Scientific Justification

Recent studies find dwarf galaxies ($M_{stellar}<10^{9.5}M_{\odot}$) hosting Low Mass Black Holes (LMBHs), mostly detected by broadened Hα signatures with v>500 km/s. These outflows originate from relatively massive LMBHs (M_{BH}~10^5-10^6 $M_{\odot}$; e.g., Greene & Ho 2004, Reines et al. 2013) that are mostly classified as AGN or composite (galaxies between the solid and dashed lines in Fig. 1a) by the BPT plot (Baldwin, Phillips & Terlevich 1981; hereafter NII plot). The NII plot classifies galaxies with high [NII]/Hα at a given [OIII]/Hβ as AGN (Fig. 1), but the [NII]/Hα ratio is a known metallicity proxy (Pettini et al. 2004). Thus, *traditional dwarf AGN identification methods are biased against finding AGN in typical low-metallicity dwarfs.*

Theoretical and observational work suggest that there may be 2 distinct classes of dwarf AGN: (a) Dwarf AGN in high-mass dwarfs may be analogous to AGN in giants, where star formation (SF) is quenched by strong AGN outflows (Penny et al. 2018, Manzano-King et al. 2019). (b) Dwarf AGN in lower-mass dwarfs may be fundamentally different from AGN in giants, where strong SF feedback quenches AGN fueling. The latter class of AGN may turn on only after the SF has died down, and may not be powerful enough to drive ionized gas outflows resulting in broad Hα (Habouzit et al. 2017, Anglés-Alcázar et al. 2017, Bradford et al. 2018, Latimer et al. 2019). Techniques identifying AGN via Hα outflows may miss milder dwarf AGN where SF dominates the feedback, warranting the need for a different identification method.

We adapt the method of Kewley et al. (2006) who combine the NII plot with [SII]/Hα and [OI]/Hα diagnostics (Veilleux & Osterbrock 1987; hereafter SII and OI plots), classifying galaxies as star-forming, composite, Seyferts or LINERs. Galaxies with conflicting classifications among the three plots are left unclassified. Our modified classification scheme uses the three plots together, to define a new AGN category called **'Star-Forming AGN' (SFing-AGN)- galaxies classified as star-forming by the NII plot, but as AGN by the SII or OI plot**. Fig. 1 shows theoretical motivation for our new scheme: *a simulated low-metallicity dwarf AGN from photoionization modelling is not classified as AGN by the NII plot but is easily identified by the OI plot*. We have applied this new scheme to the z~0 RESOLVE survey (Kannappan et al. 2008) using emission line fluxes from SDSS catalogs. SFing-AGN are mostly gas-rich dwarfs with high long-term SF but moderate short-term SF (Fig. 2) implying a recent slump in SF activity (scenario (b)). Our new method yields a preliminary dwarf AGN frequency of ~8% versus ~1% from previous searches (Sartori et al. 2015, Reines et al. 2015 etc.). Unfortunately, the SDSS spectra cannot confirm the presence of SFing-AGN due to insufficient S/N for [OI]. Better data for 2 of our candidates from the SAMI survey show evidence of AGN-like [OI]/Hα ratios within the central kpc (Fig. 3). With high S/N GMOS IFU data of 5 more candidates, we can:

1. confirm AGN-like line ratios in the central kpc of SFing-AGN- High S/N is key for reducing uncertainty on the weak [OI] line measurements (Fig. 3) to confirm the presence of AGN-like [OI]/Hα ratios in low metallicity gas-rich dwarfs.

2. check for AGN outflows using broad Hα- We can test for the presence of ionized gas outflows from AGN by detecting broad wings of Hα. Thus, we can check whether SFing-AGN are missed by broad-line studies because they are a distinct class of AGN that do not power outflows.

Our preliminary results and existing models show promising evidence of a new exciting technique that uncovers ~10x as many spectroscopically identified dwarf AGN as previously known. By obtaining only a few confirming high S/N GMOS measurements of SFing-AGN with diverse properties, we will be well positioned for a rapid publication of this new method.

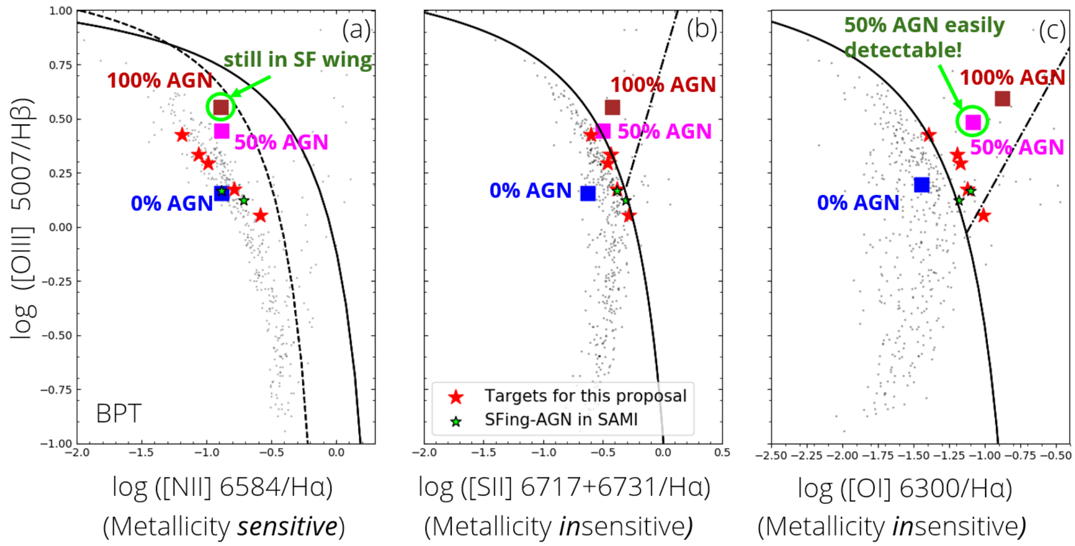

Figure 1 - RESOLVE galaxies (light gray) over plotted with calculations of a low-metallicity theoretical dwarf galaxy with metallicity $Z=0.4Z_{\odot}$ and $M_{BH}=10^5\,M_{\odot}$ with 0, 50 and 100% AGN contribution to its spectrum. Demarcation lines are from Kewley et al. (2006). Galaxies above the solid black line in all three plots are classified as AGN, and those between the dashed and solid line in the NII plot (BPT; panel (a)) are classified as composite. The NII plot does not identify even the 100% AGN due to its bias against low-metallicity AGN. The SII and OI plots do identify dwarf AGN due to their metallicity insensitivity. The OI plot even identifies 50% AGN contribution, making it the best suited to find AGN in star-forming dwarfs.

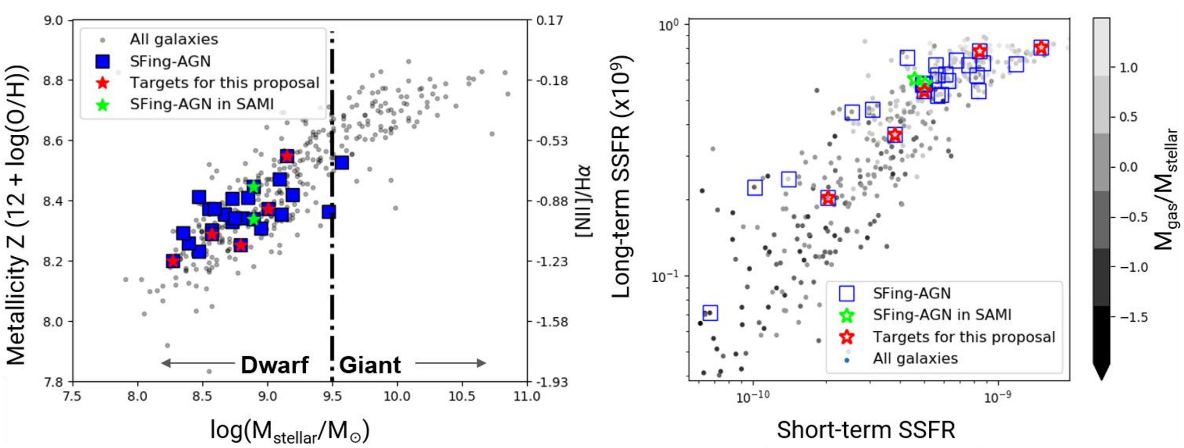

Figure 2 - ***Left****:* Mass-metallicity relation for RESOLVE galaxies (light gray), SFing-AGN galaxies (blue squares), SFing-AGN targets for this proposal (red stars), and SFing-AGN with SAMI data (green squares). Metallicity is calculated using [NII]/Hα. Most SFing-AGN are dwarfs (left of black dashed line) and have low metallicity. ***Right****:* Long (~1 Gyr-averaged) vs. short term (~100 Myr-averaged) specific star formation rates of RESOLVE galaxies in our sample (circles), coloured by their gas-to-stellar mass ratios (zoomed in to clearly show SFing-AGN candidates). SFing-AGN are shown as blue squares, SFing-AGN in SAMI as green stars and the SFing-AGN targets for this proposal as red stars. SFing-AGN galaxies are gas-rich with moderately high long term SSFR, but low short-term SSFR, implying a recent slump in SF. (Note: One of the green stars has been slightly offset for visibility).

