GEMINI OBSERVATORY

observing time request summary

Semester: 2018B **Observing Mode:** Queue **Gemini Reference:**

Instruments: GNIRS

Time Awarded: NaN **Thesis:** No

Band 3 Acceptable: No

Title: **AGN feedback during the peak of cosmic star formation**

Principal Investigator: **Allan Schnorr Müller**
PI institution: Universidade Federal do Rio Grande do Sul (UFRGS), Departamento de Astronomia - IF Av. Bento Gonçalves, 9500 Campus do Vale 91540-000 - Porto Alegre - RS, Brazil
PI status: PhD
PI phone/e-mail: +55 51 33087257 / allanschnorr@gmail.com
Co-Investigators: **Cristina Furlanetto**: Universidade Federal do Rio Grande do Sul (UFRGS), cristina.furlanetto@ufrgs.br
Thaisa Storchi-Bergmann: Universidade Federal do Rio Grande do Sul (UFRGS), thaisa@ufrgs.br

---

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

	PI Request			NTAC Recommendation			
Partner	**Lead**	**Time**	**Min**	**Reference**	**Time**	**Min**	**Rank**
Brazil	Schnorr Müller	8.8 hr	3.5 hr		NaN	NaN	
	Total Time	*8.8 hr*	*3.5 hr*		*0.0 hr*	*0.0 hr*	

Total Time of Observations

Band	GN	GS
Band 1/2	8.8 hr	0.0 hr
Band 3	0.0 hr	0.0 hr

Abstract

This proposal consists in using GNIRS in cross-dispersed spectroscopic mode to observe a sample of 5 carefully selected emission line lensed galaxies at 1.3 < z < 2.4 aiming at measuring accurately their emission line fluxes, as well as investigating some properties of their interstellar gas, such as kinematics (e.g. looking for AGN driven outflows) and excitation mechanisms. The optical rest-frame nebular emission lines shifted to the near-infrared region can be used to study the star formation properties and for BPT and WHAN diagram diagnostics, which can distinguish if the lensed sources are pure star-forming galaxies or they also host AGNs. In the latter case, the [OIII] emission, as a good tracer of outflows, will allow us to measure the outflow velocity and determine if the outflowing gas can escape the host. This will allow us to identify the most compelling cases for a future follow-up program with integral

field instrument assisted by adaptive optics aimed to study AGNs feedback at the peak of the cosmic star formation.

TAC Category / Keywords

Extragalactic / Gravitational lensing, Star formation, Active galaxies, Evolution, High-redshift

Scheduling Constraints

Observation Details (Band 1/2)

Observation	RA	Dec	Brightness	Total Program Partner
SDSSJ0801+4727	08:01:05.299	47:27:49.540		1.8 hr 1.4 hr 0.3 hr
Conditions: CC 50%/Clear, IQ 85%/Poor, SB Any/Bright, WV Any **Resources:** GNIRS Spectroscopy 0.15"/pix 32 l/mm grating SXD 0.45 arcsec < 2.5um				
SDSSJ0830+5116	08:30:49.733	51:16:31.840		1.8 hr 1.4 hr 0.3 hr
Conditions: CC 50%/Clear, IQ 85%/Poor, SB Any/Bright, WV Any **Resources:** GNIRS Spectroscopy 0.15"/pix 32 l/mm grating SXD 0.45 arcsec < 2.5um				
SDSSJ2122+0409	21:22:52.042	04:09:35.530		1.8 hr 1.4 hr 0.3 hr
Conditions: CC 50%/Clear, IQ 85%/Poor, SB Any/Bright, WV Any **Resources:** GNIRS Spectroscopy 0.15"/pix 32 l/mm grating SXD 0.45 arcsec < 2.5um				
SL2SJ084909-041226	08:49:09.510	-04:12:26.700		1.8 hr 1.4 hr 0.3 hr
Conditions: CC 50%/Clear, IQ 85%/Poor, SB Any/Bright, WV Any **Resources:** GNIRS Spectroscopy 0.15"/pix 32 l/mm grating SXD 0.45 arcsec < 2.5um				
SL2SJ084959-025142	08:49:59.750	-02:51:42.800		1.8 hr 1.4 hr 0.3 hr
Conditions: CC 50%/Clear, IQ 85%/Poor, SB Any/Bright, WV Any **Resources:** GNIRS Spectroscopy 0.15"/pix 32 l/mm grating SXD 0.45 arcsec < 2.5um				

