Alt-Az Aerospace Telescopes

For Research, Astrophotography, and Education

Russ Genet, Howard Banich, Richard Berry, Mel Bartels, and Dan Gray met this past June to discuss alt-az control systems. To the right is Dan's 14-inch alt-az telescope, known as the "Lollipop." It is constructed from honeycomb composites. The Lollipop has an instrument rotator (far side) and has been used to test out several of the concepts discussed in this article.

by Russ Genet, Dan Gray, Howard Banich, Dave Rowe, Tom Smith, and Tom Krajci

This paper presents the case that the combination of low-cost alt-az telescope control systems and affordable aerospace materials has reached a point where a revolutionary new class of light weight, highly capable alt-az telescopes is emerging. Similar to SCTs, they will not only be used visually, but for CCD-based scientific research and astrophotography. Similar to Dobs, they will have larger apertures than SCTs yet will be light in weight. Unlike visual-only Dobs but similar to their closely related giant mountaintop alt-az relatives, this emerging class of precisely controlled telescopes will handle a variety of instruments mounted on a field de-rotator with generous back focus.

Introduction

Thanks very much to Tom Johnson, Schmidt-Cassegrain telescopes (SCTs) revolutionized astronomy by making production telescopes compact, portable, and affordable. Computerized go-to capabilities and quantum efficient, affordable CCD cameras, pioneered by SBIG and now also available from Apogee, Finger Lakes Instrumentation, QSI, Starlight Xpress, Yankee Robotics, and others—transformed SCTs into powerful instruments for research, astrophotography, and education. Beyond an aperture of 14 inches, however, the cost of SCTs rises sharply.

Enter altitude-azimuth (alt-az) Dobsonian telescopes (Dobs) which, thanks to their transportability and relatively low cost, now dominate the class of visual only telescopes with apertures greater than 14 inches. Dobs, because they can be built with ordinary woodworking tools from readily available materials, inspired numerous amateur telescope makers and manufacturers into action.

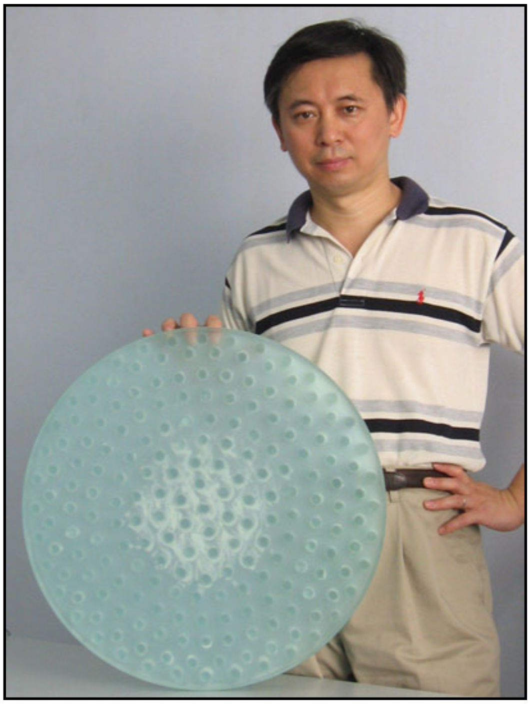
Human vision is amazingly adaptive, easily compensating for image motion. Cameras, however, are unforgiving. Thus the use of the large aperture Dobs in research and astrophotography is limited by their lack of precise, variable rate, two axes computerized tracking, their need for field de-rotation, and their susceptibility to wind gusts. Dobs also generally lack the backfocus and weight capacities required to accommodate instrumentation.

For reasons of compactness and economy, all recent large mountaintop telescopes have been alt-az, not equatorial. The availability of computerized control systems to constantly calculate the ever changing drive rates in altitude, azimuth, and field rotation made this revolution possible. Although these telescopes weigh many tons, they are actually very lightweight, stiff structures when one considers the weight of their mirrors. Steel, pound for pound, is one of the stiffest of all materials, and on a cost per pound basis it has no peer. Only aerospace materials such as Kevlar and carbon fiber are, pound for pound, stiffer than steel. Similarly, aluminum honeycomb panels, for their weight, resist bending better than sheet steel. Although in the past, aerospace materials were deemed too expensive to be used in large telescopes, this situation is changing rapidly as costs continue to decrease and telescope makers become more familiar with the use of aerospace materials.

The cost of alt-az telescope control systems has plummeted over the years. Initially, PDP-8 control computers and telescope control electronics cost tens of thousands of dollars and filled entire equipment racks. Today, Sidereal Technology makes a microcomputer-based alt-az telescope control system for about $1,000 that you can pack in your briefcase with room to spare. Meanwhile, the cost of aerospace materials has also plummeted as their use has moved beyond aircraft and spacecraft to outdoor signs and building exteriors. Given these two dramatic drops in cost, research class alt-az telescopes fabricated from lightweight aerospace materials are now economically viable, at least for modest to intermediate apertures where the cost of aerospace materials is not prohibitive.

The primary reason for developing lightweight alt-az telescopes with apertures larger than SCTs is to conduct research on, image, and view fainter objects. Dark skies are also helpful, but the costs of establishing and maintaining dark site observatories are considerable. Light weight yet large aperture portable research grade telescopes avoid these costs. Many backyards are blessed with modestly dark skies. Observational pads accommodate light weight telescopes which can be covered when not in use. During extended periods of inclement weather these telescopes can be safely stored in garages or basements. Alternatively, these alt-az telescopes can be permanently installed in unobtrusive roll off roof shelters or even under domes.

