Comparison of 3 astronomic Hydrogen-Alpha, narrowband, interference filters with different FWHM for CCD use on a f/2 optical system.

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Introduction

I decided to upgrade my Celestron C11 Schmidt Cassegrain telescope with the Hyperstar III lens assembly. The obvious advantage of this upgrade is a much faster optical system of f/2. Since I am imaging in a moderately light polluted area, I wanted to use narrowband filters with the Hyperstar system. In the Internet you can not find much practical information about the use of narrowband filters on such fast optics, and the little information you can find is partly contradictory. The problem is that the light rays of fast systems like f/2 have an oblique angel of incidence and this affects the filter performance.
There is a shift of the transmission peak of interference filters when the incidence angle of the incoming light differs from normal (typically perpendicular to the filter surface). As higher the difference from the ideal angle as higher is the peak transmission shift towards shorter wavelengths. Additionally, at oblique incidence the FWHM increases and the peak transmission decreases.
All these effects have a significant impact on the actual filter performance for astronomic CCD imaging. It is obvious that the shift of the peak transmission wavelength is of major concern. The desired emission line may suffer a significant transmission loss and may be even blocked when the shift is big enough. In order to avoid this there are two solutions. The best, but more difficult solution is to use a filter which is specially designed for the desired f-ratio. The other solution is to use filters with a higher FWHM, so that the emission line is still within the shifted transmission peak.

Materials and Methods

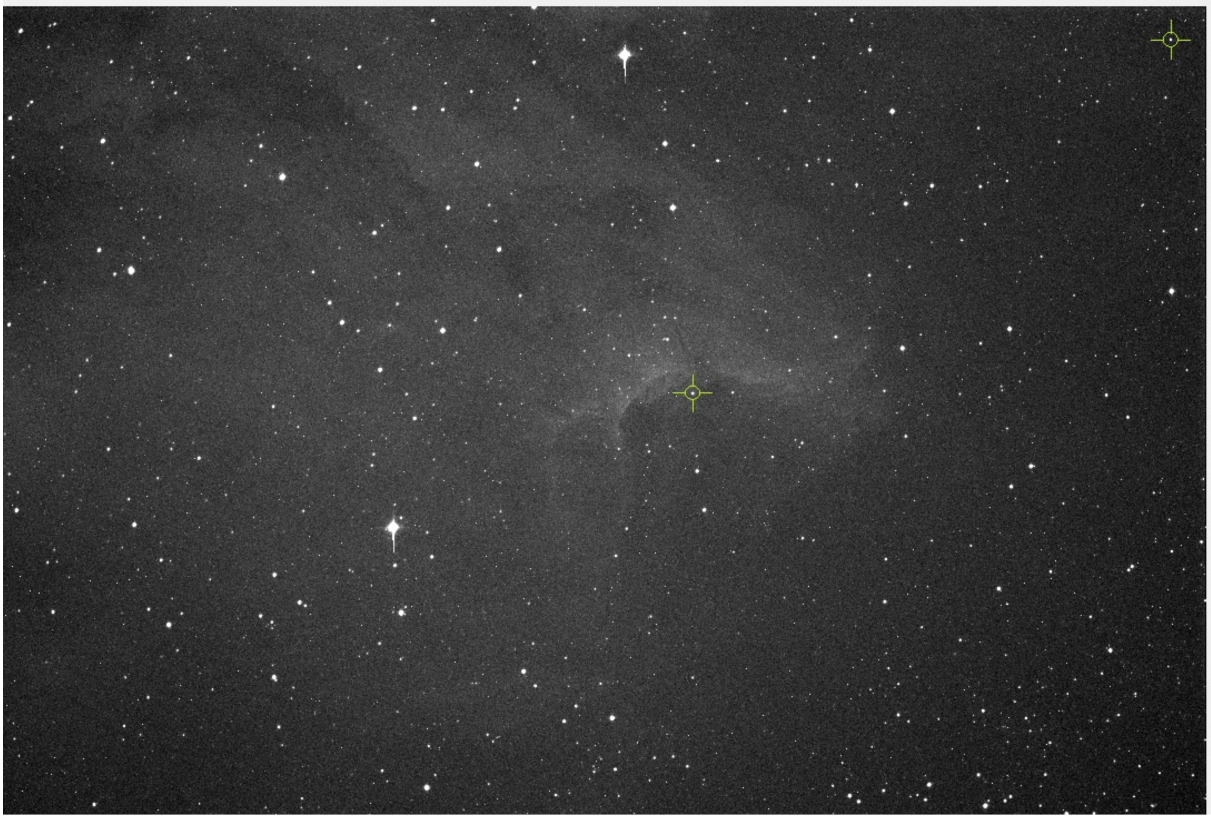
Commercially available narrowband filters for astronomic use have a FWHM ranging from 3nm to 35nm with peak transmissions ranging from 87-97%.
I have decided to test three 2” Ha narrowband filters in for their performance with the Hyperstar system:

