MSE 2020 Virtual Meeting

Maunakea Spectroscopic Explorer

Progress on optical design for the MSE HR spectrograph

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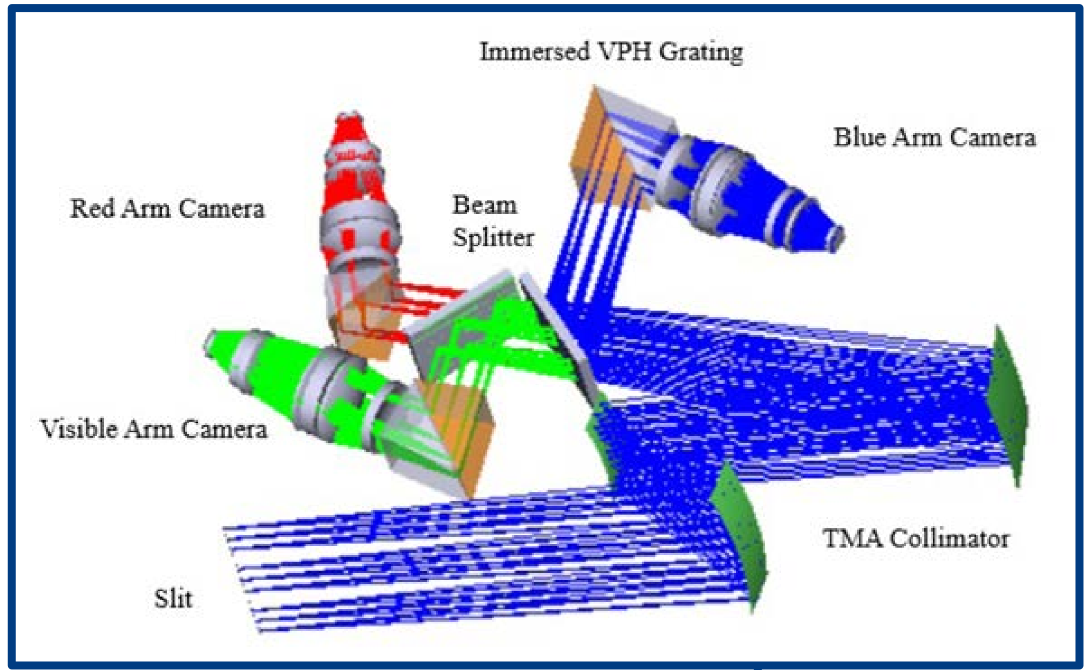
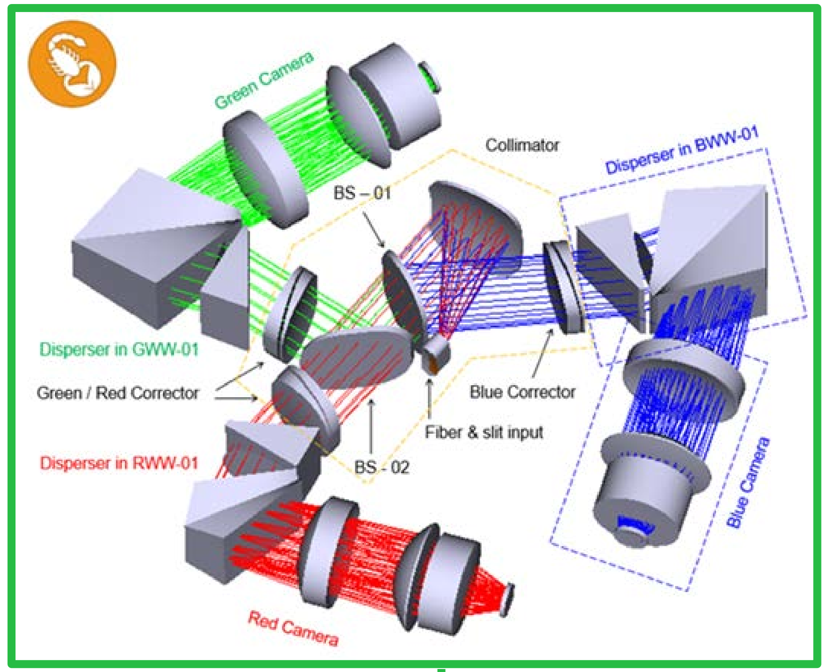
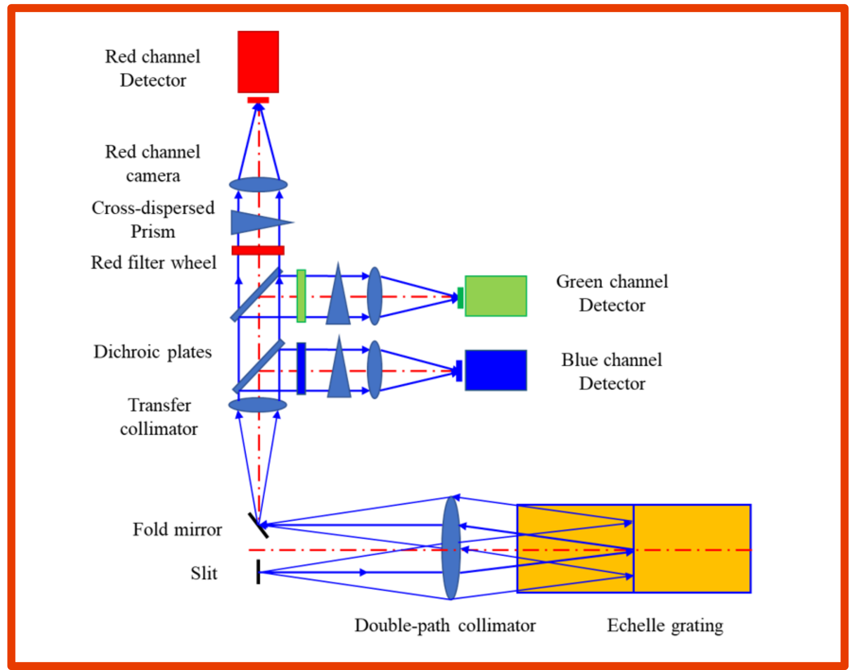
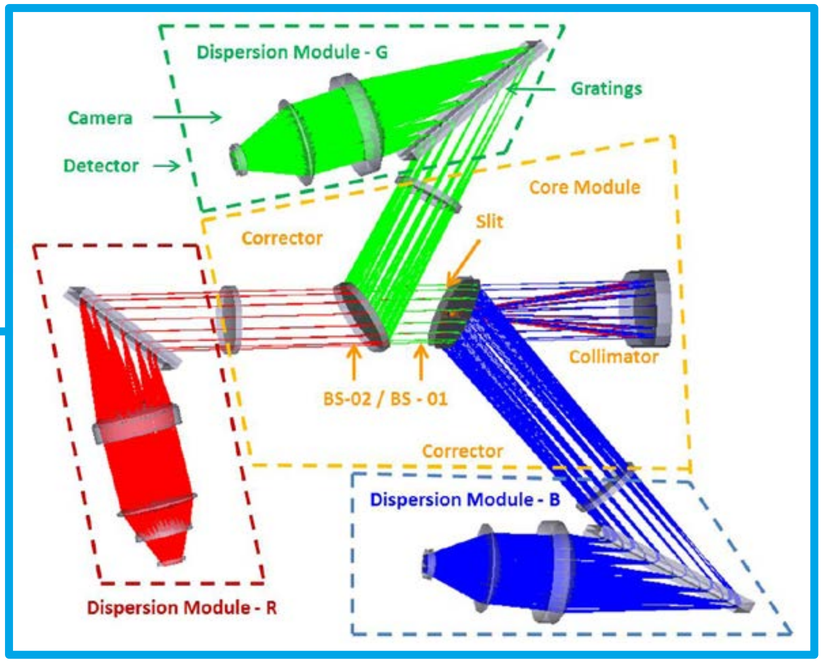
MSE HR Designs In The Past 4 Years

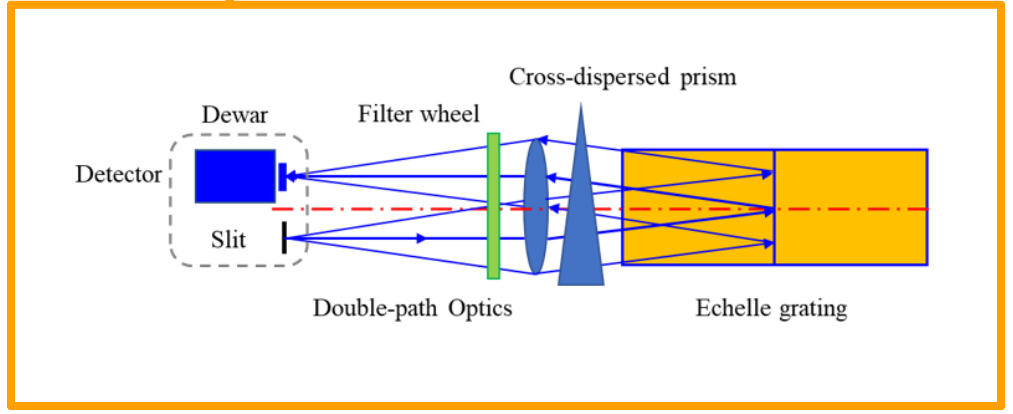






2015 — 2016 — 2017 — 2018 — 2019 — 2020





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Balance Between Science And Technology (1)

Design Requirement

Year	Multiplexing	Wavelength Coverage	Spectral Arms	Resolution	Window Bandpass	Interesting Windows	Instrument Sensitivity (m=20, 1hrs)
2017	1156 fibers (Φ0.7”-0.8”)	360 – 900nm	B=360-450nm G=450-610nm R=610-900nm	RB=40K RG=40K RR=20K	B=1/30 G=1/30 R=1/15	B: 408.55nm G: 481nm R: 650.5nm	SNR=5@<400nm SNR=10@>400nm
2018	1084 fibers (Φ0.75”-0.8”)	360 – 900nm	B=360-430nm G=430-510nm R=510-900nm	RB=40K RG=40K RR=20K	B=1/30 G=1/30 R=1/15	B: 408.55nm G: 481nm R: 650.5nm	SNR=5@<400nm SNR=10@>400nm
2019	500 – 1084 fibers (Φ0.75”-0.8”)	360 – 900nm (360 – 700nm)	B=360-500nm G=500-600nm R=600-700nm	RB=40K RG=30K RR=20K	B=1/30 G=1/22 R=1/15	420-425nm 500nm 515-530nm 600-620nm 645-680nm	SNR=5@<400nm SNR=10@>400nm (m=19-19.5@R=40K)
2020	500 – 1084 fibers (Φ0.75”-0.8”)	360 – 900nm (360 – 820nm)	B=360-420nm G=420-580nm R=580-820nm	RB=30K-40K RG=20K-30K RR=30K-40K	B=1/22-1/30 G=1/15-1/22 R=1/22-1/30 ?	B: 393-402nm G: 434-462nm R: 640-673nm 777, 820nm	SNR=5@<400nm SNR=10@>400nm (m=19-19.5@R=40K) ?