Scientific Justification

In the last two decades, a number of observations [1] have shown that supermassive black hole (SMBH) masses are tightly correlated with host galaxy properties, implying that SMBH play a major role in the evolution of their hosts. The process by which this is believed to occur is called AGN (Active Galactic Nucleus) feedback. It consists of injection of mechanical energy (through radio jets) and/or radiative energy (through accretion radiation coupling to the gas on small scales and launching outflows) on the host interstellar medium by the AGN. These two modes of energy injection are referred to as mechanical and radiative AGN feedback, respectively.

While there is observational evidence that, in the densest environments and in the local Universe, radio jets driven by AGN can maintain host galaxy star formation at low levels by suppressing the ability for hot halo gas to cool [2], the impact of radiative AGN feedback on the host galaxy evolution is still a matter of debate. Observations of local low to intermediate luminosity AGN have found that, in these objects, AGN-driven outflows do not extend beyond the inner 1 kpc [3,4]. Meanwhile, at higher redshifts, most studies have focused on luminous quasars, where galaxy wide AGN-driven outflows, which sweep away or heat up large amounts of gas hence suppressing star formation, have been observed [5]. Luminous quasars, however, are rare objects, comprising less than <1% of the star-forming population in the same mass range [6].

A sample of 89 x-ray detected AGNs, covering an ample range of luminosities, have been studied by Harrison et al. [7], which found that ≈50% of the objects have ionized gas velocities indicative of outflows and/or highly turbulent material. In a study of 110 massive star-forming galaxies between z = 0.8–2.6, Genzel et al. [8] reported that more than 50% of the objects in the sample had broad Hα, [N II], and [S II] emission lines, which they argue are due to AGN-driven outflows (see Fig.1).

Our goal is to probe AGN feedback in the redshift range 1 < z <3, as this epoch witnessed both peaks of accretion activity of SMBH and of star formation rate (SFR) in the Universe [9; figure 1]. Although the aforementioned studies point to a high incidence of outflows in high-z AGN, current facilities, including those assisted by adaptive optics (AO), limit the spatial resolution achievable to around $1 - 1.5$ kpc at $z \sim 2$, which restricts what can be concluded on the impact of the nuclear activity on the host galaxy gas (and consequently star formation). Besides, due to sensitivity reasons, most of the studies on galaxy evolution at $z > 1$ focus on luminous and massive galaxy populations; there is a lack of studies on AGN feedback in a less massive galaxy population at this redshift range. We propose to use the elegant solution of gravitational lensing to circumvent these limiting factors, as lensed objects appear to have their angular size and flux increased. This effect allows us to resolve sub-kpc scales and study small and compact galaxies at higher z [10,11,12,13].

The current proposal consists in using GNIRS in cross-dispersed spectroscopic mode to observe a sample of 6 carefully selected emission line lensed galaxies at $1.3 < z < 2.2$ aiming at confirming the redshift of the lensed sources, measuring accurately their emission line fluxes, as well as investigating some properties of their interstellar gas, such as kinematics (e.g. looking for outflows) and excitation. Optical rest-frame nebular emission lines (Hα, Hβ, [OIII] and [NII]) shifted to the near-infrared (NIR) region can be used to study the star formation properties and for BPT diagram diagnostic, which can distinguish if the sources are pure star-forming galaxies or they host AGNs.

The most compelling cases will be followed up with NIR integral field unit (IFU) instruments assisted by AO. Combining the gravitational lensing effect with the power of IFU+AO observations, we will be able to spatially resolve the outflows and study its impact on the host interstellar medium at sub-kpc scales. This will be crucial to distinguish between different quenching mechanisms and obtain new insights into the physics of high-z galaxies.

