USING FILTERS FOR LUNAR/PLANETARY OBSERVATION

by: *William A. Paolini, September 17, 2020*

1. OVERVIEW

For the vast majority of my astronomical observing life, over 50 years, I have never used filters of any kind for planets or otherwise. But after half a century of reading the extraordinary claims by manufacturers and observing organizations alike about the many benefits of the various color filters on planets, I finally decided to give them a try myself to determine if what is written about them is more fact or is more fiction and hyperbole handed down over time.

Fig 1: Planetary and color filters tested to ascertain any benefit for lunar and planetary observing. Image Credit: Author.

2. OBSERVATIONAL PARAMETERS

LOCATION

Field testing was conducted over four months during June through September, 2020 in forested rural Virginia (Yellow Zone) approximately 50 miles Southwest of Washington, D.C. Sky Quality Meter readings at this location range between 20.5 to 21.3 mag/arcsec^2 on moonless nights. Outdoor temperatures during field testing ranged from +60° to +80° F with humidity ranging from 60-90%. Elevation of the observing site is approximately 300 feet above sea level.

PROCESS

All outcomes were recorded at the time of occurrence at the telescope using a voice recorder. Each performance test was replicated multiple times across multiple observing sessions to ensure they were consistent. Observations were only conduction during periods of very good to excellent seeing when the Moon and planets were showing highly detailed and stable views. When results were compiled, if there were any discrepancies or conflicting test results, then those tests are redone until the root cause of the initial discrepancy was identified and eliminated. Optical equipment was checked for collimation, cleanliness, and was thermally acclimated for all observational tests.

EQUIPMENT

The telescope I used was my preferred planetary observing tool, the Takahashi TSA-102 Super Apochromat. This telescope is a 4-inch (102mm) aperture triplet with a focal ratio of f/8. The diagonal used was a Baader Zeiss 2" Prism diagonal in combination with Pentax XW eyepieces and a Tele Vue 2.5x Powermate, so the effective focal lengths used ranged from 4mm to 5.6mm.

Fig 1: Eyepieces used for the test: Tele Vue 2.5x Powermate, Pentax 14mm XW, and Pentax 10mm XW.

For the observational testing I used what is my typical for my planetary observing without filters, which is to use a magnification that produces between a 0.75mm to 0.5mm Exit Pupil (4-6mm eyepieces in the TSA-102). I find that using an Exit Pupil smaller than 0.5mm is generally dim enough that low contrast features on the planets fade and become unobservable. A 0.5mm Exit Pupil is also equal to the popular rule of thumb of not exceeding a magnification of 50x per inch of aperture. Since I kept the observations leveled in this Exit Pupil range, the results should be fairly extensible to any aperture telescope using magnifications in this same Exit Pupil range. Figure 2 provides a table of magnifications in this Exit Pupil range for popular aperture sizes.

APERTURE		**MAGNIFICATION**	
Inches	**Millimeters**	**0.75mm Exit Pupil**	**0.5mm Exit Pupil**
2.4	60	80x	120x
3.1	80	107x	160x
4	102	136x	204x
5	130	173x	260x
5.5	140	187x	280x
6	152	203x	304x
8	203	271x	406x
10	254	339x	508x
12	300	400x	600x

Fig 2: Table of magnifications that produce 0.75mm to 0.5mm Exit Pupils for various aperture telescopes.

For many observers it is not typical that the atmospheric seeing where they live is regularly steady enough to support magnifications in excess of 250-300x for planetary observing. Due to the faint nature of many features on a planet, and their small angular size, planets are generally very sensitive to less than very good seeing. Therefore, for observers with larger aperture telescopes who cannot operate at magnifications in support of this Exit Pupil range due to seeing limitations, they will have to use lower magnifications with correspondingly brighter Exit Pupils. If this is the case the use of neutral density or polarizing filters to reduce the brightness of the planetary view may be needed to attain similar results. This may particularly be the case if the Exit Pupils reach 1.5mm or larger as these Exit Pupil will yield at least a 9x brighter image.

