Deep Sky Filters for Visual Observation

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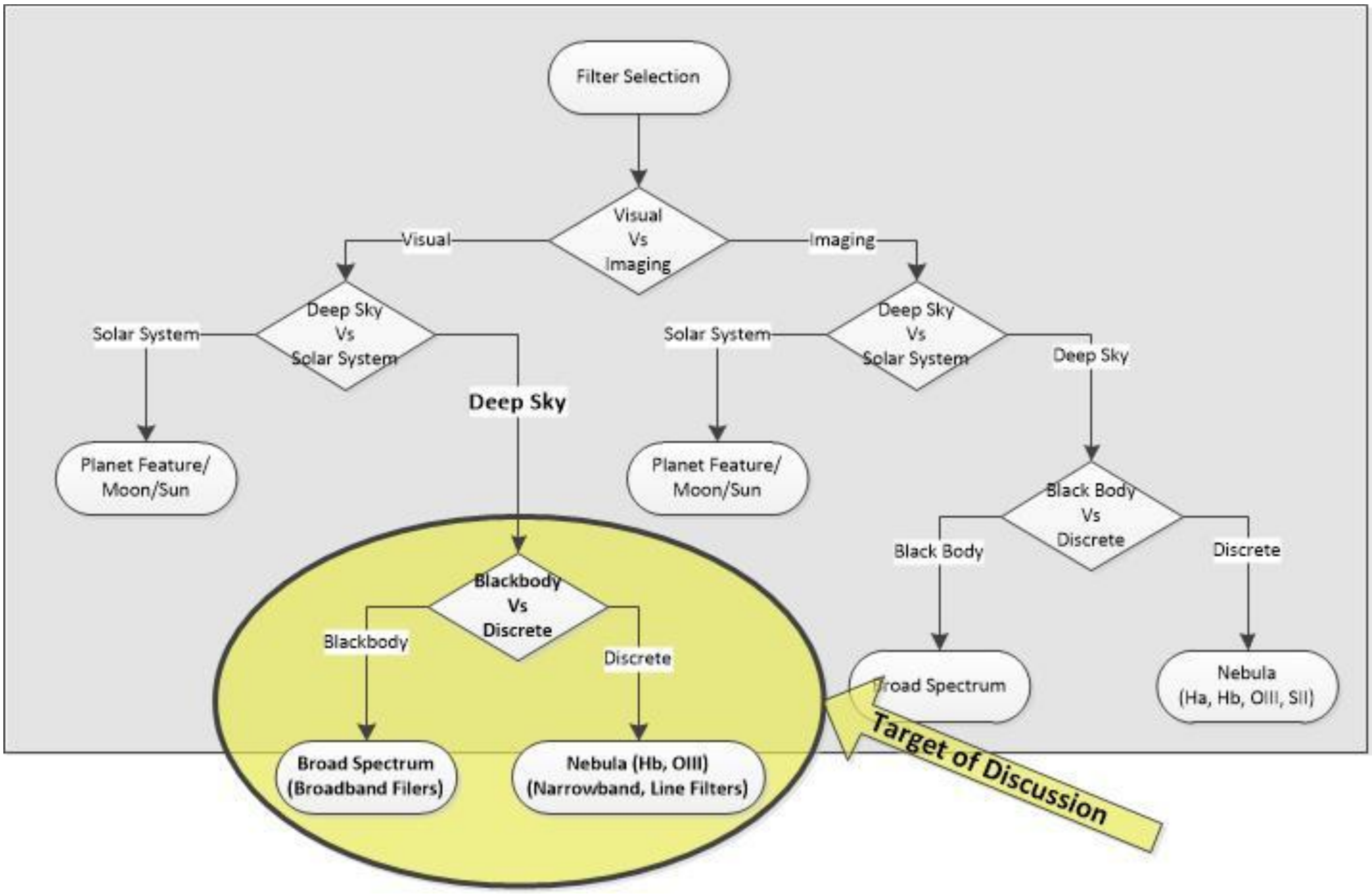
Deep Sky Filters for Visual Observation

Introduction

In this article we discuss some considerations when trying to determine what filters may be appropriate to supplement visual observations. This discussion is restricted to deep-Sky targets (objects outside of our solar system).

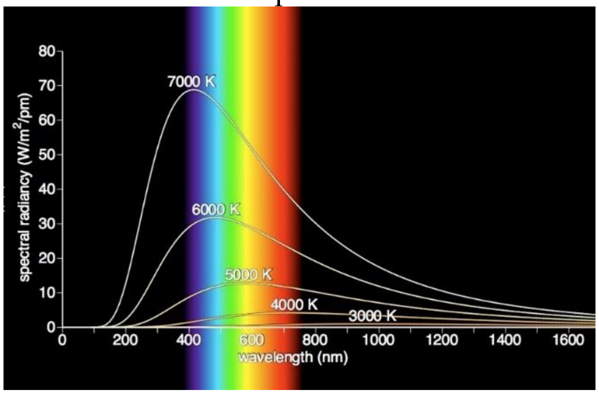
Filter Selection Flow Diagram



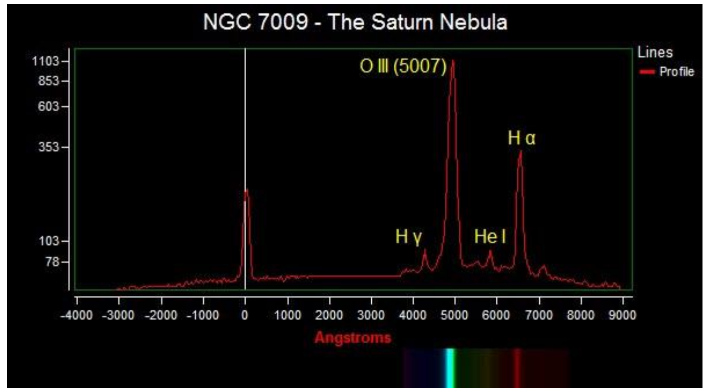
The Nature of Matter and Light in Astronomy

Deep-sky objects we observe are made of mostly of Hydrogen with trace amounts of other gasses like Oxygen, Nitrogen, Helium, Sulfur, etc. However, the nature of the light they emit can be drastically different. Objects composed of very hot gases such as stars, galaxies, open clusters and globular clusters radiate light similar to a blackbody, this is a broad-spectrum radiation. In contrast, objects composed of relatively cool gasses (aka Nebula) such as planetary nebula, emission nebulae and supernova remnants that show discrete spectra.

