GEMINI OBSERVATORY

observing time request summary

Semester: 2015A **Observing Mode:** Fast Turnaround **Gemini Reference:**

Instruments: GMOS North

Time Awarded: NaN **Thesis:** Yes

Band 3 Acceptable: No

Title: **An Ultraluminous Supersoft X-ray Source**

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Polina Zemko **(thesis)**: Universita' di Padova, Italy, polina.zemko@gmail.com
Reviewer: Marina Orio

Partner Submission Details *(multiple entries for joint proposals)*

		PI Request		NTAC Recommendation			
Partner	**Lead**	**Time**	**Min**	**Reference**	**Time**	**Min**	**Rank**
	Total Time	*5.0 hr*	*4.9 hr*		*0.0 hr*	*0.0 hr*	

Abstract

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An intriguing ultraluminous and supersoft X-ray source in M51 may be either a black hole accreting from a companion star, or an accreting and hydrogen burning white dwarf. If the first scenario is true, it must be a very massive object, perhaps one of the long-sought intermediate mass black holes. If instead it is a white dwarf emitting X-rays from the atmosphere, it must be as hot as only a near-Chandrasekhar mass white dwarf can become. The optical counterpart of the X-ray source, or a nebulosity that appears to be associated with it, should reveal prominent emission lines in either case. These lines can be detected, measured and used as fundamental diagnostics. The optical emisison spectrum should will allow us to discriminate between different possibilities, revealing the true nature of this "extreme" object, of great interest at all levels, from stellar evolution to cosmology.

TAC Category / Keywords

Extragalactic / Variable stars, White dwarfs, Stellar populations, Massive stars , Emission lines, Black hole physics

Scheduling Constraints

Observation Details (Band 1/2)

Observation	RA	Dec	Brightness	Total Time *(including overheads)*
M51 ULS	13:29:39.960	47:12:36.900		5.0 hr
Conditions: CC 50%/Clear, IQ 70%/Good, SB 20%/Darkest, WV Any **Resources:** GMOS-N LongSlit None B600 None 0.75 arcsec slit				

Scientific Justification

We propose a fast turnaround project that fits the description of a "speculative/high risk–high reward observation of short duration"; it is also a "pilot study" and a "short, self-contained project". Our goal is to obtain a spectrum of an ultra-luminous super-soft X-ray source (ULS) in M51. Luminous supersoft X-ray sources may arise from two distinct important classes of interacting binary stars: those with massive white dwarfs near the Chandrasekhar limit, undergoing nuclear burning, or those hosting accreting high mass black holes (see e.g. Fabbiano et al. 2003). Optical spectroscopic studies such as we propose here distinguish between these two possibilities, revealing the nature of the binary system hosting the X-ray source (e.g. Liu et al. 2013).

Our target belongs to a group of about 70 sources (Liu et al. 2011), a borderline region of overlap of the class of Ultra Luminous X-ray Sources ("ULX"), non-nuclear sources with luminosity exceeding 10^{39} erg s^{-1} (above the canonical Eddington luminosity for a massive white dwarf or a neutron star, $\simeq 2 \times 10^{38}$ erg s^{-1}), and accreting and hydrogen burning white dwarfs (see e.g. Orio 2013). Although theoretical models of both hard and soft ULX have focused on black hole systems, recently one "hard" ULX has been proven to be a neutron star (Bachetti et al. 2014). A new interpretation key worth invstigating is the scenario of the "soft" ULX as hydrogen burning white dwarfs. Massive white dwarfs become in fact so hot and luminous once CNO burning starts, that they appear as supersoft X-ray sources (SSS), at near-Eddington luminosity (see e.g. Orio 2013). The ULS have attracted attention because of the very soft spectrum, which can be fitted with a blackbody at 80-120 eV, with or without a low luminosity component of harder flux. The most common working hypothesis is still that of black hole binaries. Their soft X-ray spectra would be emitted by an accretion disk, allowing a relatively straightforward estimate of the black hole mass, largely above 100 $M_\odot$. Some ULS are thus considered the most promising candidate intermediate mass black holes ("IMBH"). IMBH have long been sought because they have several important astrophysical roles: remnants of massive population III stars, vestiges of minor mergers, massive black hole nuclei of globular clusters. However, the only ULS that has been spectroscopically studied has revealed a stellar mass black hole, below 30 $M_\odot$, so the X-ray spectrum requires new physical phenomena to be explained, like a super-efficient wind from the secondary to the compact object, which is extremely interesting in its own right (Liu et al. 2013). We are quite interested in the alternative scenario to explain the ULS, that is white dwarfs accreting and burning hydrogen (or helium) on the surface, near the Chandrasekhar limit. *Such objects would be the most promising observable candidate type Ia supernova progenitors.* The X-ray luminosity of many ULS does not exceed 10^{39} erg s^{-1}, leaving a reasonable doubt that it may have been overestimated due to uncertainties in the absorbing column N(H), which is crucial to determine the absolute luminosity of the softest X-ray sources.