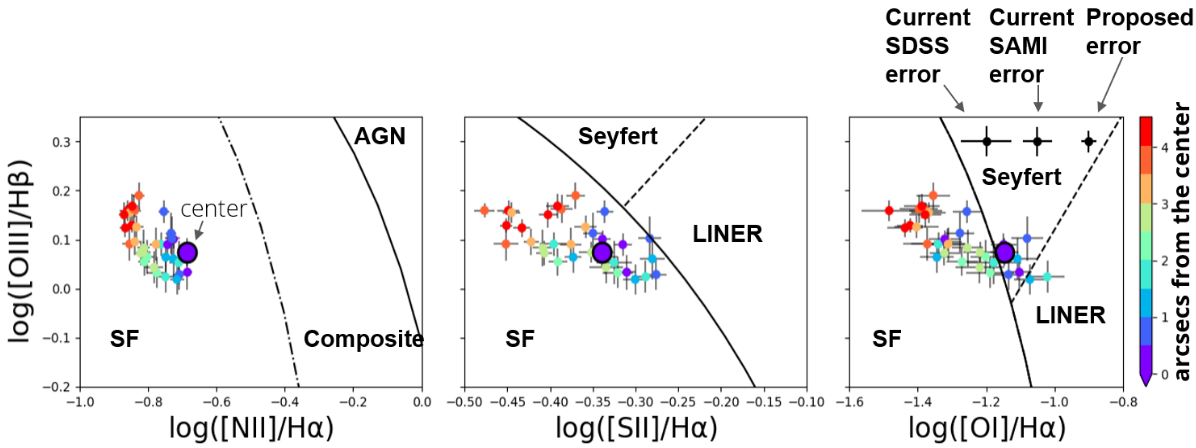

Figure 3 - Demonstration of the need for high S/N GMOS IFU data for SFing-AGN galaxies. SAMI DR2 IFU data for an SFing-AGN (rs0010) show AGN-like [OI]/Hα ratios for several spaxels within ~2" (0.5 kpc) of the center. Error bar on log([OI]/Hα) from the 2" SDSS fibre (0.07 dex) and the central spaxel of SAMI data (0.04 dex) is shown on the top right, along with the much lower target error bar for this proposal (0.02 dex). Likewise, SOAR spectroscopy of the same galaxy (not shown) is insufficient for high S/N [OI], showing that all standard survey depth observations are inadequate for high S/N [OI] detection.

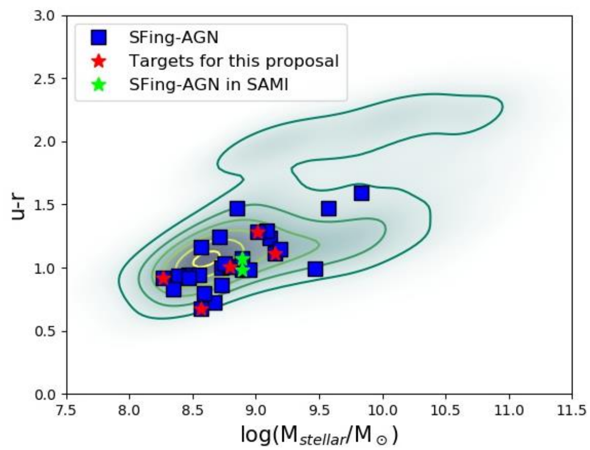

Figure 4 - Colour-mass plot for all galaxies in the volume-limited RESOLVE survey shown as contours. Low metallicity, gas-rich SFing-AGN (blue squares) are spread throughout the entire range of the blue sequence. The targets for this proposal (red stars) span a diverse range of properties among the SFing-AGN that are observable in this FT period, complementary to the SFing-AGN with existing SAMI data (green stars).

References

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Technical Description

Sample Selection: Our dwarf AGN candidates have diverse properties within the parent volume-limited RESOLVE survey (Fig 2, 4). We use emission line fluxes from SDSS MPA-JHU (Tremonti et al. 2004), Portsmouth (Thomas et al. 2013) and NSA catalogs (Yan et al. 2011), and apply a S/N>5 cut on all lines relevant to the diagnostic plots- Hβ, [OIII] 5007, [OI] 6300, Hα, [NII] 6584, [SII] 6717+6731. Our final sample has 437/1519 galaxies (295 dwarfs) and our new method flags 24 galaxies as dwarf AGN candidates. Among these, we chose 5 candidate dwarf AGN with 0.5<RA<18.5 for this Fast Turnaround period.

Observing Setup: We use the B600 grating with FWHM resolution of 1.69Å (σ_{instr}~33 km/s at 6563Å), centered at 5400Å, GMOS IFU in 1-slit mode (5"x3.5") for spectral coverage from 4750-7250Å. *GMOS IFU spectroscopy is essential for confirming the presence of dwarf AGN, as archival SAMI IFU data is available only for 2/24 dwarf SFing-AGN, and archival SDSS data or even new RESOLVE data using the SOAR telescope cannot match the S/N for the weak [OI] line that we can get from the setup proposed below*. The large field of view of the GMOS IFU is essential as recent observations and BH simulations predict that ~50% LMBHs exist off-center in dwarf galaxies within the central kpc (Bellovary et al. 2019, Reines et al. 2019) corresponding to ~2.3-2.7" at the redshifts of our targets. The 1-slit mode will allow us to get spatial coverage of the central kpc while maximizing the spectral coverage, enabling us to measure all relevant emission lines from Hβ to [SII]. We request SB/IQ/CC/WV=80/70/70/any, airmass=1.5. The seeing for IQ=70 is FWHM=0.75" (~0.3 kpc for our sample) which is still small enough to be able to localise AGN-like emission line ratios within the central kpc. We use the GMOS-S ITC to estimate S/N for [OI], Hα, [OIII] and Hβ based on the SDSS emission line and continuum fluxes of one of our low-metallicity dwarf AGN candidates, rs0010. *Our goal is to be able to measure the weak [OI] line with S/N>20, in order to reduce the error on $\log_{10}$([OI]/Hα) to <0.03 dex to be better than ~0.04 dex error of existing SAMI data, and much better than the ~0.07 dex error typical of SDSS spectra. The higher S/N will allow us to accurately classify dwarf AGN using the OI plot (Fig. 3)*. The ITC indicates that an exposure time of 2x800s gives us a S/N~2.5 per spectral pixel per fibre at the [OI] line peak, resulting in S/N~23 for binning up to 5x5 fibres. The binning corresponds to 1.2" radius, which is more than the worst seeing, but still within the central kpc for our targets. This setup simultaneously reduces the error on $\log_{10}$([OIII]/Hβ) to ~0.02 dex, compared to ~0.03 dex from SDSS. The same setup with 5x5 fibre binning provides S/N~23 for the broad Hα wings that mimic observed outflows from SDSS spectra (Reines et al. 2013) with FWHM=500 km/s and ~20% of narrow Hα flux. Thus, we can check if Hα outflows are present in low-metallicity star-forming dwarf AGN, allowing us to verify if there is a distinct class of dwarf AGN that are too mild to power ionized gas outflows. An estimate of the pointing time with overheads per target is: 18m (IFU setup) + 2x800s (exposure) + 4x92.5s (readout/write) + 3x7s (telescope offset) = 47m52s. We request 2 arc calibrations to be taken with each exposure; we will use sky lines to improve the wavelength solution. For arc calibrations, the time estimate is 2x15s + 2x40s setup + 2x92.5s (readout/write) = 295s. The total time for 5 galaxies is 5x53m = **4.4 hr**.