Blackbody Radiation is a function of Temperature

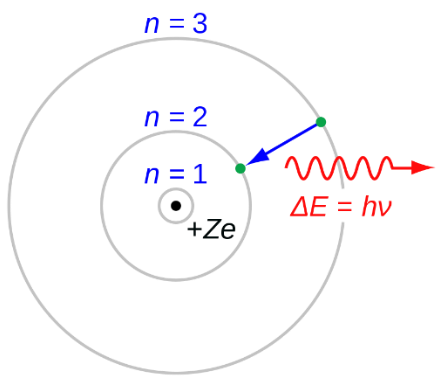


Most Nebulae have descrete spectra



The color of objects behaving like black bodies (stars, etc) is dependent upon their temperature (ie red stars are cooler than blue stars). In contrast, most nebulae are cool enough that the gases they are composed of emit distinct wavelengths corresponding to transitions of various energy states of the elements making up the gas following Bohrs Model of the Atom.

Atomic Energy State Transition



Since this document is focused on visual observations, we need to keep in mind that we are interested in light in the visible spectrum with wavelengths between 380 to 750 nm. While there are filters that transmit the Hydrogen α (656nm) and Sulfur II (671nm, 673nm) wavelengths, their application tends to be more for astrophotography since the eye is not particularly sensitive to the lower range of light, so these wavelengths will be ignored for this conversation. This leaves the OIII (501nm), and Hβ(486nm) wavelengths as targets for nebulae filters used for visual observation.

Light pollution is composed of many different types of sources such as street lights that were mostly Sodium vapor or Mercury vapor that have more discrete spectra. This was great for astronomy since filters could be made to reduce or eliminate the transmission of these wavelengths through a filter. Unfortunately, street lights are being rapidly replaced with LED lighting that emit more of a black-body broad spectrum light.

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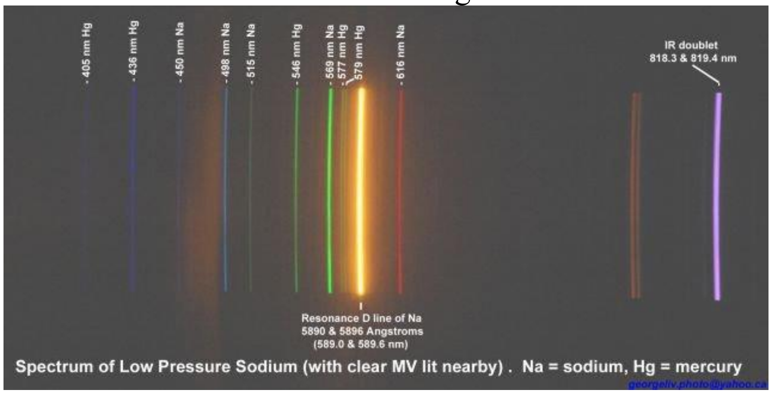
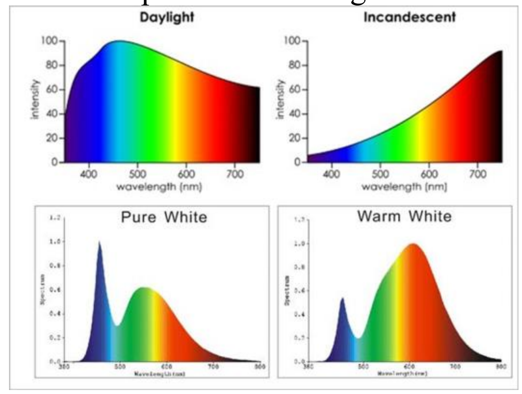
Older Street Lights



Spectra of LED lights



Signal to Noise Ratio

The intent of filters is to help make the target of interest stand out more from the background. This is accomplished by increasing the contrast between the background and the targeted object. Essentially, increasing the Signal of the targeted object to the signal of the Noise (the light pollution).

Light pollution is mostly from city lighting and to a lesser extent airglow. As you can see in the images below, identification of an object and its features becomes more difficult with more pollution, and the dimmer the object is.


DARK SKY


LIGHT-POLLUTED SKY

Filter Types

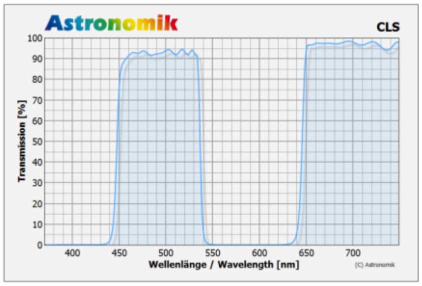
Common terms and acronyms associated with filters

- **City Light Suppression** (**CLS**): Broad band filters used to suppress city light pollution, but also useful in airglow suppression. Good for observing nebulae and may help with galaxies, globular clusters, open clusters, etc.
- **Deep Sky**: Usually referring to a Broad band Filter. Same use case as the CLS filters.
- **Ultra High Contrast** (**UHC**): Also known as Nebula filters, narrow band filters best used for observing nebula.
- **Line** Filters: Also called Nebula filters at times eliminate most light except one or two wavelengths. Ideal for planetary nebulae and some nebulae, these filters may require larger aperture telescope to be effective.

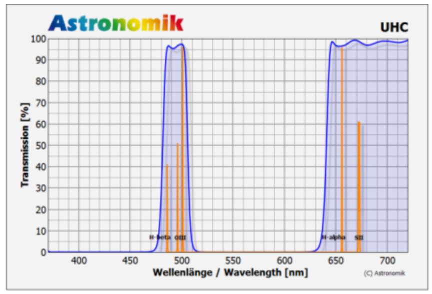
There is no precise definition of what constitutes a broadband vs narrowband filter. Generally broadband filters are considered to have a bandwidth of about 50-70nm wile narrowband filters are in the range of 20-30nm.
What filter is the best for the object you are observing depends on a number of factors. The table below may help in making this decision. There are also line filters that attempt to exclude all light except the transition lines associated with distinct wavelengths linked to energy state transitions such as OIII (501nm), and Hβ(486nm), these filters tend to have bandwidths between 3-9nm.