Bright sky locations can also benefit from large aperture, precision alt-az telescopes. Narrow-band astrophotography produces good results by observing H-alpha, O III, and S II emissions, which are brighter than even their urban sky backgrounds. Such narrow band, photon limited astrophotography, much like spectroscopy, benefits from raw aperture.



Tong Liu and a 20-inch Hubble-Optics fused sandwich mirror. Because cooling air can circulate between the relatively thin front and back plates, the mirror cools up to ten times faster than a solid mirror with an equivalent thickness. A similar 20-inch mirror with a hyperbolic primary and matching corrector with generous backfocus will be used in a prototype alt-az telescope being designed by several of the authors. A 40-inch sandwich mirror in a corrected Dall Kirkham configuration (with a tertiary folding mirror) is planned for a follow-on prototype. Hubble Optics has produced about 1,000 mirrors, with some 200 being sandwich mirrors.

The emergence of this new class of light weight, highly capable "aerospace" alt-az telescopes is being facilitated by innovative solutions to challenges in six vital areas:

(1) Light weight affordable optics
(2) Back focus for autoguiders
(3) High natural frequency mechanical structures
(4) Precision control systems and drives
(5) Field de-rotation
(6) Ease of construction and affordability

Each challenge area is discussed below, followed by a brief consideration of structural alternatives.

Light Weight Affordable Optics

Significant research and education, not to mention public outreach, is still visual. A Newtonian optical configuration on an alt-az mount places both eyepieces and instruments at a comfortable working height for telescopes of modest to intermediate aperture. If the sole purpose of a telescope is non-visual, a prime focus configuration can save weight and cost and is slightly more efficient in optical transmission. However, for the general purpose telescopes we are primarily considering, placing instruments at the Newtonian (secondary) focus is not only convenient, but it shortens the optical tube assembly (OTA). The small telescope community is blessed with a plethora of high quality, thin Pyrex, finished parabolic mirrors for Newtonian telescopes. They are available from Galaxy Optic, Hubble Optics, Kennedy Optics, Lockwood Optical, Pegasus Optics, Orion Optics, Zambuto Optics and others.

In this paper we are concerned with somewhat larger than normal apertures, so we offer several optical guidelines. Focal ratio is the key determinant of the difficulty in figuring primary mirrors. A 20- to 30-inch f/4 mirror is relatively standard these days. An f/3 mirror in this size range is difficult to figure, but still doable by the best opticians, but one pays for it in cost, delivery time, surface accuracy, and tight collimation tolerances. Mirrors faster than f/3 should be avoided, thus setting a lower bound on the focal length of larger aperture mirrors.

Opinions vary as to an upper bound to focal lengths. Eyepiece access and observer safety are obvious issues. Also, as the OTA gets longer, its resistance to bending decreases by approximately the cube of its length. Thus to retain stiffness, the structural members must grow in cross sectional area, which causes wind loading to increase. Furthermore, longer OTAs give these wind gusts an increased lever arm. Countering highly leveraged wind gusts with an active control system—most likely a must with any large imaging Newtonians out in the open—requires high torque drive motors. In general, shorter telescopes will always perform better in the wind than longer ones.

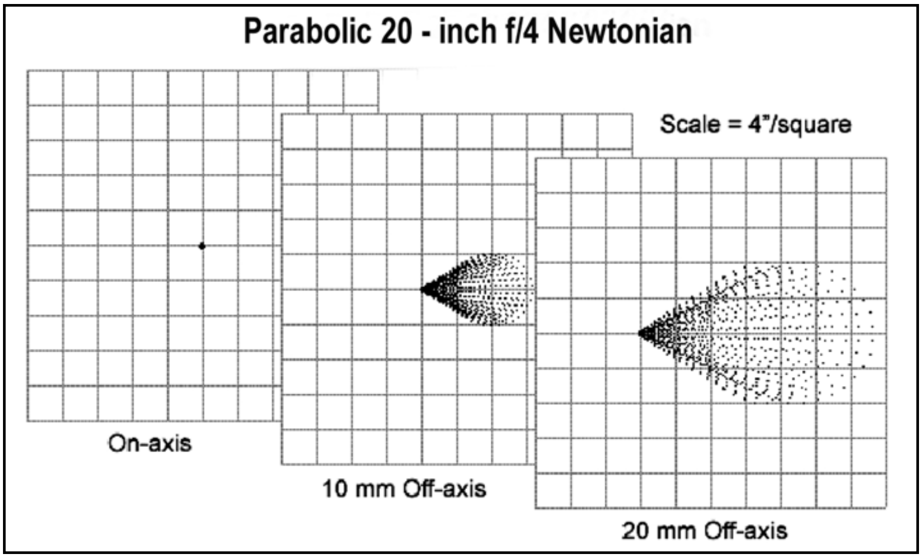
Higher torque motors won't solve all one's problems, however. Instruments at the Newtonian focus provide wind gusts added leverage for movements of the entire telescope with respect to the ground, and motion and vibration at the mechanical interface between the altitude axis and the OTA. Thus as apertures increase, one should increasingly consider folding the optical path to bring the instruments nearer the intersection of the telescope's axes, a design change that also reduces the moment of inertia and hence increases the natural frequency.