CURRENT PRODUCTION FILTERS TESTED

Baader Neodymium Moon & Skyglow with UV & IR Cut
Baader Semi-APO
Baader Contrast Booster
Celestron Mars
#8 Light Yellow (83%T)
#11 Yellow-Green (40%T)
#12 Deep Yellow (74%T)
#15 Dark Yellow (66%T)
#21 Orange (46%T)
#23A Light Red (25%T)
#25 Red (14%T)
#29 Dark Red (06%T)
#30 Magenta (27%T)
#38 Blue (43%T)
#38A Blue (17%T)
#47 Blue (03%T)
#56 Light Green (53%T)
#58 Green (24%T)
#80A Blue (28%T)
#82A Pale Blue (73%T)

Note: "%T" = %Transmission

CELESTIAL OBJECTS OBSERVED

The Moon, Venus, Mars, Jupiter, and Saturn were observed for the testing. The Moon was observed through a full range of phases during the nighttime hours when it was positioned 40° or more above the horizon, including when in its full phase as the flat illumination makes some details more difficult to see. The Moon was also observed during the daytime hours to ascertain the best approach to render a high contrast view when the background sky is brightly lit. Venus was only observed during the daytime hours with its position being more than 50° above the horizon. Mars was observed during the nighttime hours ranging from 45° to 58° above the horizon. Finally, Jupiter and Saturn were observed during the nighttime hours at their peak position during the period which was approximately 30° above the horizon.

3. RESULTS

MOON (NIGHTTIME)

BEST RESULTS:	1) Baader Moon & Skyglow + #82A Pale Blue stacked together -or- 2) Baader Contrast Booster + #8 Light Yellow stacked together

Fig 3: Color mosaic of Moon assembled from 18 images taken by the NASA spacecraft Galileo's imaging system using a green filter. Upper left is the dark, lava-filled Mare Imbrium, Mare Serenitatis (middle left), Mare Tranquillitatis (lower left), and Mare Crisium, the dark circular feature toward the bottom of the mosaic.
Image Credit: NASA/JPL/USGS

Since the Moon at nighttime is so very bright and vibrant, even unfiltered, with filters I was looking for which would most dramatically bring out the less vibrant features on the Moon such as the dark shadings of the maria and the more subtle ejecta patterns across much of the surface. I focused on these particular feature types because the highland features of the Moon, being so bright and highly contrasted, need no help from filters. Of all the different color filters used singly, the blues and yellows were most preferred as they did not show the Moon in an overly unnatural color. Specifically I felt that the Baader Moon & Skyglow, #82A Pale Blue, #8 Light Yellow, and #11 Yellow-Green filters did the best job at accentuating the maria and ejecta features a little better than unfiltered while keeping the Moon's color not too far from the natural. Of these four I preferred the cooler nature of the blues tones a little better, so I preferred the Baader Moon & Skyglow and the #82A Pale Blue for their general contrast increase of features while only adding a very slight blue tint.

What I felt where the best performers however, were the stacked combination of filters. One of my favorites was the Baader Moon & Skyglow stacked with the #82 Pale Blue. This combination added a moderate blue tint to the view but resulted in an excellent level of contrast to the regolith shades in the maria, lava flows, and the whites of the impact ejecta. And for those who aesthetically prefer a warmer yellow cast instead of a cooler blue cast to the view, the Baader Contrast Booster stacked with the #8 Light Yellow filter similarly resulted in an excellent level of contrast to the regolith shades in the maria, lava flows, and the whites of the impact ejecta, but added a moderate yellow tint instead of blue to the view.

MOON (DAYTIME)

BEST RESULTS:	#23A Light Red & Polarizer filter stacked together

Observing the Moon during the daylight hours can be both enjoyable and productive. Unfortunately, when viewed without filtration the Moon will appear washed-out, with features typically seen as very high contrasted during nighttime now appearing faint and low contrast. With proper filtration however, testing revealed that the view can be improved to the point where contrast is increased enough that many features again appear contrasted sufficiently for enjoyable study and exploration. The goal was to find which color filter in combination with a Polarizer filter would darken the background sky the most, while simultaneously not overly dimming the brightly lit features on the Moon. In my experimenting, only the more strongly colored filters did the best job. So in order to maximize the contrast of the daytime Moon, a more unnatural lunar coloration was needed.