1. Baader Ha CCD 7nm FWHM (Tmax 87% - measured)
2. Astronomik Ha CCD 12nm FWHM (Tmax >97% - manufacturer specs)
3. Baader Ha CCD 35nm FWHM (Tmax 95% - manufacturer specs)

The test have been performed with a Celestron C11 Schmidt-Cassegrain telescope (Celestron LLC, Torrance, USA) where the secondary mirror was replaced with a Hyperstar III lens assembly (Starizona,Tucson, USA).
The CCD camera was a Sigma 3200 (Astroelektronik Fischer, Weissenbrunn-Hummendorf, Germany) mounted to the Hyperstar lens using a custom made adapter and a filter drawer. The filters had a distance to the CCD plane of approx. 30mm and the distance between Hyperstar (measured from Hyperstar end of adapter) and filter was approx 32mm.

A 60s and 120s single exposure of the same object was taken with each filter and the performance was evaluated in terms of vignetting, transmission and contrast. For all measurements the uncalibrated raw images in FITs Format were used. The luminance measurements have been performed using the aperture photometry feature of the Astroart 4.0 software (MSB-Software, Ravenna, Italy).

Vignetting was measured as the luminance ratio between not saturated stars in the image center and in one corner of the image (Picture1). This value is not the absolute vignetting, because the two stars have not the same magnitude. It should be used for comparison only.