Transmission curves of different type of filters.

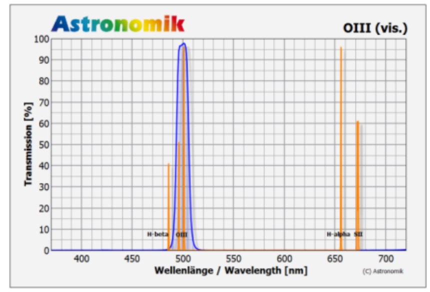
Broadband Filter



Narrowband Filter



Line Filter



Types of Visual Filters

Filter Type	Typical Bandwidth	Ideal Targets Types	Ideal Application	Comments
Broadband Nebula	50-70nm	Nebula	Dark Sky	• May provide slight benefit to blackbody type objects. • Filters may be overwhelmed by light pollution in urban skies.
Narrowband Filters	20-30nm	Nebula	Urban Sky	• Will cut out too much light to be useful when applied to blackbody type sources. • Generally, these filters are called Ultra High Contrast (UHC) filters, but there are exceptions to this naming convention.
OIII (Line Filter)	9-15nm	Planetary Nebula, *Supernova Remnants	Urban Sky *Dark Sky	• Best result may require aperture of 8” or more. • Suitable for most emission nebulae, planetary nebulae and supernova remnants. Especially effective on Veil Nebula. • Dark Sky – may help provide more details of target in dark sky.
Hβ (Line Filter)	9-15nm	*Nebula	Urban Sky *Dark Sky	• Highly specialized filter for a few individual targets such as Horsehead, California, and Cocoon Nebula. • Requires moderate to large aperture

Magnification/Exit Pupil Interplay

It is important to select the correct magnification for an object to ensure you have the best chance of locating and viewing the most detail possible. This is where the *exit pupil* (a measure of the diameter of the beam of light exiting the eyepiece) value of a telescope/eyepiece combination comes into play. First and foremost is to make sure the resulting exit pupil of your system does not greatly exceed your (individual) pupil size since you would be wasting light (spillover) if it does. However, a small amount of spillover may be desired since an exact match between the observer’s pupil and the exit pupil of the telescope system would require exact placement of the observer head to enjoy the full benefit of the field of view. Unless you use a clamp to attach your head to the telescope eyepiece, keeping your head in this exact position is unlikely.

The table below shows the average maximum pupil diameter of a person based on age. However, this value is known to vary widely from person to person and can deviate up to as much as 3mm from the average values provided below. You can ask your eye doctor to measure your maximum pupil size, or ideally you will perform this measurement at the location(s) that you commonly observe since observing sites can vary greatly in regards to light pollution and will have a direct impact on this measurement. One method to perform this measurement using a set of metric Allen wrenches[Ref].

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Dark-adapted Pupil Diameter of the Average Human Based on Age

Note: Maximum pupil diameter can vary greatly from person to person and site to site based on lighting conditions

Age (years)	Night (mm)
20	**8.0**
30	**7.0**
40	**6.0**
50	**5.0**
60	**4.1**
70	**3.2**
80	**2.5**

Recommended Exit Pupil Based on Viewing Conditions and Filter Type [Ref]

Sky Conditions	Filter Type	Target Types	Examples	Eye Pupil Range (mm)
Urban Sky	Broadband	Nebula, Blackbody	Generally, any deep sky objects	0.5 – 2.0
Urban Sky	Narrowband	Nebula	All nebulae should benefit from this filter	1.0 – 4.0
Urban Sky	Line (OIII)	Planetary, * Supernovae remnants, *Emission Nebula	Helix Nebula, Crab Nebula, Veil Nebula	2.0 – 5.0
Urban Sky	Line (Hβ)	*Specialized Application	Horsehead, California, Cocoon nebula	3.0 – *7.0
Dark Sky	Narrowband	Nebula	All nebulae should benefit from this filter	2.0 – *6.0
Dark Sky	Broadband	Nebula	Generally, any deep sky objects	1.0 – 4.0
Dark Sky	Line (OIII)	Planetary, * Supernovae remnants, *Emission Nebula	Helix Nebula, Crab Nebula, Veil Nebula	3.0 – *7.0
Dark Sky	Line (Hβ)	*Specialized Application	Horsehead, California, Cocoon nebula	4.0 – *7.0

* This value may be restricted further based on your age.

The table above is a good guide to help identify the ideal eye pupil range for viewing various deep sky objects under the different sky conditions. However, in order for this information to be actually useful we need to translate this into the equivalent eyepiece range for a given telescope and person. The exit pupil for a telescope/eyepiece combination is calculated as the focal length of the eyepiece divided by the focal ratio of the telescope. Provided below are two methods of calculating the exit pupil (EX), one given the focal length (*f*) of the telescope, the other given the focal ratio (FR) of the telescope. The third equation shows the focal length of the eyepiece associated with the exit pupil and focal ratio of the telescope.

NOTE: typically, the focal ratio is notated as f/ or f-number *we are not using this notation in this document for clarity in the equations provided.*

Exit Pupil Equation 1

$$XP = \frac{f_e}{FR_t}$$

Exit Pupil Equation 2

$$XP = \frac{A_t \times f_e}{f_t}$$

Focal Length of Eyepiece

$$f_e = XP \times FR_t$$

Where:

- XP = Exit Pupil in millimeters
- f_e = Focal Length of Eyepiece in millimeters (mm)
- FR_t = Focal Ratio of Telescope
- f_t = Focal Length of Telescope in millimeters
- A_t = Aperture of telescope in millimeters

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We can now update the table to show the corresponding eyepiece Focal Lengths for a few common F-Ratios.