Our target is one of 7 ULS in M51. We find that the other ULS of M51 are located in star formation and H II regions, but this particular ULS is more likely to be a red star surrounded by a ionization nebula (often present around the ULX). The V magnitude is $\simeq$23, but in Hα (and in the red r filter) the source is at least half a magnitude more luminous.

In order to assess the feasibility of this proposal, we have carefully analyzed the work done with the Gemini North telescope by Liu et al. (2013) who studied the M101 ULS, by Grise' et al. (2011) who optically identified a ULX in Holmberg IX, by Clark & Crowther (2004) for IC 10 X-1 and more recently (Crowther et al. 2010) for NGC 300 X-1 with the VLT, as well as the observations of the M31 symbiotic stars (which in some cases become ULS at some evolutionary stage, see e.g. Orio et al. 2007) of Mikolawjeska et al. (2014) with the MMT telescope.

• Bachetti, M., et al. 2014, Nature, 514, 202 • Clark, J.S., & Crowther, P.A. 2004, A&A, L45 • Crowther, P.A., et al. 2010, MNRAS, 403, L45 • Fabbiano, G., et al. 2003, ApJ, 571, 843 • Liu, J.

2011, ApJS, 192, 10 • Liu. J. et al. 2013, Nature, 503, 500 • Orio, M.,et al. 2007, ApJ, 661, 1105 • Orio, M. 2013, AstRv, 8, 71 • Mikolajewska, J. et al. 2014, MNRAS, 444, 586