To get the optimum contrast effect, the best combination I found was the #23A Light Red stacked together with a single Polarizing filter. To stack the filters, either both can be attached to each other, then attached to the eyepiece, or if separated, the color filter can be placed on the nosepiece of a 1.25" diagonal while the Polarizer must be on the eyepiece. In either of these scenarios, once attached the eyepiece is then be rotated in the focuser to achieve the desired amount of darkening of the background sky from the Polarizer. The Sun's light in the daytime sky is strongly polarized, and more polarized the further apart in the sky the Moon is from the Sun. When the Polarizer is rotated, it will darken the background sky sometimes very significantly and visually increase the contrast of the lunar view.

With both filters in place even fairly high magnification views of most features on the Moon appeared very pleasing. Magnifications that produced as low as a 0.75mm Exit Pupil still showed a vibrant and high visually contrasted view. Subtle maria shadings remained apparent, ejecta streaks and patterns were clearly visible and bright, and all the rich lunar detail one sees in the lunar highlands during nighttime observing was there in all its glory to explore now during the daytime. The only downside was that everything was unnaturally red due to the #23A Light Red filter, but of all the specially filters and color filters the #23A Light Red performed the best with the #21 Orange filter coming in second place. After a short while however, I quickly got used to the red view and thoroughly enjoyed the daytime lunar observing experience.

VENUS (DAYTIME)

BEST RESULTS:	1) Baader Semi-APO & #80A Blue & Polarizer stacked together	(*best*)
	2) #80A Blue & Polarizer stacked together	(2nd best)