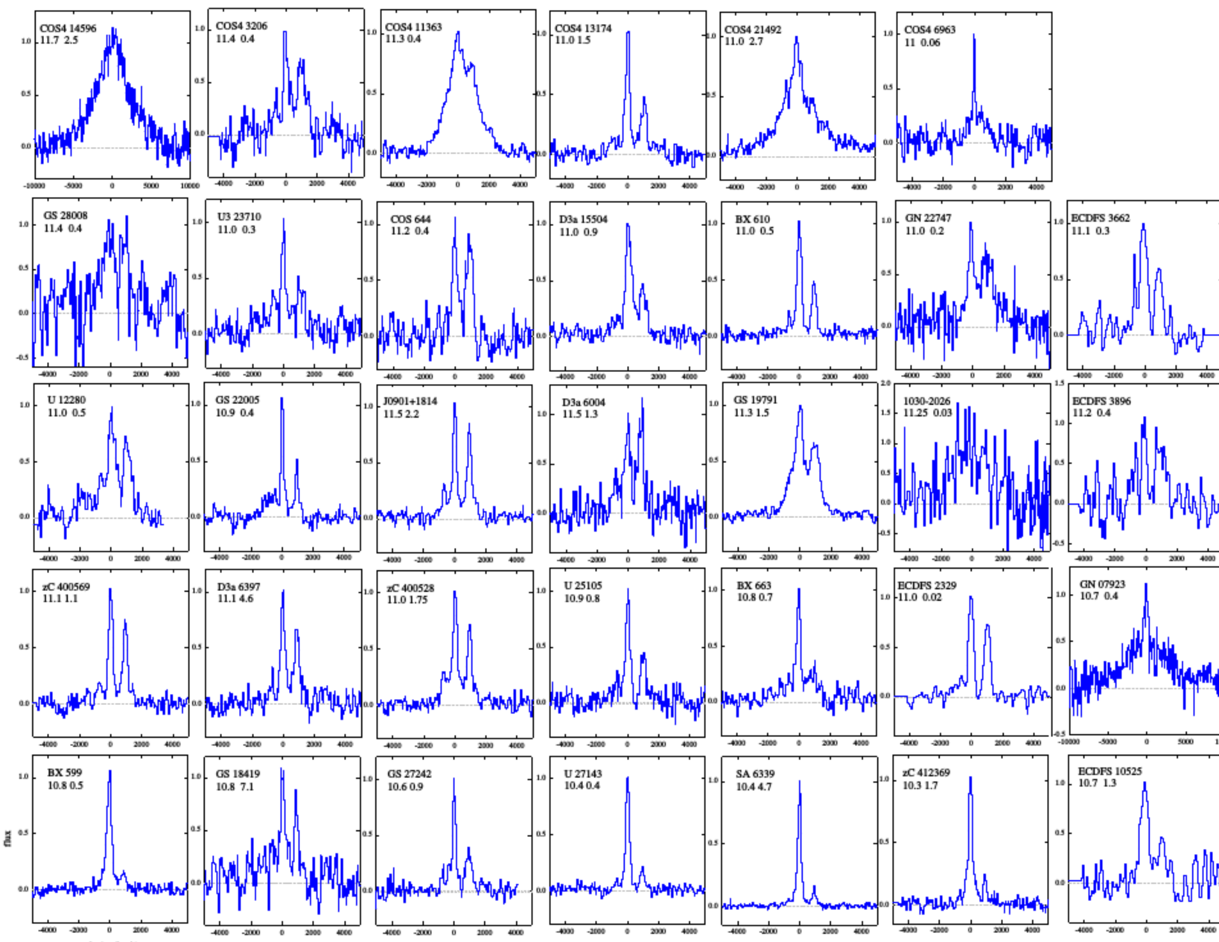


Figure 1: [N II]+Hα emission from $1 < z < 3$ star forming galaxies (Fig. 2 from Genzel et al. 2014 [8]). The broad (σ of the order of hundreds of km/s) base in the [N II] and Hα is due to AGN-driven outflows, while the narrow core of the lines is likely due to gas ionized by young stars. The proposed instrumental setup will provide us with similar high quality spectra. Additionally, the observed spectra will also include the [OIII] 5007Å line, which will make the task of identifying AGN driven outflows easier as these "broader bases" are stronger on [O III] compared to [N II] and Hα, as seen in the spectra of many local AGN.