If one is willing to settle for significantly longer effective focal lengths, classical or Ritchey Chrétien (RC) Cassegrain, or corrected Dall Kirkham optics, can be used along with a tertiary flat to bring the optical path out on one side. If one is not concerned with the UV or far IR—a limitation with any lens-based correction system—corrected Dall Kirkham optics with a spherical secondary mirror and spherical corrector lenses are not only economical to produce, but the spherical secondary, compared to Cassegrain or RC systems, is less sensitive to misalignment.

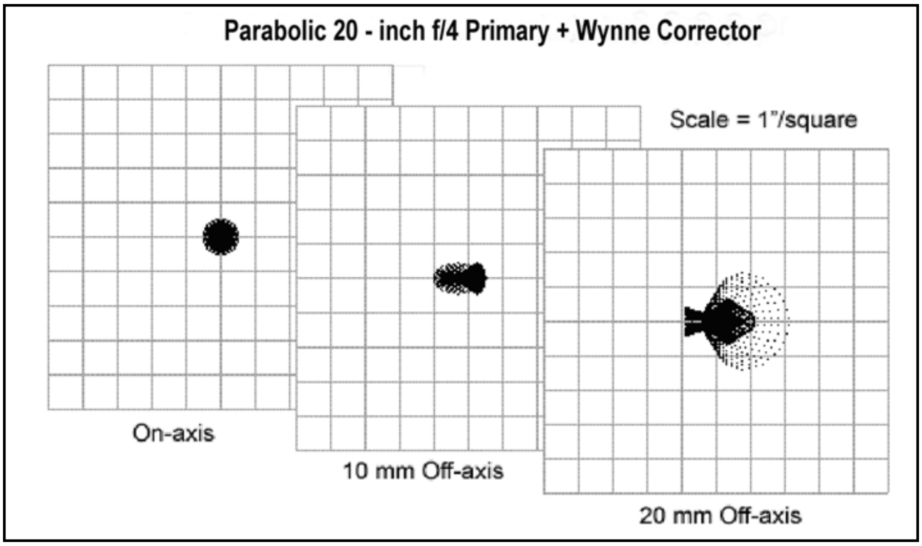
Although Newtonian telescopes with parabolic primaries provide acceptable visual images over a small field, coma is objectionable for even small CCD chips and is unacceptable for large format chips. For example, a 20-inch f/4 Newtonian with an uncorrected parabolic primary has 50-micron RMS diameter comatic spots 10 mm off axis. Fortunately, off-the-shelf Wynne coma correctors are available for parabolic systems, such as the two-inch Baader MPCC and Teleview Paracorr correctors, and the three- and four-inch Keller correctors.

Thin, monolithic annealed Pyrex mirrors supported by whiffletrees have worked well for apertures up to 32 inches and beyond. However, other types of mirrors may weigh less, cool faster, or be easier to support. These include cast mirrors, cellular mirrors (Wangsness Optics), and fused sandwich mirrors (Hubble Optics). Furthermore, although parabolic primaries coupled with off-the-shelf Wynne coma correctors provide good images, a hyperbolic primary—when coupled with a matching Ross-type corrector—can provide excellent images with significant cost and mechanical advantages.

Although hyperbolizing the primary mirror can add 10-15% to its cost, the corresponding Ross corrector is much lower in cost than a Wynne corrector, and much smaller for the same unvi



Ray trace of a standard 20-inch f/4 parabolic mirror without any corrective optics. Each square represents 4 arcseconds.



Ray trace of a parabolic 20-inch f/4 primary mirror with a three-element Wynne-type corrector over a flat field. The corrector is 6" long, 4" in diameter, and has a 95-mm back focal length. It does not vignette a 40 mm diameter image circle. Note that each square now represents only 1 arcsecond. The simulated wavelengths are 400 nm, 550 nm and 800 nm.

gnetted image circle. The on-axis performance of corrected hyperbolic optics is superb, with Strehl ratios >0.97 achievable in good designs. Furthermore, correctly designed Ross correctors, as contrasted to Wynne correctors, have fewer problems with ghosting, baffling, and reflections, take up less space, and have sufficient back focus for easy insertion of off-axis guiding hardware. Hubble Optics offers an affordable 20-inch, f/4 hyperbolic primary with a matching Ross corrector with generous back focus.

