# MIRROR VS. DIELECTRIC VS. PRISM DIAGONAL COMPARISON

*By: William Paolini, 3/6/2014 v2*

Back Row ( 2" )
Baader Zeiss Prism, Takahashi Aluminum Mirror, Astro-Tech Dielectric, Baader Dielectric, Astro-Physics MaxBright Dielectric

Center Row ( 1.25" )
Baader T2 Zeiss Prism, VERNONscope Enhanced Silver Mirror, Takahashi Prism, Tele Vue Everbrite Dielectric

Front Row ( 1.25" )
Vixen Prism, Astro-Tech Dielectric, Celestron Prism (vintage 1980s)

Figure 1
Diagonals used in this comparison
*Image by the Author*
*Equipment courtesy of the Author, B. Brown, Daniel Mounsey, Roy McCoy, Steve Stapf (aka Starcam on CN), & Tamiji Homma*

## I. Introduction

The diagonal is often a little scrutinized component in the telescope's optical chain. Reflectivity efficiency and presumed wavefront accuracy are often the only attributes of attention. The purpose of this comparison was to instead determine if a diagonal's technology type (i.e., aluminum, silver, dielectric, or prism) plays any significant role in the telescope's performance, primarily for lunar/planetary observing and secondarily for deep sky object (DSO) observing. Note that only standard right-angle diagonals were evaluated. For lunar/planetary performance, the Moon and Jupiter were used (Jupiter was optimally positioned near the zenith). The primary criteria for lunar/planetary performance was: level and clarity of details observed, perceived contrast, presence of chromatic aberration, and scatter. On DSO, the primary criteria evaluated was threshold brightness of the furthest extents of nebula, ability to see stars at the threshold of vision, chromatic aberration on bright stars, and scatter around bright stars. The Takahashi TSA-102 f/8 Super APO was used for all tests. However, since it is popularly reported that a prism diagonal can induce chromatic aberration (CA) with faster focal ratios, for CA tests a Celestron f/6.25 80mm Onyx APO was also used. A TEC 140 APO was also used in a single-blind test with an experience observer to validate any significant outcomes seen in the TSA-102. All observations were conducted from a suburban location west of Washington, D.C., USA over a three month period from December 2013 to February 2014. The observing site had light-to-moderate light pollution with limiting magnitudes during observation evenings generally around magnitude 4.0 to 4.5. Finally, great appreciation goes out to the many generous members of the online astronomy community at www.cloudynights.com for their support and loan of valuable personal equipment as this comparison would not have been possible without them!

## II. Diagonal Technologies

In today's market, diagonals are varied and come in four common technologies for amateur equipment: the aluminized (Al) mirror, the silvered (Ag) mirror, the dielectric mirror, and the glass prism. The aluminum and silver mirror technologies come in two main varieties: protected and enhanced. Generally, enhanced coated mirrors have greater reflectivity than protected ones, and silver mirrors have greater reflectivity than aluminum ones. In all cases, a protected aluminum or silver mirror is easy to scratch and needs to be cleaned carefully, whereas enhanced mirrors offer greater protection.

Mirrors advertised as being "protected" typically have a single coating applied to protect the mirror, which is usually silicon monoxide (SiO) or magnesium fluoride (MgF2). When the aluminum or silver mirror is advertised as being "enhanced", this typically means several dielectric coatings are added to both protect the surface, and also increase reflectance of the mirror by several percent over what can be achieved with only a protected SiO or MgF2 overcoat. The dielectric coatings used in enhanced mirrors are much harder than SiO or MgF2 and further increase the reflectance, typically allowing enhanced aluminum mirrors to have 96% or more reflectivity, and enhanced silver mirrors are typically 97%-98% reflective.

When dielectric materials are used exclusively to create a mirror, then 20 or more layers of dielectrics are usually needed to achieve a high reflectivity rate. The materials used for dielectrics are usually oxides of silicon, titanium, aluminum, and tantalum, or fluorides of magnesium, lanthanum and aluminum, and they are applied in alternating thin layers of high- and low-index dielectrics. While a fully dielectric mirror is very tough, making cleaning a care free chore, careful attention needs to be paid to the number of layers as more layers can compromise the overall wavefront accuracy of the substrate glass. As reported in the Photonics Handbook (www.photonics.com), "*...a 100-layer coating with thickness variations of 2 percent across the surface (a typical coating uniformity tolerance) would distort the wavefront of the reflected beam by several wavelengths*." Given this, it is important to know the final wavefront of the dielectric mirror *after* the coatings are applied as even the most precisely polished glass substrate can have greater than one wave of error if the many dielectric coatings are not applied with consistent high precision.

Finally, probably the most mature technology used for diagonals is the simple glass prism. BK7 is the typical material used for telescope diagonal prisms. Reflectivity internal to the prism is 100%, with no light loss. Light loss does however occur at the air-glass interfaces of the prism, like for all optics. With a prism's two air-glass interfaces, if a typical modern 99.5% efficient multicoating is used then the expected reflectivity should be 99% for the prism, not accounting for any loss to absorption by the glass, which is approximately 0.2% or less in the visible spectrum for each 10mm of glass path for BK7 glass (Ref: http://www.hoyaoptics.com/pdf/MasterOpticalGlass.xls).