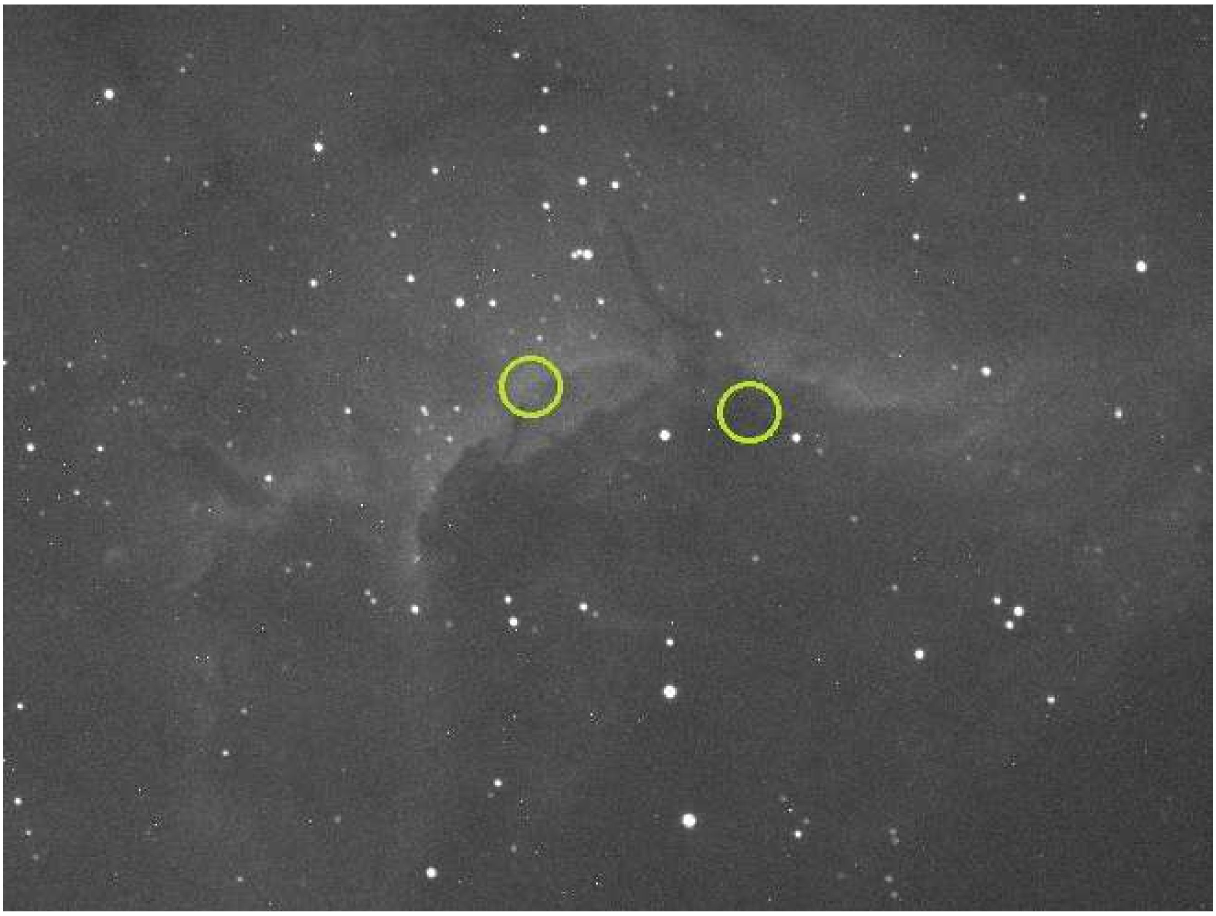


Picture1: Stars used for calculating relative vignetting.

The **Total transmission** was compared by looking at the Sum-Luminance (in ADU) of a star in image center. This value has nothing to do with the Ha peak transmission; it mostly depends on the FWHM since stars emitting a nearly continuous spectrum.

Ha contrast was determined as the luminance contrast between a Ha emitting region (Lmax) and a "dark" region (Lmin) near the image center (see Picture2) calculated as Michelson contrast:

$$K_m = \frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$



Picture2: Areas used for calculating the Ha contrast.

Results

The following table shows the results of the luminance measurements:

	Baader 7nm		Astronomik 12nm		Baader 35nm	
	60s	**120s**	**60s**	**120s**	**60s**	**120s**
Lum star center	37625	62369	95060	173716	150818	289453
Lum star corner	31676	50058	66717	120899	113875	216890
Luminance Ratio corner/center	**0.84**	**0.80**	**0.70**	**0.70**	**0.70**	**0.75**
Lum Ha region	22963	32153	44376	76644	66805	128371
Lum dark region	21166	29073	39464	67762	63985	122723
Michelson contrast Ha	**0,041**	**0.050**	**0,059**	**0.061**	**0,022**	**0.022**

The relative **vignetting** shows no significant difference between the filters. The relatively lowest vignetting of the 7nm filter may be explained by the overall low transmission. This low transmission cuts off a lot of the central light and does not allow that an ADU difference between center and corner builds up. This is especially valid for the 60s exposure, while for the 120s exposure there is more time to collect photons and subsequently a bigger ADU difference.

Total transmission increases with FWHM. This is expected as the measured stars emitting a nearly continuous spectrum and peak transmission and peak location have nearly no influence.

As mentioned before the location where these measurements have taken place suffers from moderate light pollution. This affects significantly the Ha luminance measurements. If the same tests would be repeated under dark skies the results would look much different. However most people use these filters in light polluted areas and so the performance under these conditions is of greatest interest.
The best **Ha contrast** is delivered by the 12nm filter for both exposure times. It seems that its (shifted) FWHM is large enough to cover the Ha emission line, but small enough to cut out unwanted light pollution.
The 7nm filter performs still acceptable because it cuts off most of the light pollution. However, its transmission peak with its narrow FWHM is obviously so much shifted that the Ha line suffers a severe transmission loss. Obviously the contrast gets somewhat better when increasing the exposure time (see table1), but even the 120s exposure does not reach the contrast of the 12nm filters 60s exposure.
At last, the contrast of the 35nm filter is constantly very poor, independent from the exposure time. Although it surely has a good transmission for the Ha emission, it allows too much light pollution to enter the camera and this “drowns” the Ha signal.

Below pictures demonstrate the overall filter performance. Each image was stretched in the same way using digital development:

Picture3: 120s exposure of IC5070 using the Baader 7nm filter

Picture4: 120s exposure of IC5070 using the Astronomik 12nm filter

Picture5: 120s exposure of IC5070 using the Baader 35nm filter