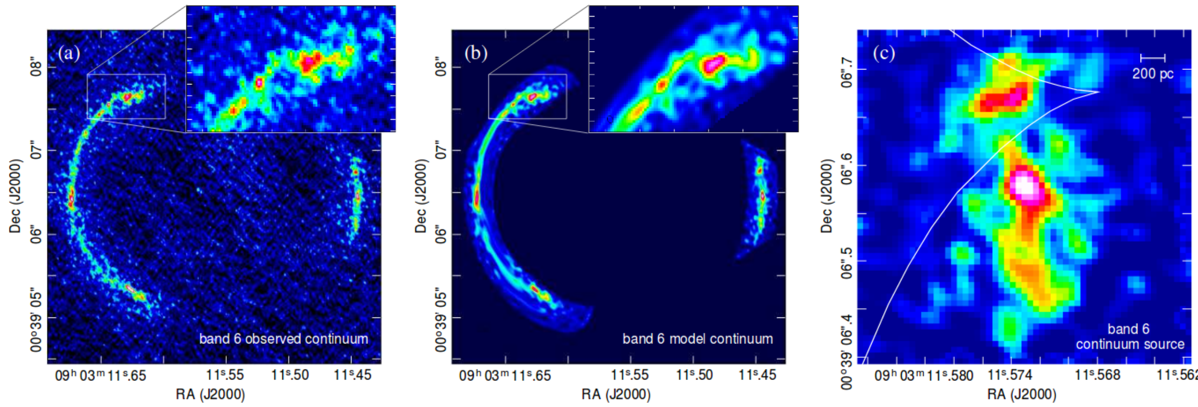


Figure 2: Figure from Dye et al. 2015 [13] showing the reconstruction of an ALMA band 6 continuum image of a lensed galaxy at $z \approx 3$. The reconstruction was performed by Co-I Cristina Furlanetto. The observed images are shown in panels (a), the model images of the reconstructed source are shown in panels (b) and the reconstructed sources are shown in panels (c). The white line in the source maps shows the position of the caustic. The inset zooms indicate the fidelity of the reconstruction.

References

[1] Kormendy, J. & Ho, L. C. 2013, ARA&A, 51, 511

[2] Fabian, A. 2012, ARA&A, 50, 455

[3] Schnorr-Muller, A. et al., 2014, MNRAS, 437, 1708.

[4] Karouzos, M. et al., 2016, ApJ, 833, 171.

[5] Cano-Daz, M. et al., 2012, A&A, 537, 7.

[6] Boyle, B. J. et al., 2000, MNRAS, 317, 1014.

[7] Harrison, C. M. et al., 2016, MNRAS, 456, 1195.

[8] Genzel, R. et al. 2014, ApJ, 796, 7.

[9] Madau, P. & Dickinson, M. 2014, ARA&A, 52, 415

[10] Marshall, P. et al. 2007, ApJ, 671, 1196

[11] Riechers, D. A. et al. 2008, ApJ, 686, 9.

[12] Stark et al. 2008, Nature, 455, 775

[13] Dye S., Furlanetto, C. et al. 2015, MNRAS, 452, 2258

[14] Moustakas et al. (in prep)

[15] Warren & Dye, 2003, ApJ, 590, 673

[16] Livermore, R. et al. 2015,MNRAS, 450, 1812

Experimental Design

We propose to conduct GNIRS cross-dispersed spectroscopy of a sample of 5 emission line lensed galaxies at redshift of $1.3 < z < 2.4$. This redshift range was chosen in order to cover both peaks of the cosmic star-formation rate and of the accretion activity of SMBHs. We aim to provide diagnostic information about the energetics of these lensed sources, using the optical rest-frame nebular emission lines shifted in the NIR region. We also aim to confirm the redshift of these sources, as they are measured only from a single emission line.