## III. Physical and Mechanical Examination

The diagonals used for this comparison ranged from inexpensive to premium, 2" sizes and 1.25" sizes, and represented all the major technologies (aluminum mirror, silver mirror, dielectric, and prism). The table in figure 2, summarizes the major marketing features advertised for these diagonals.

| Diagonal | Size | Type | Reflectivity Claim | Wave Front Claim | Body Build |
|---|---|---|---|---|---|
| Astro-Physics MaxBright | 2" | Dielectric | >99% | Inconsistent* | CNC Machined |
| Astro-Tech | 1.25" | Dielectric | 99% | 1/10th wave before coating | Machined Aluminum |
| Astro-Tech | 2" | Dielectric | 99% | 1/10th wave before coating | Machined Aluminum |
| Baader | 2" | Zeiss Prism | Not specified, Zeiss T-coatings | Not specified | CNC Machined |
| Baader Clicklock | 2" | Dielectric | 99% | 1/10 wave after coating | Metal |
| Baader T2 | 2" Capable** | Zeiss Prism | Not specified, Baader multicoatings | Not specified | Machined Aluminum |
| Celestron | 1.25 | Prism | Not specified | Not specified | Plastic & metal |
| Takahashi | 2" | Enhanced Aluminum on Pyrex | Not specified | 1/10th wave | Metal |
| Takahashi | 1.25" | Prism | 100% internal reflectivity, multicoated | Not specified | Plastic & Metal |
| Tele Vue Everbrite | 1.25" | Dielectric | 99% | 1/10th wave before coating | Solid Aluminum |
| VERNONscope | 1.25" | Enhanced Silver (Ag) | 99% | 1/20th wave or better after coating with Zygo report | CNC Machined |
| Vixen | 1.25" | Prism | Not specified | Not specified | Plastic & Metal |

* - Marketing on AP website makes no wave front claim. Some resellers make claims from 1/10 to 1/20 wave over the portion of the mirror in the light path. No specification in these claims if this is before or after dielectric coating.

** - While the Baader T2 does come with optional 2" accessories, the diagonal only has a clear light path to accommodate 2" eyepieces with a field stop of 34mm or less.

Figure 2
Manufacturer supplied data

Each diagonal possessed a build, fit, and finish quality commensurate with its price class. For the most part, all the diagonals showed excellent builds, with well appointed painting, anodized finishes, and graphics. Two exceptions were as expected, the Vixen 1.25" Prism diagonal and the Celestron 1.25" Prism diagonal. Both of these diagonals represent the economy price class and use thin metal parts (where metal is used) and plastic main bodies to hold the prism. The Takahashi 1.25" prism was the only unexpected member of the group giving the impression of being more from the economy class instead of from a higher echelon that one expects from a Takahashi product. The Takahashi 1.25" Prism, like the Vixen and Celestron, used a plastic main body, as well as plastics or polymers in other areas, such as using some sort of flexible plastic instead of brass for its compression ring. Overall, these three diagonals were the lightest of the group and did not give near as solid of a fit and feel as the more robust metal construction of the other diagonals.

The diagonals that gave the strongest impression of an exceptional build were the Astro-Physics 2" MaxBright Dielectric, the Tele Vue Everbrite Dielectric, the Baader 2" Zeiss Prism, and the VERNONscope 1.25" Enhanced Silver. These five diagonals possessed machined metal components, and in particular they each had a very thick solid metal base plate providing substantial heft to their feel. The remaining diagonals also showed a strong and highly refined build quality, but they did not have as massive metal components as the five mentioned above. Of these, the Baader 2" Prism diagonal was the heaviest, due in part to its massive 2" glass prism.

While several of the premium diagonals conveyed a very solid level of quality, being machined from solid blocks of metal, this was not an advantage in every situation. In particular, access to the mirror or prism surfaces was restricted for some of these as either or both the eyepiece holder or nosepiece were not removable as a result of being machined from a block of metal. The VERNONscope, Tele Vue, and Astro-Physics diagonals fell into this category. For these, cleaning is therefore less convenient as either or both the eyepiece holder or nosepiece were not removable, making access to the mirror or prism surfaces difficult.

Of the non-prism diagonals, the Takahashi 2" Aluminum Mirror was the most unique. All the other aluminum mirror, silver mirror, and dielectric diagonals used a square glass plate as a substrate. The big 2" Takahashi however took a different approach and used a conventional elliptical mirror, like those commonly used as secondary mirrors in Newtonian telescopes. While unconventional, it was a clever approach as the elliptical mirror market for Newtonian telescopes is very mature.