Definition of Spectral Arms and Working Window

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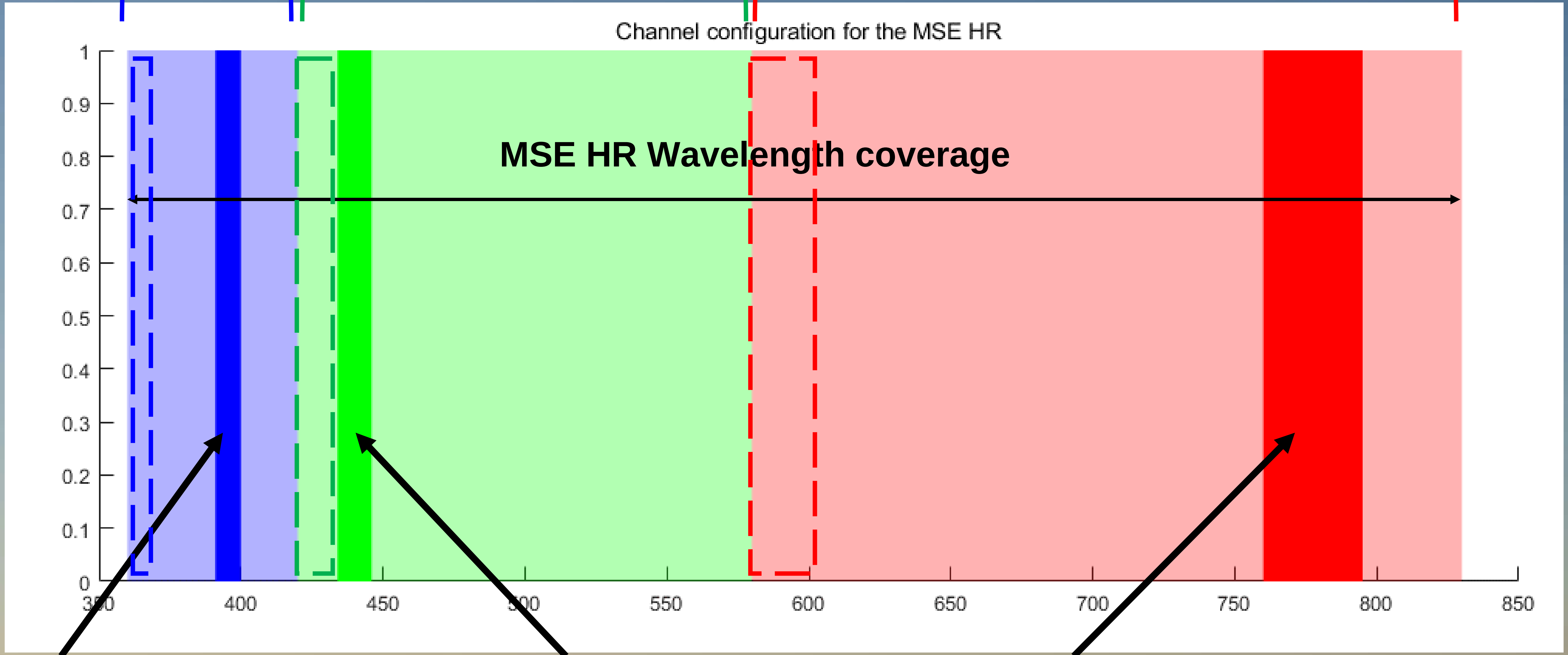
Blue Spectral Arm (Fixed)

Blue Spectral Arm (Fixed)

Blue Spectral Arm (Fixed)



Blue Working Windows (switchable)

Green Working Windows (switchable)

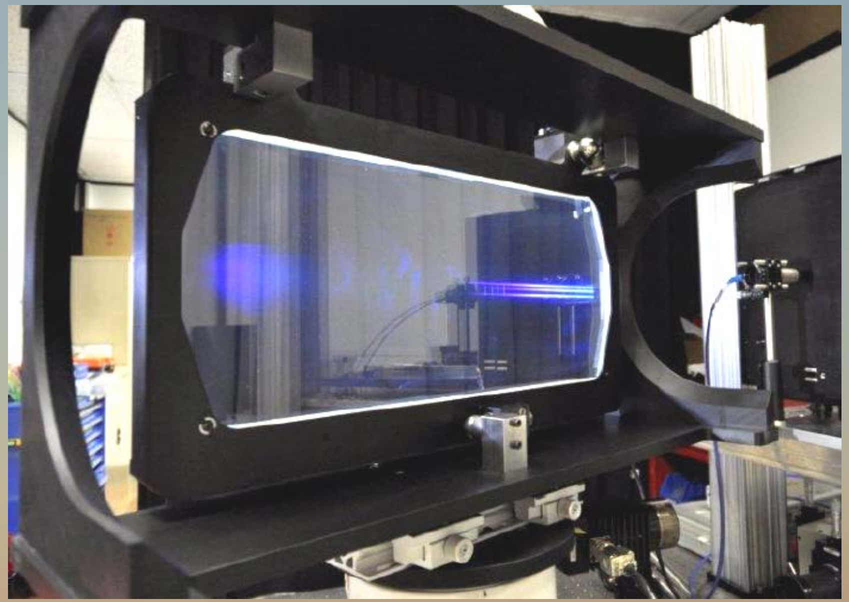
Red Working Windows (Switchable)

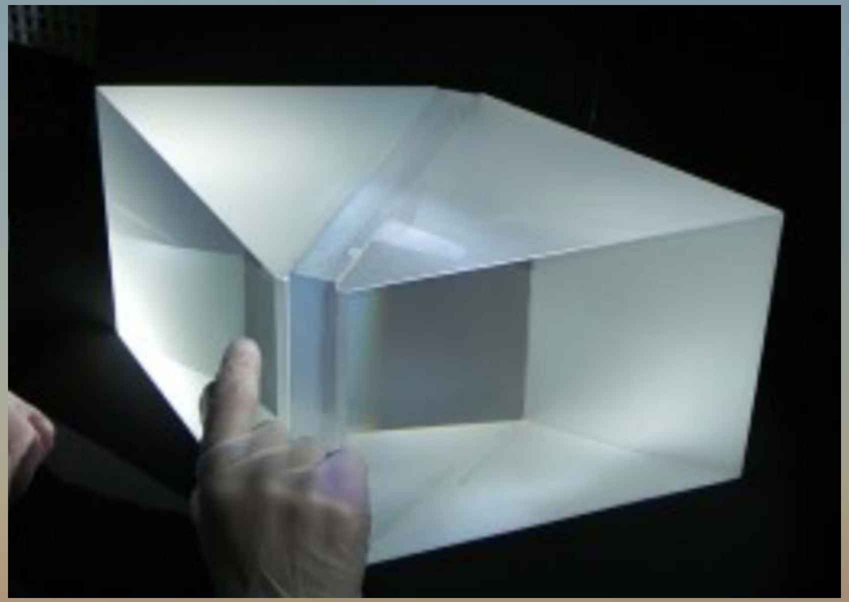
Balance Between Science And Technology (2)

Technical Challenge from High-resolution of R=40K

Normally, a multi-object fiber-fed spectrograph (MOS) provide the required resolution by using a single order of dispersion, in order to maximize the number of fibers covered by the same detector.

It leads a challenging grating with high line density of > 6000 l/mm and large aperture of 300mm x 700mm. According to investigation in 2018 and 2019, this kind of grating or grism require higher than 1M USD for technical development. And **MSE has to change gratings when switch to another working window.** It takes longer time and exists risk.





Balance Between Science And Technology (3)

Technical Challenge from High-resolution of R=40K

It promotes us to think of using Echelle grating instead of single-order grating. A conventional Echelle grating is capable of providing high-resolution at higher diffractive orders. But it raises another problem about bandpass at each window.

This kind of grating needs 2 – 4 orders to cover the required window band. It results in rapidly reducing the number of fibers at every spectrograph at the same ratio.

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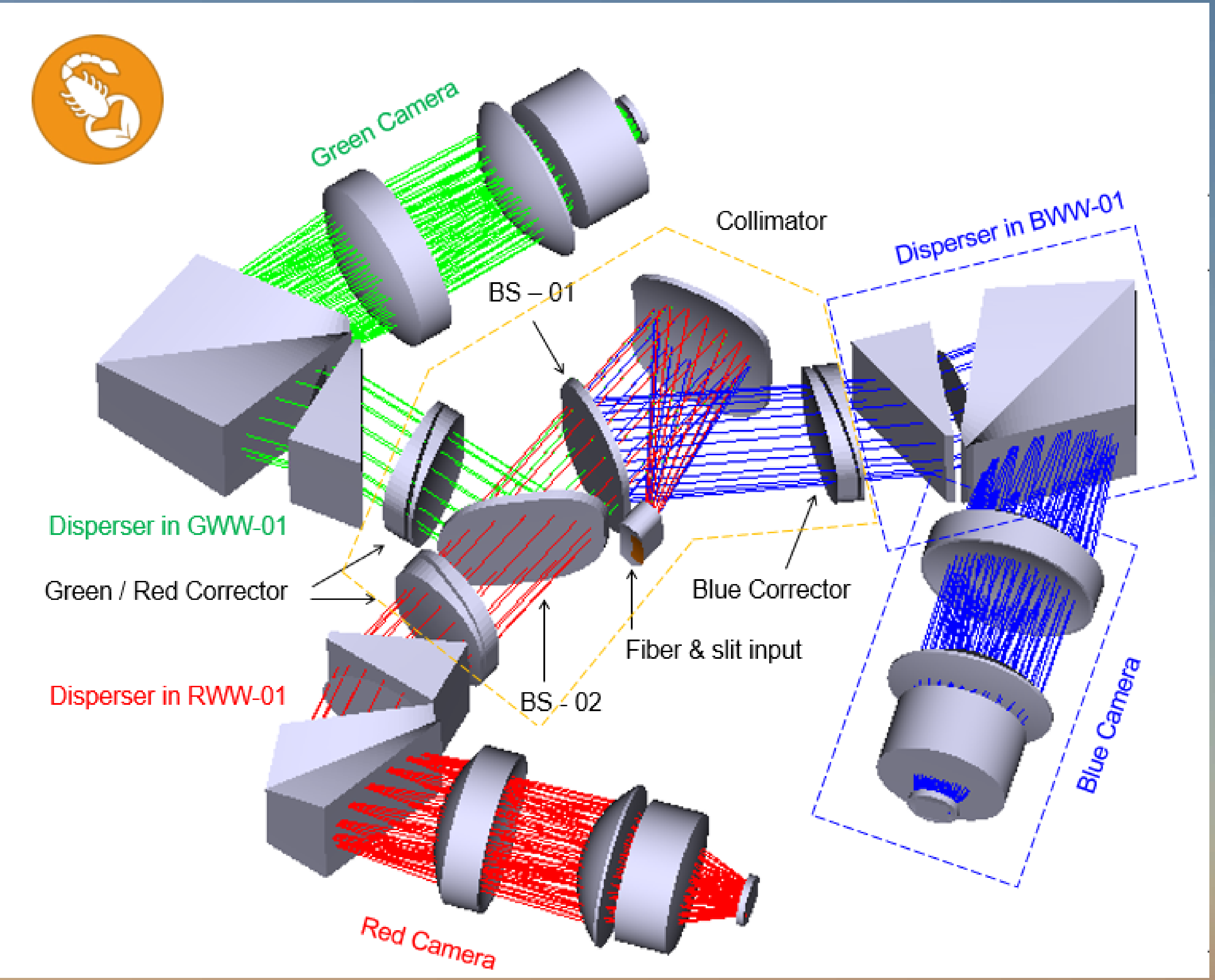
Comparison Between Two Kinds of Gratings (1)