Recommended Filters and Eyepieces for Identified Conditions Based on Filter Selection

Sky Condition	Target Type	Filter	Pupil Range (mm)	Some Common Telescope Focal Lengths (FR)			
				FR_t = F14 Eyepiece Range (mm)	FR_t = F10 Eyepiece Range (mm)	FR_t = F5 Eyepiece Range (mm)	FR_t = F2 Eyepiece Range (mm)
Urban Sky	Nebula, Blackbody	Broadband	0.5 – 2.0	**7.0 – 28**	**5.0 – 20**	**2.5 – 10**	**1.0 – 4.0**
Urban Sky	Nebula	Narrowband	1.0 – 4.0	**14 – 56**	**10 – 40**	**5.0 – 20**	**2.0 – 8.0**
Urban Sky	Planetary, SN Remnant	Line (OIII)	2.0 – 5.0	**28 – 70**	**20 – 50**	**10 – 25**	**4.0 – 10**
Urban Sky	*Specialized	Line (Hβ)	3.0 – 7.0	**42 – 98**	**30 – 70**	**15 – 35**	**6.0 – 14**
Dark Sky	Nebula	Narrowband	2.0 – 6.0	**28 – 84**	**20 – 60**	**10 – 30**	**4.0 – 12**
Dark Sky	Nebula	Broadband	1.0 – 4.0	**14 – 56**	**10 – 40**	**5.0 – 20**	**2.0 – 8.0**
Dark Sky	Planetary, SN Remnant	Line (OIII)	3.0 – 7.0	**42 – 98**	**30 – 70**	**15 – 35**	**6.0 – 14**
Dark Sky	*Specialized	Line (Hβ)	4.0 – 7.0	**56 – 98**	**40 – 70**	**20 – 35**	**8.0 – 14**

* Green values may be limited based on age of the observer due to pupil dilation limitations.

Highest Useful Magnification

At this point we have identified the appropriate filters to utilize based on viewing conditions and the actual object we are viewing. We have also identified the appropriate range of exit pupil and corresponding eyepiece focal lengths. However, we have not discussed what the appropriate Magnification for a telescope/eyepiece combination may be for deep-sky objects and the corresponding eyepieces associated with this. Here we assume 15x per inch of aperture of the telescope is the Highest Usable Magnification (HUM) for both small and large deep-sky objects under normal viewing conditions. Based on this assumption we can derive the relationship (See appendix):

$$\boldsymbol{f_e^{HUM} \approx 1.7 \times FR_t}$$

Where:

f_e^{HUM}= Focal Length of eyepiece for Highest Useful Magnification for a given F-Ratio of a telescope

FR_t = Focal Ratio of the telescope

An interesting observation on this equation is that the same eyepiece will provide you with the HUM for all telescopes with the same F-Ratio regardless of the aperture size of that telescope. For example, I would use the same 17mm eyepiece for both my Celestron SCT 6" telescope and my Celestron SCT 11" telescope since they have the same F-Ratio to provide me with the Highest Useful Magnification of 88x and 164X respectively for each telescope.

The Highest Useful Magnification expressed as focal length of the eyepiece might further restrict the lower limit of the focal length range. Lower limit calculations based on this equation result in the following table:

Lower Limit of eyepiece Focal Length for HUM

(FR_t)	(f_e^{HUM})
F14	23.8 ≈ 24mm
F10	17 mm
F5	8.5 ≈ 8 mm
F2	3.4 ≈ 3 mm

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We can see at this point the original table indicating the appropriate exit pupil for viewing deep-sky objects based on the type of object (Broadband vs Discrete) and the observation conditions (Dark Sky vs Urban) is further restricted based on the aperture of your telescope (Highest Useful Magnification) and your maximum pupil size(Exit Pupil). The table below shows a typical result of these restrictions for and observer who is less than 40 years old since Exit Pupil restrictions do not come into play for the original recommended values until age 40. Reference the tables in the Appendix values of this table for specific age ranges up to the 80s.

Final Recommended Eyepiece Recommendations (Age < 40)

Sky Condition	Target Type	Filter	Pupil Range (mm)	FR_t = F14 Eyepiece Range (mm)	FR_t = F10 Eyepiece Range (mm)	FR_t = F5 Eyepiece Range (mm)	FR_t = F2 Eyepiece Range (mm)
Urban Sky	Nebula, Blackbody	Broadband	0.5 – 2.0	**24 – 28**	**17 – 20**	**8 – 10**	**3 – 4**
Urban Sky	Nebula	Narrowband	1.0 – 4.0	**24 – 56**	**17 – 40**	**8 – 20**	**3 – 8**
Urban Sky	Planetary, SN Remnant	Line (OIII)	2.0 – 5.0	**28 – 70**	**20 – 50**	**10 – 25**	**4 – 10**
Urban Sky	*Specialized	Line (Hβ)	3.0 – 7.0	**42 – 98**	**30 – 70**	**15 – 35**	**6 – 14**
Dark Sky	Nebula	Narrowband	2.0 – 6.0	**28 – 84**	**20 – 60**	**10 – 30**	**4 – 12**
Dark Sky	Nebula	Broadband	1.0 – 4.0	**24 – 56**	**17 – 40**	**8 – 20**	**3 – 8**
Dark Sky	Planetary, SN Remnant	Line (OIII)	3.0 – 7.0	**42 – 98**	**30 – 70**	**15 – 35**	**6 – 14**
Dark Sky	*Specialized	Line (Hβ)	4.0 – 7.0	**56 - 98**	**40 – 70**	**20 – 35**	**8 - 14**

Orange values may be further restricted due to HUM limitations

Green values may be further restricted due to Age limitations (see tables in appendix for your age)

Some Filters available in the market

Listed below is a list and brief details of some of the filters appropriate for visual astronomy in the market today.

List of Some Filters Currently Available

Manufacture	Name	Type	List Price (1.25”)	Comments
Baader Planetarium	Neodymium	Broadband	$92	Great all-purpose filter good for planets, and slight improvement for deep sky. Doesn’t seem to dim the view any. Consider keeping this in your telescope and stacking other filters as needed.
Lumicon	Deep-Sky	Broadband	$135	
Astronomik	UHC-E	Broadband	$76	For telescopes with aperture less than 5”
Astronomik	UHC	Broadband	$100	For telescope with larger than 5” aperture
Orion	SkyGlow	Broadband	$45	
DGM	NPB Nebula	Narrowband	$75	A highly rated narrowband filter
Orion	UltraBlock	Narrowband	$72	
Lumicon	UHC	Narrowband	$143	
Baader Planetarium	UHC-L	Narrowband	$106	Narrowband filter for LED lighting
Baader Planetarium	O-III Super G	Single Line	$96	Oxygen III single line filter

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Manufacture	Name	Type	List Price (1.25”)	Comments
Lumicon	O-III	Single Line	$150	Oxygen III single line filter
Lumicon	H-Beta	Single Line	$300	Recommend 8” or larger aperture
Baader Planetarium	H-Beta	Single Line	$217	Recommend 8” or larger aperture

Provided below is further information provided by the manufacture for these filters.