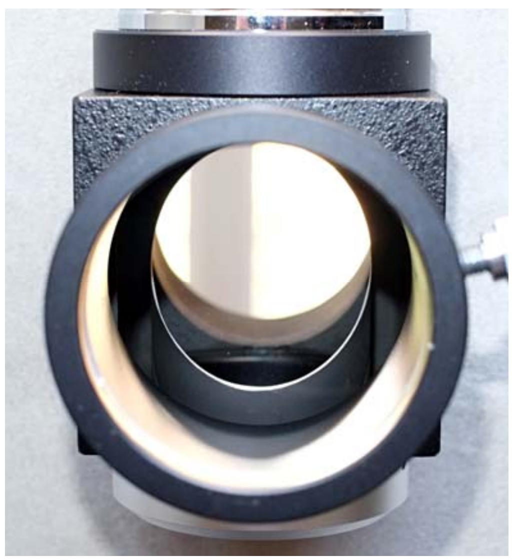

Figure 3
Takahashi 2" aluminum mirror diagonal showing its unconventional elliptical secondary mirror
*Image by the Author; Diagonal courtesy of Daniel Mounsey*

Aside from the use of an elliptical mirror in the Takahashi 2", the only other highly unconventional features were the twist lock mechanism on the Takahashi 1.25" Prism and the Clicklock mechanism on the Baader Dielectric. Not being familiar with these mechanisms, they were initially uncomfortable to use. As field use proceeded however, the Clicklock mechanism on the Baader 2" Dielectric quickly became a favorite, making it a quick and easy task to remove or secure eyepieces in the holder as less than a 1/4 rotation of the Clicklock was necessary to fully engage or disengage an eyepiece. And thankfully, the Clicklock also seemed to have less of an issue with eyepiece barrel undercuts than did the conventional set screw compression rings. So while having eyepieces getting caught on compression rings was common during field use, it was an uncommon occurrence with the Baader Clicklock mechanism. The Takahashi 1.25" Prism's twist lock mechanism, unfortunately did not prove to be as ergonomic as the Baader Clicklock. Insertion and extraction of eyepieces was often cumbersome, requiring excessive amounts of twisting to either firmly secure or to get it loose enough to free the eyepiece.

Another aspect of diagonals which can be very important, depending on their application, is the amount of light path they require. As example, when a binoviewer is going to be used with a diagonal, some telescopes do not have a long enough light path available to accommodate the long light path being used by the prisms in the binoviewer in addition to the extra light path being required by the diagonal. Using a 1.25" diagonal instead of a 2" diagonal can help this situation greatly. However, a prism diagonal uses even less light path, and can be a better choice. Figure 4 shows the measured light path requirements of each diagonal. To obtain these figures, first the TSA-102 telescope was focused on a distant target without using any diagonal. The focuser extension was then measured. When the diagonal was used, the adjusted focuser extension was re-measured and the difference represents the light path being used by the diagonal. As example, if the distance from the base of the refractor's tube to the eyepiece shoulder at the end of the visual back is 200mm when viewing without a diagonal, and when the diagonal is inserted without the addition of any other accessories, refocused and re-measured to the eyepiece shoulder as 88mm, then we know that the diagonal is using 200-88=112mm of light path.

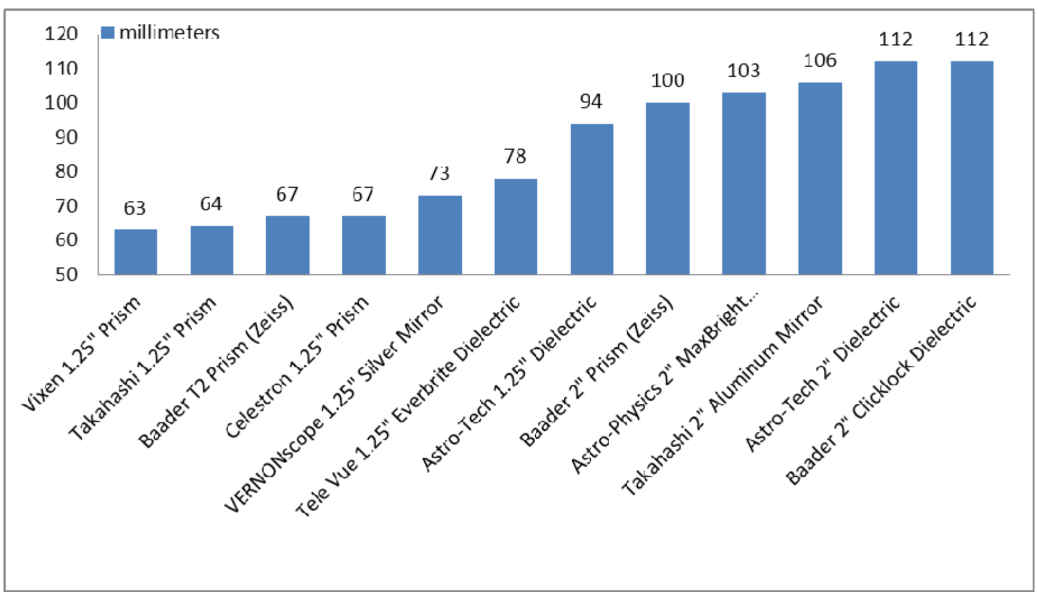


Figure 4
Approximate direct measure of the diagonal light path (millimeters)