Instrument Specification

Designs	HR Design-2018	HR Design-2020
Multiplexing	542 fibers each spectrographs	90 fibers each spectrographs
Spectral Arms	B=360-430nm G=430-510nm R=510-900nm	B=360-420nm G=420-580nm R=580-820nm
Resolution	RB=40K RG=40K RR=20K	RB=30K RG=30K RR=30K
Window Bandpass	B=1/30 G=1/30 R=1/15	B=1/45 – 1/35 G=1/35 – 1/25 R=1/25 – 1/20
Diffraction Grating	Single-order Transmission (m=1) 'Diamond' Grism (θb≈53°)	Multi-order Reflection (m=98-43) R2.6 Echelle grating (θb=69°)
Collimated Aperture	Dc = 300mm	Dc = 245mm
Detector	6K x 6K pixels, 15um/pixel (Fiber image ≈ 4 pixels @ F/1.55)	2K x 4K pixels, 15um/pixel (Fiber image ≈ 5 pixels @ F/1.72)

Comparison Between Two Kinds of Gratings (2)

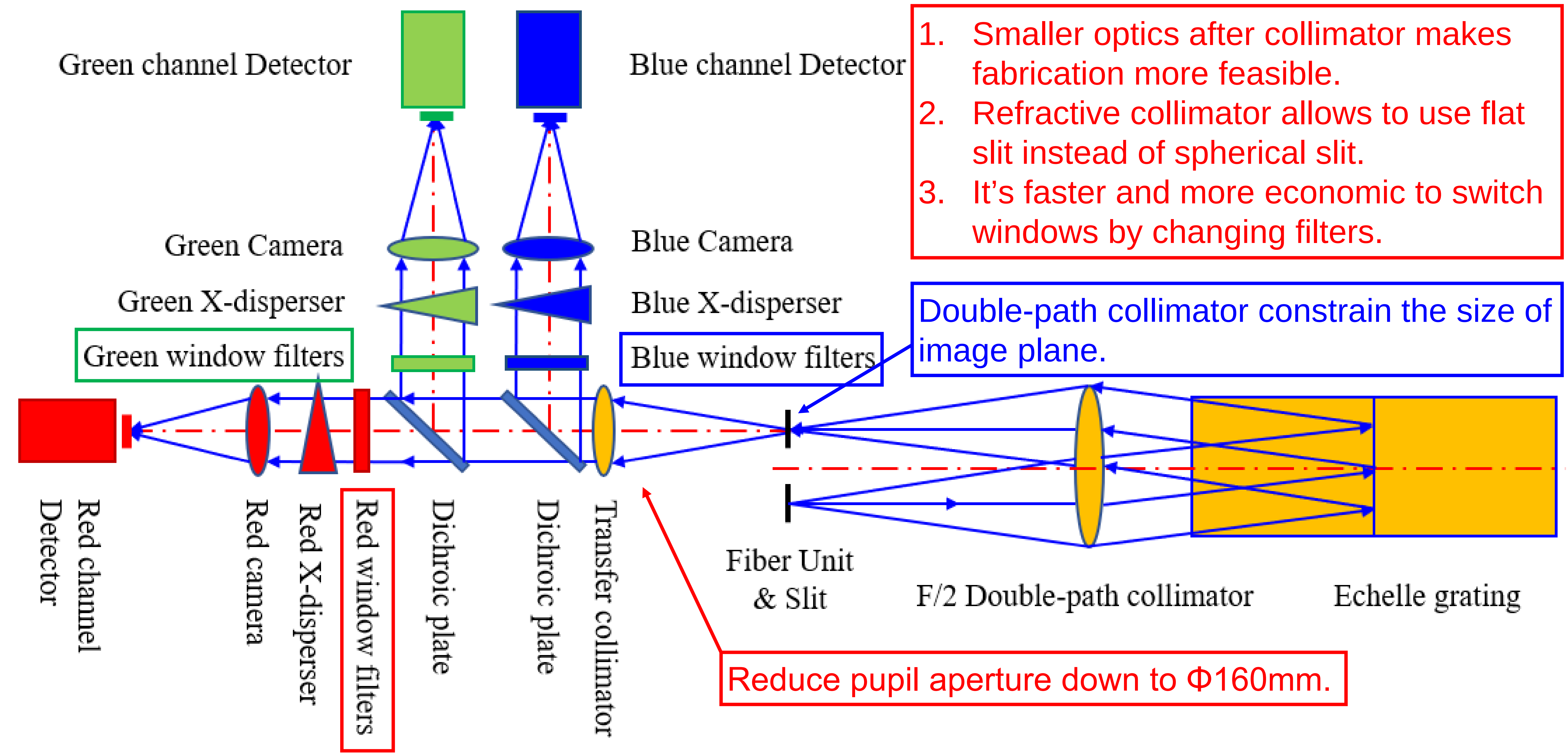
Design with ‘Diamond’ Grism (2018)



1. The design uses the normal optical layout for multi-object spectrograph.
2. F/2 reflective collimator takes higher fabrication risk.
3. ‘Diamond’ grism gives high diffraction efficiency than the others, but its fabrication is very challenging and expensive.
4. Clear aperture of refractive camera is about 500mm in diameter. Its glass materials and fabrication are challenging as well.

Comparison Between Two Kinds of Gratings (2)

New Design with Echelle Grating (2020)



1. Smaller optics after collimator makes fabrication more feasible.
2. Refractive collimator allows to use flat slit instead of spherical slit.
3. It's faster and more economic to switch windows by changing filters.

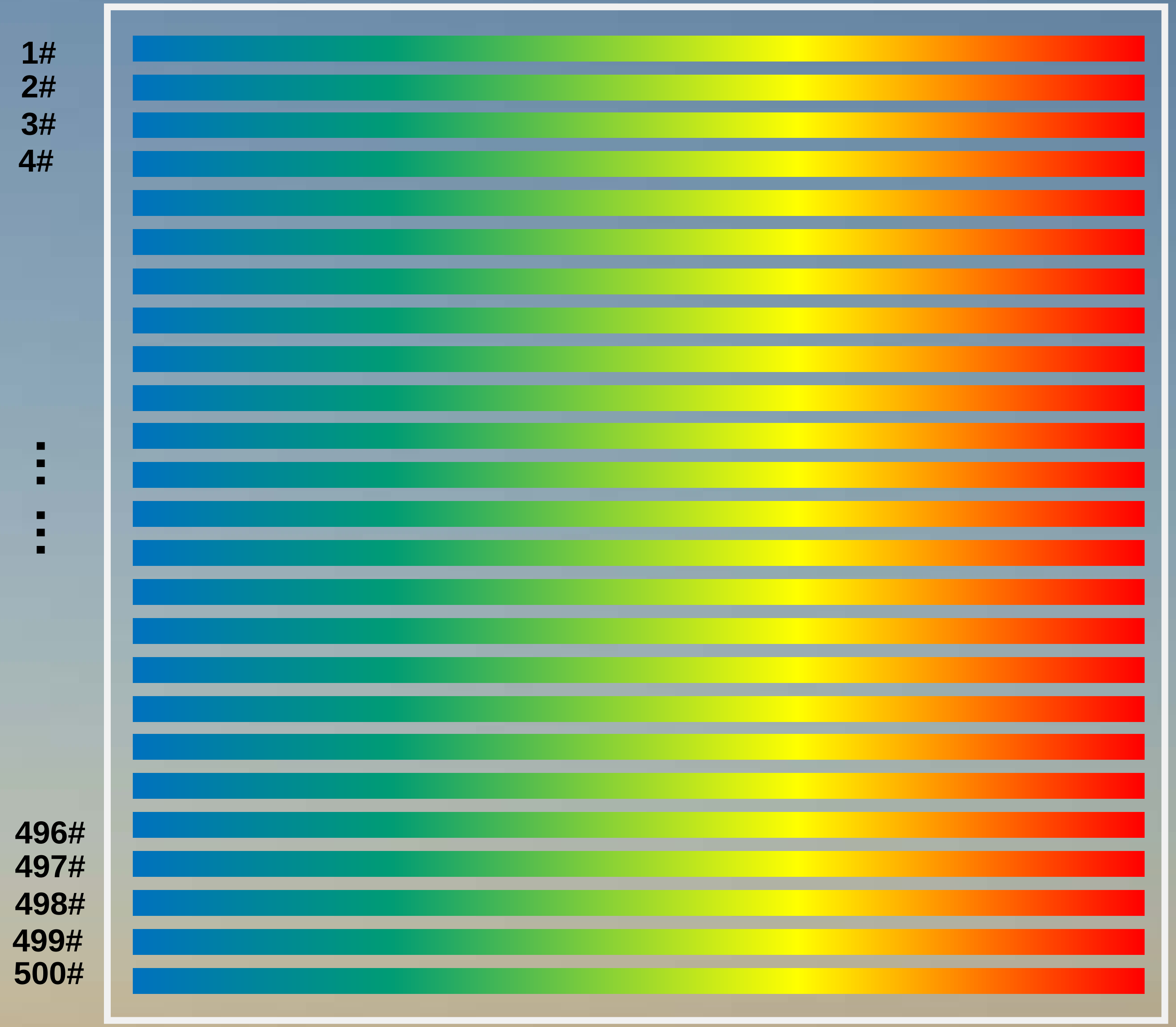
Double-path collimator constrain the size of image plane.

Reduce pupil aperture down to Φ160mm.