Data Analysis: The RESOLVE team has developed a custom pipeline for GMOS IFU data with the B600 grating, which we will quickly adapt to be suitable for the specific setup outlined in this proposal. After reduction, we will use the GIST Pipeline (Bittner et al. 2019) to fit the stellar continuum using pPXF (Cappellari, M. 2019) and the extract emission line measurements using GandALF (Sarzi et al. 2006). We will also perform multi-component gaussian fitting using GaussPy+ (Manuel et al. 2019) to detect the broad component of Hα, if present.

Justify Target Duplications

The GOA search revealed no duplicate observations within our target list.

Publications

Richardson, C., Polimera, M., Kannappan, S. et al. 2019, MNRAS, 486, 3541

Polimera, M., Kannappan, S., Richardson, C. et al. 2019, AAS Meeting Abstracts, 233, 412.06

Previous Use of Gemini

As a graduate student, the PI, Mugdha Polimera, has had no previous allocations of telescope time through NOAO. However, she is a member of the RESOLVE team, which was awarded 14 SOAR nights and 88hr on Gemini to complete the B-semester footprint of the survey (NOAO Survey Program 13B-0512, PI Kannappan). We received observations for only 52.5hr out of the 88 awarded hours (60%). A custom Gemini reduction pipeline has been developed for our blue stellar kinematics setup (with B1200 grating) and red gas kinematics setup (with B600 grating). The red setup pipeline will be adapted to reduce data obtained with the setup outlined in this proposal.

Reference	Allocation	% Useful	Status of previous data
NOAO 13B-0512	88hr	~60%	Pipeline developed, partially reduced, Palumbo et al. 2019 in refereeing process

ITC Examples

Gemini Integration Time Calculator
GMOS-S - 2019B.1.1.1

Click here for help with the results page.
Read noise: 4.1
derived image size(FWHM) for a point source = 1.03 arcsec

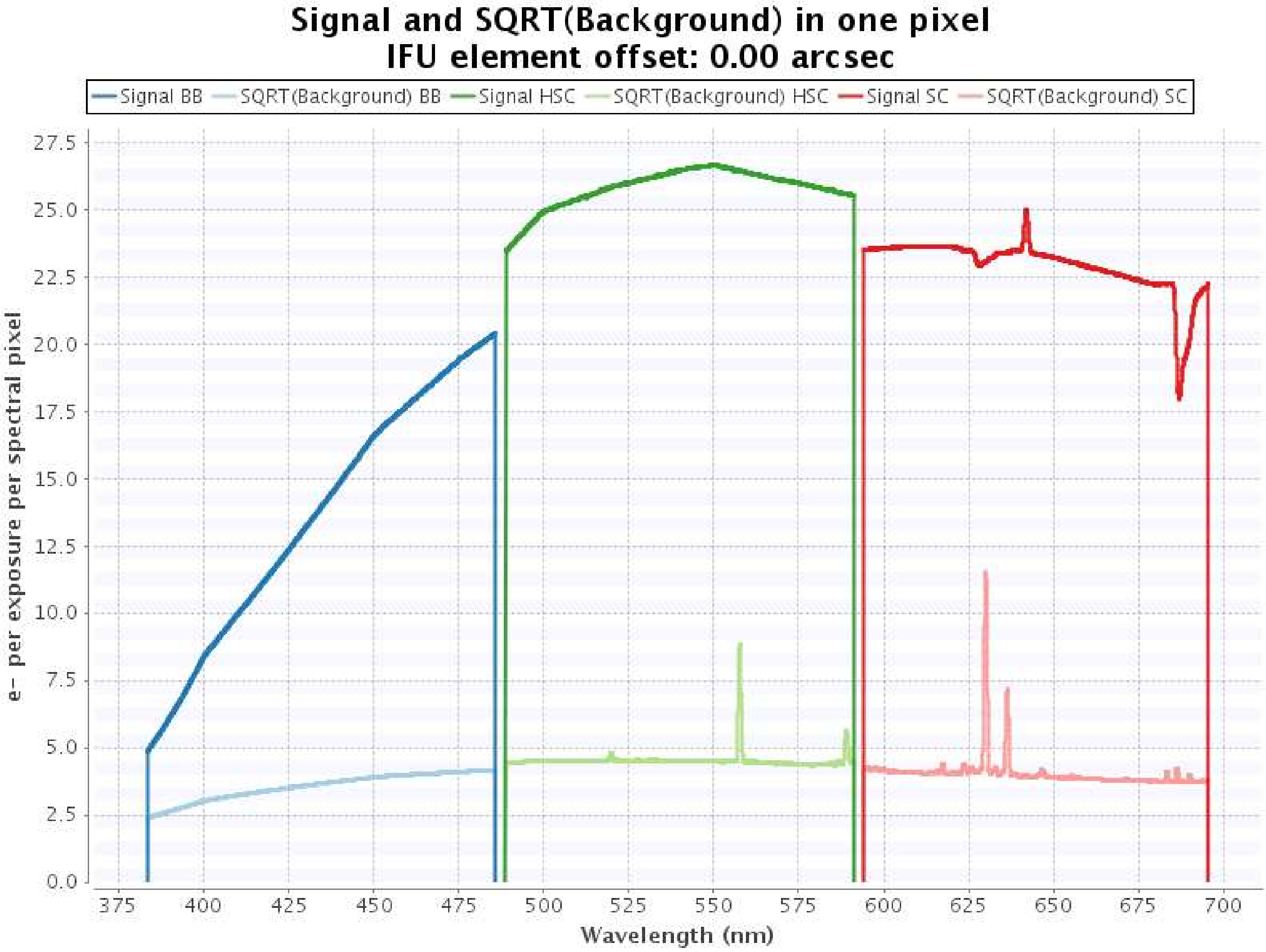
Sky subtraction aperture = 250.0 times the software aperture.

Requested total integration time = 1600.00 secs, of which 1600.00 secs is on source.

The peak pixel signal + background is 156 e- (86 ADU). This is 0% of the saturation limit of 117963 e-.

Observation Overheads		
Setup	1080.0 s	
Telescope offset	1 x 7.0 s	assuming ABAB dithering pattern
Exposure	2 x 800.0 s	
Readout	2 x 82.5 s	
DHS Write	2 x 10.0 s	
Total time	**47 mins 52 secs**	

Click here for ASCII signal spectrum.
Click here for ASCII background spectrum.
Click here for Single Exposure S/N ASCII data.
Click here for Final S/N ASCII data.