The table in figure 5 provides further information about it eyepiece locking mechanism, any safety features on the nosepiece, and assessment if the diagonal possessed an eyepiece stop to prevent inadvertent contact with the mirror or prism surface. For those without an eyepiece stop, care needs to be taken when using them as accessories such as Barlows can have very long barrels that can then contact and damage either the mirror or the prism surface.

| Diagonal | Eyepiece Holder | Eyepiece Stop | Nosepiece |
|---|---|---|---|
| Astro-Physics 2" MaxBright Dielectric | 1-Screw Compression Ring | Yes | Tapered |
| Astro-Tech 1.25" Dielectric | 1-Screw Compression Ring | Yes | Tapered |
| Astro-Tech 2" Dielectric | 1-Screw Compression Ring | Yes | Tapered |
| Baader 2" Prism (Zeiss) | 2-Screw Compression Ring | Yes | Undercut |
| Baader 2" Clicklock Dielectric | Click-Lock Compression Ring | Yes | Undercut |
| Baader T2 Prism (Zeiss) | Click-Lock Compression Ring | **No** | Undercut |
| Celestron 1.25" Prism | 1-Screw | Yes | Smooth |
| Takahashi 2" Aluminum Mirror | 1-Screw Compression Ring | Yes | Undercut |
| Takahashi 1.25" Prism | Twist-Lock Compression Ring | **No** | Smooth |
| Tele Vue 1.25" Everbrite Dielectric | 1-Screw Compression Ring | Yes | Undercut |
| VERNONscope 1.25" Silver Mirror | 1-Screw | Yes | Smooth |
| Vixen 1.25" Prism | 1-Screw | Yes | Smooth |

Figure 5
Misc. diagonal features

The internal baffling and blackening were also scrutinized on each diagonal, as lack of sufficient baffling can lead to reduced contrast views, flare, or a general brightening of the field of view, particularly when very bright targets like the Moon are viewed. As expected, the price class of the diagonal often aligned with how much attention was paid to internal light suppression. Figure 6 shows the diagonals which incorporated micro-baffles in addition to interior flat black paint.

Figure 6
Micro-baffling in the Astro-Physics MaxBright (Left) and Tele Vue Everbrite (Right)
*Image by the Author; Diagonals courtesy of Daniel Mounsey & Steve Stapf*

Surprisingly, one of the very expensive diagonals did not possess superior light suppression features. On the more exotic VERNONscope 1.25" Silver Mirror diagonal, the inside of the nosepiece was left as shiny black anodized metal. As a result, light is highly reflected as can be seem in figure 7, where it is compared to the less expensive and better blackened Takahashi Prism.

Figure 7
Flat black surface on Takahashi 1.25" prism shows little stray light (Left)
Gloss black surface on nosepiece of VERNONscope 1.25" enhanced silver (Ag) mirror shows significant stray light (Right)
*Image by the Author; Diagonals courtesy of Tamiji Homma & Steve Stapf*

Aside from the VERNONscope, all other diagonals provided good to excellent stray light suppression off of their internal surfaces. Figure 8 is an example of an excellent level of outstanding stray light control provided by the Tele Vue Everbrite Dielectric. When looking from the eyepiece end of this diagonal, no additional stray light can be seen outside of the circle formed by the end of the nosepiece of the diagonal. Also note in the figure the oversized compression ring set screw used on the Tele Vue Everbrite. This feature was noted as being highly ergonomic during field use, proving much easier to use than the smaller set screws used on the other diagonals.


Figure 8
Example of excellent stray light control
Tele Vue 1.25" dielectric diagonal shows no stray or reflected light around opening of nosepiece
Also note the oversized thumbscrew which provides easy function even when wearing gloves
*Image by the Author; Diagonal courtesy of Daniel Mounsey*

Finally, prior to field tests, the collimation of the diagonals were tested by using a collimating eyepiece in a refractor without diagonal to ensure proper collimation, then repeating the check with each diagonal placed in the optical train. Eight of the twelve diagonals showed proper collimation. Those that were off-collimation were: Astro-Tech 1.25" Dielectric, Takahashi 1.25" Prism, Vixen 1.25" Prism, and the Celestron 1.25" Prism. The Astro-Tech and Takahashi were only slightly off-collimation and left as is for the field testing. Both the Vixen and the Celestron were severely off-collimation. However, after disassembly and shimming and re-seating of the prisms, the Vixen was brought back into full collimation and the Celestron was brought back to a position of being moderately off-collimation.

