GEMINI OBSERVATORY

observing time request summary

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

Instruments: NIFS

Time Awarded: NaN **Thesis:** No

Band 3 Acceptable: No

Title:	**Nature and Dynamics of Clumps in Star-Forming Galaxies at z ~ 1-2**
Principal Investigator:	**Vivian U**
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Reviewer:	Vivian U

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

	PI Request			NTAC Recommendation			
Partner	**Lead**	**Time**	**Min**	**Reference**	**Time**	**Min**	**Rank**
	Total Time	*3.5 hr*	*2.5 hr*		*0.0 hr*	*0.0 hr*	

Abstract

The advent of near-infrared integral field spectrographs with AO has enabled detailed characterization of small-scale properties of galaxies out to high redshifts. Combining the proposed NIFS observations with resolved property maps from modeling multi-band HST images and ISM morphology from ALMA, we aim to investigate the nature of clumps, calibrate small-scale star formation rate diagnostics, measure dust extinction, and constrain the dynamical timescale for gas clouds in star-forming galaxies. For this pilot study, we request 3.5 hours of NIFS+Altair to obtain Halpha distribution and kinematics in two star-forming galaxies at z ~ 1-2.

TAC Category / Keywords

Extragalactic / Structure, Starburst galaxies, Spiral galaxies, Emission lines, High-redshift, Dynamics

Potential Problems

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The submitted proposal has 1 observation with a low probability of suitable guide stars.

Scheduling Constraints

Given the available FT windows and availability of NIFS + Altair, the first ~4 hours of May 8 is the only time that our targets will be observable.

Also, the stated hours requested include overhead, where standards may be observed soon after sunset.

(This is not a classical request. However, given that the only combination of NIFS availability + FT window + observability of the COSMOS field (+ LGS nights) is the first ~4 hours on the night of May 8, we identified it as the only plausible observing time for this program.)

Observation Details (Band 1/2)

Observation	**RA**	**Dec**	**Brightness**	**Total Time** *(including overheads)*
6496	09:59:53.794	01:38:36.640	18.90 K Vega	2.0 hr
Potential problems: Guiding is problematic (0%) **Conditions:** CC 50%/Clear, IQ 70%/Good, SB Any/Bright, WV Any **Resources:** NIFS LGS None J (1.15 - 1.33um)				
125792	09:58:59.138	02:05:04.270	21.00 K Vega	1.5 hr
Conditions: CC 50%/Clear, IQ 70%/Good, SB Any/Bright, WV Any **Resources:** NIFS LGS None K (1.99 - 2.40um)				

Scientific Justification

Nature and Dynamics of Clumps in Star-Forming Galaxies at $z \sim 1-2$

With the proposed NIFS observations we aim to investigate the nature of clumps, calibrate small-scale star formation rate diagnostics, measure dust extinction, and constrain the dynamical timescale of gas clouds in star-forming galaxies. *For this pilot study, we request 3.5 hours of NIFS+Altair to obtain Hα distribution and kinematics in two star-forming galaxies at $z \sim 1-2$.*

Science Goals

A picture of galaxy formation is emerging where clumpy, irregular systems undergo high rates of early accretion and merging, leading to star formation activity, and subsequently settling into secularly evolving Hubble types at intermediate redshifts. However, the specific details of this transition are not well established. To better understand the physics that contribute to the evolution of the Hubble sequence, morphological and dynamical properties of the gas and stellar populations at kpc scales in this epoch of cosmic star formation are key. The powerful combination of space-based high-resolution images, ground-based multiwavelength data, and AO-assisted integral field observations will shed light on the resolved physical and kinematic properties of star-forming galaxies at high redshifts and address the following science objectives.

1. Nature of Clumps in Star-Forming Galaxies

Using high-quality *HST* images we have derived spatially-resolved kpc-scale maps of physical properties (e.g. stellar mass surface density, SFR, extinction) for a sample of star-forming galaxies (Figure 1). The rest-frame $U-V$ color maps revealed distinct red and blue regions inside the galaxies. While the clumps are similar to those seen at higher redshifts (e.g. Wuyts et al. 2012), the corresponding stellar mass surface density maps look smooth with mass concentrated at the central regions. This disparity raises the question for the nature of these clumps. Might the high SFR be due to high fraction of gas content, and/or because of a higher efficiency in their conversion from gas to stars? A direct comparison of Hα maps at similar regions and resolutions with the resolved color and mass maps will constrain the morphology of dust and star-forming gas clouds.

