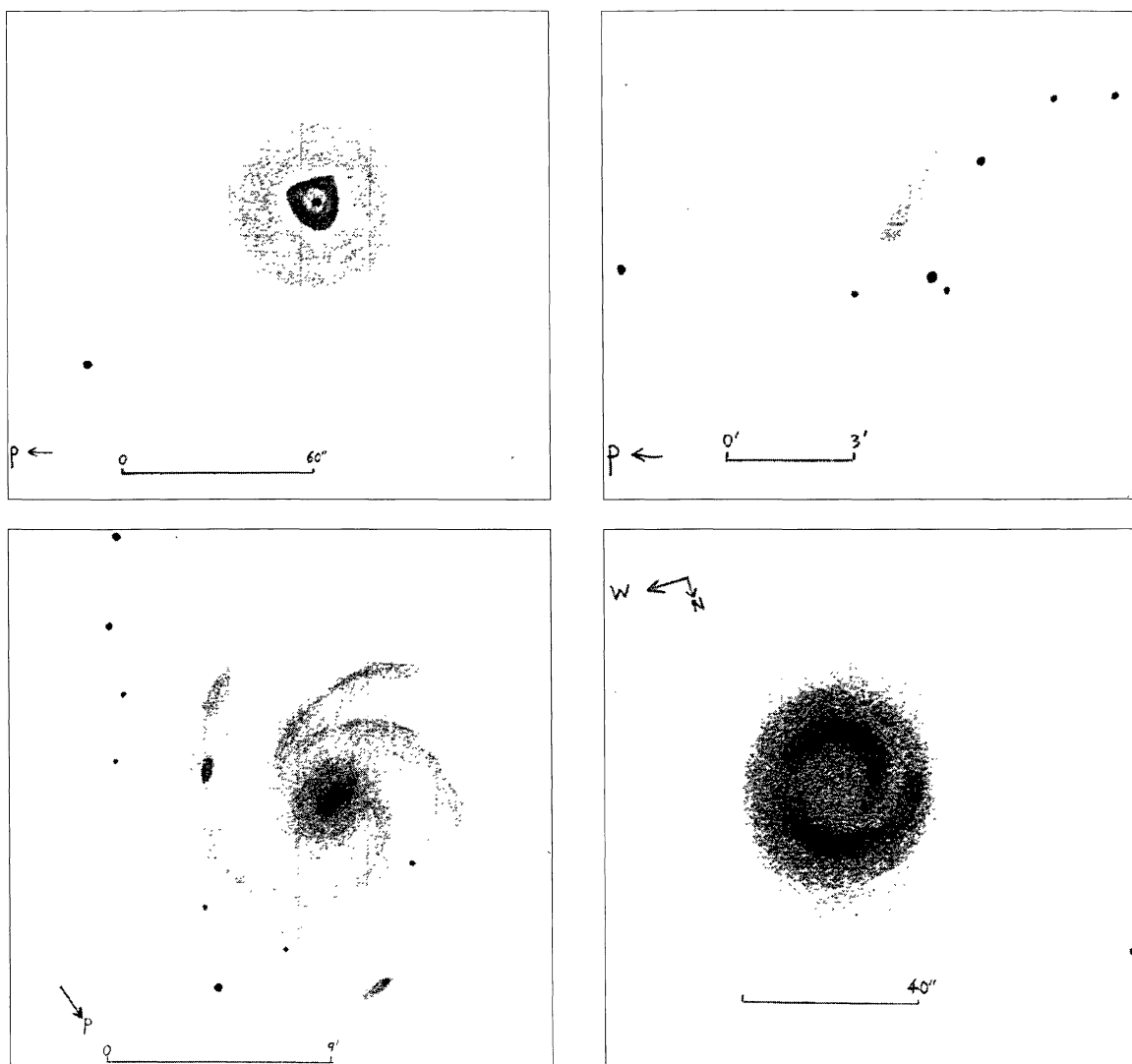


Figure 9. Drawings of deep-sky objects seen through *Fossil Light*. Clockwise from top left: Eskimo Nebula (NGC 4392), Gemini, $\times 762$; IC 2233, Lynx, $\times 156$; 'Blue Snowball' (NGC 7662), Andromeda, $\times 680$; M101 (NGC 5457), Ursa Major, $\times 102$.

objects on my list to work through over the years, with *Fossil Light* as my trusty companion on dark nights.

Finally, two quotations from Steve Overholt's book, one which inspired me to start building *Fossil Light* and one which helps me keep things in perspective now it is built:

'Whatever you can do, or dream you can, begin it. Boldness has genius, power, and magic in it.' (Goethe)

'Large telescopes are tools that hopefully will receive hard use. They will quickly gather battle scars as you travel around the country committing astronomy.' (Tom Clark of Tectron telescopes)

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- Overholt S., *Lightweight Giants – Affordable Astronomy at Last*, Owl Books, 1993. Available from HB Publishers, Box 2933, Paso Robles, CA 93447 USA
- This name derives from one of the 'Cosmic Gnomes' on the side of Swansea Astronomical Society's very elegant 'Tower of the Ecliptic'. The verse goes; '*Fossilised Light – nothing disappears, Though all is rearranged, Lost are they who are unamazed*'. The words were written by Nigel Jenkins, who I wish to thank for the haunting beauty he conveys in the lines.
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- Texereau J., *How to Make a Telescope*, Willmann-Bell Inc., 1994, p.375
- Suiter H. R., *Star Testing Astronomical Telescopes – A manual for Optical Evaluation and Adjustment*, Willmann-Bell, Inc., 1994
- My article about the frictional requirements of Dobsonian bearings is due to be published in *Sky and Telescope* this year, under the title 'Understanding and improving Dobsonian motion'. The article goes into depth about what features are needed in good Dobsonian telescope bearings and recommends an excellent combination of bearing materials.
- Due to the large azimuthal but small altitude movements required to follow objects in this region of the sky.

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