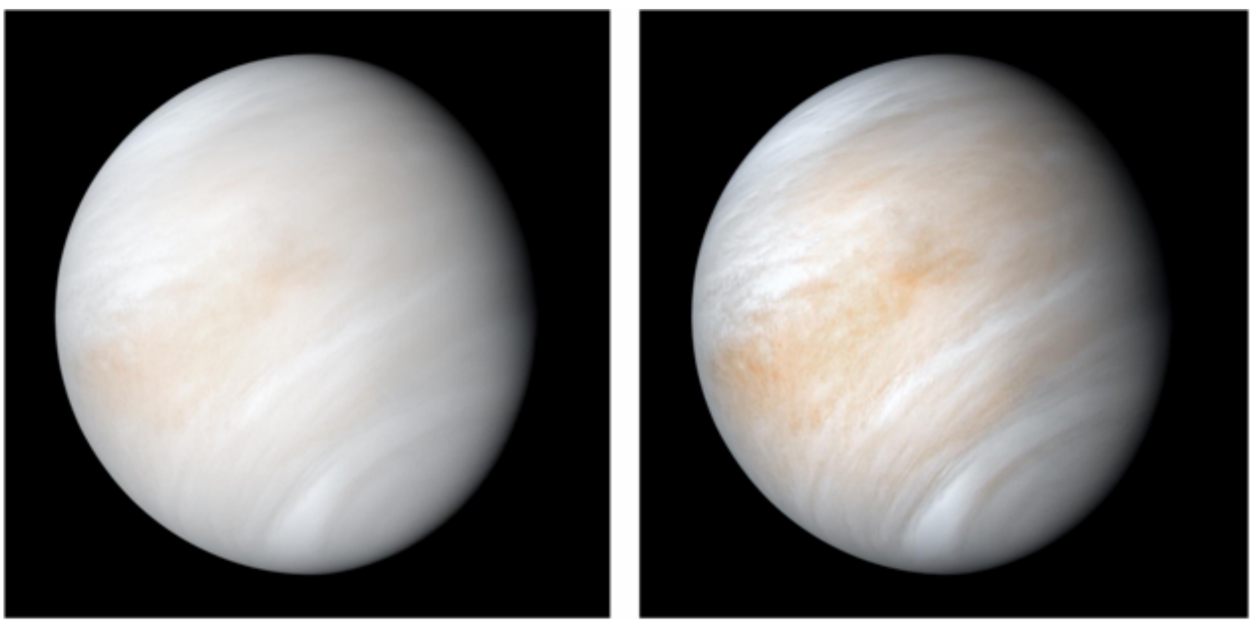

Fig 4: A color enhanced image of Venus from the Mariner 10 spacecraft. This view is a false color composite created by combining images taken using orange and ultraviolet spectral filters. The clouds shown are located about 40 miles above the planet's surface, at altitudes where Earth-like atmospheric pressures and temperatures exist. They are comprised of sulfuric acid particles. The cloud particles are mostly white in appearance; however, patches of red-tinted clouds also can be seen. Image credit: NASA/JPL-Caltech.

Like with daytime observing of the Moon, a Polarizer filter is necessary to darken the background sky when observing Venus during the daytime. Unlike with the Moon however, the blue filters worked better both aesthetically and practically for me on Venus than the red filters. So my preference was to stack the Polarizer filter with the stronger #80A Blue filter to help reduce the excessive brightness of Venus as well. This combination also darkened the background sky very nicely while keeping it fairly natural looking.

When I added the Baader Semi-APO filter to the stacked Polarizer and #80A Blue filter, I felt the view improved even more as a still bright Venus was now dimmed just a little more resulting in some cloud details becoming visible near the terminator on Venus (note - during my daytime observations Venus was in the slightly less than half phase). I could not achieve bringing out these clouds by adding a neutral density filter. With the Semi-APO filter added to the stack, the background sky shifted from a strong dark blue to a strong pale blue with a slight green undertone. I felt this coloration change was actually a bit more natural looking compared to the view without the Semi-APO filter in the stack of filters.

Finally, I also tried substituting the Baader Contrast Booster and Moon & Skyglow filters for the Semi-APO in this triple stack, but either of those filters excessively dimmed the view compared to what the Semi-APO was showing. While I did not try daytime observing of Mercury, I would extrapolate that this triple stack filter combination for Venus will likely work well for Mercury too.

MARS (NIGHTTIME)

BEST RESULTS:	1) Baader Contrast Booster	(*best general contrast improvement all features*)
	2) #30 Magenta	(*specialty: brightens polar caps, limb haze, fog*)
	3) #58 Tricolor Green	(*specialty: brings out Lowell Bands around poles*)

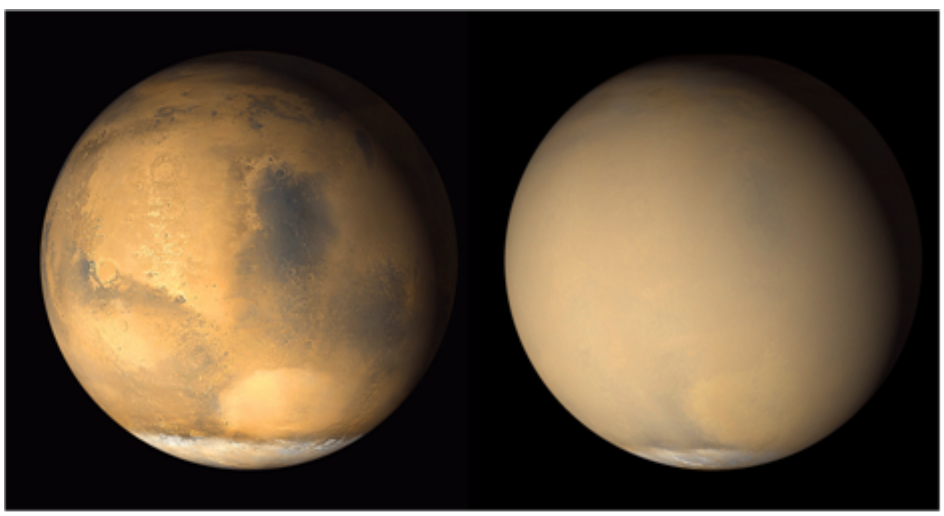

Fig 5: Two 2001 images from the Mars Orbiter Camera on NASA's Mars Global Surveyor orbiter show a dramatic change in the planet's appearance when haze raised by dust-storm activity in the south became globally distributed. Image Credit: NASA/JPL-Caltech/MSSS