2. Star Formation and Dust Calibration

One of the most widely used SFR indicators is the Hα nebular emission (e.g. Kennicutt 1998). While SED modeling infers the past average SFR, Hα measures the instantaneous SFR. For galaxies out to $z \sim 2$ there is good agreement between these two diagnostics (e.g. Erb et al 2006), but does this trend hold on small scales? Comparing the high spatial resolution Hα maps afforded by NIFS to our SED-fitting derived SFR maps will provide useful calibrations at the kpc scales. One complication of comparing different SFR diagnostics is dust reddening, which is often assumed to be distributed in spherical shells around the galaxy and a standard dust model (e.g. Calzetti et al. 1996) would be applied. Combining the Hα-derived star formation per resolution element with the resolved SED-inferred SFR, UV inferred SFRs, and our derived extinction maps, we will investigate the selective effect of dust obscuration for UV stellar continuum and ionized gas emission.

3. Dynamics and Outflows from Clumps

Using the Hα spectral profile at the clumps of five $z \sim 2$ galaxies, Genzel et al. (2010) measured the gas expulsion rate from these star-forming regions. Although their sample size was small, they showed that giant clumps are the launch sites of powerful outflows, which play an important role in setting the life times of the clumps. From NIFS kinematics, we will measure dynamical time scales, such as the orbital times and survival timescales of gaseous clumps, and compare these to the ages derived from our SED modeling. This will allow us to determine whether stars were formed in situ, or accreted from satellites of the host halo. A resolved and detailed analysis of this nature will enlighten the supposed dynamical settling of rotationally-supported galaxies.

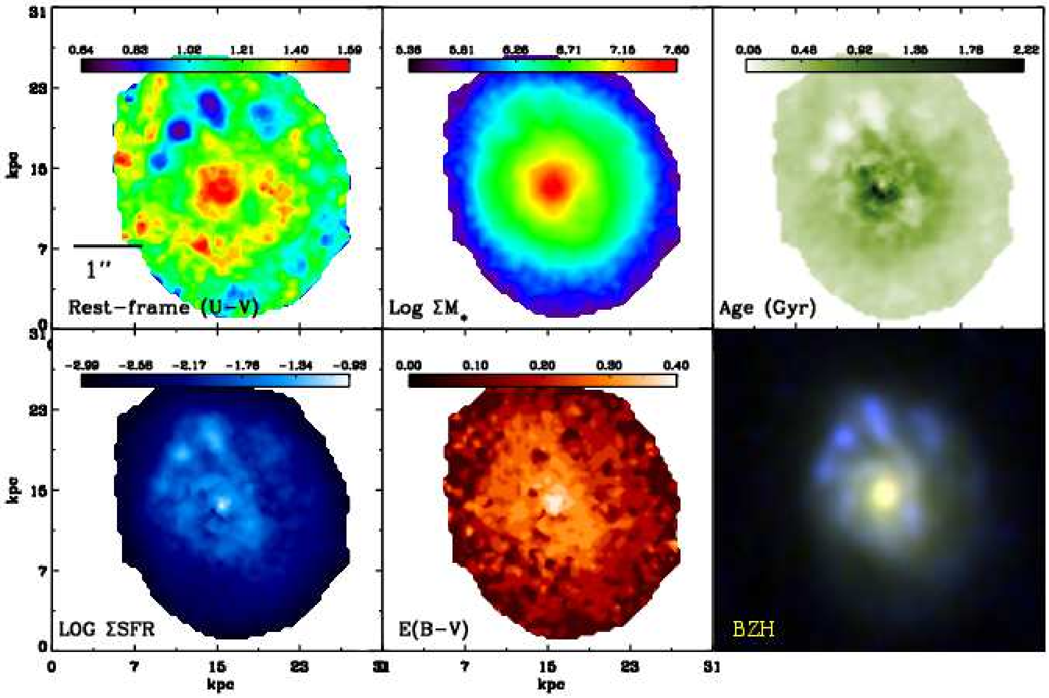


Figure 1: $(U-V)_{\rm rest-frame}$, stellar mass surface density, age, star formation rate surface density, extinction and RGB image of $(B+Z+H)$ from top-left to bottom-right for a galaxy at $z=0.56$. The resolved physical property maps were generated from fitting the observed SED with stellar population synthesis models pixel-by-pixel (Hemmati et al. 2014). This galaxy is representative of the general trends seen in our star-forming galaxies: red bulges and some blue clumps in the underlying green disks, very smooth stellar mass distribution with most of the mass concentrated in the central bulge.