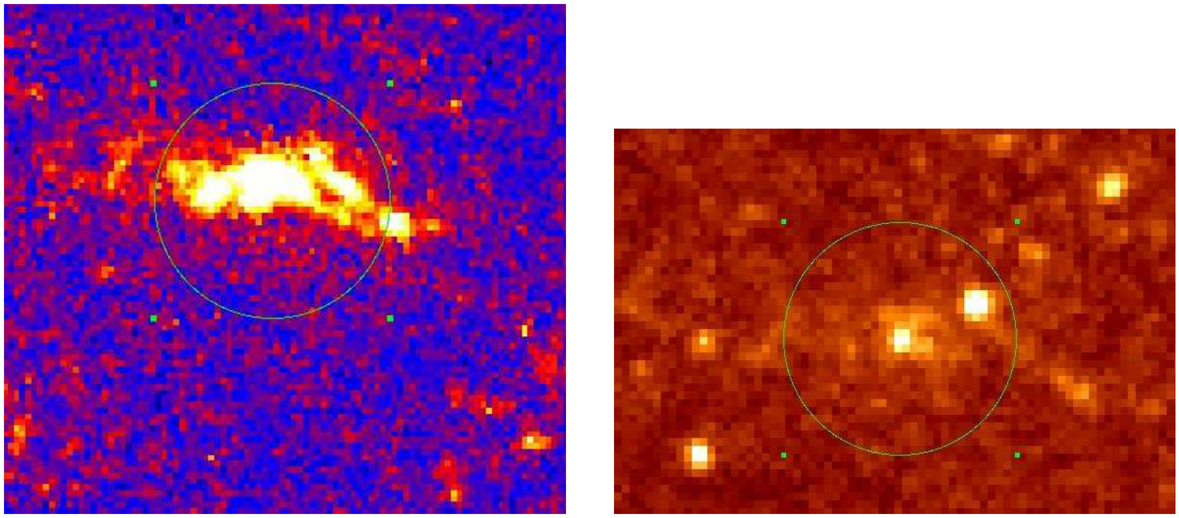


Figure 1: On the right, the HST image of the field of the M51 ULS in F555W (V) filter. The green circle shows the Chandra position (given by Liu 2011) once the Chandra and HST images were registered using three 2MASS luminous objects. A circle with radius of 0.75" (proposed slit width) is drawn around the Chandra position, determined with an accuracy of 0.4". On the left is the Hα HST ACS image obtained with the Hα filter. (and a 1" radius circle).

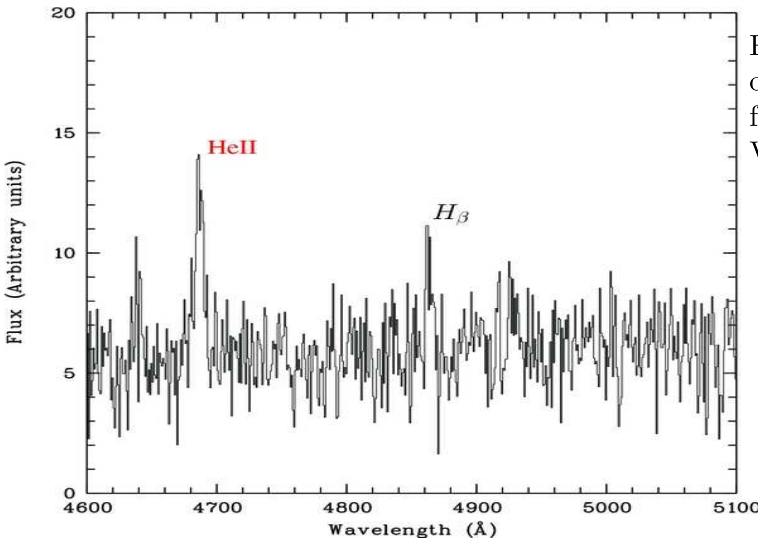


Figure 2: A portion of the spectrum obtained by Grise' et al. (2011) for Holmberg IX X-1, a ULX with V=22.6

Experimental Design

We propose to use the B600 grism, centered on 5300 A using a 0.75" slit. This setup has successfully been used by similar studies (Liu, 2013, and by Grise', 2011), and covers the wavelength range from 3800-6800 at resolution R$\simeq$1700 or $\leq$4 Å across the entire spectral range. We will use a 2x2 binning, in both spectral and spatial direction, resulting in a pixelscale of 1.0 Å per pixel, to minimize read-noise while providing adequate spectral sampling.

We request 10 exposures of 1500 s each, that we plan to co-add. The S/N we plan to achieve in the emission lines that we expect to detect varies significantly depending on the true nature of the source, but we expect to obtain S/N$\geq$5 (see below). We know that our target is luminous in Hα, and that the Hα emission often originates in an accretion disk. We would like to distinguish broadly between physical types of spectra through these simple diagnostics:
a) An H II region that is not associated with the X-ray source would have strong and narrow lines, including [O III], and no helium lines (see simulation);
b) Our main diagnostic is the He II line at 4686 Å which is typical of X-ray binaries;
c) An X-ray (XRB) binary has much broader and less strong emission lines than an H II region (see the attached simulation for details);
d) In an XRB hosting a black hole, the Balmer lines may be completely absent, and most likely H α would be comparable or even much weaker than He II line at 4686 Å, which is very distinctive;
d) Balmer lines may originate in an IMBH disk, but in this case they should be very distinctly broadened (e.g. width of 750 km s^{-1}, see Cseh et al. 2011), much more than in a symbiotic or other WD binary;
d) An extremely hot WD in a hydrogen burning symbiotic would display a [Fe X] forbidden line iat 6374 Å, which we may be able to detect and measure (see Orio et al. 2007);
e) If the X-ray source is a background AGN, which cannot be completely ruled out (a SSS in M31 has been associated with an AGN), we will be able to measure a red shift of Hα or other emission lines and find that it is *not* consistent with memberhip in M51.