I found that using filters for Mars was a bit of a different experience than for the other planets. I felt that I was more sensitive to when a filter changed the natural color pallet of the Mars than with other planets. Of all the different filters from the test suite, I felt that the Baader Contrast

Booster enhanced contrast across all features on Mars the best. It was an excellent generalist at darkening maria without losing edge details, brightening white or bright features like the deserts, polar caps, and limb haze, and it also kept the color pallet of Mars within what I felt was reasonable for Mars. I tried stacking other filters with the Contrast Booster but did not like any of the combinations. I also felt that the Baader Moon & Skyglow or Semi-APO were not as effective as the Contrast Booster was on Mars.

For the narrow task of wanting to accentuate the polar caps, limb haze, or ice fog on Mars, and not caring about the other features, I found that the VERNONscope #30 Magenta filter did this task the best. This filter was very good at making those Martian features show more brightly than the Contrast Booster. However, the #30 Magenta also overly darkened the maria features on Mars, losing their edge details. I also felt the #30 Magenta added what I felt was a bit of an unnatural purple hue to the planet. I did experiment with a lighter magenta than the #30, using a Rosco #3314 1/4 Minus Green gel filter, and found that this lighter magenta kept the colors of Mars looking more natural than the #30 Magenta, but it only subtly brightened or contrasted the whites of the polar caps, limb haze, and ice fog compared to the #30 Magenta. So the lighter magenta of the Rosco #3314 1/4 Minus Green gel filter did not show these features of Mars as vibrantly as the #30 Magenta. On the other end of the spectrum I also tried magenta filters that were a stronger magenta color than the #30, like the Celestron Mars Filter. I found that the stronger magenta color was very much less effective than the #30 Magenta, overly dimming all features, including the whites of the polar caps, limb haze, and ice fog. So the VERNONscope #30 Magenta was best in this specialty role. However, it was ergonomically not as pleasant to use as other filters because it uses a non-standard threading which requires an adapter. This branding of filter further limits it to being placed only on the top of the stack as it has no female-threads on its receiving end and therefore cannot be placed anywhere in the stack. Its adapter also makes the filter longer, requiring more care when placing in the diagonal to prevent accidental contact with the mirror or prism of the diagonal.

While trying all the different color filters on Mars, I did not like any of the other colors as they altered the natural color pallet of Mars to the point of looking too unnatural for my tastes. They also did not accentuate any of the Martian features better than the Baader Contrast Booster or the #30 Magenta filters. The one exception however was the #58 Tricolor Green filter. This filter dramatically darkened the Lowell Bands that are seasonal dark bands around the polar caps. During my observations these bands were not visible unfiltered, showed light to moderately with the Baader Contrast Booster, but showed dramatically dark with the #58 Green filter. Even though Mars was now very unnaturally green in color, seeing the extreme contrast between a very dark Lowell Band against a very bright, albeit light green, polar cap was quite dramatic. The polar cap looked more like a giant bulls-eye on the edge of the planet! As a specialty filter for Mars, I now keep a #58 Tricolor Green filter for just this purpose as it produces a very spectacular view on this feature.