Signal and SQRT(Background) in one pixel
IFU element offset: 0.00 arcsec
Signal BB
SQRT(Background) BB
Signal HSC
SQRT(Background) HSC
Signal SC
SQRT(Background) SC
e- per exposure per spectral pixel
Wavelength (nm)
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
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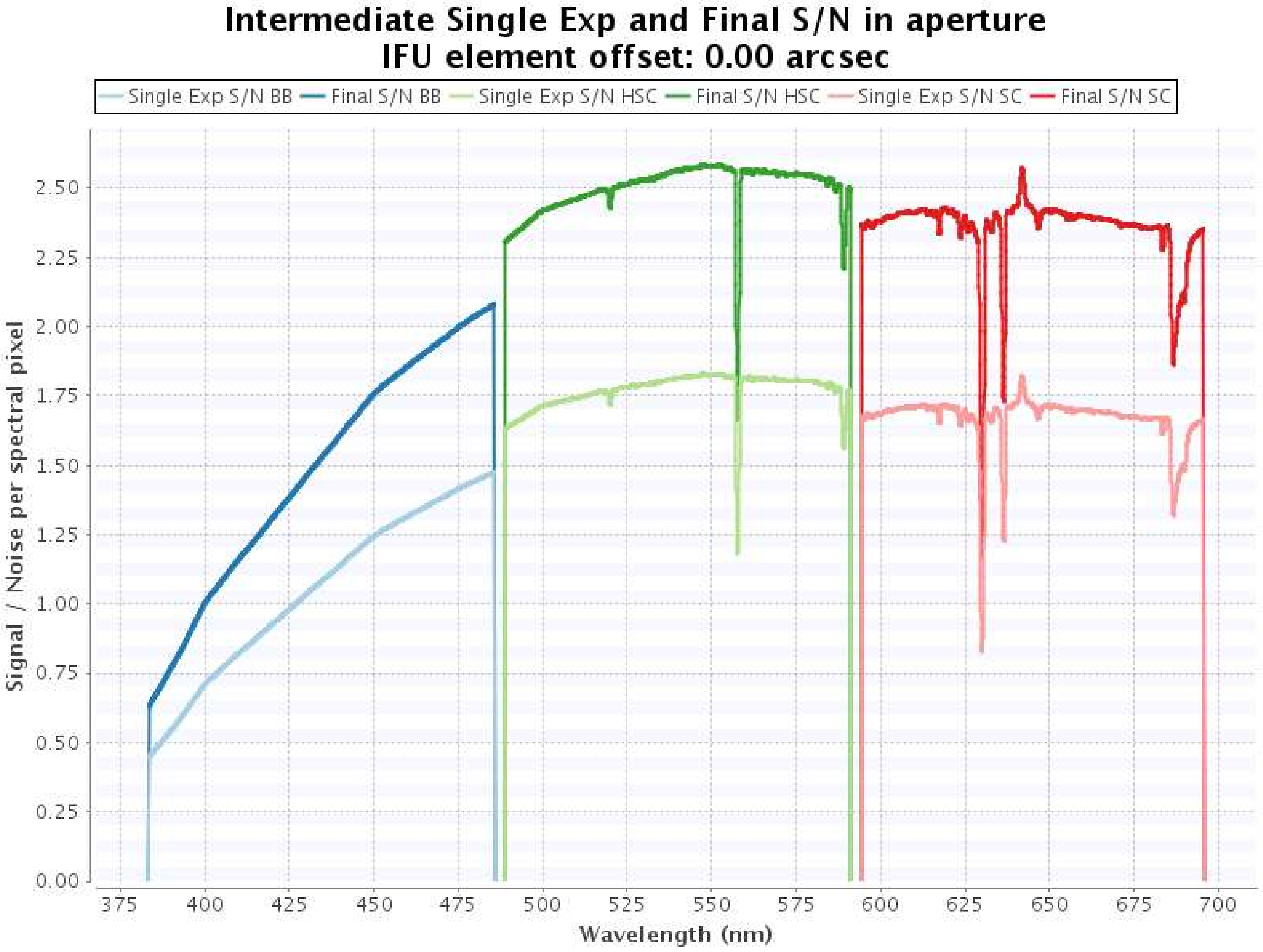

Output:

- Spectra autoscaled.

Input Parameters:
Instrument: GMOS-S

Source spatial profile, brightness, and spectral distribution:
The z = 0.01900 uniform surface brightness source is an emission line at a wavelength of 0.63 μm with a width of 610.0 km/s.
It's total flux is 9.0E-17 erg/s/cm² on a flat continuum of flux density 1.0E-16 erg/s/cm²/Å.

Instrument configuration:
Optical Components:

- Fixed Optics
- IFU Transmission
- Grating Optics: B600_G5323
- Detector - Hamamatsu array

Amp gain: Low, Amp read mode: Slow

- Focal Plane Mask: IFU Right Slit (red)

Central Wavelength: 540.0 nm
Spatial Binning: 1
Spectral Binning: 1
Pixel Size in Spatial Direction: 0.080778arcsec
Pixel Size in Spectral Direction: 0.05nm
IFU is selected,with a single IFU element at 0.0arcsecs.

Telescope configuration:

- silver mirror coating.
- side looking port.
- wavefront sensor: oiwfs

Observing Conditions:

- Image Quality: 70.00%
- Sky Transparency (cloud cover): 70.00%
- Sky transparency (water vapour): 100.00%
- Sky background: 80.00%
- Airmass: 1.50

Likelihood of execution: 39.20%

Calculation and analysis methods:

- Mode: spectroscopy
- Calculation of S/N ratio with 2 exposures of 800.00 secs, and 100.00% of them on source.
- Analysis performed for aperture that gives 'optimum' S/N and 250 fibres on sky.

Gemini Integration Time Calculator
GMOS-S - 2019B.1.1.1

Click here for help with the results page.
Read noise: 4.1
derived image size(FWHM) for a point source = 1.00 arcsec

Sky subtraction aperture = 250.0 times the software aperture.

Requested total integration time = 1600.00 secs, of which 1600.00 secs is on source.

The peak pixel signal + background is 156 e- (86 ADU). This is 0% of the saturation limit of 117963 e-.

Observation Overheads		
Setup	1080.0 s	
Telescope offset	1 x 7.0 s	assuming ABAB dithering pattern
Exposure	2 x 800.0 s	
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Total time	**47 mins 52 secs**	

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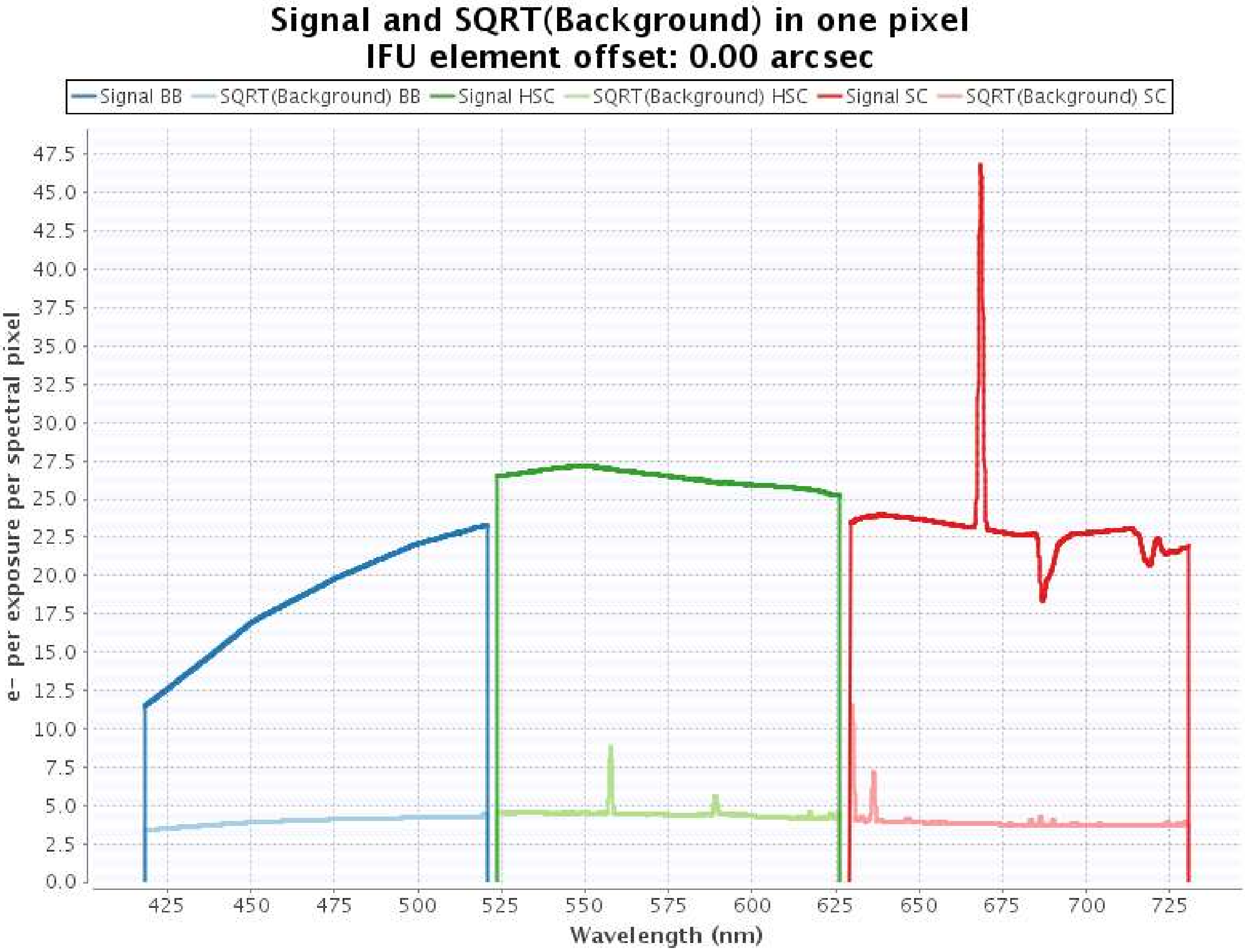
Click here for Final S/N ASCII data.