Back Focus for Autoguiders

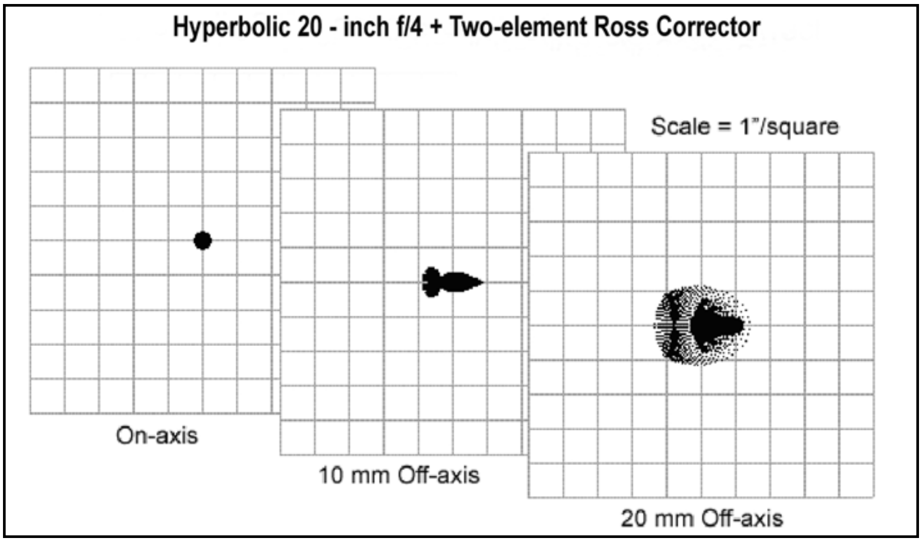
Long-exposure spectroscopy, astrophotography, and time-series photometry can all benefit from the precise tracking provided by autoguiders. A small pick-off prism or mirror on the periphery of the field directs the light from a guide star to a small autoguide camera such as the Trifid Nugget made by Yankee Robotics, or to an auxiliary CCD chip built into the main camera itself, as in many SBIG cameras. Deviations of the guide star from its desired position are sensed and appropriate corrections are provided by the telescope's control system or by a small, refractive "deviator plate" (SBIG and Starlight Xpress) tilted in two dimensions. Because deviator plates have low inertia, they can be moved much more rapidly than entire telescopes. This allows them to correct for mount errors and, perhaps, atmospheric turbulence if a sufficiently bright guide star is available.

However, there is a problem with Wynne correctors for parabolic mirrors mentioned previously. The back focus distance between the outer surface of their last corrector lens and the CCD camera's chip is, typically, only 55 mm. CCD cameras and their accompanying filter wheels take up most of this back focus, leaving insufficient room for an off-axis guider (OAG) pickoff prism or mirror, let alone a deviator plate. Fortunately, two Wynne coma correctors with greater back focus will soon be available. One is a modified 4-inch Keller, available soon from Dream Telescopes (82 mm backfocus), while the other is a new entry from Hubble Optics (89 mm backfocus).

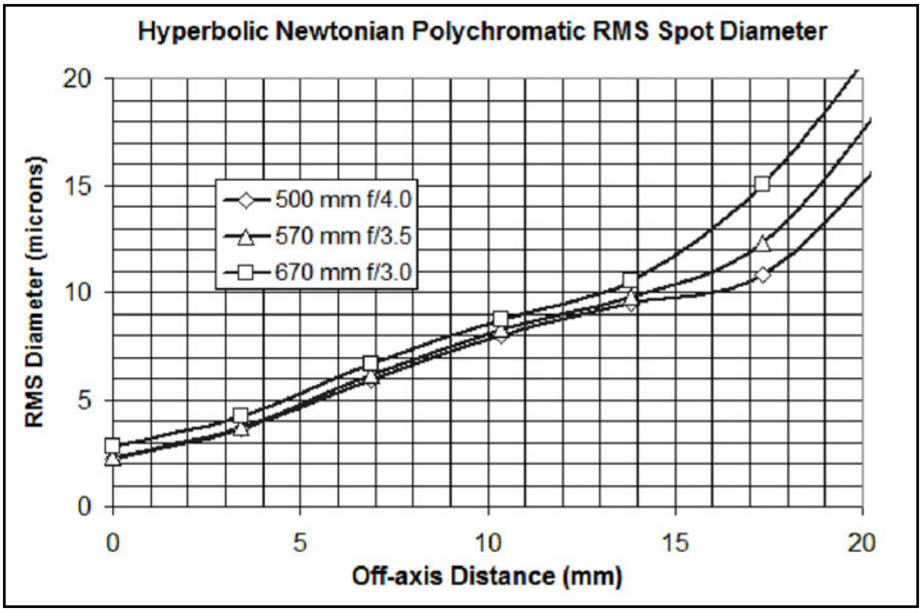
Alternatively, there are four solutions compatible with 55 mm of back focus.
First, if exposure times are kept short, autoguiding may not be required. Furthermore, control systems can be designed that track stars with considerable precision for long periods of time. Control systems can even be designed to sense and counter wind gusts, as will be described below. Thus an autoguider may not be required for longer exposures.

Second, one can employ an SBIG camera with an in-camera OAG CCD chip that fits within 55 mm. This works well for many applications, although one often needs to rotate the camera to find a suitably bright guide star—a task easily accomplished by alt-az telescopes equipped with instrument rotators. Such autoguider chips may not work well for narrow-band astrophotography, however, as there may be insufficient photons passing through a narrow filter for guiding.

Third, one can use a low profile cam-



Ray trace of a hyperbolic 20-inch f/4 primary with a two-element Ross-type corrector over a flat field. The corrector is 1 inch long, 3 inches in diameter and has 95-mm back focal length. It does not vignette a 40-mm image circle. The primary mirror has a conic deformation constant of -1.20 (over corrected by 20%). Note that each square represents one arc-second. The simulated wavelengths are 400 nm, 550 nm, and 800 nm.



This graph shows the polychromatic RMS spot size as a function of off-axis distance when the same two-element Ross-type corrector is used with hyperbolic primary mirrors having different focal ratios. In each case, the primary mirror is 20% over corrected. The simulated wavelengths are 400 nm, 550 nm, and 800 nm.

era such as the SBIG ST-402 with its built-in filters. With the ST-402 there is enough back focus within the 55-mm space for an OAG pickoff. Similarly, astrophotographers can use a color camera, such as those from Starlight Express, where the "filters" have been incorporated into the CCD chip itself.