JUPITER (NIGHTTIME)

BEST RESULTS:	1) Baader Contrast Booster	(best improvement *for all features*)
	2) #8 Light Yellow	(*very subtle improvement for all features*)
	3) #82A Pale Blue	(*specialty: GRS color appear more vividly*)

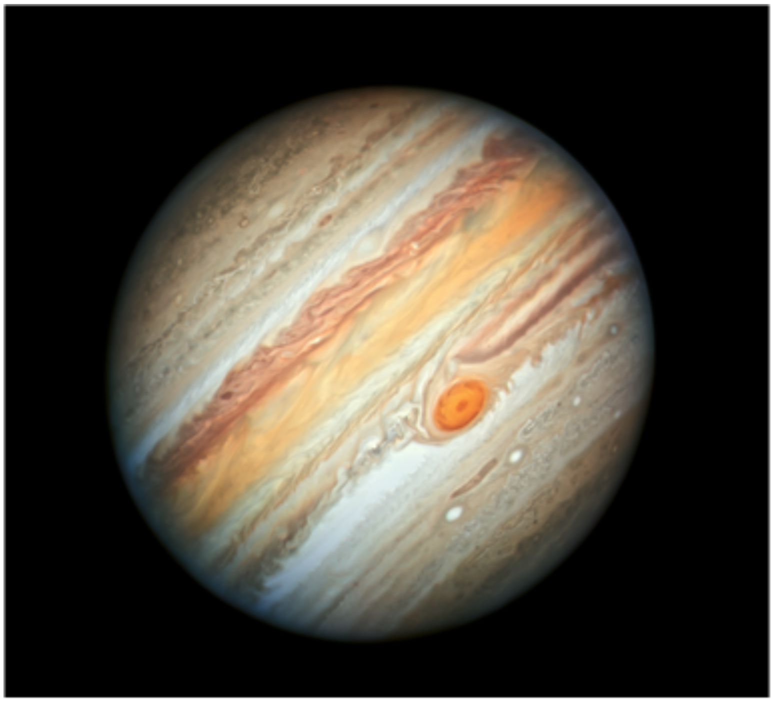

Fig 6: Hubble Space Telescope view of Jupiter, taken on June 27, 2019. The Belts in Jupiter's atmosphere are created by differences in the thickness and height of the ammonia ice clouds. Lighter Belts are higher and thicker than the darker Belts. The Belts flow in different directions at various latitudes due to different atmospheric pressures. Image Credit: NASA, ESA, A. Simon (Goddard Space Flight Center), and M.H. Wong (University of California, Berkeley)

Overall, the following filters all provided good result and improvement to the contrast and visibility of features on Jupiter: Baader Contrast Booster, Baader Semi-APO, Baader Moon & Skyglow, #8 Light Yellow, and #82A Pale Blue.

The most subtle improvement to general feature contrast was from the #8 Light Yellow filter. The perceptual impact when using just this filter was as if the seeing improved just a little, making all features on the planet subtly improved. Due to the very light yellow color of this filter, it also did not tint Jupiter unnaturally.

The most color-neutral results that also had very good enhancement of feature contrast on Jupiter was from the Baader Contrast Booster. The Belts, Polar Regions, and GRS on the planet were nicely contrasted and more distinctly visible while it only slightly dimmed the view. The Contrast Booster made the Belts easier to see compared to unfiltered, while accentuating their finer internal and edge details, including festoons off the Belts. The Contrast Booster also revealed some Belts or portions of Belts that were not be visible unfiltered, like the Equatorial Belt. Some lighter zones between the Belts on the planet seemed to be visibly brightened, further enhancing contrast. Finally, the GRS retained its natural coloration which for me is an essential characteristic as it is such a sought after feature on the planet. Overall the Contrast Booster did an exemplary job improving the visibility of features on Jupiter.

The Baader Semi-APO filter also worked quite well on Jupiter. The view using this filter was similar to that rendered by the Contrast Booster, except the contrast gain was slightly greater for the Belts and the polar region. However, the planet appeared warmer and slightly more yellowish, so the view was less color-neutral with the Semi-APO on Jupiter than the Contrast Booster and aesthetically less desirable for me. The Baader Moon & Skyglow also showed results similar to the Contrast Booster on Jupiter, however features were not contrasted as well and it imparted a slight blue tint to the view. Of the three I liked the Contrast Booster the best.