• Cseh, D. et al. 2011, ApJ, 728, L5

Technical Description

The exposure times and sky-conditions have been chosen to provide a continuum signal-to-noise ratio ≥ 5 in the lines, adequate to measure line fluxes and equivalent widths as required by our science case. The S/N would however greatly depend on the specific line and on the physical nature of the object, which we want to reveal.
We calculated an overhead of 20 minutes for the acquisition of each target, assuming that it will take longer than the average 16 minutes in crowded fields with faint objects. The acquisition will be done twice during a night. The configuration time will be 170 s, the read-out time for the full frame will be 49s, adding a total of 490 s. The total time is thus 5.02 hours.
As outlined above, there are two possible stellar candidates 0.4" apart from each other although only the fainter one is at the center of the Hα nebula. We ask to include both of them in the slit, with the less luminous one at the center edge of the nebula at the slit center, the other at the side, orienting the slit by using another luminous star, far from the targets.
The challenge in this observations is the elevated galactic background because the source is in a spiral arm. We observed M51 in Hα and in broad band filters with the WIYN 3.5m telescope and the pODI imager, and we are aware that the background varies from magnitude 19.5 to 20 per arcsecond in the different filters. Therefore, in simulating the exposures with the ITC, we assumed grey sky conditions even if we do require dark time. Fig. 2 shows the He II λ4696 region observed for the M101 ULX by Grise' et al. (2011), obtained by adding 5 exposures of 1000 s. This source is much less effected by the background of the galaxy. We tried simulating the single lines one by one, but here we attach the case model that may look more similar to an XRB, that of a QSO. In addition, we simulated a completely different case in which we just observe the spectrum of an H II region, without detecting the XRB or the nebula associated with it. The simulation indicate that we would definitely be able to assess whether the Hα emission in the images is due to a small H II region or, as we expect, to the XRB observed with *Chandra*.

Band 3 Plan

Classical Backup Program

Justify Target Duplications

Publications

Use of Other Facilities or Resources

We have used the multi-filter HST ACS image in the legacy archive, and our WIYN exposures in g, r, and Hα of M51.