## IV. Field Observations

The initial set of field tests conducted where to determine if visually impacting chromatic aberration was induced by prism diagonals in fast (f/6.25) vs. moderate (f/8) focal ratio telescopes. A 4mm TMB Supermonocentric and 6mm ZAO-II were used for the testing, both with and without Barlow (APM 2.7x ED Barlow). The target chosen was the bright limb of the Moon placed on-axis within the field of view. An initial check confirming no color was conducted using these eyepieces with and without Barlow in straight-through mode with no diagonal. Each diagonal was then added to the optical train, and the two eyepieces without, then with Barlow were used. In the Celestron Onyx f/6.25 APO these eyepiece-Barlow combinations resulted in magnifications as low as 83x and as high as 225x (71x/inch and 0.35mm exit pupil). Observation results are indicated in figure 9.

| Diagonal | Observed Color | Notes |
|---|---|---|
| Astro-Physics 2" MaxBright Dielectric | None | -- |
| Astro-Tech 1.25" Dielectric | None | -- |
| Astro-Tech 2" Dielectric | None | -- |
| Baader 2" Prism (Zeiss) | Very Slight | Not apparent if not searching for it. |
| Baader 2" Clicklock Dielectric | None | -- |
| Baader T2 Prism (Zeiss) | Very Slight | Not apparent if not searching for it. |
| Celestron 1.25" Prism | Slight-Moderate | Noticeable, but slight blue/purple halo off the lunar limb. More obvious blue tinge to the dark shadows from crater walls. |
| Takahashi 2" Aluminum Mirror | None | -- |
| Takahashi 1.25" Prism | Slight | Thin line of color on lunar limb. |
| Tele Vue 1.25" Everbrite Dielectric | None | -- |
| VERNONscope 1.25" Silver Mirror | None | -- |
| Vixen 1.25" Prism | Slight-Moderate | Noticeable, but slight blue/purple halo off the lunar limb. More obvious blue tinge to the dark shadows from crater walls. |

Figure 9
Observed chromatic aberration on bright lunar limb and crater shadows through a fast focal ratio (f/6.25) telescope.
Using an f/8 APO there was no observed chromatic aberration was "none" for all diagonals.

Working at magnifications from 83x to 125x in the fast f/6.25 APO (26-40x per inch aperture), chromatic aberration was fairly non-existent with all the dark shadows cast by lunar features across the Moon's surface appearing richly black. Only when the magnification reached 225x (71x per inch) did crater shadows begin to give a blue-black appearance, and this was primarily with the Vixen and Celestron prisms. All but one of the diagonals provided the same, sharply etched view of lunar features, even when the magnification was as high as 225x in the 80mm APO. The exception was the Astro-Tech 1.25" Dielectric. While all other diagonals showed sharply etched lunar features at this highest magnification, the Astro-Tech 1.25" Dielectric provided a soft view in comparison.

Moving to Jupiter, the Celestron 80mm APO provided very pleasing views, with the NEB, SEB, NTB, and STB belts being readily visible, and a rich amount of detail and structure visible within both NEB and SEB, including a nice storm within one of these belts. The polar regions were also richly portrayed with gradations of shading and with the NNTB peaking-into-view ethereally when atmospheric seeing was most stable. All the prism diagonals were showing Jupiter's details exceedingly well. The Takahashi and the two Baader prisms were fairly on-par in the amount of details and crispness of the details they showed. The Celestron and Vixen were not quite as defined as the others, lacking the more finely etched views from the other prisms, but still quite good.

After completing observations of Jupiter in the Celestron 80mm APO with the prisms, the various aluminum, silver, and dielectric mirror diagonals were tested. First impression when moving from observing with the prisms to the mirrors was, "wow...more scatter!" I felt this was a rather obvious tell. I was also surprised that the details on Jupiter were definitely softer through the mirror diagonals than they were when using the prism diagonals. As example, the NNTB was not showing though the mirror diagonals, and any structure within NEB and SEB was only hinted at as a nondescript albedo differences. Changing out the mirror diagonals to prism diagonals, and all the NEB and SEB crisp definition and structure reappeared, as well as the ethereal NNTB.

As more and more field observations were conducted with the 80mm APO on Jupiter, it became apparent that the prisms were providing another level of performance that the mirrors were not. While the mirrors were not providing as good planetary views, two of the mirror diagonals were showing some unique distinctiveness apart from the other mirror diagonals. Whenever the Astro-Physics MaxBright was used, it was noticeable that its level of scatter was less than the other mirrors, excepting perhaps the VERNONscope which seemed on-par with the Astro-Physics. So the Astro-Physics Dielectric and VERNONscope Enhanced Silver were generally showing a scatter level between that of the prisms and the other mirrored diagonals. The VERNONscope further distinguished itself as showing nearly, but not quite, the same level of detail and contrast on Jupiter as did the prism diagonals. As field observations progressed, the VERNONscope more and more distinguished itself as having a unique quality to its view and providing razor-sharp planetary views nearly as good, if not as good as the prisms.