As a special feature filter, the #82A Pale Blue filter made the natural color of the GRS appear more vividly bright and color-saturated, which was exciting to see. The GRS, Belts, and Polar features on the planet were also slightly more distinct compared to unfiltered with the #82A Blue filter. However, a light blue tint was given to the planet's lighter features which had the subtle effect of generally muting the colors other features on the planet aside from the GRS. Given how vividly this filter made the GRS color "pop" on the planet, I definitely recommend it for that purpose as it made observing the GRS all the more interesting.

<u>SATURN</u> (NIGHTTIME)

BEST RESULTS:	1) Baader Semi-APO -or- Contrast Booster	(best for contrasting all features)
	2) #8 Light Yellow -or- #82A Pale Blue	(alternative to Contrast Booster)
	3) #15 Dark Yellow	(specialty: best on Cassini Division)

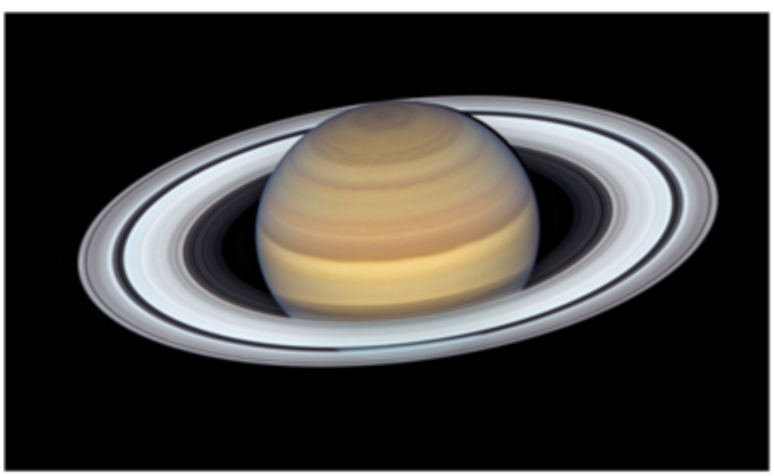

Fig 7: Hubble Wide Field Camera 3 image of Saturn taken on June 20, 2019 as the planet made its closest approach to Earth. Image Credit: NASA, ESA, A. Simon (GSFC), M.H. Wong (University of California, Berkeley) and the OPAL Team

Saturn overall was a more difficult planet to bring out significantly better views with filters. Of all filters the Baader Semi-APO was the one that more vibrantly and starkly rendered the major features, i.e., the Cassini Division, Belts, North Polar Region and Hexagon, Rings (including the C-Ring), and Cassini Division. The Semi-APO filter also added a slightly warmer cast to the already warm color pallet of Saturn. The Baader Contrast Booster rendered a view similar to the Semi-APO, and contrasted the North Polar region just a little better, but at the expense of dimming the overall view enough to make the view appear less vibrant overall. If I was observing at magnifications that yielded smaller Exit Pupils brighter than in the 0.50-0.75mm range, then the Contrast Booster might have provided the better view as it visually revealed the North Polar region more starkly. But in the 0.50-0.75mm Exit Pupil range the Semi-APO filter was showing the planet brighter and more vividly.

If I was on a tighter budget and could not afford the best filters from my tests on Saturn, the Baader Semi-APO or Contrast Booster, then good alternatives would be either the #8 Light Yellow or #82A Pale Blue filters. Of these I preferred the #8 Light Yellow as it showed the Belts, Polar Region, Rings, and Cassini Division on Saturn with more contrast than the unfiltered view, while keeping the colors on Saturn fairly natural looking. The #82A Pale Blue similarly better rendered the major features on Saturn slightly better than the unfiltered view, but I personally did not prefer it aesthetically as it also muted the colors overall on Saturn adding a slightly cooler tone to the view.

Finally, if my goal was to render the Cassini Division as dark, contrasted, and visibly discernable as possible, then of all the filters I tested the #15 Dark Yellow accomplished this task the best. The #11 Yellow-Green filter did this almost as well, so this can be used as well. However, the #15 Dark Yellow was clearly better in this regard. Note that both of these filters will cause the normal coloration of Saturn's features to have an unnaturally very warm yellow cast.