Manufacture Information for Some Broadband Filters

Manufacture	Name	Ref Spec	Manufacturer’s Description
Baader Planetarium	Neodymium (Moon & Skyglow)	Link	• The best visual and photographic filter for contrast enhancement for all telescopes, without loss of image brightness! • The effect of the element neodymium as filter material is very impressive. When added to optical glass, it enhances contrast, enhances the red color in the image (especially with Mars and Jupiter) and it darkens the spectral region which is particularly marked by street lamp light, which is the biggest contributor to the nightly "Skyglow". • Planoptically polished and MC-coated – with IR-cut coatings!, without any loss of sharpness as a single filter in front of a binocular or be used for afocal projection with digital cameras (far from the focal point!) • The IR spectral range is blocked making stars much sharper when used with dSLRs. • The Baader Moon & Skyglow Neodymium Filter are two filters in one: Neodymium contrast enhancement filter and UV/IR blocker.
Lumicon	Deep-Sky		• Intended for viewing nebulae from light-polluted skies • Blocks all mercury vapor and high & low pressure sodium vapor lamp light, neon lights, and airglow, while transmitting the rest of the visible spectrum • The best all-around visual light pollution filter for use in urban skies • This filter also provides high-contrast views of the Martian polar caps
Astronomik	UHC-E	Link	• The UHC-E Filter increases contrast of emission nebulae and comets and blocks the light of typical streetlights as well as airglow. It is best suited for telescopes up to 5" / 125mm. • The Astronomik UHC-E filter provides a FWHM of 45nm and blocks the light of typical streetlights (e.g. sodium and mercury vapour) as well as airglow. Thus it increases contrast between your target and the night sky. The contrast enhancement is less than that of the Astronomik UHC filter, but at the same time the transmitted amount of starlight is greater. It's therefore better suited to smaller telescopes. As the UHC-E filter passes a spectral line of Carbon (due to the higher FWHM) it opens up the possibility of comet observation. • Other uses ○ Observation of Jupiter’s clouds. ○ Easier resolution of Double stars. ○ Photography under light-polluted skies with DSLRs and other cameras

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Manufacture	Name	Ref Spec	Manufacturer's Description
Orion	SkyGlow		• This 1.25" SkyGlow Broadband Telescope Filter is an advanced multilayer "interference" filter that blocks the most common wavelengths of light pollution while passing desirable wavelengths with very little attenuation, yielding dramatically better deep-sky views. • It features improved blocking of mercury-vapor light and higher transmission at critical hydrogen-alpha and hydrogen-beta lines than competing filters. Bright, light-polluted skies appear much darker, and the contrast between object and sky is improved significantly. • Enhances All Objects • This contrast-enhancement effect is particularly apparent on nebulae. Unlike stars, emission nebulae give off light in a very narrow range of wavelengths. SkyGlow filters allow maximum transmission of the important wavelengths of hydrogen-alpha, hydrogen-beta, and doubly ionized oxygen-the ones most commonly emitted by nebulae. Views of galaxies and star clusters are also enhanced, although not as much.

Manufacture Information for Some Broadband and Line Filters

Manufacture	Name	Ref Spec	Manufacture Description
DGM	NPB Nebula 203200	None	The NPB is the ONE filter to have if you have just one, and now regarded as the top narrowband (UHC type) filter in the world.
Astronomik	UHC	Link	The Astronomik UHC (Ultra High Contrast) filter allows the transmission of nearly 100% of the radiation from both O-III and the H beta lines. Though the second window for the H-alpha-line is not intended for visual observing, it is important, if the filter is used with an electronic device. All annoying, scattered light from other wavelength sources, including local artificial light pollution, is reliably filtered out. With this strong blocking of the sky background an unexpected wealth of detail becomes visible for gas nebulae and planetary nebulae. Main use Astronomik UHC filters' astounding high light transmission brings better views of deep-sky-objects even to small telescopes! The high transmission of our optical glass filters means that enough light is available to allow successful visual observations with telescopes beginning at 2" (50mm) aperture. Our Astronomik filters are optimized for use with telescope focal length f / ratios of f/4 to f/15. Transmission losses and chromatic distortions, which arise with other filters, only occur with Astronomik filters when extremely bright aperture ratios of 1:2 and more come into play. Another major advantage of our Astronomik UHC filter is the high optical quality of the filter glass. When using Astronomik UHC filters you will quickly notice the same needle-sharp stars which you are familiar with from your astronomical instrument without any filter!
Lumicon	UHC		• Narrow bandpass filter (24 nm) isolates the two doubly ionized oxygen lines (496 and 501 nm) and the hydrogen-beta line (468 nm) emitted by planetary and most emission nebulae • Provides superb views of the Orion, Lagoon, Swan and other extended nebulae • The best all-around dark-sky nebular filter available