The lensed galaxies in the sample were selected from the Master Lens Database[1] [14], a compilation of all strong gravitational lenses that are known and a community repository for candidate lenses. The selection was based on the following constraints:

(i) selection of grade-A (confirmed) galaxy-galaxy lens systems, for which we can perform the lens modeling and reconstruct the background source;

(ii) availability of spectroscopic redshift of both lens and background source (to ensure that spectral lines of interest are placed within the GNIRS bands);

(iii) having the optical rest-frame nebular emission lines [OIII] 5007Å, Hα and Hβ redshifted to the Z, J, H and K region;

(iv) availability of high-resolution imaging for lens modeling;

(v) availability of guiding star and blind-offset star;

From over 674 gravitational lens systems in the database, we reduced the sample to 35 systems by applying criteria (i) and (ii). The criteria (iii) excludes 4 systems and criteria (iv) 13 more. From the 18 remaining objects, 8 are not visible in 2018B period, 3 have NIR spectroscopic data already available [16] and 2 do not satisfy criteria (v). The final sample contains 5 systems.

We aim to measure the intensity of the emission lines [OIII] 5007Å, Hα and Hβ in order to study the star formation properties, aspects of the gas kinematics and the excitation mechanisms of the lensed galaxies. In contrast to previous studies that used Hα emission to investigate the presence of outflows [8], we will probe outflows using the [OIII] 5007Å line, which is a strong emission line in shocked gas and a better tracer of outflows. This is observed in nearby AGN, where the broad wings (associated to outflows) observed in emission line profiles are much stronger in [OIII] 5007Å.

Given the redshift of the lensed sources, the emission lines of interest (Hβ, Hα, [OIII] 5007Å and [NII]) are expected to fall in the GNIRS XD spectral range. Therefore, we request to use cross-dispersed mode of GNIRS covering the Z, J, H and K spectral bands, which is a suitable choice to study the energetics of the lensed galaxies.

We will fit the emission line profiles with Gaussians in order to obtain the line fluxes, line-of-sight velocities, velocity dispersions and to separate the outflowing components from the other components, if present. We will use the Hα and Hβ emission lines to estimate extinction and to obtain Hα luminosities, which can be used to estimate the star formation rates. We will also build diagnostic diagrams, such as BPT and WHAN, to investigate the nature of the ionized source. In the case of detection of an outflow, we will compare the outflow velocities to typical values of galaxy escape velocities in order to check whether the outflowing gas can escape the host.

The results of this analysis will be used to identify the compelling cases of our sample for a future follow-up program with IFU+AO aimed to study AGNs outflows at the peak of the cosmic star formation. We will perform the source reconstruction using the semi-linear inversion method from Warren & Dye [13,15] to adequately assess the extent and power of the outflows.

[1]http://masterlens.astro.utah.edu/

Technical Description

The goal of this program is to obtain near-infrared spectroscopy in the Z, J, H and K bands using GNIRS in the cross-dispersed mode of a carefully-selected sample of emission lines lensed galaxies at intermediate redshift. We aim to confirm the redshift and potentially provide diagnostic information about the energetic of a sample of galaxies (1.3<z<2.4), using the optical rest-frame nebular emission lines shifted in the Z, J, H and K region. For this reason, we have chosen the combination of the 32 l/mm grating + 0.45″ slit, which provides a full and continuous wavelength coverage with spectral resolution of $R \approx$1500. For luminous AGNs, the velocity dispersion due to ouflows for [OIII] is tipically $\geq$ 300 km/s. This spectral resolution will allow us to resolve AGN-driven outflows, in case they are present.

The targets have $20 < \mathrm{i} < 23$ mag and we have verified that reference stars are available with separation less than 60″ for all of them. An offset accuracy of 0.2″ in centering the science targets after the reference star acquisition is acceptable for our purposes. We confirmed with the ITC that the emission lines will be detected with S/N≈ 20 by taking 12 exposures of 300 s, under the conditions IQ=85, CC=50, WV=Any and SB=Any. This will allow us to meet our primary goal of confirming the redshift and provide enough S/N to detect the diagnostic emission lines. Attached we include the ITC output obtained by assuming a typical Hα line flux of 5×10^{-16} erg/s/cm^2 to a lensed galaxy with redshift of $z = 1.4$. For fainter lines the S/N will be lower, however not lower than S/N=4.

For each target, we adopt a 1 hour on-source exposure (O), splitting into 12x300s individual exposure, using a OSO observing strategy (with S=sky frame). Due to the extended emission of the lensed galaxies we will spend half of the total time on full sky frame. We estimate 24 min for overheads, including one acquisition per visit (12 min), re-centering (6 min) and read-out (6 min). The used the Gemini Phase I Tool (PIT) to estimate calibration overheads for each observation (1h on source + 24 min other overheads), which gives a total of 1.75 hours per visit. We plan a total of 1 visit for each lensed galaxy, hence a total requested time of 8.75 hours.