Moving from the fast f/6.25 focal ratio APO to the more moderate f/8 focal ratio of the TSA-102, the chromatic aberration tests were again repeated using the bright lunar limb. With the TSA-102, no chromatic aberration could be induced using the prisms on any target at any magnification when viewing the lunar limb. Similarly, when observing bright stars like Sirius, no chromatic aberration was observed at any magnification whether the star was in-focus or out-of-focus. Only when a bright star was racked so far out of focus at high magnification that the star's diffraction pattern was almost 3/4 the size of the apparent field of view did the slightest hints of color begin to appear. And when these slight colors did appear, they were only as a slight blue-black hue to the dark spaces between the diffraction rings. While most manufacturer's seem to advertise f/7 or slower as a focal ratio for optimum prism performance, based on the observations of this comparison I feel that f/6 would also be perfectly adequate as very little color was generated even at this focal ratio. And at f/8, observations showed no negative impacts regardless of the magnification using a prism vs. a mirror, and an clear advantage for planetary observing. These results are similar to those reported by others who have done planetary comparisons for prism vs. mirror diagonals. Examples include:

- ✓ Simulations and seasoned observational experience show a prism can be preferred as a diagonal in moderate focal ratio telescopes: *Indeed. a prism will add its own aberration (overcorrected spherical and color), but until you raytrace a system with a prism (I have – with ZEMAX), your just guessing at the aberrational residuals. I own a 2" multi-coated prism (Badder Planetarium) and at f/9, it works superbly. With 99% transmission, and the lack of light scatter, this diagonal beats any mirror diagonal I've ever used. Of course, a well made prism will cost more, but until interference coated supersmooth diagonals are available, the high quality prism for moderate to long focal length refractors will reign supreme. … In an achromatic or apochromatic lens, the variations of spherochromatic aberration and secondary and tertiary color make the use of a prism very interesting indeed. Raytracing in ZEMAX -- various APO designs with 25mm and 50mm prisms with f/ratio's of f/6 to f/12 -- shows that the OPD spherical levels for different wavelengths change in different amounts, sometimes improving a system at some wavelength at the cost of others. The ONLY way to know what is really happening is to know the exact design, raytrace the total system, or star test the system, and check to see if the contrast is higher with the prism, or the mirror diagonal. But even with these spherical and color variations, the aberration levels do get excessive at around f/7 or f/8.* (Ref: groups.google on 12/1996, Thomas Back, Subj: Prism Diagonals Pros & Cons)
- ✓ Simulations support the observations that at f/8, any color or spherical aberration that might be induced by a prism should be non-detectable: *If you do use a prism, the small 1.25" won't make a difference that you can see or measure. The 2" will introduce a very small amount of color and spherical, but again it probably won't be visible under normal circumstances. I don't think it will hurt planetary performance at all. I just did a simulation in ATMOS lens design on a perfectly corrected lens. The spherical correction with 50mm of prism inserted into the optical path changes by only 1/40 wave. The color correction changes only minutely to the point where you cannot see any difference at all in the focused star image. I did the simulation at F8.* *(Ref: Astromart Forums on 2/2005, Roland Christen, Subj: Prism vs mirror diagonal in APQ's - Msg: 306947, 306950, 307121)*
- ✓ Refractive surfaces produce less scatter than reflective surfaces given a same surface smoothness: *"A surface irregularity on a refracting surface produces a much smaller wavefront error than on a reflecting surface, by something like a factor of six [countered to be a factor of four]. Thus unless reflecting surfaces are extremely well polished, and have coatings that are extremely regular, they will scatter more light than refracting surfaces." (Ref: yahoogroups on 3/2002, Subj: Prism Diagonals, Msg: 12138)*
- ✓ www.cloudynights.com/item.php?item_id=1854; www.astrosurf.com/laurent/apo140e.htm; www.cloudynights.com/item.php?item_id=82

When observing Jupiter through the TSA-102 results were consistent with what the Celestron 80mm APO showed, and the prism diagonals, the Baaders in particular, were putting up a more detailed and higher contrast view than the mirrors could provide (note - the Takahashi 1.25" prism was slightly behind the Baaders, and the Vixen and Celestron prisms were at the bottom of the prism performance pack). Again, the exception was the VERNONscope Enhanced Silver diagonal which was close if not on-par with the view the best prisms were providing. To illustrate, on one evening using the TSA-102, Jupiter's NEB, SEB, NTB, were clearly visible showing edge and interior details. The EB and STB were partially visible and excellent shading in the polar regions was also visible, along with areas of turbulence in the south polar region. The mirrors would not show the faint EB nor the STB, and NTB became more of a hinted or albedo feature -- this was true even for the premium mirrors. Structure on the belt borders and internal structure was also washed out in the mirrors. The exception was the VERNONscope which was able to show a little more detail than the other mirrors, with better edge details on the belts as well as interior detail within SEB. Overall, the mirrors gave a less distinct and more washed out view, and the two inexpensive Vixen and Celestron prisms, while showing the features with more contrast, behaved like the mirrors showing a softer view. These behaviors were also replicated in a TEC 140 f/7 APO, although the TEC seemed to get a slightly better view using the Baader 2" Prism whereas the TSA-102 got a slightly better view using the Baader T2 Prism. Aside from this small nuance in behavior, prism vs. mirror planetary performance differences noted in an 80mm f/6.25 APO and a 102mm f/8 APO, remained fairly consistent in a 140mm f/7 APO. Planetary observing of Jupiter was uniformly more advantageous in terms of details present and contrast when using a quality prism diagonal, in particular the Baader Zeiss prisms.