Finally, one can forego an OAG and, instead, autoguide with a camera on a separate guide scope sturdily mounted to minimize differential flexure. Although the autoguider's field will rotate and the optical axes of the two telescopes might not coincide, these difficulties could be handled in software.

High Natural Frequency Mechanical Structures

Portable and roll-off-roof alt-az research telescopes must, obviously, be designed to operate out in the open. A good share of small telescope research involves time series "movie" follow-ups to "snapshot" observations made with larger survey telescopes. Thus science alt-az telescopes are workhorses. Observing cannot be suspended with the first significant breeze, even though instruments and baffles are exposed to wind gusts. Furthermore, a Newtonian configuration gives these gusts a long lever arm. One good, although expensive, solution is to place telescopes under permanent domes, but there are other solutions. A low aerodynamic cross section at the top ends of Newtonian telescopes, for instance, can help reduce the effects of gusts, as can an open truss design, although they are more susceptible to stray light.

Al Kelly points the apex of a V-shaped wind screen upwind to deflect gusts around his portable imaging alt-az telescope. Placing portable telescopes inside portable observatories reduces the effects of gusts, not to mention stray light. Commercially manufactured portable observatories are available from AstroGizmos, Kendricks, and Observa-Tech. Although portable observatories require transport and setup, they are low in cost and provide significant protection from both wind and light.

Whether operating out in the open or under a dome, how can the telescopes themselves be designed to be less susceptible to wind gusts? In the past, when control systems were mere clock drives, the immense rotational inertia of massive mounts resisted wind gusts. That approach still works but is no longer necessary. Today, modern mountaintop telescopes with their high resolution encoders and backlash free drives counter wind gusts with servo loops closed through high torque motors. When a wind gust pushes on the telescope, encoders sense this motion and servo motors generate appropriate counterbalancing torques revised in sub-millisecond time scales. Thus active control systems provide "electronic stiffness," obviating the need for "inertial stiffness." Alt-az telescopes with active wind-countering control systems can have much lighter weight structures than would otherwise be possible. Besides costing less, such light weight structures also have lower moments of inertia, allowing the use of lower torque, less expensive drive motors. Furthermore, lighter structures deflect less due to the weight of the structures themselves.

Any system that is excited by a broadband energy source, such as wind gusts, tends to concentrate energy at its resonant frequency. Most of the energy transferred to telescopes by wind gusts is below 10 Hertz, therefore modern telescopes are designed so that their lowest resonance (their natural frequency) is greater than 10 Hertz. This allows control systems to directly counter wind gusts without encountering destabilizing resonances. The advantage of even higher natural frequencies is that control system bandwidths can be increased so telescopes settle faster and track with smaller following errors.

The Sidereal Technology control system handles four servo loops: typically alt and az (or RA and Dec), rotation, and focus. The ASCOM-compliant system can either operate stand-alone via a wireless (RF) control paddle, or under the supervision of a PC with control software such as Maxim DL or The Sky. Over 100 systems are in operation on a wide range of telescopes, and an active Yahoo group discusses its fine points daily.

A small mass suspended from a stiff spring will vibrate at a high frequency. Similarly, a low inertia (light weight) stiff telescope will have a high natural frequency. Unlike yesteryear's passive, low natural frequency telescopes where high mass was an asset, now just the opposite, low mass, is a virtue with today's active, high natural frequency, gust countering telescopes. Besides being stiff and lightweight, modern alt-az telescopes keep their rotational inertias low by placing their OTA centers of gravity coincident with the intersection of the telescope axes, not offset and counterweighted as in some other telescope configurations.

Most materials are strongest in compression and tension and are weakest in bending and torsion. Truss geometries, which avoid bending and torsion, have high natural frequencies, while cantilevers have low natural frequencies. Although Dobs, especially those with truss tubes, use geometry to good effect, even the best birch plywood is not very stiff and is quite heavy compared to the advanced composite materials used in aircraft and spacecraft. Thus it is not surprising that light weight aerospace materials which, as mentioned earlier, are pound for pound stiffer than steel, are ideal for use in smaller alt-az telescopes. The relatively small amount of such expensive material does not preclude its use.

Modern aerospace materials include Kevlar and carbon-fiber laminates as well as foam and honeycomb core panels. Geometric shapes formed from aluminum alloy extrusions, covered with thin aluminum sheets, and filled with structural foam, can also be used to good effect. Honeycomb panels, which act as thousands of miniature I-beams running in two directions at once are incredibly resistant to bending. Carbon fiber laminates, besides being one of the stiffest known materials for their weight, also have a near zero coefficient of thermal expansion, a property that can be used to good effect in truss tubes to reduce focus shift due to temperature change.

Precision Control Systems and Drives

Alt-az telescopes require constantly-varying motions in three axes (altitude, azimuth, and field rotation). Typically, a dedicated low-level control microcomputer, such as the one in Sidereal Technology's control system, adjusts these three motions at millisecond intervals. A PC provides both mid-level servo control and high-level supervision via a telescope control program such as Maxim DL, TheSky, or MPO Connections. Compatibility between the PC's servo and telescope control software can be assured if both adhere to the ASCOM (Astronomical Common Object Model) interface standard.

To actively counter wind gusts, not only must telescope structures be very stiff, with natural frequencies well above 10 Hertz, but their drive systems must be both stiff and backlash free. Changes in torque and position must take effect within a few milliseconds. Encoders with sufficiently high resolution on both telescope axes allow direct closure of the altitude and azimuth servo loops during tracking. This enables control systems to actively counter wind gusts. The use of high resolution encoders also obviates the effects of friction roller slippage or gear errors in drive trains.