Previous Use of Gemini

Reference	Allocation	% Useful	Status of previous data

ITC Examples

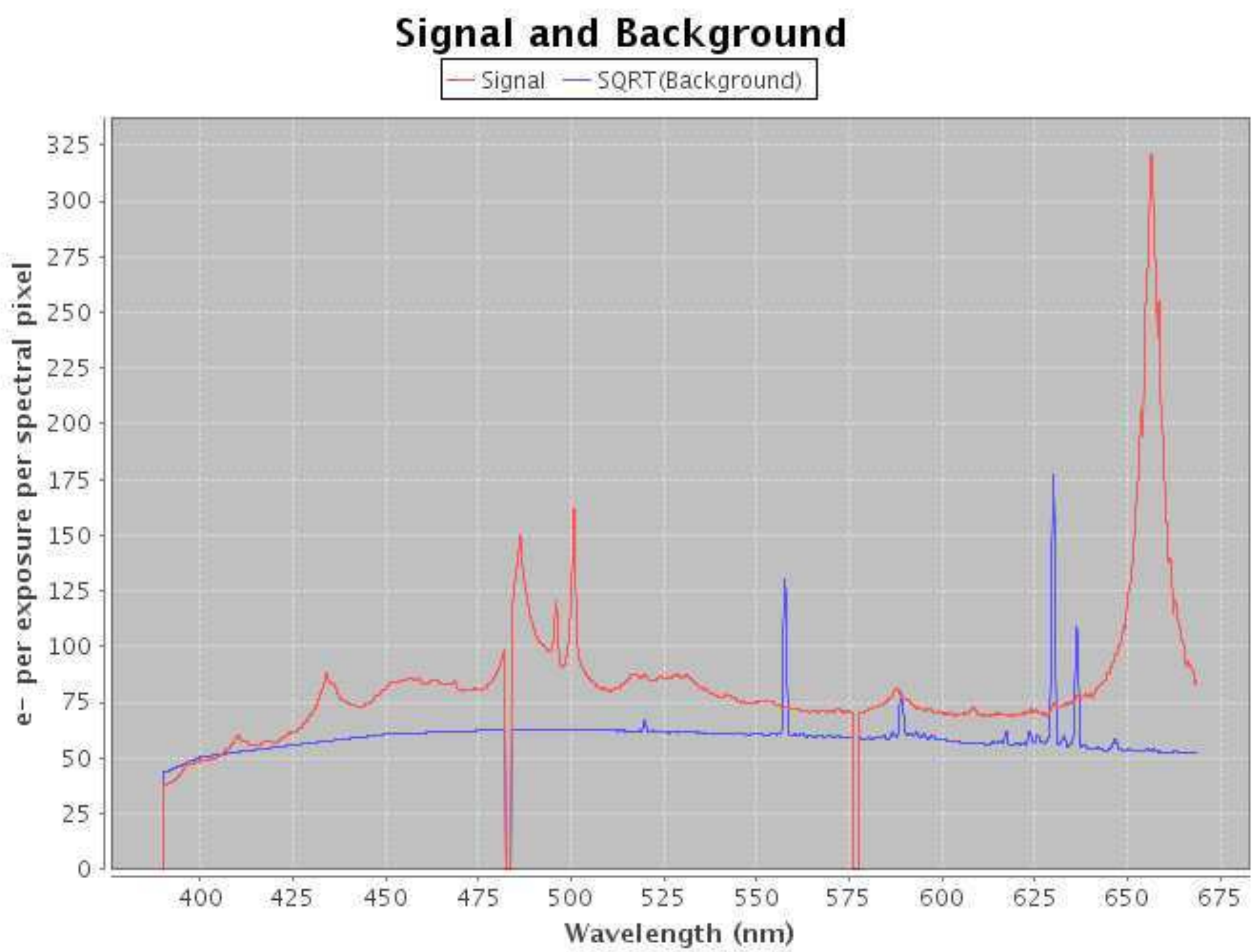
Gemini Integration Time Calculator
GMOS version 5.0