As far as scatter, the Takahashi and Baader prism diagonals both showed least extent of scatter compared to the mirrors, with the Baader T2 Prism showing notably less. Of the mirror diagonals the Astro-Physics and VERNONscope, followed by the Tele Vue and Baader Mirror diagonals showed the least scatter around Jupiter. The Astro-Physics it should be pointed out, was very close to the prisms in regards to scatter, and was particularly close to that of the Baader 2" Prism, but not quite its equal. So for observers who are extremely sensitive to the amount of scatter displayed around bright planets or bright stars, the prism diagonals and the Astro-Physics MaxBright and VERNONscope Enhanced Silver diagonals showed the least scatter, with the prisms doing the best job. Also note that when conducting observations without diagonals to assess scatter, it was a fairly obvious tell that in straight through viewing scatter was noticeably reduced. So while straight through observing is difficult with a refractor, it does show little scatter compared to diagonal viewing.

Lateral color was also checked to see if this often eyepiece-induced aberration was impacted with different diagonals. Sirius was used as the target and several different eyepieces were used, including Pentax XWs, Explore Scientific 100s, and Meade 4000 UWAs. Regardless of the diagonal used, the lateral color generated by the eyepiece remained consistent. However, during the lateral color tests another issue became apparent. With the Takahashi 2" Aluminum Mirror and the Astro-Tech 2" Dielectric diagonals there was significant light falloff near the field stop when a 2" eyepiece was used with a maximum field stop. As example, when the 40mm XW was used in either of these two diagonals (approximate 46.5mm field stop size), dimming near the field stop was apparent. The light falloff was slight in the Astro-Tech and more apparent in the Takahashi. When 2" eyepieces with smaller field stops were used, the issue disappeared.

Brightness was assessed in several ways between the diagonals: a) several nebula were observed looking for which diagonals, if any, would show more of the nebula extending further into the field of view, and b) several star clusters were also observed to determine if adverted vision only stars could be seen more easily or not at all with any diagonal. These tests were conducted in both the f/8 TSA-102 and some of them were repeated in an f/7 TEC 140. Overall. no diagonal seemed to have an advantage over the other in terms of how deep they could penetrate DSO. While there were a few instances where the Baader Zeiss Prism diagonals would show a slightly deeper view of nebula, it was not entirely consistent and on some evenings they were on-par with mirror diagonals, or the mirrors would seem to show faintest stars with more authority, especially on evenings where the skies were the darkest. Given this inconsistency, little conclusions can be drawn.

Finally, a variety of targets were observed throughout the field comparisons. Representative notes for some of those observations follow below:

M1 - From the suburban location near Washington, D.C. this nebula was very dim in the TSA-102. Using a Pentax 30mm XW it was just hinted at with adverted vision and there was no difference between any of the diagonals. Using the Pentax 10mm XW the nebula was more clearly seen and with direct vision, but still dim. Again, no diagonal offered an advantage compared to another diagonal on this target.

M42 - All diagonals showed the nebula excellently, with similar levels of details. Trapezium A-E were clearly visible in all using the Pentax 7mm XW and Trapezium F showed intermittent. Any differences in the rendering of the nebula between diagonals was at a nuance-level at best. On some evenings, particularly with the Takahashi 1.25" Prism and the Baader T2 Zeiss Prism, the prisms seemed to show a little more contrast with the nebula's wisps and mottled structure being more distinctly defined. On other evenings the aluminum, silver, and dielectric mirrors took advantage showing just a little more of the nebula, in particular M43 at times showed larger and brighter. All these differences were extremely slight at best, and not at all like the differences in performance when doing planetary observing.

M36 / M37 / M38 / Perseus Double Cluster - When observing the dimmest stars of these open clusters, no difference was observed using any diagonal. Primary eyepieces used where the Pentax 14mm XW and the 10mm XW.

Bright Stars - All the 2" diagonals were able to attain a sharp star point at the field stop using a Pentax 40mm XW eyepiece. A small amount of astigmatism was present, however it was consistent across all the diagonals and was most probably from the eyepiece. Two of the diagonals showed light falloff, unable to handle this eyepiece's maximum field stop. The Takahashi 2" Aluminum Mirror and the Astro-Tech 2" Dielectric showed slight to moderate light falloff near the field stop. The Takahashi showed more was enough to be distracting.