The cost of high resolution encoders has dropped dramatically in recent years. Top-of-the-line "Mercury II" encoders from Micro-E Systems, with an amazing resolution of 256,000,000 counts per revolution, cost well under $2,000. Renishaw and Micro E Systems produce encoder stick-on tapes that can be fastened to drive wheels and decoded with small read heads. Friction roller schemes have been successfully used to mechanically step up lower cost, medium resolution encoders such as the 230,000 counts per revolution encoder from Gurley which costs less than $400.

Mountaintop alt-az telescopes often employ direct-drive torque motors. However, these large diameter torque motors—which are built right into the telescopes themselves—are very expensive. A lower cost approach is to mechanically step up the torque with a small friction roller pressed against a large diameter disk. A smaller, less expensive torque motor, such as the "pancake" DC motors on electric bicycles, can then be used.

If one is willing to forego the very considerable advantage of actively countering wind gusts, there are other, lower-cost control system options. The most basic just employs low-resolution encoders integral to gearhead servo motors. For slews, the controller simply commands the number of encoder "ticks" required to arrive at the desired destination. There is no independent check to see if the system actually arrived at its destination, which could be off if there was slippage in a friction-roller drive or error in a gear train.

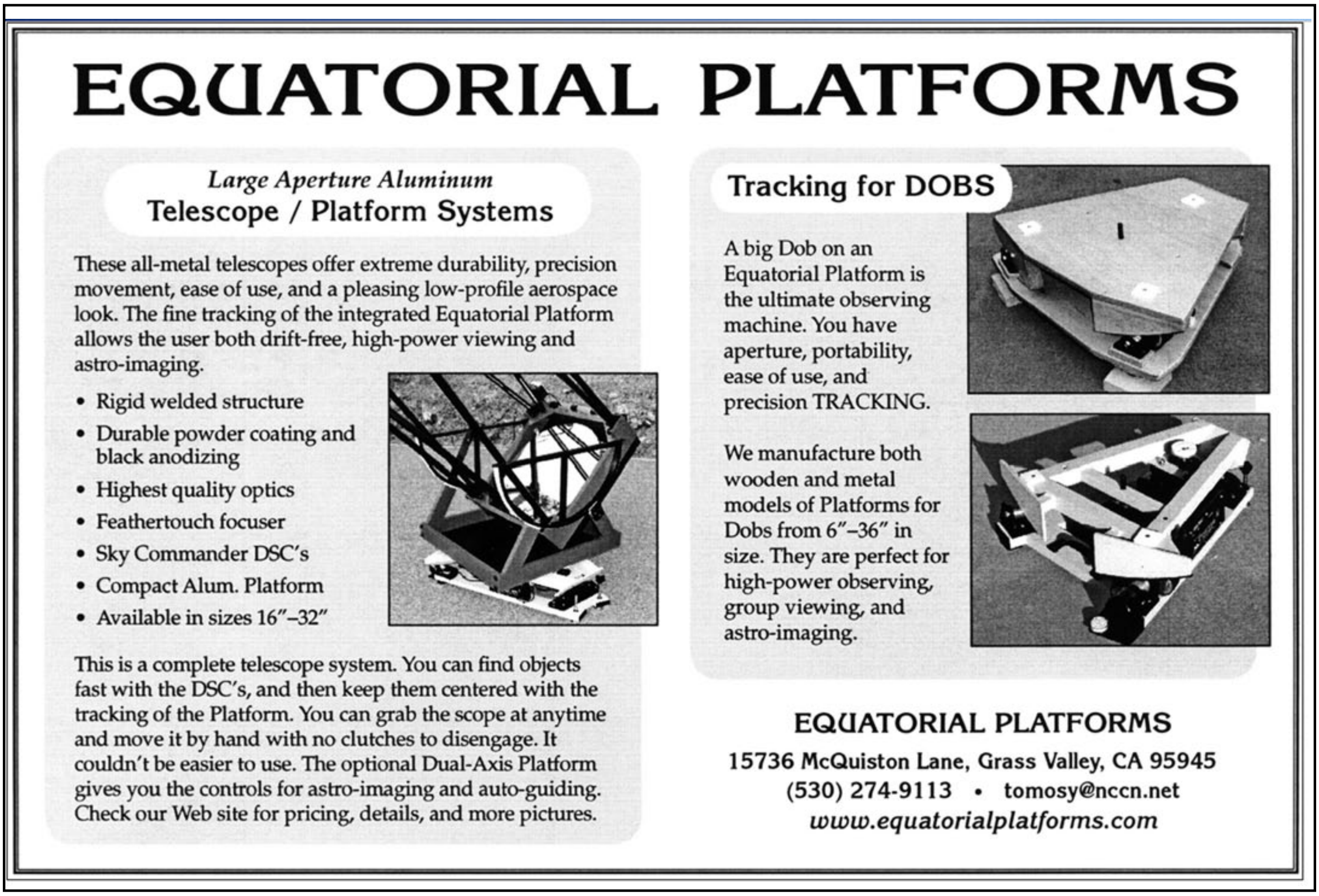
Another approach utilizes low resolution encoders built into the servos, as above, but adds other low-resolution encoders on the telescope axes to position the telescope. Once positioned, typically with a precision of an arc-minute or so, the rather coarse telescope axis encoders are ignored during tracking, and the highly geared-down servo motor encoders simply implement the constantly calculated, ever changing, drive rates.