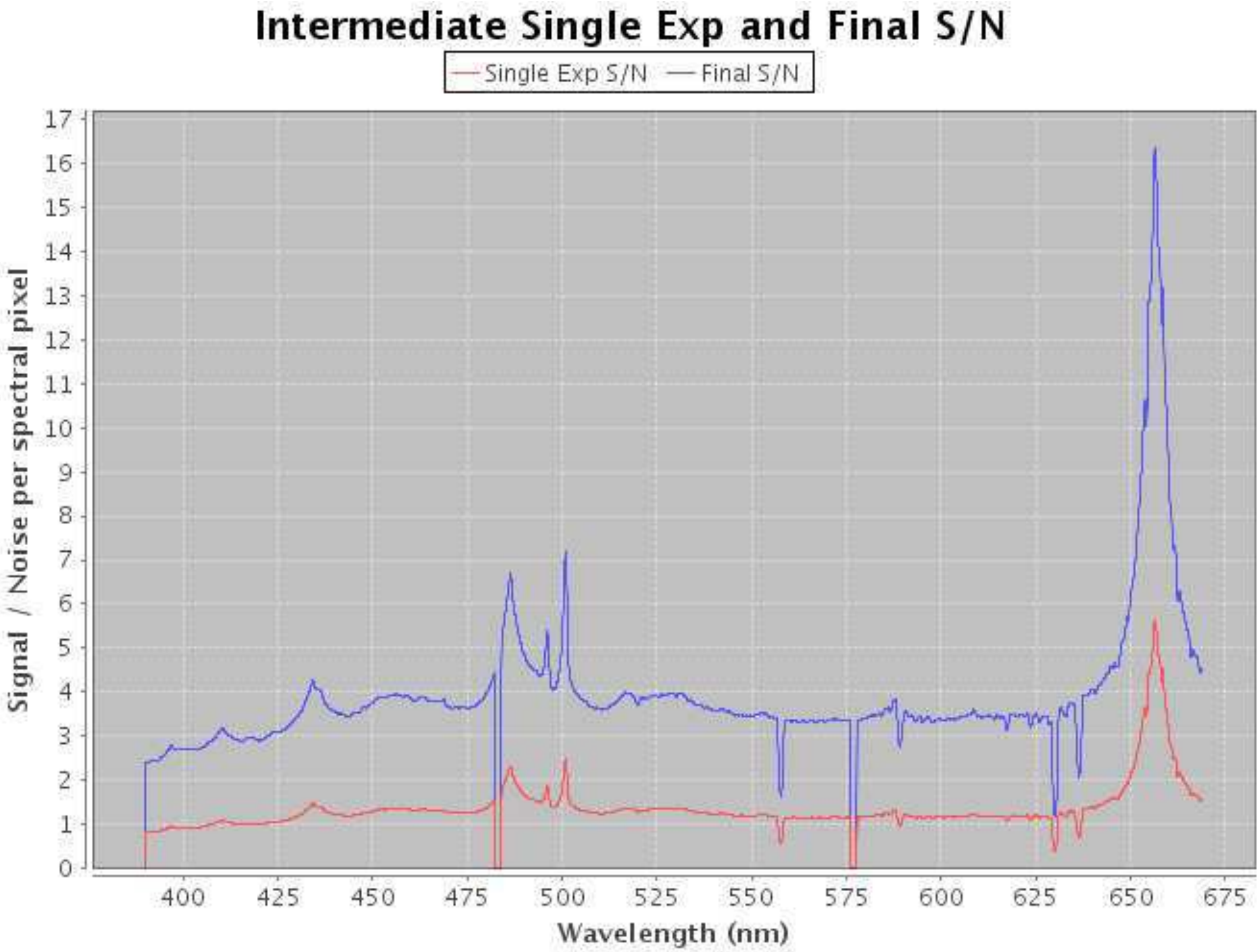
Click here for help with the results page.
Read noise: 3.6
software aperture extent along slit = 1.27 arcsec
fraction of source flux in aperture = 0.60
derived image size(FWHM) for a point source = 0.90arcsec

Sky subtraction aperture = 5.0 times the software aperture.

Requested total integration time = 15000.00 secs, of which 15000.00 secs is on source.

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.





Output:

- Spectra autoscaled.

Input Parameters:
Instrument: GMOS-N

Source spatial profile, brightness, and spectral distribution:
The z = 0.0 point source is a 22.9 mag QSO2 in the V band.

Instrument configuration:
Optical Components:

- Fixed Optics
- Grating Optics: B600_G5303
- Detector - EEV DD array
- Focal Plane Mask: slit0.75

Central Wavelength: 530.0 nm

Spatial Binning: 2
Spectral Binning: 2
Pixel Size in Spatial Direction: 0.1454arcsec
Pixel Size in Spectral Direction: 0.09nm

Telescope configuration:

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

Observing Conditions:

- Image Quality: 70.00%
- Sky Transparency (cloud cover): 50.00%
- Sky transparency (water vapour): 100.00%
- Sky background: 80.00%
- Airmass: 1.20

Frequency of occurrence of these conditions: 27.99%

Calculation and analysis methods:

- mode: spectroscopy
- Calculation of S/N ratio with 10 exposures of 1500.00 secs, and 100.00 % of them were on source.
- Analysis performed for aperture that gives 'optimum' S/N and a sky aperture that is 5.00 times the target aperture.