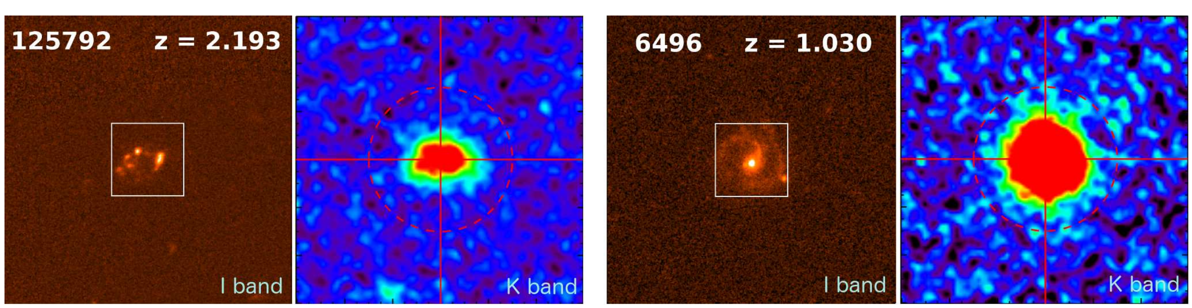


Figure 2: Multi-band (IK) images of our two proposed sources shown in $12'' \times 12''$ frames. The white square $(3'' \times 3'')$ represents the FoV of NIFS. The I-band images of both sources show clumpy nature in the rest-frame UV-optical emission, while the K-band images illustrate the extended optical-NIR continuum.

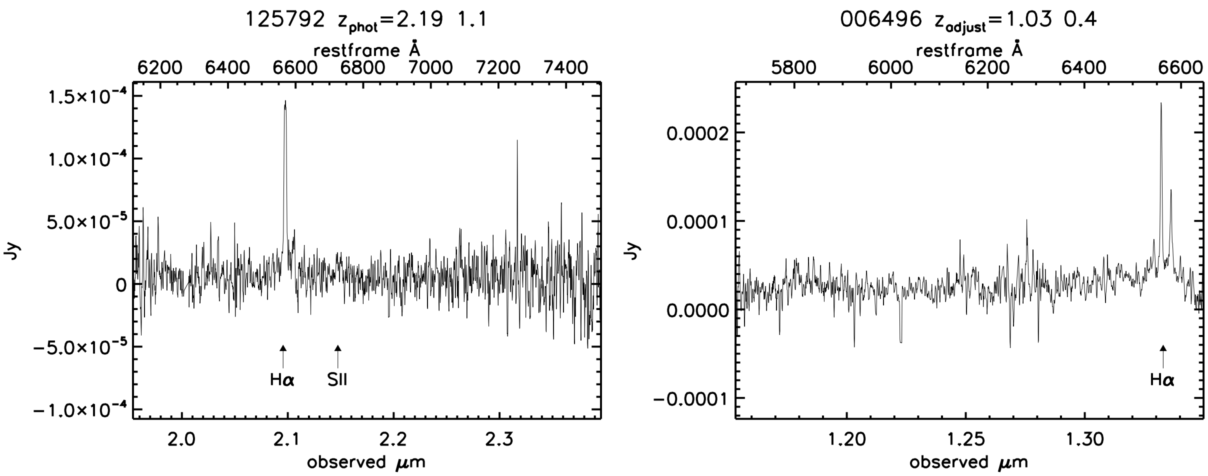


Figure 3: Calibrated MOSFIRE spectra of the two proposed sources showing the nice detection and strength of the Hα lines.

Table 1: Properties of Proposed Targets

ID	RA	Dec	z	$f_{H\alpha}$ (erg s^{-1} cm^{-2} Hz^{-1})	$\lambda_{H\alpha}$ (μm)	$M_\star$ ($M_\odot$)	SFR$_{\rm total}$ ($M_\odot$ yr^{-1})
125792	09:58:59.138	+02:05:04.27	2.193	1.062e-15	2.096	3.467e10	135.4
6496	09:59:53.794	+01:38:36.64	1.030	2.527e-15	1.332	7.586e10	143.8

Table 2: Properties of Guide Stars

Stars	RA	Dec	$b-r$	$b-v$	mag$_r$	Separation (")
125792_tt	09:59:00.3790	+02:05:06.14	0.81	0.45	14.87	18.69
6496_tt	09:59:55.2530	+01:38:31.58	1.96	1.09	16.78	22.45

References

Calzetti et al. 1996, ApJ, 458, 132

Erb et al. 2006, AJ, 647, 128

Genzel et al. 2010, MNRAS, 407, 2091

Hemmati et al. 2014, ApJ, 797, 108

Kennicutt 1998, ARA&A, 36, 189

Law et al. 2007, ApJL, 669, 929

Law et al. 2009, ApJL, 697, 2057

Ravindranath et al. 2012

Scoville et al. 2014, ApJ, 783, 84

Wuyts et al. 2012, ApJ, 753, 114

Experimental Design

This proposal is a pilot study to obtain resolved 2D morphology and kinematic information of the star-forming regions in galaxies at $z \sim 1-2$ using Hα as a probe. This observational approach has previously proven fruitful in discerning the kpc-scale kinematics in actively star-forming galaxies at similar redshifts (e.g. Law et al. 2007, 2009; Genzel et al. 2010). **More importantly, our unique sample coupled with ample ancillary data and analysis technique will generate high-impact results with relatively low investment of observation time.**