Signal and SQRT(Background) in one pixel
IFU element offset: 0.00 arcsec
Signal BB
SQRT(Background) BB
Signal HSC
SQRT(Background) HSC
Signal SC
SQRT(Background) SC
e- per exposure per spectral pixel
Wavelength (nm)
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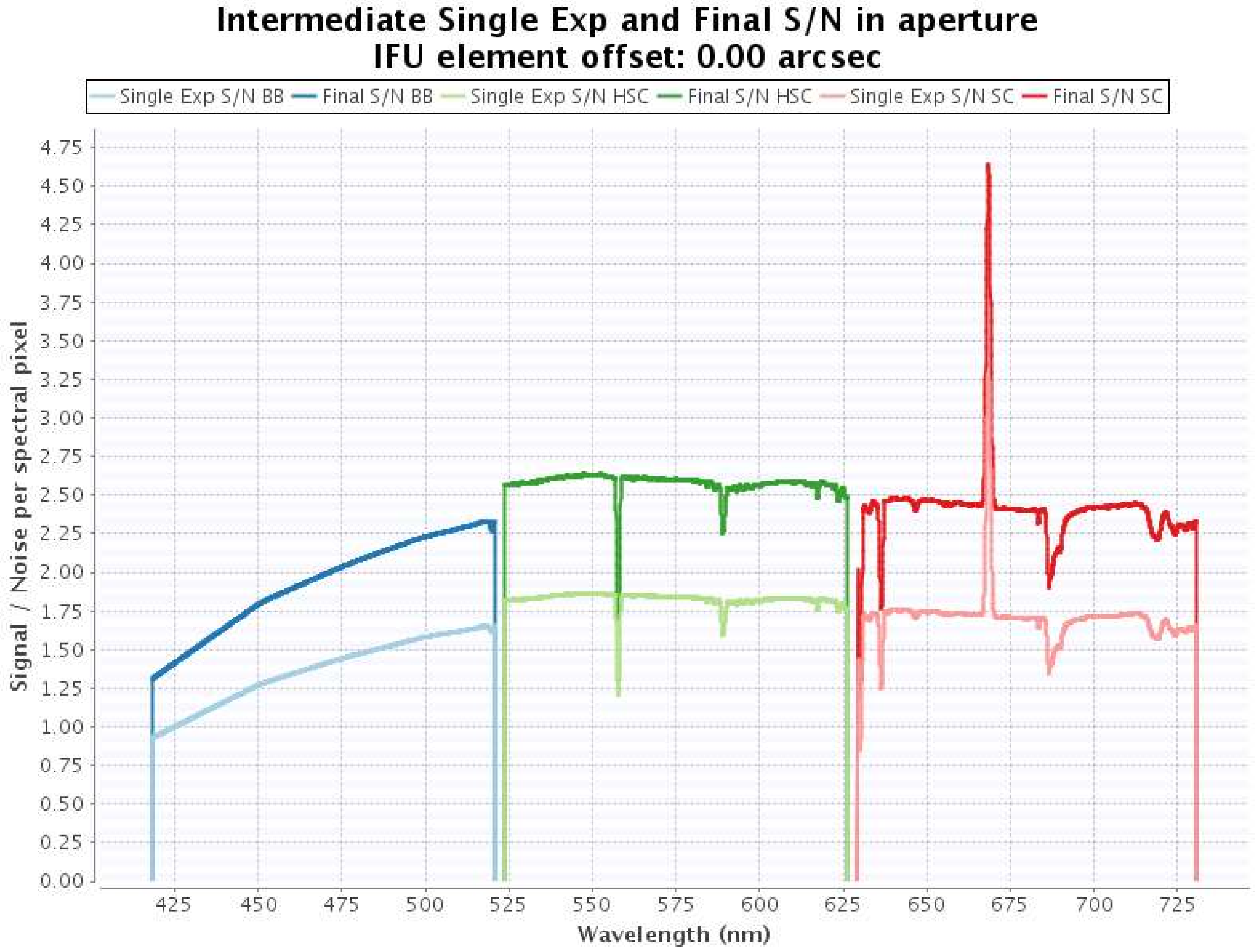

Output:

- Spectra autoscaled.

Input Parameters:
Instrument: GMOS-S

Source spatial profile, brightness, and spectral distribution:
The z = 0.01900 uniform surface brightness source is an emission line at a wavelength of 0.656 µm with a width of 610.0 km/s.
It's total flux is 1.45E-15 erg/s/cm² on a flat continuum of flux density 9.8E-17 erg/s/cm²/Å.

Instrument configuration:
Optical Components:

- Fixed Optics
- IFU Transmission
- Grating Optics: B600_G5323
- Detector - Hamamatsu array

Amp gain: Low, Amp read mode: Slow

- Focal Plane Mask: IFU Right Slit (red)

Central Wavelength: 575.0 nm
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Spectral Binning: 1
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Pixel Size in Spectral Direction: 0.05nm
IFU is selected,with a single IFU element at 0.0arcsecs.

Telescope configuration:
- silver mirror coating.
- side looking port.
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Observing Conditions:
- Image Quality: 70.00%
- Sky Transparency (cloud cover): 70.00%
- Sky transparency (water vapour): 100.00%
- Sky background: 80.00%
- Airmass: 1.50

Likelihood of execution: 39.20%

Calculation and analysis methods:
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GMOS-S - 2019B.1.1.1

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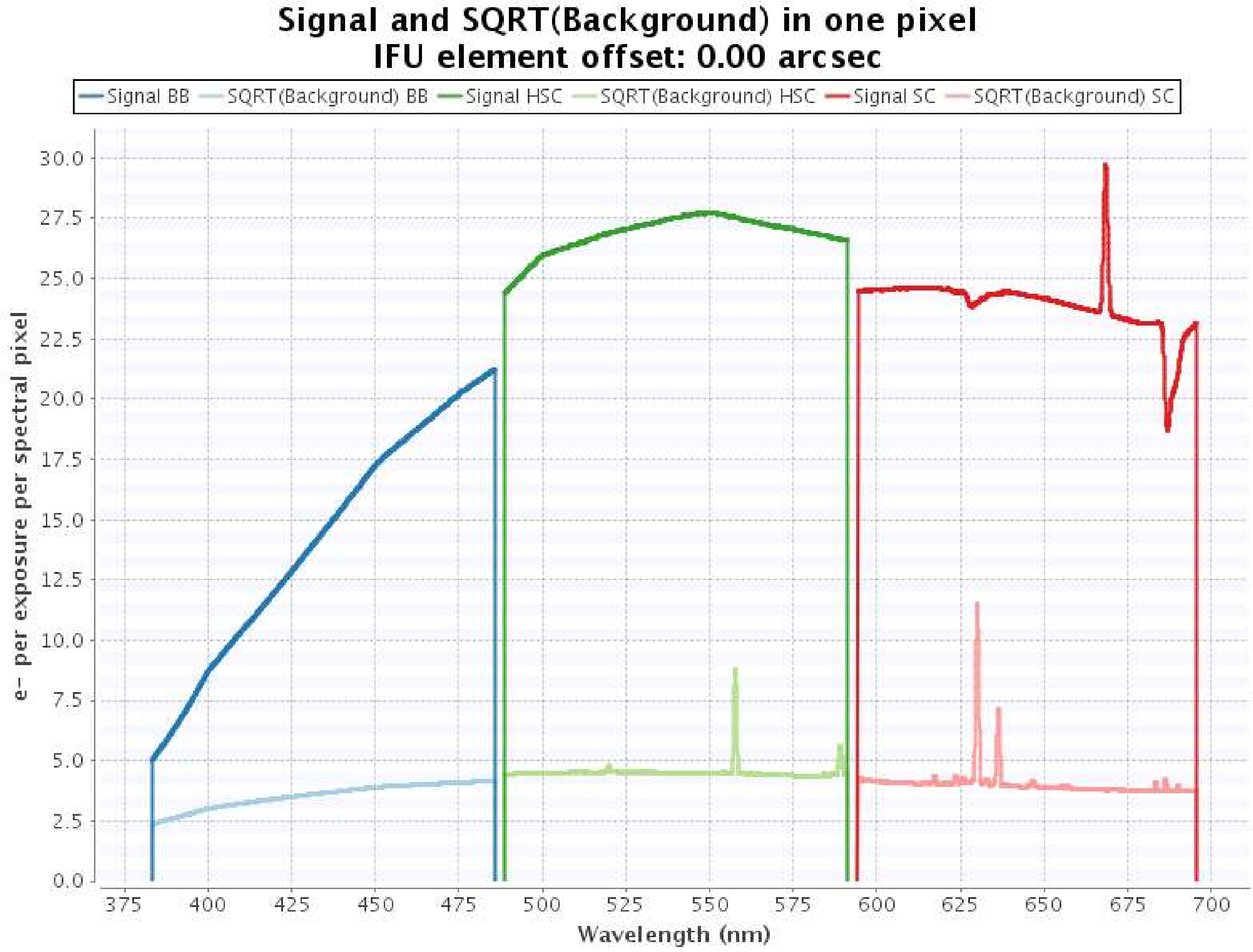