Comparison Between Two Kinds of Gratings (3)

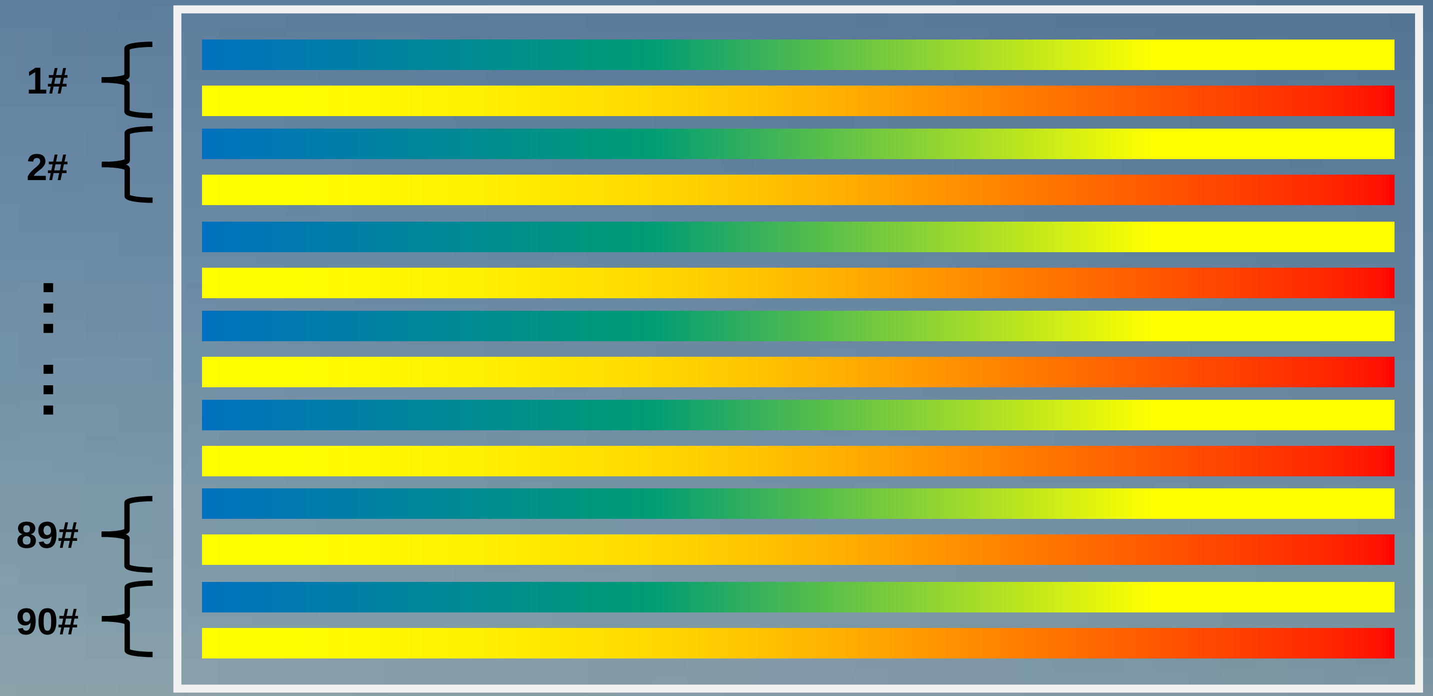
Different Spectra Pattern at Detector

6K x 6K pixels @ 15um/pixel



Single-diffractive-order Grating / Grism

2K x 4K pixels @ 15um/pixel

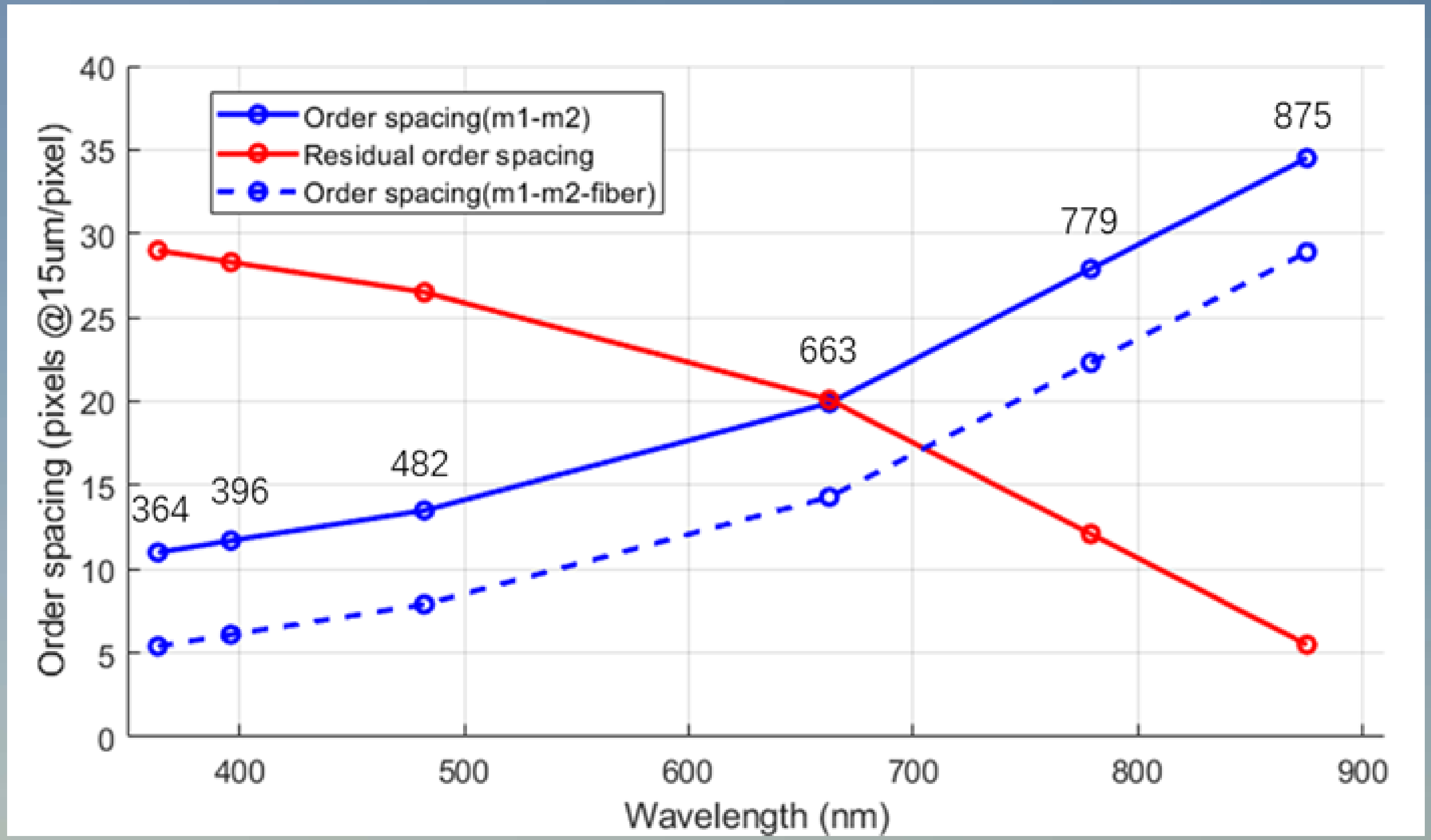


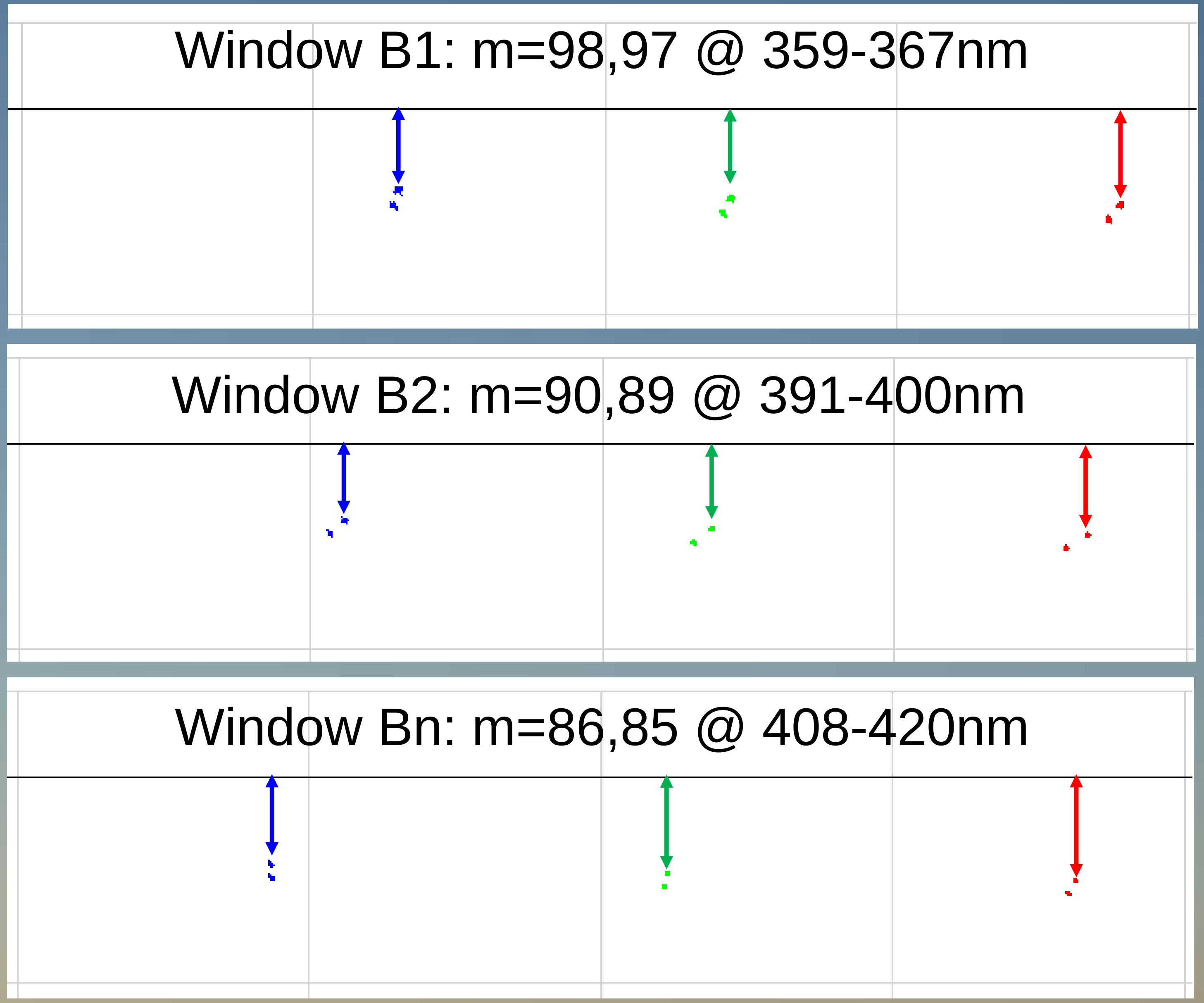
Echelle Grating

1. Lower multiplexing number requires more spectrographs to accommodate the same number of fibers.
2. Each fiber produce 2 orders of spectra, and different window has the FSR of each spectra. It requires different method of data reduction.