Jupiter - The prism diagonals stole the show, particularly the Baaders. Difference in performance between the prisms and the mirrors was like going from an average quality Abbe eyepiece to a premium ZAO. So much more details popped and became visible when using the prism diagonals. In the mirrors the GRS and trailing swirls were visible as gross structures but no fine details were visible in and around them. Also, contrast of features in Jupiter's belts between internal lighter and darker regions was "mushy" in appearance. In the prisms, those contrast regions in the belts popped alive and crisp with detail. The surrounding swirls and eddies around the GRS became visible and distinct as did the trailing turbulence. While the prisms seemed to show no significant advantage or disadvantage on non-planetary, they were markedly superior for planetary.

Moon - Comparing Lunar features I used an 8.8mm Meade 4000 UWA and a 4mm Meade Research Grade Ortho (RGO). With the UWA no readily apparent differences between prisms and mirrors could be detected. All features were sharply rendered and Maria shadings highly contrasted. Moving to the 4mm RGO the prisms showed a slight advantage on Maria shadings and ejecta patterns. These features appeared more distinct, and more contrasted. Comparatively, in the mirrors they were more milky in appearance and less distinct. The VERNONscope 1.25" Enhanced Silver diagonals however came very close to the performance of the best prisms, if not equaling them. The lower quality Vixen and Celestron prisms, while still showing a more contrasted view than the mirrors, were not as distinct as the mirror diagonals either in Maria features or in high contrast brightly lit features. These differences did not show until higher magnifications were used (200x, exit pupil 0.5mm).

## IV. Summary

- ✓ The diagonal as an absolutely critical component in the telescope's optical chain, particularly where planetary observation is concerned. The diagonal should therefore be selected with as much care and consideration as the eyepiece.

- ✓ Overall, the Baader T2 Zeiss Prism, Baader 2" Zeiss Prism, and VERNONscope Enhanced Silver Mirror diagonals performed the best for planetary observation, clearly showing more details, higher contrast, and less scatter when viewing Jupiter. In comparison, even premium aluminum and dielectric mirror diagonals showed softer, less distinct views of Jupiter.

Figure 10
The Baader Modular T2 Diagonal with Zeiss Prism, 1.25" Nosepiece, and 1.25" Helical Focusing Eyepiece Holder
*Image by the Author*

- ✓ Observing DSO, the negligible few percent of reflectivity differences advertised between the diagonals did not make a consistent observational difference. However, it should be noted that on the very darkest evenings at the suburban observing site that the silver/aluminum/dielectric mirrors sometimes gave an *impression* of being ever so slightly brighter, less so on stars and more so on brightness and extent of nebula, and the prisms sometimes gave the *impression* of showing slightly more detail and structure in the wisps of M42.

- ✓ Observing the Moon showed very little advantage whether a prism or non-prism diagonal was used. While the more premium prism diagonals did show the most subtle of Maria details and ejecta patterns better, it was so slight as to be considered inconsequential.

- ✓ In assessment of scatter around Jupiter and bright stars, straight-through observing without any diagonal was very clearly and distinctively better, perhaps showing only half as much scatter as the best diagonal. After that, the diagonals came in showing scatter in the following four tiers, from least scatter to most:
  a. Baader T2 Zeiss Prism, followed by: Baader 2" Zeiss Prism, Takahashi 1.25" Prism
  b. Astro-Physics 2" MaxBright and VERNONscope 1.25" Enhanced Silver Mirror, followed by: Baader 2" Clicklock Dielectric, Takahashi 2" Aluminum Mirror, Tele Vue 1.25" Everbrite Dielectric
  c. Astro-Tech 2" Dielectric, Astro-Tech 1.25" Dielectric

  *Note – the inexpensive Vixen and the Celestron diagonals were not included in this ranking since their overall performance level was not up to the standards of the rest of the field.*

- ✓ Quality prisms are prime candidates for the diagonal component in telescopes with focal ratios of f/7 or greater. Prism diagonals tested did not introduce any visually apparent chromatic aberration or spherical aberration in f/7 or f/8 telescopes and showed views just as brightly while notably higher in planetary contrast and notably lower in scatter on all celestial targets than similar high quality aluminum or dielectric mirrors. At f/6.25 chromatic aberration became apparent, but was inconsequential on all but the very brightest targets.

- ✓ There was little distinction in the views between the field of aluminum and dielectric mirrors except the slightly increased scatter from some of the less-premium dielectrics.

- ✓ The most distinctive diagonals ergonomically were the Baader Clicklock Dielectric and the Tele Vue Everbrite. The Baader Clicklock mechanism was a complete joy to use, requiring a very short twist for full lock or full unlock and eyepiece. Further, the mechanism was more immune to eyepiece barrel undercut hang-ups than any other diagonal. The Tele Vue's oversized set screw also made use more enjoyable than the others as the larger screw had a more positive feel and operation.

- ✓ Diagonals absolutely require thermal acclimation time for best planetary performance! Going from a 70ºF inside temperature to a 30ºF outside temperature took a toll on the diagonals, particularly the 2" non-Prisms as they showed astigmatism even directly on-axis. The prisms did not show astigmatism, but did show a less sharp view until thermal equilibrium was achieved. Generally 15-30 minutes was required for optimal high magnification performance.

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