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Signal SC
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7.5
10.0
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17.5
20.0
22.5
25.0
27.5
30.0
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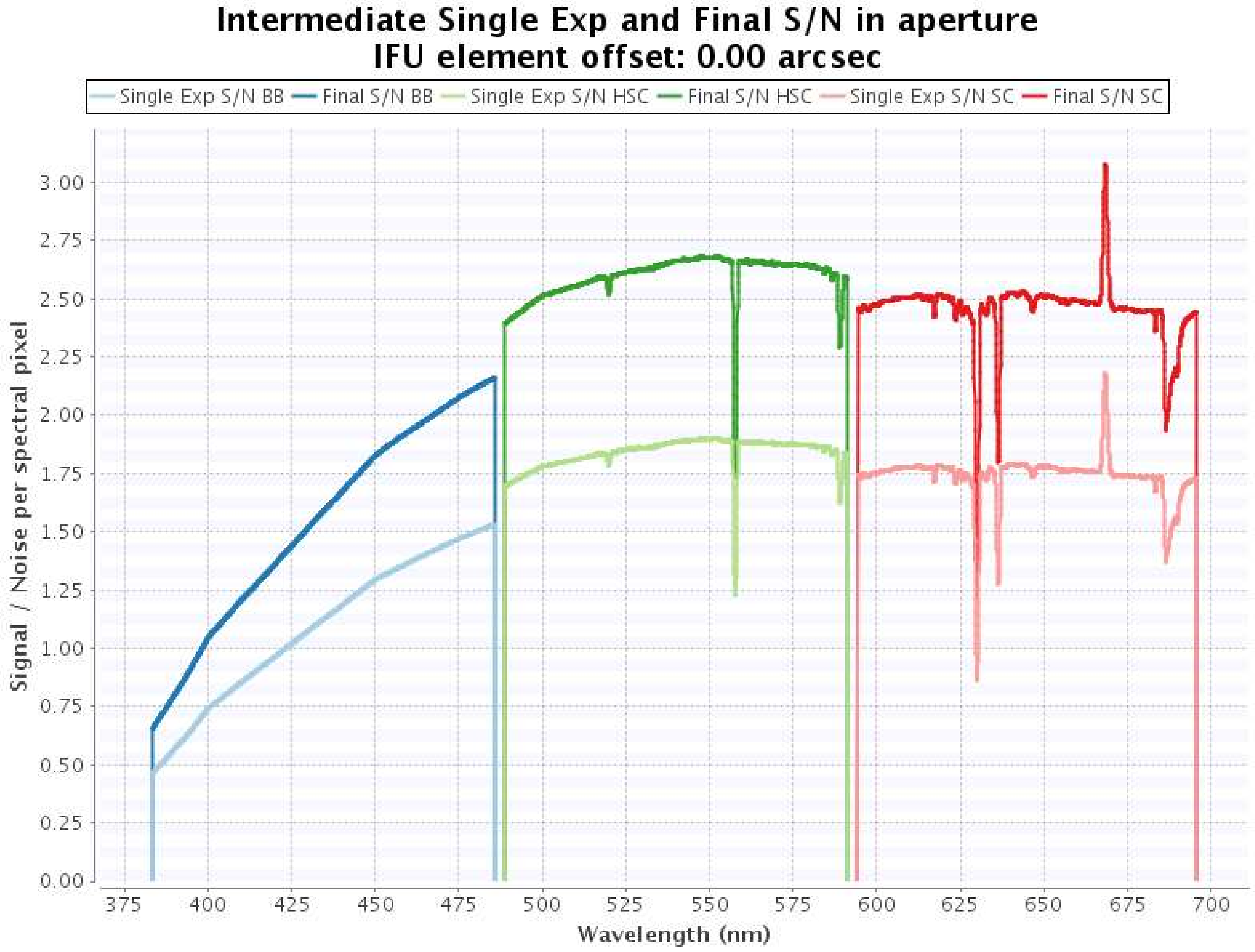
650
675
700
Wavelength (nm)



Output:
- Spectra autoscaled.

Input Parameters:
Instrument: GMOS-S

Source spatial profile, brightness, and spectral distribution:
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- Sky transparency (water vapour): 100.00%
- Sky background: 80.00%
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Likelihood of execution: 39.20%

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- Analysis performed for aperture that gives 'optimum' S/N and 250 fibres on sky.

Gemini Integration Time Calculator
GMOS-S - 2019B.1.1.1

Click here for help with the results page.
Read noise: 4.1
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Sky subtraction aperture = 250.0 times the software aperture.