Although the above scheme largely overcomes drive inaccuracies during initial positioning, these errors reappear once the system starts tracking without the benefit of telescope encoder "tick" updates which—with low-resolution encoders—occur too infrequently to provide smooth closed-loop servo tracking. Sidereal Technology recently implemented a "tick management" scheme that, as each low-resolution encoder tick occurs, "stamps" its location in its low-level microcomputer and then hands off this information to the control system software in the higher level PC which uses it to interpolate the telescope's actual position and adjust the tracking rate commands to the telescope's servo motors. Tick management has improved the tracking precision of lower-resolution encoders by a factor of ten on several systems.

Field Rotation

Image rotation in alt-az telescopes is countered by an instrument rotator, although if exposures are short enough, images can be rotated and stacked in software. Highly capable, Peltier-cooled CCD video cameras, such as MallinCam and StellaCam, have been used to good effect on alt-az telescopes without de-rotation. However, rotating and stacking consumes memory, increases reduction time, and reduces time on target with frequent image downloads. Furthermore, each sub image adds additional camera read noise which, cumulatively, can create problems for faint-object photometry, spectroscopy, or narrow-band astrophotography—all primary applications of large aperture telescopes.

There are several stepper controlled instrument rotators available off the shelf (Meade, Optec, and RC Optical Systems). They are primarily used to rotate off-axis guiders (OAGs) to a suitably bright guide star, although the 3-inch Optec rotator has also been used for field de-rotation. RC Optical Systems has announced that a servo-controlled system specifically intended for alt-az imaging de-rotation will soon be available. Sidereal Technology plans to develop a combined de-



Aerospace telescopes should have aerospace mirrors! Carbon fiber composite mirrors—in development by NASA, ESA and others since the 1980s—are fast becoming a reality. A 40-inch composite mirror will weigh between 10 and 20 lbs. With an all-composite structure, an entire aerospace alt-az telescope with such a mirror might weigh less than 50 lbs.

Progress in the past few years has included the fabrication of a six-inch composite mirror that is diffraction limited (<1/14 wave) at optical wavelengths, a 20 inch hexagonal mirror telescope that was shown at Stellfane in 2000, and a 20-inch 'Gossamer' mirror that can be lifted by a 2 foot diameter helium filled balloon. Present work is concentrated on improving mirror performance under cold and humid conditions, and on an exciting new development, carbon nano-tubes (CNTs), which are up to four times stiffer than carbon fibers.

Sisters Hannah (l) and Sarah (r) Keyes hold an uncoated 36-inch f/1.2 composite mirror that weighs 9 lbs; about the same as my four year old cat, Prince Henry, being held by a third girl behind the mirror—you can see her legs.

rotator/focuser/coma corrector/OAG pickoff as an integrated, lightweight unit.

Although "dust donuts" and other near-field irregularities in filters and coma correctors rotate with the camera, and can thus be removed via normal flat fielding, far field irregularities and asymmetries vary with the position angle of the rotator and cannot be removed via flat fields taken from a single position angle. Thus telescope designs with non-symmetrical vignetting in their far fields should be avoided. Although mountaintop alt-az telescopes routinely obtain high precision photometric data with flats taken at a single position angle, some astronomers take a series of flats at different position angles and interpolate between them.

Ease of Construction and Affordability

In the aerospace industry, riveting and welding are being replaced with structural adhesives. The latest Boeing airliners are quite literally glued together, albeit not with any ordinary adhesive. The preferred gap-filling, stronger-than-steel, stick-to-anything structural adhesives are methacrylates and their ilk, with trade names such as Fusionbond (Heron Manufacturing). Fusionbond is easy to use and inexpensive. A 400 ml dual plunger is only $20. The two components are combined in a disposable static mixer when the plunger is depressed. Structural components need to be held in place while the adhesive sets—fully hardened in less than 24 hours. Full scale drawings, three feet wide and any length printed out at Kinko's, can be used as assembly templates, all rather similar to building model airplanes from balsa wood glued together with model plans as positioning templates.

Aerospace materials can be cut and shaped with ordinary woodworking tools and, as suggested above, fastened together with adhesives. Thus "aerospace" telescopes do not require machining or welding capabilities, and can be built by students and amateurs, a source of "free" labor that can significantly reduce telescope costs.

Structural Alternatives

Finally, having covered the six major challenges to the development of light weight alt-az telescopes, we will consider a few of their many structural design variations. Our overriding goal was the development of a telescope with a high natural frequency. Stiffness, lightweight (low inertia), and appropriate geometry were our mantra. We had no intention of forgoing the vital advantage of actively countering wind gusts that is possible with high natural frequencies and active control systems.

For Newtonian configurations, we favor, for lower wind resistance and lighter weight, a single as opposed to a double ring upper end, although only if the instrument load is well braced. A square "ring" is` favored because the spiders load the square members in pure compression. Round or octagon top ends, when tensioned by the spiders, encounter bending forces (which we wished to avoid throughout the telescope). Instruments need to be well supported, such as with a stiff Clements focuser.

We do not favor conventional secondary mirror holders because they are cantilevered from the top. For Newtonian telescopes, we suggest placing the secondary mirror inside a cylinder with a large hole in one side. The spiders can fasten to the top and bottom of this cylinder. To maintain rigidity against rotational forces, the spider vanes should not form a symmetrical "X" but should be offset.