Band 3 Plan

This program is not suitable for band 3.

Classical Backup Program

This is not a classical request.

Justify Target Duplications

The GOA search revealed no duplicate observations.

Publications

Dye S., **Furlanetto, C.** et al. 2015, MNRAS, 452, 2258

Dye S., **Furlanetto, C.** et al. 2017, arXiv:1705.05413

Schnorr-Müller, A. et al. 2016, MNRAS, 462, 3570

Riffel, R. A., **Storchi-Bergmann, T.** et al. 2017, MNRAS, 470, 992

Lena, D., Robinson, A., **Storchi-Bergman, T.**, **Schnorr-Müller, A.** et al., 2017, ApJ, 806, 84

Lemoine-Busserolle, M. et al. 2010, MNRAS, 401, 1657

Use of Other Facilities or Resources

We intent to use NIR IFU facilities (e.g. NIFS, VIMOS, etc) in the near future as a consequence of this proposal, since IFU has not been explored so far for such lensed systems.

Previous Use of Gemini

Reference	Allocation	% Useful	Status of previous data
GN-2018A-Q-206	4.4h	–	Objects have not been observed yet

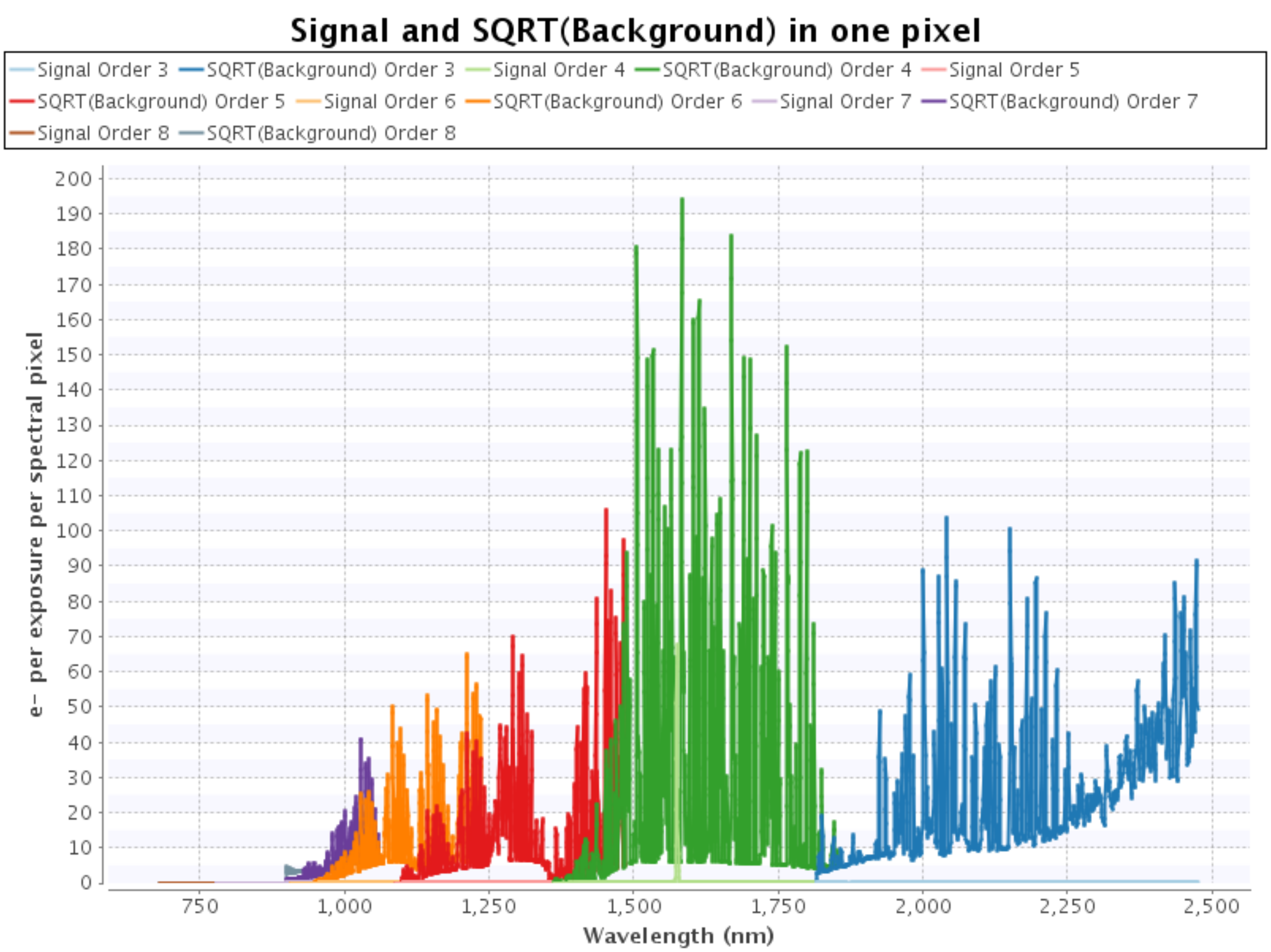
Gemini Integration Time Calculator
GNIRS - 2018A.1.1.3