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Manufacture	Name	Ref Spec	Manufacture Description
Orion	SkyGlow UltraBlock		• The Orion UltraBlock Narrowband telescope eyepiece filter is the filter of choice for deep-sky observers viewing from highly light-polluted sites. • Light pollution can significantly decrease the quality of telescopic views of deep-sky objects. The UltraBlock filter blocks all forms of light pollution from incandescent and fluorescent lighting, including mercury vapor and sodium emission bands, while passing critical hydrogen-beta and ionized oxygen wavelengths. With an UltraBlock telescope eyepiece filter, emission and planetary nebulae "surface" from the washed-out background sky seen from light-polluted areas. With contrast increased, you'll be able to discern more detail in deep-sky observations. • In dark skies, the UltraBlock also enhances the sky presence of a significant number of fainter deep-sky celestial objects. You'll see more of these faint nebulae, galaxies, and clusters with an UltraBlock compared to unfiltered and wideband-filtered views. You'll simply see more with an Orion UltraBlock filter!
Baader Planetarium	UHC-L Ultra Booster	Link	• Visual and photographic 1¼" UHC-L Nebula filter with highest transmission • Ultra High Contrast L Filter blocks city lights and increases contrast of nebulae and comets (C2 lines) • Can be used as LED-opimized Luminance filter for RGB-Imaging wtih skyglow suppression • Blue transmission optimized to block blueish skyglow caused by LED car- and streetlights. • Creates a much brighter image than a conventional Nebula filter • Ideal for deep-sky observers. This UHC-L filter is the perfect visual complement to narrowband OIII filters. • Reflex-Blocker™ hard coated and planeoptically polished – with sealed coating edges (Life-Coat™) • Blackened edges all around, with filter-lead-side-indicator in the form of a telescope-sided black outer rim
Baader Planetarium	O-III Super-G (9nm) #2961550	Link	• O-III Super-G filter with 9 nm FWHM and a maximum transmission of 97%. • For visual and photographic observation of planetary nebulae and supernova remnants, even with small telescopes • Can be used as a "Super-G filter" replacement for RGB photography. While regular G-filters suffer from bad seeing due to air turbulences, the narrow range of 9 nm passes less thermal noise, i.e. sharper images. Nevertheless, the transmission window is large enough not to be considered a pure narrowband filter. • CMOS-optimized coating technology with much steeper slopes of the filter passband - for increased contrast, longer life and to avoid reflections
Lumicon	O-III		• Narrow bandpass filter (11 nm) isolates just the two doubly ionized oxygen lines (496 and 501 nm) emitted by planetary and extremely faint nebulae • Produces near-photographic views of the Veil, Ring, Dumbbell, Orion, plus many other nebulae

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Best Practices for Visual Observation

Regarding actually using the filters and general best practices for visual observing techniques and practices:

- **Dark Adaptation** – Make sure to give yourself 30 minutes away from white light to achieve near full dark adaption[Ref]. Select a viewing location away from the glare of any lights if possible, or even place a towel or blanket over your head if needed when viewing an object to cut out glare.
- **Dark Skies** – Select a dark observation site. The darker the sky the better the contrast (SNR) between the object and the background, and better chance you have of identifying an object.
- **Optimize Your Equipment** – You may not have much wiggle room here with your current equipment. Just remember factors such as larger telescope aperture size and quality optics (including telescope and eyepiece) go a long way to helping locate objects.
- **Proper Filter** – Make sure to select the proper filter for the target of observation, but start with no filter so you can see the difference (with the exception of having the Baader Neodymium filter integrated in the optical train, more on this later).
- **Magnification** – When looking for an object try starting with a low power eyepiece. Once the object has been located utilize the information presented in this document to select the correct eyepiece focal length to maximize the contrast/detail of the subject.
- **Dark Background** – Related to the magnification, when using the narrowband or line filters some manufacturers recommend increasing the magnification of the view until the background appears black to ensure maximum contrast between the nebula and the background (Although I prefer a slight hint of the background being visible myself).
- **Averted Vision** – Make sure to use averted vision when examining the object; the rods in the eye are about 40 times more sensitive to light than the cones (located in the center of the eye).
- **Blink** – When trying to locate a planetary nebula utilizing a narrowband or OII filter, one method of identifying these object is to take the filter in hand and while viewing the eyepiece field of view that contains the nebula, move the filter between the eyepiece an your eye to see what "Star" may remain relatively unaffected by the filter when comparing the no-filter/filter view. The "Star" that appears unaffected by the filter is likely the planetary nebula.
- **Take Your Time** – Once you locate an object take at least a couple of minutes to observe it. The atmosphere is very dynamic; make sure to allow time for the brief moments of clarity that can occur when viewing an object.

Unexpected Discoveries

When researching the topic on exit pupil and associated calculations I found it fascinating that the results of these calculations implies that as you get older the benefit of some of the lower power eyepieces may no longer exists. For example, for a person in their 60s (with pupil diameter of about 4.1mm) who owns a telescope with a F-Ratio of f10 would technically not benefit from any eyepieces with greater than 41mm of focal length! Go ahead and donate those eyepieces to the local astronomy club 😊. This means as we get older, the range of various focal length eyepieces that we can use slowly decreases.

I also find it interesting that the appropriate eyepiece focal length for viewing objects is constant across all telescopes with the same f-Ratio regardless of the aperture size of the telescope (granted the actual magnification will change between telescopes).

Closing Thoughts

Information provided in this paper represent a starting point for helping the visual astronomer identify what filters and eyepieces they may want to consider when observing an object for observation. Optical performance, viewing conditions and variation in individual abilities and skills all come into play when evaluating what combination of telescope, eyepiece and filter works best for you. As a result, I would feel uncomfortable making a broad recommendation to any individual filter.

However, the Baader Neodymium (Moon & Skyglow) filter is almost universally hailed as an excellent all-around filter. It's reduction in light is almost imperceptible, and it does not noticeably distort color but helps clean up noise in all situations, this is a jack of all trades type filter, with good to excellent performance for not only deep sky objects, but planetary, moon, multiple star system viewing and even when used in astrophotography. It seems to eliminate some of the wavelengths responsible for distorting images and helps generally crisp things up. Because of its characteristics, I recommend having this filter integrated in your optical train at all times (I have mine threaded in my star diagonal) and add other filters (stacking) depending on the particular object I am targeting.

I highly recommend the reader to review some of the in-depth reviews sited in the references section where you may find direct comparison of a number of filters for various situations. Ideally the best approach is to see if you can borrow or rent a filter from someone or a club to compare filters for your particular configuration before pulling the trigger on a purchasing one.