We favor wind resistant, open truss structures over fully enclosed tubes. Our preliminary calculations suggest that for a 20-inch, f/4 OTA, 1-inch diameter carbon fiber laminate tubing trusses will be stiff enough so that a telescope's natural frequency will not be degraded by this portion of the system.

Compared with visual Dobs, Newtonian alt-az research telescopes—with their top end instrument rotator, coma corrector, OAG, and instruments—have higher OTA balance points. Counterweighting to adjust balance points would significantly lower the natural frequency of the system and was rejected. Thus we favor two truss structures, one upward from the altitude axis and one downward.

The forks should be very stiff and lightweight. A geometric structure can be formed from aluminum honeycomb panels or, alternatively, from aluminum extrusions (such as square tubing), filled with polyurethane foam cut from sheets or block, with the exterior covered with sheet aluminum. The forks can be mounted on a horizontal honeycomb panel. Honeycomb panels are extremely resistant to bending.

Conclusion

We welcome others to join us in our developmental efforts. A special issue of Amateur Astronomy (# 57) is planned that will report in greater depth on the developments summarized in this article. To facilitate discussions, the editor of Amateur Astronomy, Charlie Warren, has set up a Yahoo discussion group, AATrends. You are welcome to join this group. Also, two conferences are being organized that will consider all aspects of the development of lightweight alt-az telescopes for research, astrophotography, and education. One is the Small Telescope Astronomical Research (STAR) Conference, June 20-22, 2008, in San Luis Obispo, California (www.STARConference.org). The other is Galileo's Legacy: Small Telescope Science 1609 and 2009, an international conference January 1-5, 2009, in Makaha, Oahu, Hawaii (www.GalileosLegacy.org).

We envision, just a few years from now, a virtual army of lightweight alt-az aerospace telescopes. Built by amateurs, students, and commercial firms, they will be widely used for research, astrophotography and education. Their superior light grasp, wide sharp fields, and precise go-to and tracking control will please scientists and delight both astrophotographers and visual observers. Their active, gust countering control systems will facilitate their operation in the field or in roll-off-roof observatories. Narrow band astrophotography, as well as the astrometry of faint asteroids, precision follow-up photometry of the many exciting objects now being uncovered by robotic surveys, and long-term spectroscopic studies of variable stars, will all benefit from the raw photon-gathering power of this revolutionary new breed of telescopes.

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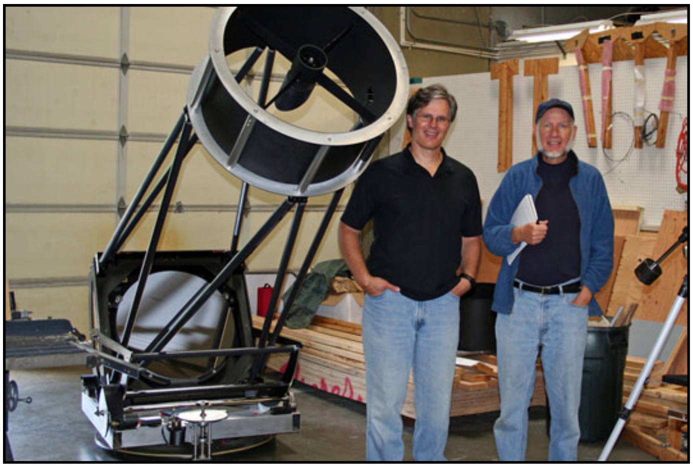

Howard brought his 28-inch computer-controlled alt-az telescope to the meeting in his mid-sized van and set it up by himself, demonstrating true portability (if you have a strong back).

Dan Gray is President and Director of Engineering of both Technical Marine Service (TMS), and Sidereal Technology. Dan founded TMS, a marine controls company, in 1987, and Sidereal Technology in 2003. He has innovatively developed many types of control systems for ocean-going vessels as well as telescopes. An active telescope maker for 30 years, Dan created and popularized the "string" telescope. www.SiderealTechnology.com, **www.tms-usa.com**.

Howard Banich is a Senior Development Engineer with Nike, and has been an ATM and visual observer since 1969. His 28-inch Newtonian portable telescope pioneered several features relevant to alt-az "aerospace" telescopes. Howard's computer-controlled telescope is being modified to include instrument de-rotation. **http://hbanich.googlepages.com/**

David Rowe is Chief Technology Officer and Co-founder of Sierra Monolithics. An avid amateur astronomer, optical designer and ATM, Dave has designed and fabricated many telescopes, including a corrected Dall-Kirkham, a flat-field concentric Schmidt Cassegrain, and several Schmidt cameras and corrected Newtonians.

Thomas C. Smith, Director of the Dark Ridge Observatory, is a retired software and nuclear engineer and advanced amateur astronomer. Tom established the Dark Ridge Observatory as a non-profit organization in Weed, New Mexico, and has been working with students and faculty from several colleges and universities as a mentor for CCD photometry and image data reduction. Tom also conducts research on eclipsing binaries. **www.DarkRidgeObservatory.org.**

Tom Krajci, Major, USAF (retired), is an amateur scientist specializing in photometry. He operates the Astrokolkhoz Observatory at an elevation of 9,440 feet near Cloudcroft, New Mexico. Tom is translating several books on telescope making and optics design from Russian into English, including the works of Dmitry Maksutov. **http://overton2.tamu.edu/aset/krajci/**