Click here for help with the results page.
software aperture extent along slit = 1.52 arcsec
fraction of source flux in aperture = 0.33
derived image size(FWHM) for a point source = 1.10 arcsec

Sky subtraction aperture = 1.0 times the software aperture.

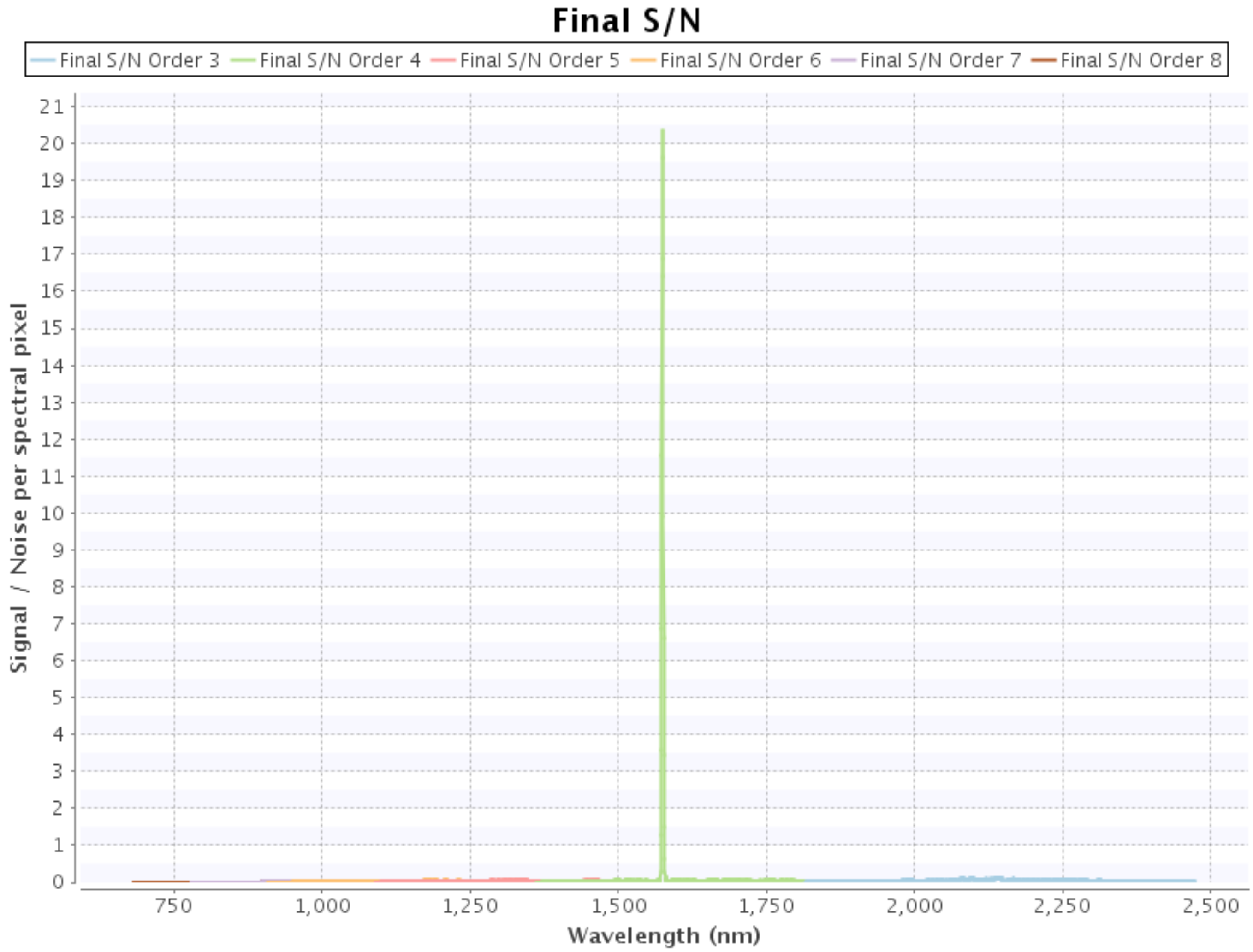
Requested total integration time = 3600.00 secs, of which 3600.00 secs is on source.