Appendix

Development of Highest Useful Magnification (HUM) for a given Focal Ratio (FR) of a Telescope

Based on the assumption that **15x** the telescope Aperture size (in inches) is the Highest useful magnification for both smaller and larger deep sky objects[1] , we can develop a relationship showing that the eyepiece focal length for any given F-Ratio telescope will be the same.

$$\boxed{\boldsymbol{f_e^{HUM} \approx 1.7 \times FR_t}}$$

Where:

f_e^{HUM} = Focal Length of eyepiece for Highest Useful Magnification for a given F-Ratio of a telescope
FR_t = Focal Ratio of the telescope

Starting with the Highest Useful Magnification (HUM) of a given aperture relationship:

$$HUM_t^{"} = 15A_t^{"}$$

Where:

$HUM_t^{"}$ = Highest Useful Magnification of a given Telescope with aperture measured in inches
$A_t^{"}$ = Telescope aperture Size measured in inches

This relationship converted to mm of aperture is:

$$HUM_t^{mm} = \left(\frac{15}{25.4}\right) A_t^{mm}$$

Where:

HUM_t^{mm} = Highest Useful Magnification of a given Telescope with aperture measured in millimeters
A_t^{mm} = Telescope aperture Size measured in millimeters

The magnification of a telescope/eyepiece combination is defined as Focal Length of the Telescope divided by the Focal Length of the eyepiece, replacing the HUM with this on the left side of the equation we have:

$$\frac{f_t}{f_e} = \left(\frac{15}{25.4}\right) A_t$$

Where:

f_t = Focal Length of the Telescope measured in millimeters
f_e = Focal Length of the Eyepiece measured in millimeters
A_t = Telescope aperture Size measured in millimeters

Solving for the Focal Length of the eyepiece we have the equation:

$$f_e = \left(\frac{25.4}{15}\right)\left(\frac{f_t}{A_t}\right)$$

The F-Ratio of a telescope is defined as the Focal Length (in mm) divided by the aperture size (in mm):

$$FR_t = \left(\frac{f_t}{A_t}\right)$$

Where:

FR_t = Focal-Ratio of the Telescope
f_t = Focal Length of the Telescope measured in millimeters
A_t = Telescope aperture Size of the Telescope measured in millimeters

Finally, substituting the F-Ratio in the previous equation we have the final steps:

$$f_e = \left(\frac{25.4}{15}\right)\left(\frac{f_t}{A_t}\right) \equiv \left(\frac{25.4}{15}\right) FR_t \approx \boldsymbol{1.7 \times FR_t}$$

Deep Sky Filters for Visual Observation

Recommended Focal Length Tables

In this section we provide recommended Eyepiece Focal Lengths for some common F-Ratios and based on the age of the observer. These calculations are based on the following information:

Focal Length of Eyepiece

$$f_e = XP \times FR_t$$

Exit Pupil for Average Human

Age (years)	Day (mm)	Night (mm)
20	4.7	8.0
30	4.3	7.0
40	3.9	6.0
50	3.5	5.0
60	3.1	4.1
70	2.7	3.2
80	2.3	2.5

Up to 40 Years Old Recommended Eyepiece Focal Lengths (XP_{max} = 8.0mm and 7.0mm)

Note: No restrictions imposed due to age

Sky Condition	Target Type	Filter	Pupil Range (mm)	FR_t = F14 Eyepiece Range (mm)	FR_t = F10 Eyepiece Range (mm)	FR_t = F5 Eyepiece Range (mm)	FR_t = F2 Eyepiece Range (mm)
Urban Sky	Nebula, Blackbody	Broadband	0.5 – 2.0	**24 – 28**	**17 – 20**	**8 – 10**	**3 – 4**
Urban Sky	Nebula	Narrowband	1.0 – 4.0	**24 – 56**	**17 – 40**	**8 – 20**	**3 – 8**
Urban Sky	Planetary, SN Remnant	Line (OIII)	2.0 – 5.0	**28 – 70**	**20 – 50**	**10 – 25**	**4 – 10**
Urban Sky	*Specialized	Line (Hβ)	3.0 – 7.0	**42 – 98**	**30 – 70**	**15 – 35**	**6 – 14**
Dark Sky	Nebula	Narrowband	2.0 – 6.0	**28 – 84**	**20 – 60**	**10 – 30**	**4 – 12**
Dark Sky	Nebula	Broadband	1.0 – 4.0	**24 – 56**	**17 – 40**	**8 – 20**	**3 – 8**
Dark Sky	Planetary, SN Remnant	Line (OIII)	3.0 – 7.0	**42 – 98**	**30 – 70**	**15 – 35**	**6 – 14**
Dark Sky	*Specialized	Line (Hβ)	4.0 – 7.0	**56 - 98**	**40 – 70**	**20 – 35**	**8 - 14**

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40s Recommended Eyepiece Focal Lengths (XP_{max} = 6.0mm)

Sky Condition	**Target Type**	**Filter**	**Pupil Range (mm)**	FR_t = **F14** **Eyepiece Range (mm)**	FR_t = **F10** **Eyepiece Range (mm)**	FR_t = **F5** **Eyepiece Range (mm)**	FR_t = **F2** **Eyepiece Range (mm)**
Urban Sky	Nebula, Blackbody	Broadband	0.5 – 2.0	**24 – 28**	**17 – 20**	**8 – 10**	**3 – 4**
Urban Sky	Nebula	Narrowband	1.0 – 4.0	**24 – 56**	**17 – 40**	**8 – 20**	**3 – 8**
Urban Sky	Planetary, SN Remnant	Line (OIII)	2.0 – 5.0	**28 – 70**	**20 – 50**	**10 – 25**	**4 – 10**
Urban Sky	*Specialized	Line (Hβ)	3.0 – 6.0	**42 – 84**	**30 – 60**	**15 – 30**	**6 – 12**
Dark Sky	Nebula	Narrowband	2.0 – 6.0	**28 – 84**	**20 – 60**	**10 – 30**	**4 – 12**
Dark Sky	Nebula	Broadband	1.0 – 4.0	**24 – 56**	**17 – 40**	**8 – 20**	**3 – 8**
Dark Sky	Planetary, SN Remnant	Line (OIII)	3.0 – 6.0	**42 – 84**	**30 – 60**	**15 – 30**	**6 – 12**
Dark Sky	*Specialized	Line (Hβ)	4.0 – 6.0	**56 – 84**	**40 – 60**	**20 – 30**	**8 - 12**

50s Recommended Eyepiece Focal Lengths (XP_{max} = 5.0mm)