Comparison Between Two Kinds of Gratings (3)

2 Orders Of Spectra At A Single Window





Fiber spacing can accommodate 2 orders of spectra

Low Cross-Talk Risk!

Spectra location shifts small at different windows

Comparison Between Two Kinds of Gratings (3)

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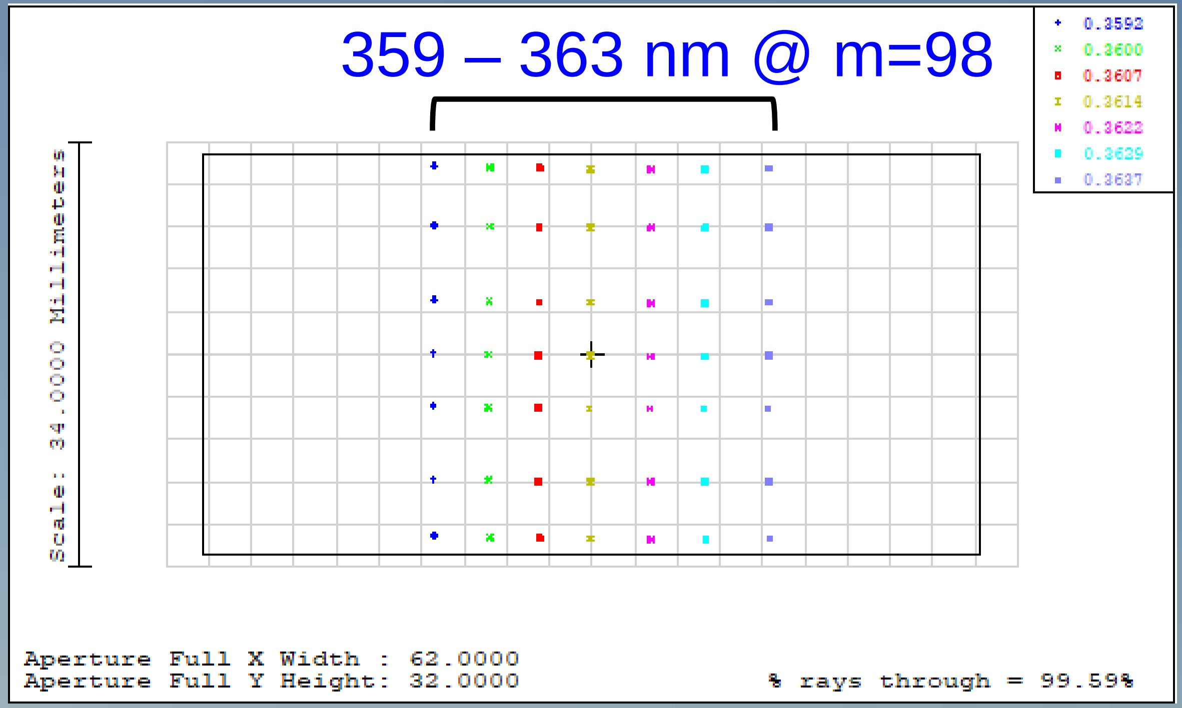
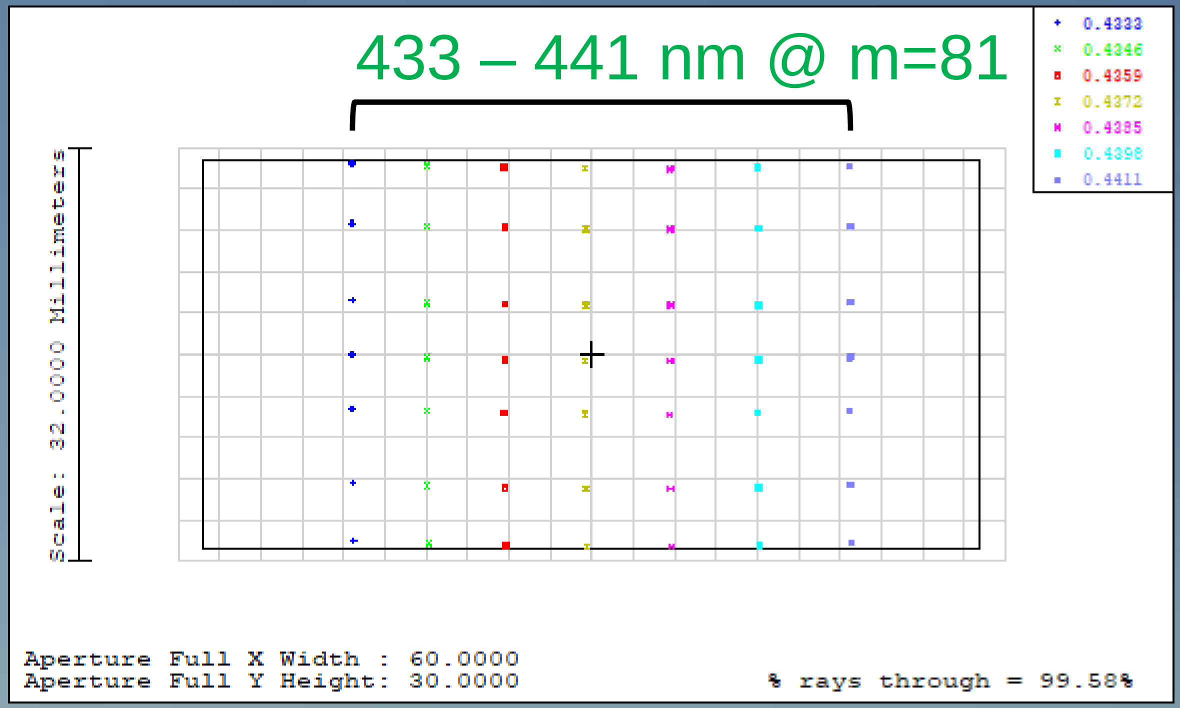
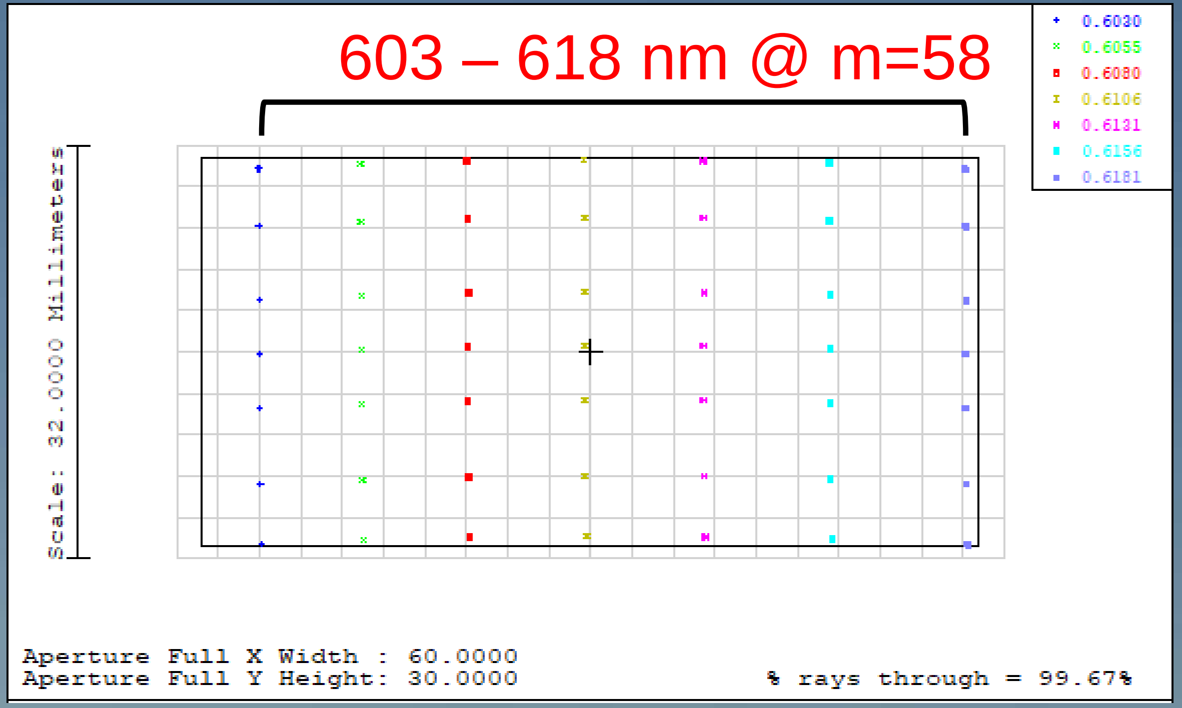
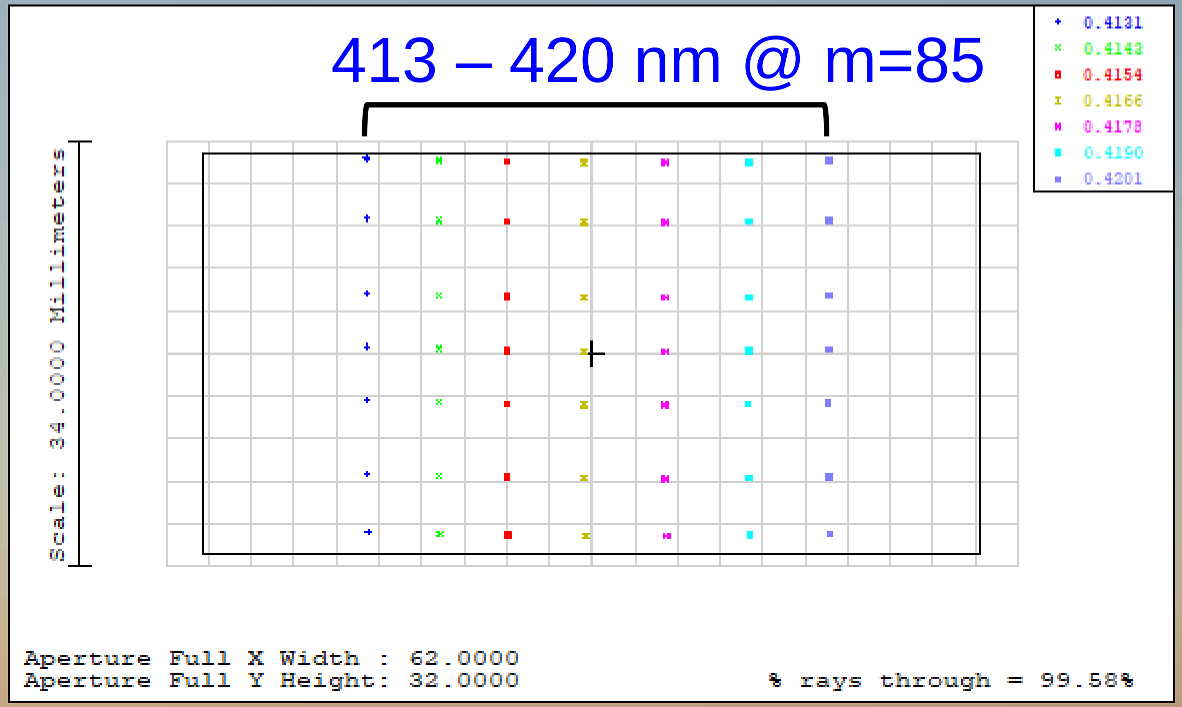
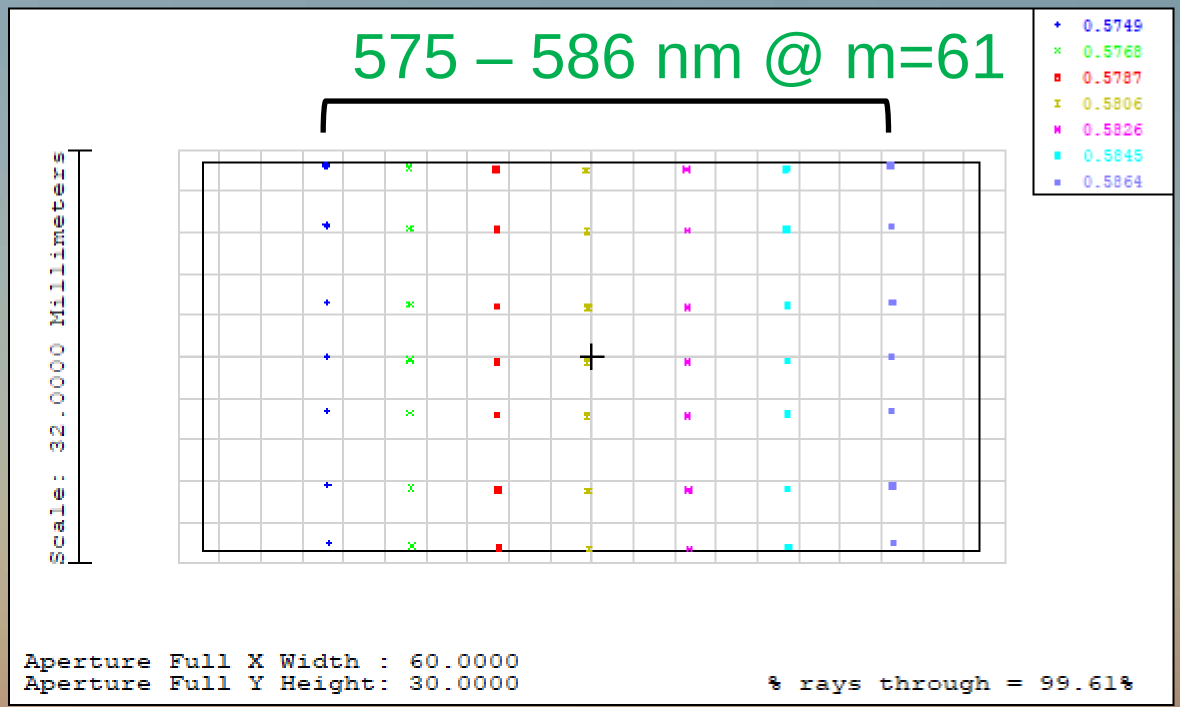
Free Spectral Range at Different Windows