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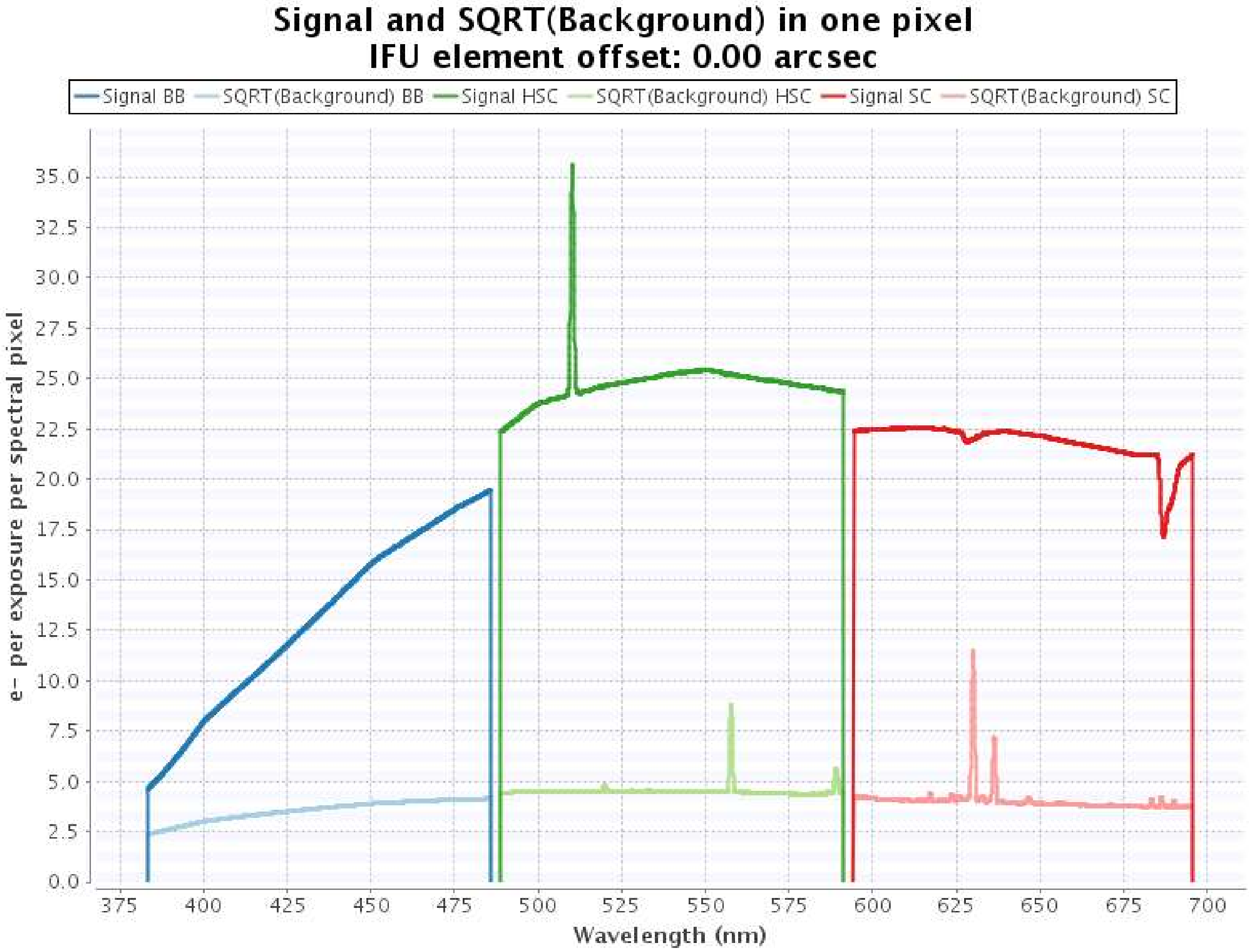
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SQRT(Background) BB
Signal HSC
SQRT(Background) HSC
Signal SC
SQRT(Background) SC
e- per exposure per spectral pixel
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35.0
32.5
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12.5
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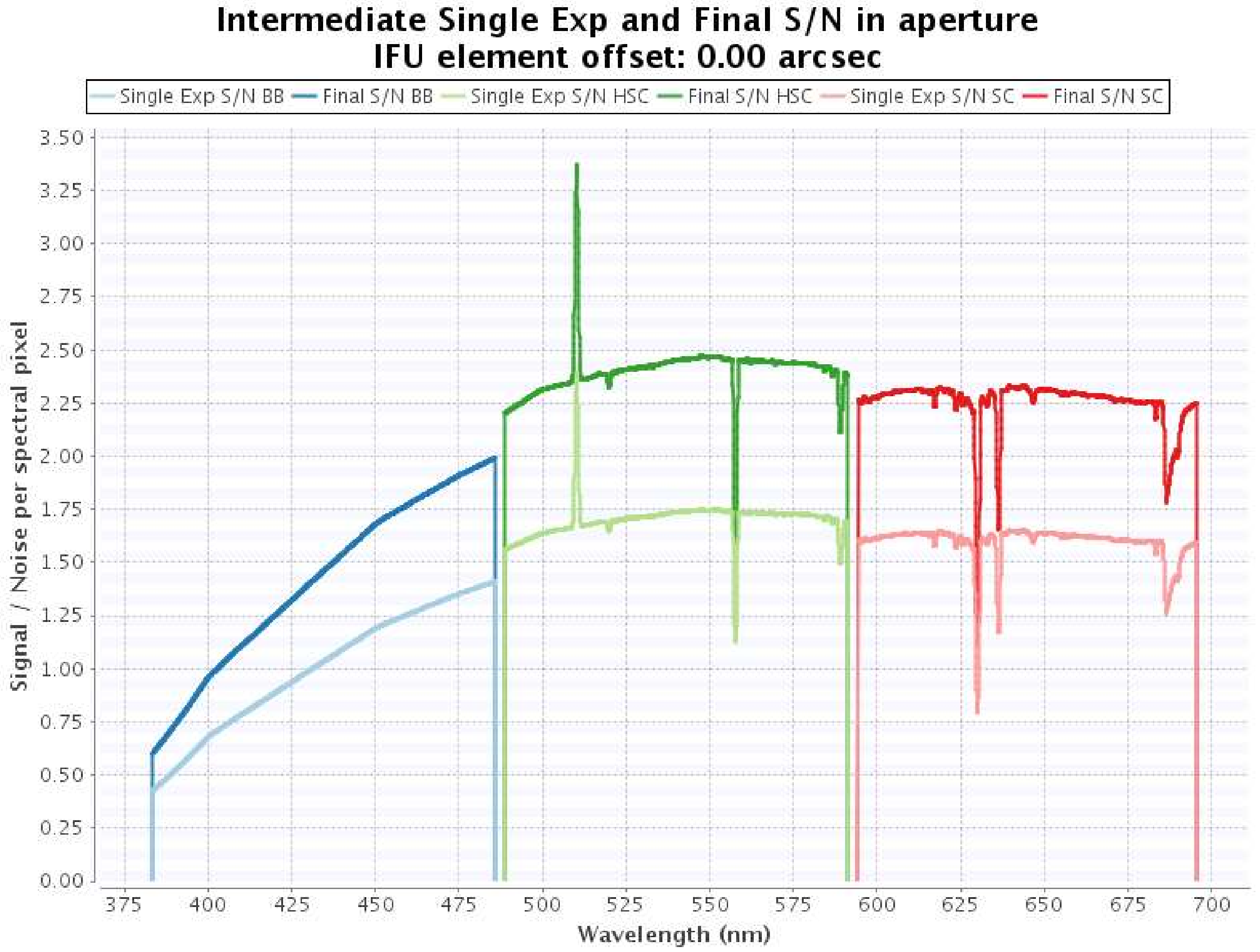


Output:

- Spectra autoscaled.

Input Parameters:
Instrument: GMOS-S

Source spatial profile, brightness, and spectral distribution:
The z = 0.01900 uniform surface brightness source is an emission line at a wavelength of 0.5007 µm with a width of 610.0 km/s.
It's total flux is 6.2E-16 erg/s/cm² on a flat continuum of flux density 1.2E-16 erg/s/cm²/Å.

Instrument configuration:
Optical Components:

- Fixed Optics
- IFU Transmission
- Grating Optics: B600_G5323
- Detector - Hamamatsu array

Amp gain: Low, Amp read mode: Slow

- Focal Plane Mask: IFU Right Slit (red)

Central Wavelength: 540.0 nm
Spatial Binning: 1
Spectral Binning: 1
Pixel Size in Spatial Direction: 0.080778arcsec
Pixel Size in Spectral Direction: 0.05nm
IFU is selected,with a single IFU element at 0.0arcsecs.

Telescope configuration:

- silver mirror coating.
- side looking port.
- wavefront sensor: oiwfs

Observing Conditions:

- Image Quality: 70.00%
- Sky Transparency (cloud cover): 70.00%
- Sky transparency (water vapour): 100.00%
- Sky background: 80.00%
- Airmass: 1.50

Likelihood of execution: 39.20%

Calculation and analysis methods:

- Mode: spectroscopy
- Calculation of S/N ratio with 2 exposures of 800.00 secs, and 100.00% of them on source.
- Analysis performed for aperture that gives 'optimum' S/N and 250 fibres on sky.