4. Conclusion

Top Recommendations:	1) Baader Contrast Booster	(jack-of-all-trades for planets)
	2) #8 Light Yellow	(contrasts features for Jupiter & Saturn)
	3) #15 Dark Yellow	(specialty: highlights Cassini Division best)
	4) #82A Pale Blue	(same as #8 and brightens GRS color)
	5) #58 Tricolor Green	(specialty: reveals Lowell Bands on Mars)

As far as the popular information one finds on the internet touting how almost every color filter is beneficial for planetary observing, my test of 21 different filters did not yield such benefits. Many filters were actually a detriment to the view. Instead just a very few provided what I considered to be practical and worth while improvement of planetary features. And by far, the specialty planetary filters and not the common color filters provided the superior results. However, in my opinion as a long time planetary observer, the use of filters for planetary observing is not a necessity to obtain excellent views of the planets and their features. Instead, steady seeing, well collimated optics, thermally acclimated optics, and proper magnification/Exit Pupils are the key to impressive planetary views, even from small aperture telescopes. So my recommendation is that before you venture into the realm of filters to improve your planetary views, first make sure that you are getting detailed views of planets without filters, as the filters will not perform any magic making a poor view all of a sudden good with many details. So make sure the seeing is steady, and that your telescope performs well under higher magnification observing. Generally, for a good high contrast unfiltered view of a planet, use an eyepiece with your telescope that produces an Exit Pupil that is larger than 0.5mm. I would recommend an optimum Exit Pupil for planetary being around 0.75mm so the planet is bright with a good level of contrast to bring out the details. When the Exit Pupil gets smaller than 0.5mm the view dims enough that some details will begin to fade. To calculate the Exit Pupil of an eyepiece with a particular telescope, use the following formula:

EXIT PUPIL (MM) = EYEPIECE FOCAL LENGTH (MM) / TELESCOPE FOCAL RATIO

While some planetary observers will always strive for the best views possible, therefore wanting an array of different filters, others cannot be so opulent and therefore streamline their capabilities with fewer filters that will do a good-enough job across most or all the planets. For those wishing to do the latter, my recommendation would be to just use the Baader Contrast Booster as it did an excellent job on the Moon and all the planets tested for nighttime observing (i.e., Mars, Venus, Jupiter, and Saturn). In my testing this one filter really did prove itself to be a jack-of-all-trades for the Moon and Planets. However, if one only wishes to use standard color filters, since these are generally the least expensive, then my recommendation would be both the #8 Light Yellow and #82A Pale Blue for Jupiter and Saturn. Both of these color filters render improved the view of planetary features giving different perspectives making the planets look cooler or warmer in tone. Additionally, the 82A Pale Blue also made the Jupiter's GRS color on show more vividly. For special purposes I would also recommend the #15 Dark Yellow filter if you are having difficulty observing the Cassini Division on Saturn, and the #58 Tricolor Green filter solely for Mars to accentuate the Polar Caps and seasonal dark Lowell Bands that sometimes surround the Martian Polar Caps. The #30 Magenta would be a better general-purpose filter for Mars but unfortunately is much more expensive than other color filters and is difficult to find with standard 1.25" eyepiece treads.

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About the Author

William "Bill" Paolini has been actively involved in optics and amateur astronomy for more than 50 years, is author of the desk reference on astronomical eyepieces: *Choosing and Using Astronomical Eyepieces* which is part of the Patrick Moore Practical Astronomy Series published by Springer of New York, has published numerous product reviews on major online amateur astronomy boards, and has worked as a tour guide volunteer for the United States Naval Observatory's historic 1873 26" and 12" Alvan Graham Clark refractors.

Bill has been active in astronomy since the mid-1960's, grinding mirrors for homemade Newtonian telescopes and eventually owning, using, and testing over 400 eyepieces in a wide variety of telescopes including Achromatic Refractive, Apochromatic Refractive, Newtonian, Maksutov-Cassegrain, and Schmidt-Cassegrain optical designs. Now retired he enjoys observing under darker skies at his rural home an hour's drive from Washington, D.C.