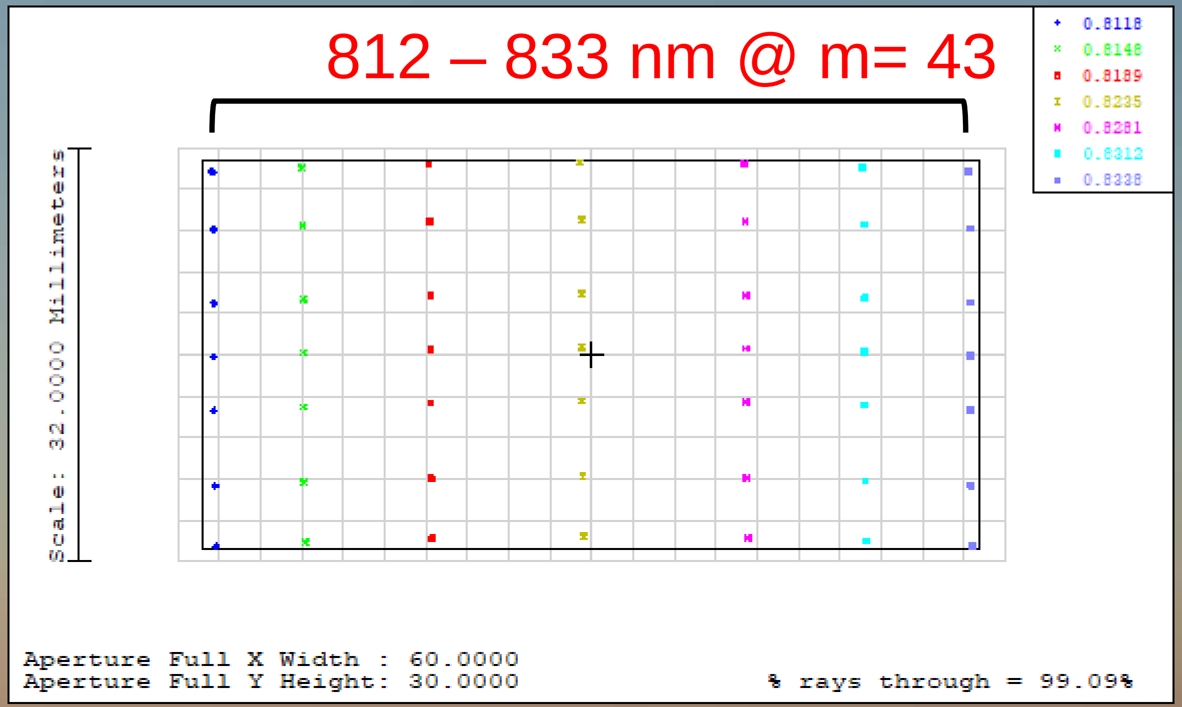












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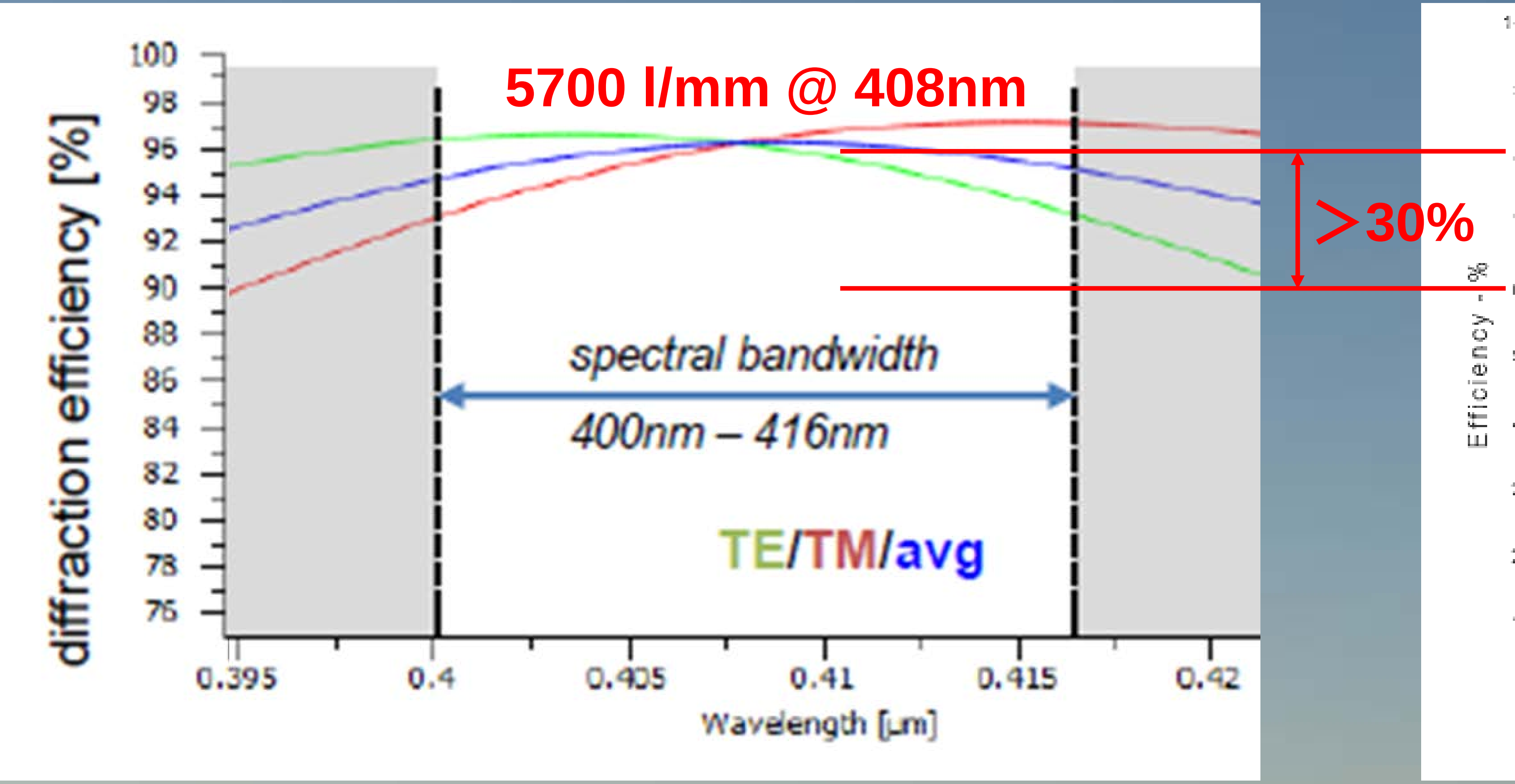
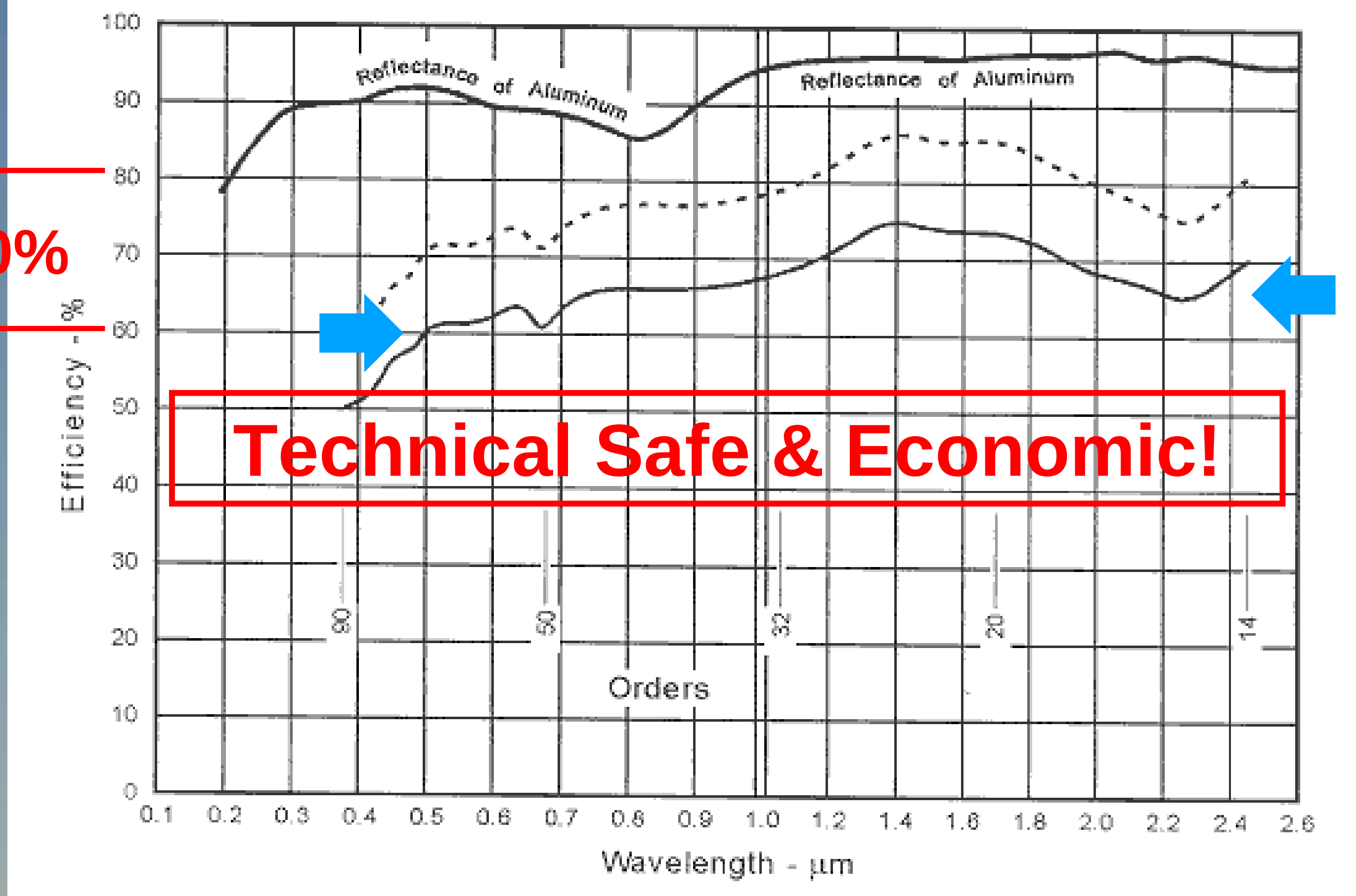
Comparison Between Two Kinds of Gratings (4)