The peak pixel signal + background is 37665 e- (2790 ADU). This is 42% of the full well depth of 90000 e-.



Click here for ASCII signal spectrumOrder 3.
Click here for ASCII signal spectrumOrder 4.
Click here for ASCII signal spectrumOrder 5.
Click here for ASCII signal spectrumOrder 6.
Click here for ASCII signal spectrumOrder 7.

Click here for ASCII signal spectrumOrder 8.
Click here for ASCII background spectrumOrder 3.
Click here for ASCII background spectrumOrder 4.
Click here for ASCII background spectrumOrder 5.
Click here for ASCII background spectrumOrder 6.
Click here for ASCII background spectrumOrder 7.
Click here for ASCII background spectrumOrder 8.



Click here for Final S/N ASCII dataOrder 3.
Click here for Final S/N ASCII dataOrder 4.
Click here for Final S/N ASCII dataOrder 5.
Click here for Final S/N ASCII dataOrder 6.
Click here for Final S/N ASCII dataOrder 7.
Click here for Final S/N ASCII dataOrder 8.

Input Parameters:
Instrument: GNIRS

Source spatial profile, brightness, and spectral distribution:
The z = 1.40000 extended source is an emission line, at a wavelength of 0.6563 μm, and with a width of 500.0 km/s.
It's total flux is 5.0E-16 erg/s/cm² on a flat continuum of flux density 1.0E-19 erg/s/cm²/Å.

Instrument configuration:
Optical Components:

- Filter: X_DISPERSED
- Cross-Dispersing Prism
- Fixed Optics
- Camera: 0.15arcsec/pix (Short Blue)
- Detector - 1K x 1K ALADDIN III InSb CCD
- Focal Plane Mask: 0.45 arcsec
- Grating: 32 l/mm grating
- Read Noise: 10.0
- Well Depth: 90000.0

Central Wavelength: 1610.0 nm
Pixel Size in Spatial Direction: 0.15 arcsec
Pixel Size in Spectral Direction(Order 3): 0.647 nm
Pixel Size in Spectral Direction(Order 4): 0.485 nm
Pixel Size in Spectral Direction(Order 5): 0.388 nm
Pixel Size in Spectral Direction(Order 6): 0.324 nm
Pixel Size in Spectral Direction(Order 7): 0.277 nm
Pixel Size in Spectral Direction(Order 8): 0.243 nm

Telescope configuration:
- silver mirror coating.
- side looking port.
- wavefront sensor: pwfs

Observing Conditions:
- Image Quality: 85.00%
- Sky Transparency (cloud cover): 50.00%
- Sky transparency (water vapour): 100.00%
- Sky background: 100.00%
- Airmass: 1.50

Likelihood of execution: 42.50%

Calculation and analysis methods:
- mode: spectroscopy
- Calculation of S/N ratio with 12 exposures of 300.00 secs, and 100.00 % of them were on source.
- Analysis performed for aperture of diameter 1.52 and a sky aperture that is 1.00 times the target aperture.

Output:
- Spectra autoscaled.

ITC Examples