Gemini Integration Time Calculator
GMOS-S - 2019B.1.1.1

Click here for help with the results page.
Read noise: 4.1
derived image size(FWHM) for a point source = 1.03 arcsec

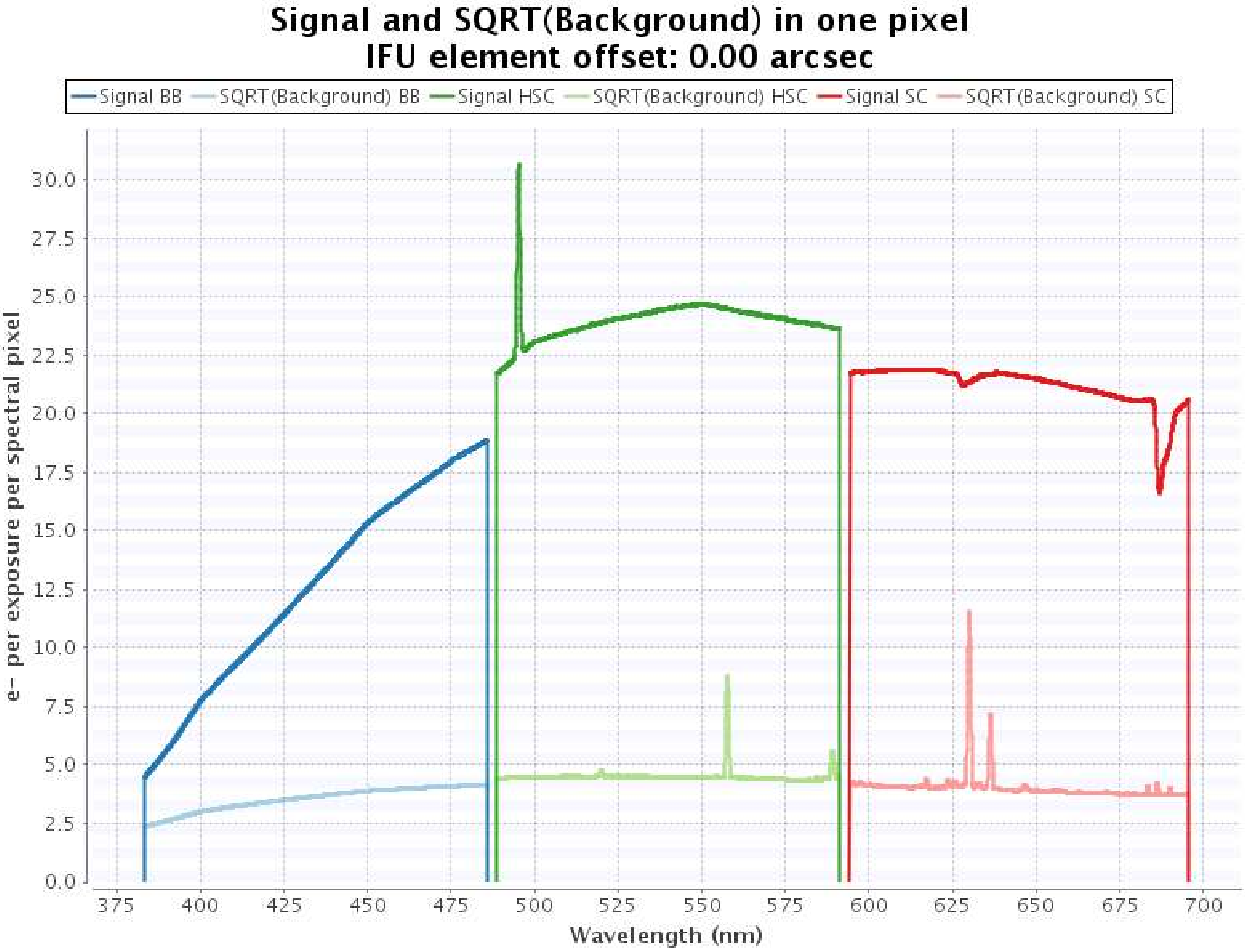
Sky subtraction aperture = 250.0 times the software aperture.

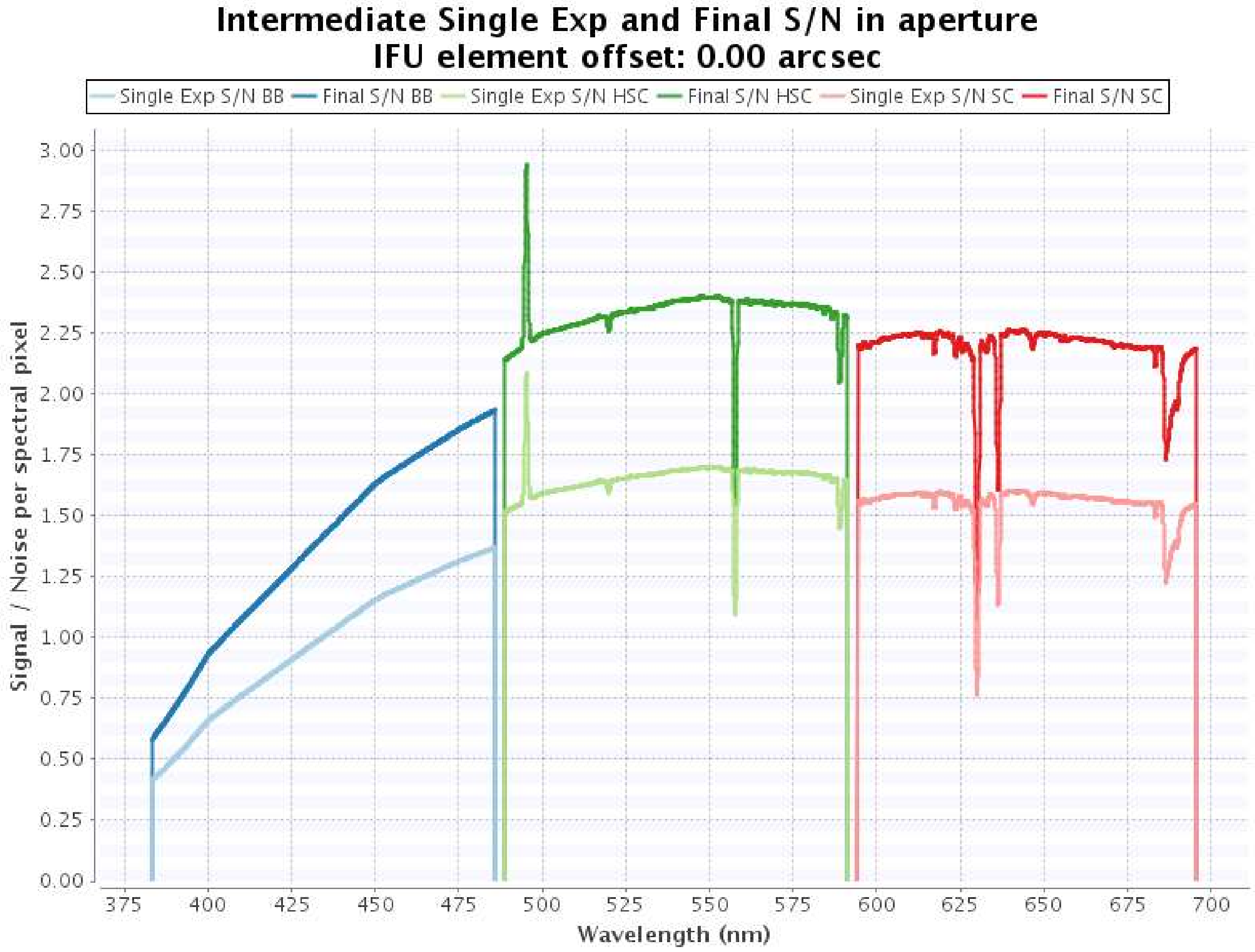
Requested total integration time = 1600.00 secs, of which 1600.00 secs is on source.

The peak pixel signal + background is 154 e- (85 ADU). This is 0% of the saturation limit of 117963 e-.

Observation Overheads		
Setup	1080.0 s	
Telescope offset	1 x 7.0 s	assuming ABAB dithering pattern
Exposure	2 x 800.0 s	
Readout	2 x 82.5 s	
DHS Write	2 x 10.0 s	
Total time	**47 mins 52 secs**	

Click here for ASCII signal spectrum.
Click here for ASCII background spectrum.
Click here for Single Exposure S/N ASCII data.
Click here for Final S/N ASCII data.


Signal and SQRT(Background) in one pixel
IFU element offset: 0.00 arcsec
Signal BB
SQRT(Background) BB
Signal HSC
SQRT(Background) HSC
Signal SC
SQRT(Background) SC
e- per exposure per spectral pixel
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
27.5
30.0
375 400 425 450 475 500 525 550 575 600 625 650 675 700
Wavelength (nm)



Output:

- Spectra autoscaled.

Input Parameters:
Instrument: GMOS-S

Source spatial profile, brightness, and spectral distribution:
The z = 0.01900 uniform surface brightness source is an emission line at a wavelength of 0.486 µm with a width of 610.0 km/s.
It's total flux is 4.6E-16 erg/s/cm² on a flat continuum of flux density 1.2E-16 erg/s/cm²/Å.

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