Different Curves of Diffraction Efficiency



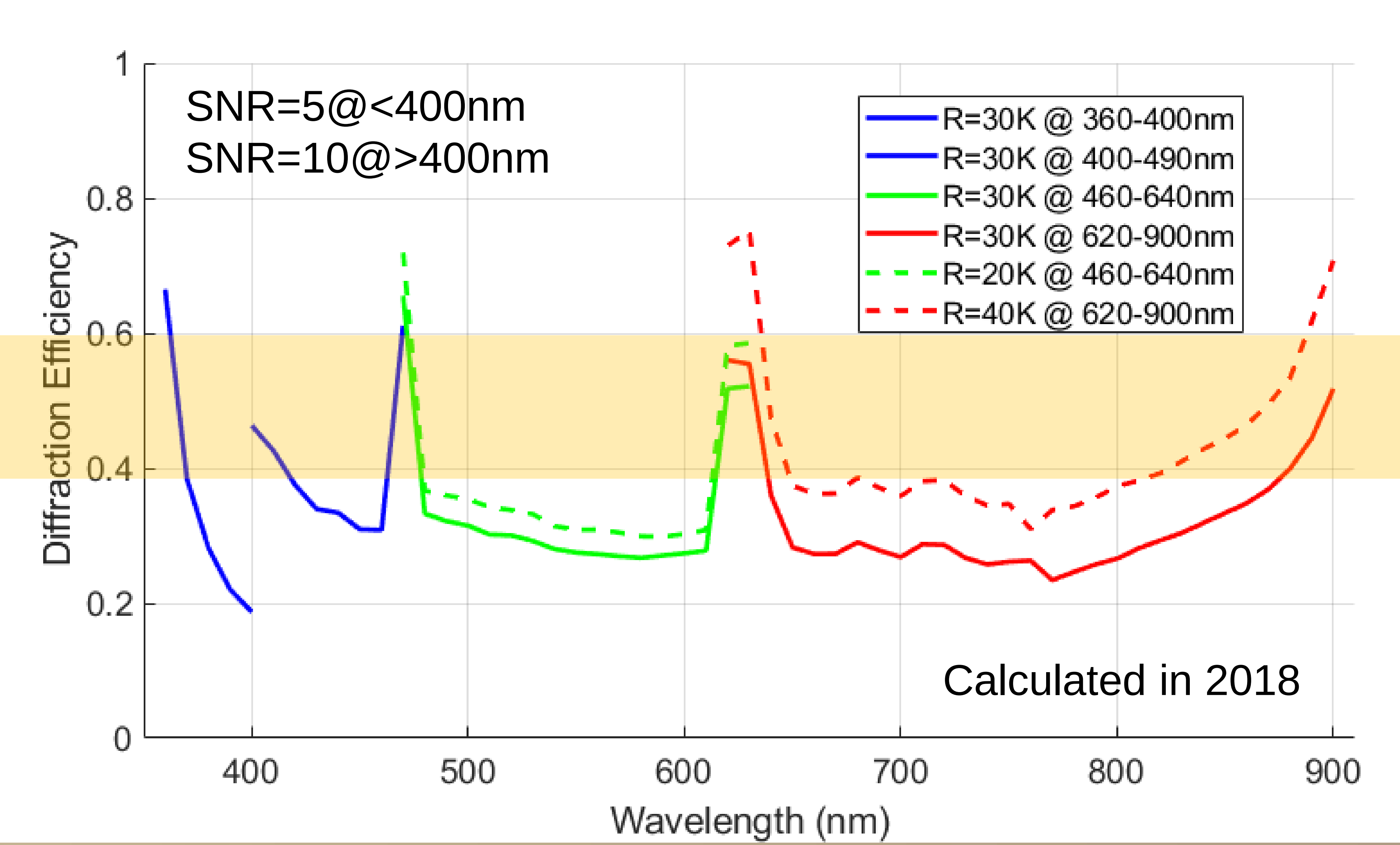


Peak ≥ 94%
Theoretical design with RIE technology
(Never confirmed by fabrication)

Peak ≥ 60% at different orders (m=14-90)
Measured efficiency by vendors

Comparison Between Two Kinds of Gratings (4)

Requirement of Diffraction Efficiency by Instrument Sensitivity



Echelle grating enable to provide the required diffraction efficiency in Free Spectral Range.