Sky Condition	**Target Type**	**Filter**	**Pupil Range (mm)**	FR_t = **F14** **Eyepiece Range (mm)**	FR_t = **F10** **Eyepiece Range (mm)**	FR_t = **F5** **Eyepiece Range (mm)**	FR_t = **F2** **Eyepiece Range (mm)**
Urban Sky	Nebula, Blackbody	Broadband	0.5 – 2.0	**24 – 28**	**17 – 20**	**8 – 10**	**3 – 4**
Urban Sky	Nebula	Narrowband	1.0 – 4.0	**24 – 56**	**17 – 40**	**8 – 20**	**3 – 8**
Urban Sky	Planetary, SN Remnant	Line (OIII)	2.0 – 5.0	**28 – 70**	**20 – 50**	**10 – 25**	**4 – 10**
Urban Sky	*Specialized	Line (Hβ)	3.0 – 5.0	**42 – 70**	**30 – 50**	**15 – 25**	**6 – 10**
Dark Sky	Nebula	Narrowband	2.0 – 5.0	**28 – 70**	**20 – 50**	**10 – 30**	**4 – 12**
Dark Sky	Nebula	Broadband	1.0 – 4.0	**24 – 56**	**17 – 40**	**8 – 20**	**3 – 8**
Dark Sky	Planetary, SN Remnant	Line (OIII)	3.0 – 5.0	**42 – 70**	**30 – 50**	**15 – 25**	**6 – 10**
Dark Sky	*Specialized	Line (Hβ)	4.0 – 5.0	**56 – 70**	**40 – 50**	**20 – 25**	**8 - 10**

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60s Recommended Eyepiece Focal Lengths (XP_{max} = 4.1mm)

Sky Condition	Target Type	Filter	Pupil Range (mm)	FR_t = F14 Eyepiece Range (mm)	FR_t = F10 Eyepiece Range (mm)	FR_t = F5 Eyepiece Range (mm)	FR_t = F2 Eyepiece Range (mm)
Urban Sky	Nebula, Blackbody	Broadband	0.5 – 2.0	**24 – 28**	**17 – 20**	**8 – 10**	**3 – 4**
Urban Sky	Nebula	Narrowband	1.0 – 4.0	**24 – 56**	**17 – 40**	**8 – 20**	**3 – 8**
Urban Sky	Planetary, SN Remnant	Line (OIII)	2.0 – 4.1	**28 – 57**	**20 – 41**	**10 – 20**	**4 – 8**
Urban Sky	*Specialized	Line (Hβ)	3.0 – 4.1	**42 – 57**	**30 – 41**	**15 – 20**	**6 – 8**
Dark Sky	Nebula	Narrowband	2.0 – 4.1	**28 – 57**	**20 – 41**	**10 – 20**	**4 – 8**
Dark Sky	Nebula	Broadband	1.0 – 4.0	**24 – 57**	**17 – 40**	**8 – 20**	**3 – 8**
Dark Sky	Planetary, SN Remnant	Line (OIII)	3.0 – 4.1	**42 – 57**	**30 – 41**	**15 – 20**	**6 – 8**
Dark Sky	*Specialized	Line (Hβ)	4.0 – 4.1	**56 – 57**	**40 – 41**	**20**	**8 - 8**

70s Recommended Eyepiece Focal Lengths (XP_{max} = 3.2mm)

Sky Condition	Target Type	Filter	Pupil Range (mm)	FR_t = F14 Eyepiece Range (mm)	FR_t = F10 Eyepiece Range (mm)	FR_t = F5 Eyepiece Range (mm)	FR_t = F2 Eyepiece Range (mm)
Urban Sky	Nebula, Blackbody	Broadband	0.5 – 2.0	**24 – 28**	**17 – 20**	**8 – 10**	**3 – 4**
Urban Sky	Nebula	Narrowband	1.0 – 3.2	**24 – 45**	**17 – 32**	**8 – 16**	**3 – 6**
Urban Sky	Planetary, SN Remnant	Line (OIII)	2.0 – 3.2	**28 – 45**	**20 – 32**	**10 – 16**	**4 – 6**
Urban Sky	*Specialized	Line (Hβ)	3.0 – 3.2	**42 – 45**	**30 – 32**	**15 – 16**	**6**
Dark Sky	Nebula	Narrowband	2.0 – 3.2	**28 – 45**	**20 – 32**	**10 – 16**	**4 – 6**
Dark Sky	Nebula	Broadband	1.0 – 3.2	**24 – 45**	**17 – 32**	**8 – 16**	**3 – 6**
Dark Sky	Planetary, SN Remnant	Line (OIII)	3.0 – 3.2	**42 – 45**	**30 – 32**	**15 – 16**	**6**
Dark Sky	*Specialized	Line (Hβ)	4.0 – 3.2	**45**	**32**	**16**	**6**

80s Recommended Eyepiece Focal Lengths (XP_{max} = 2.5mm)

Sky Condition	**Target Type**	**Filter**	**Pupil Range (mm)**	**FR_t = F14 Eyepiece Range (mm)**	**FR_t = F10 Eyepiece Range (mm)**	**FR_t = F5 Eyepiece Range (mm)**	**FR_t = F2 Eyepiece Range (mm)**
Urban Sky	Nebula, Blackbody	Broadband	0.5 – 2.0	**24 – 28**	**17 – 20**	**8 – 10**	**3 – 4**
Urban Sky	Nebula	Narrowband	1.0 – 2.5	**24 – 35**	**17 – 25**	**8 – 12**	**3 – 5**
Urban Sky	Planetary, SN Remnant	Line (OIII)	2.0 – 2.5	**28 – 35**	**20 – 25**	**10 – 12**	**4 – 5**
Urban Sky	*Specialized	Line (Hβ)	2.5	**35**	**25**	**12**	**5**
Dark Sky	Nebula	Narrowband	2.0 – 2.5	**28 – 35**	**20 – 25**	**10 – 12**	**4 – 5**
Dark Sky	Nebula	Broadband	1.0 – 2.5	**24 – 35**	**17 – 25**	**8 – 12**	**3 – 5**
Dark Sky	Planetary, SN Remnant	Line (OIII)	2.5	**35**	**25**	**12**	**5**
Dark Sky	*Specialized	Line (Hβ)	2.5	**35**	**25**	**12**	**5**

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