Gemini Integration Time Calculator
GMOS version 5.0

Click here for help with the results page.
Read noise: 3.6
software aperture extent along slit = 1.27 arcsec
fraction of source flux in aperture = 0.60
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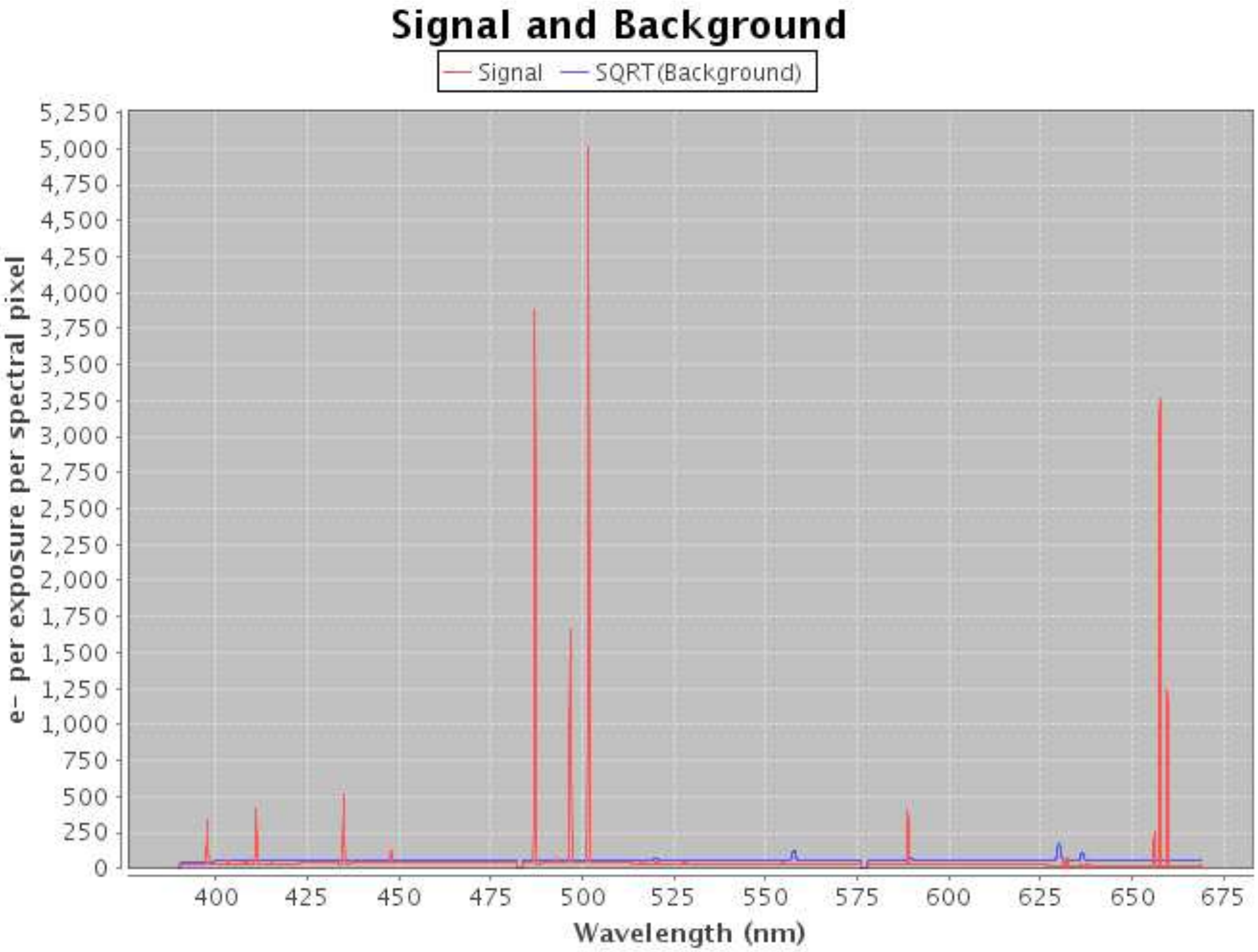
Signal and Background
Signal
SQRT(Background)
e- per exposure per spectral pixel
Wavelength (nm)
5,250
5,000
4,750
4,500
4,250
4,000
3,750
3,500
3,250
3,000
2,750
2,500
2,250
2,000
1,750
1,500
1,250
1,000
750
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500
525