Optical Design of Spectrograph

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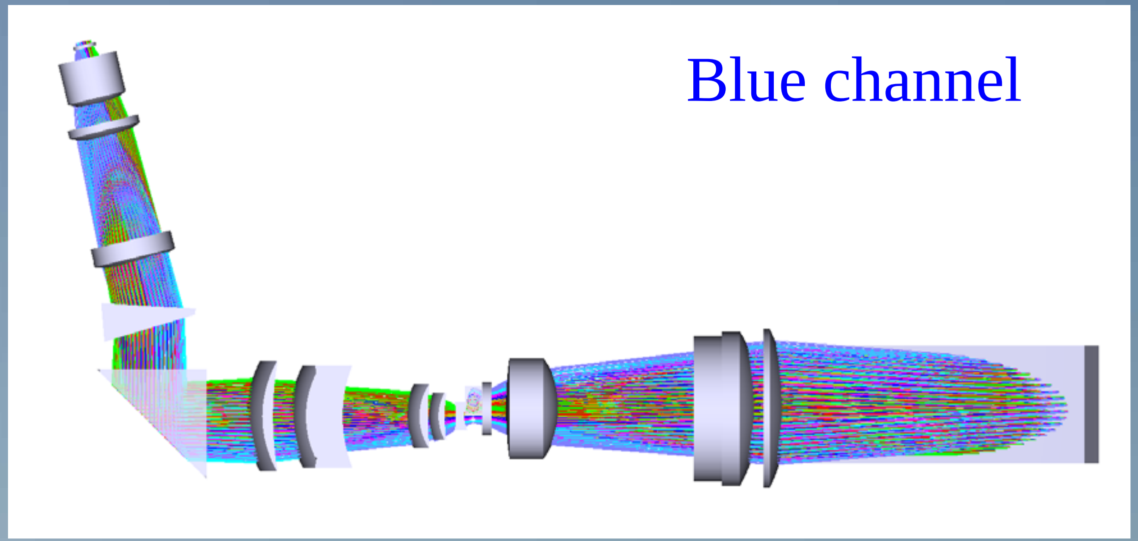
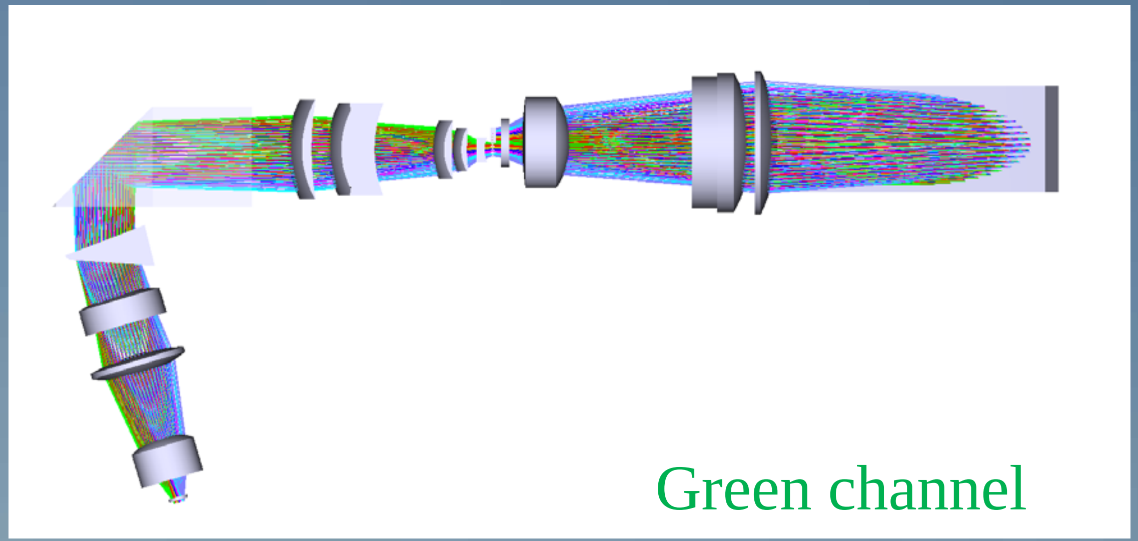
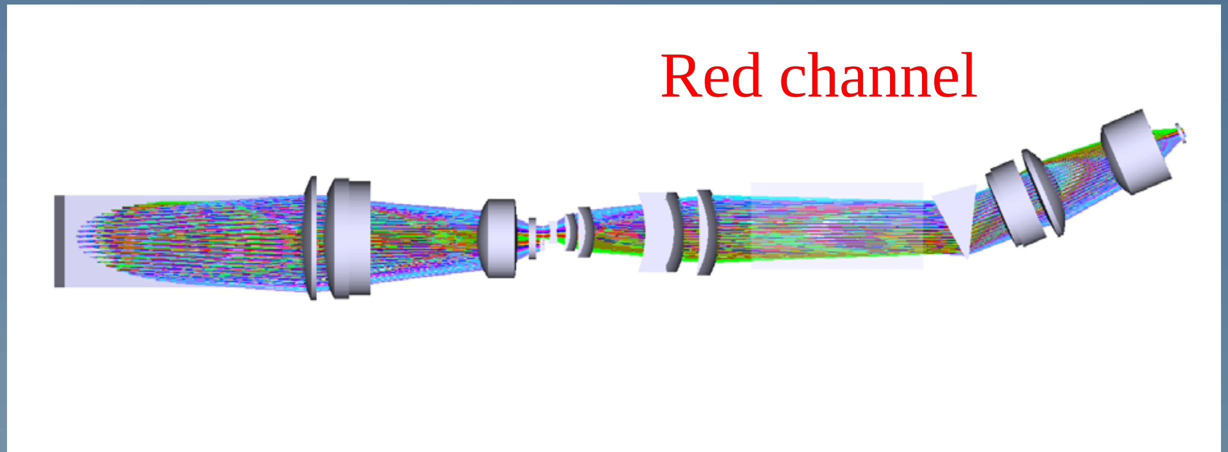
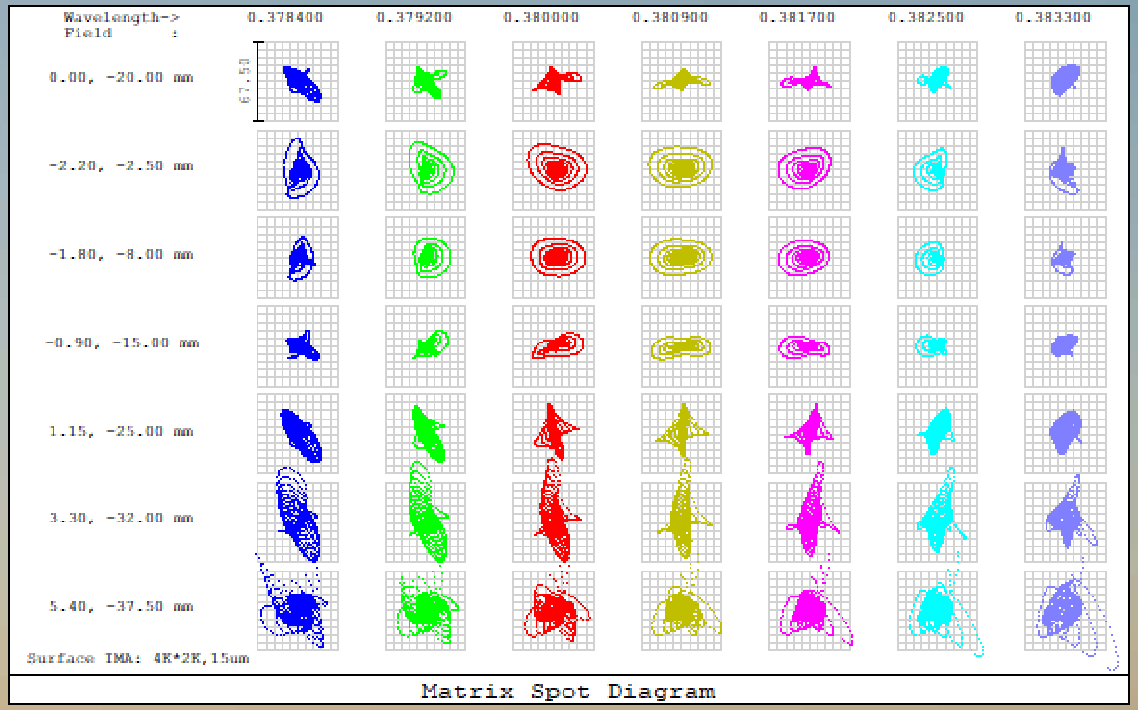
Channel Design



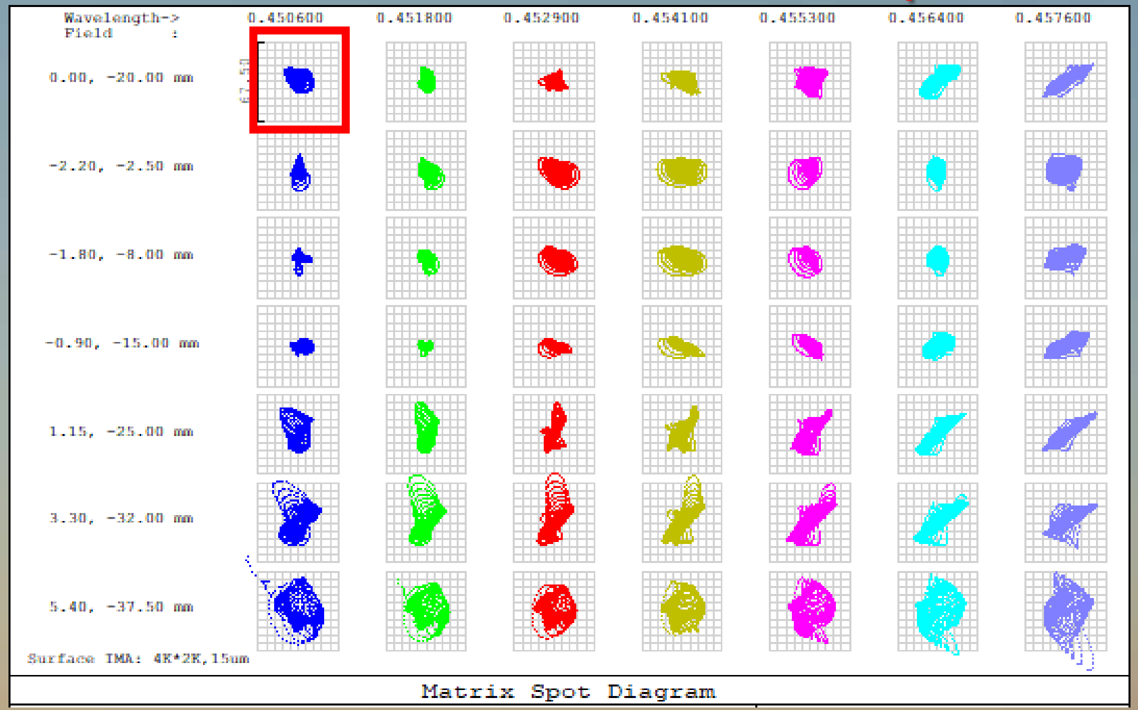




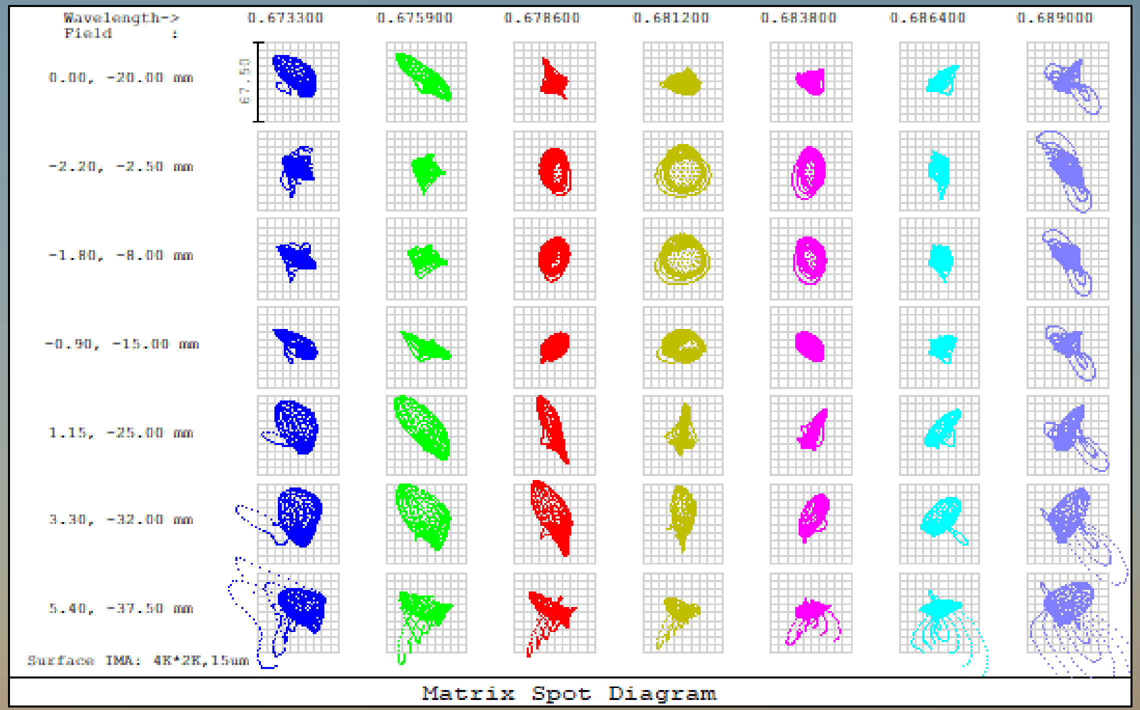
67.5um x 67.5um = 4.5 x 4.5 pixels



391-396nm



450-457nm



673-689nm

Conclusion

The new HR design with Echelle grating is possibly a trade-off solution for the technical challenge from high-density oversize grism.

Echelle grating is widely applied in single-object high-resolution spectrograph, and effectively provide high dispersion over the full wavelength range of 360-900nm. And it also enables to cover any working window by two corresponding orders. This new design provides a faster and more economic way to switch working windows by changing filters.

The new design has its own characteristics and problem to face. Low multiplexing number require more spectrographs to accommodate >1K fibers. Data reduction may face some challenge since every fiber produce 2 orders of spectra. Echelle grating has lower diffraction efficiency than the grism used in the previous design, but it almost satisfies with the requirement of instrument sensitivity.

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Thank you for attention.

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