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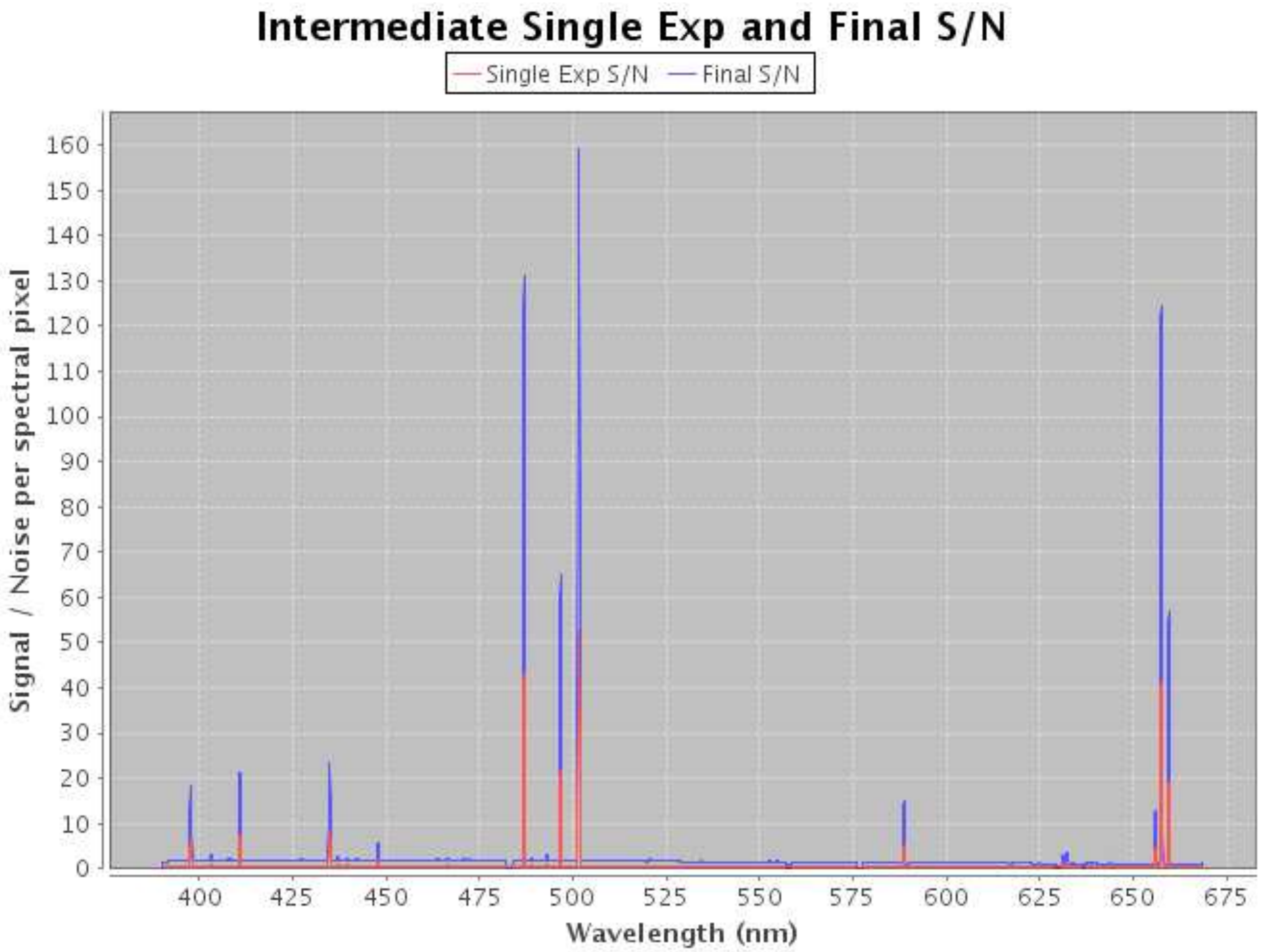
625
650
675



Output:

- Spectra autoscaled.

Input Parameters:
Instrument: GMOS-N

Source spatial profile, brightness, and spectral distribution:
The z = 0.0020013342228152103 point source is a 22.9 mag Orion-nebula in the R band.

Instrument configuration:
Optical Components:

- Fixed Optics
- Grating Optics: B600_G5303
- Detector - EEV DD array
- Focal Plane Mask: slit0.75

Central Wavelength: 530.0 nm
Spatial Binning: 2
Spectral Binning: 2
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