Target Selection

Our sample of star-forming galaxies were selected from our successful ALMA Cycle 2 program (PI: Scoville) designed to obtain ISM gas masses and mass fractions in normal main-sequence as well as starburst galaxie. We focus on the subset of 42 sources detected in ALMA and observed with the Multi-Object Spectrograph for Infrared Exploration (MOSFIRE) on Keck (PI: Scoville). The latter constraint of available near-infrared spectra ensures that our targeted feature, Hα, is strongly detected and not located at a skyline. In fact, the 2D spectra reveals potential rotation curve that will be clarified by the proposed NIFS observations. Out of these, 10 objects have nearby guide stars suited within Altair's LGS requirements (R mag < 18.5; distance $< 25''$). We focused on the two objects with the best available guide stars and strongest Hα strength to ensure a high probability of success in this pilot study.

The properties of the proposed objects are listed in Table 1. Both sources have stellar masses of a few $\times 10^{10} M_{\odot}$ and SFR $\approx 100 M_{\odot}$ yr^{-1}, so they are actively forming stars. Their rest-frame UV/optical morphology are demonstrated in the observed high-quality *HST* I-band images as clumpy and barred-sprial like, whereas the K-band images illustrate the extended optical/IR continuum, respectively (Figure 2). The morphologies of these targets promise very interesting analysis for the comparison to resolved property maps. Furthermore, the strength of the Hα line in both MOSFIRE spectra (with integration times 15-25 minutes each) offer favorable chances of success for NIFS observations. Both of these are in the COSMOS field, which will be observable for $\sim$4 hours after sunset on May 8 (the only available FT window with LGS and NIFS available). Together with the availability of decent guide stars (see Table 2), these two sources are the prime targets for this feasibility study and the Fast Turnaround Call.

Analysis

Our primary analysis involves extracting flux-calibrated Hα maps and kinematics from the NIFS data cubes, thus we will require observations of standard stars for flux calibrations. The resulting Hα and SFR maps will be compared directly to the spatially-resolved kpc-scale maps of physical properties derived from high-quality multi-band *HST* images. These maps would be generated from fitting the observed SED with stellar population syntheis models pixel-by-pixel (e.g. Figure 1; Hemmati et al. 2014). Because we will be making direct comparisons, thus we require that the NIFS observations to have high spatial resolution matching that of *HST* and be close to diffraction limited with AO, so that clumps may be identified and studied in detail.

Since we can extract gas and ISM mass estimation from ALMA observations (Scoville et al. 2014) and stellar mass estimateion from SED fitting, we can compute total mass from the IFU observations and rotation curves and help constrain the gas and stellar mass fractions to the total mass in these systems. The results will give insight on whether the high SFR in these clumpy systems is due to the higher fraction of their gas content, and/or because of a higher efficiency of conversion of gas to stars.

Technical Description

We request NIFS+Altair for the 3.5 hours after sunset on May 8 during which our sources will be observable. We will use the K and J grating to obesrve the Hα line at 2.096 and 1.332 μm, respectively. Since the $3'' \times 3''$ FOV will comfortably cover the extent of 125792, we do not have to dither off-target for sky images. Target 6496 may require dithering off-target for sky subtraction, but we could employ the object-sky-object pattern so to reduce the overhead time. Its Hα flux is also $\sim 2.5\times$ greater than 125792.

In order to measure dynamics from the Hα line, we aim for a S/N of $\gg 5$ per spaxel (before any smoothing) over the spatial extent of the Hα emission. The integrated Hα luminosities of the sources are 3.85×10^{43} and 1.45×10^{43} erg s^{-1}, respectively. (Fluxes are reported in Table 1.) Due to our LGS request, we require weather with CC=50% and IQ=70% or better, and Sky Brightness SB = Any.

We use the integration time calculator provided for NIFS on the Gemini website. If we integrate over four pairs of 900s exposures, our S/N for the single and final exposures are $\sim$ 30 and 55, respectively, per resolution element. Thus, with overhead for imaging tip-tilt and standard stars, we request 1.5 hours for 125792 ($4 \times$ 900s on-source integration + 30 minutes overhead) and 2 hours for 9469 ($4 \times$ 900s on-source integration, sandwiching $2 \times$ 900s sky exposures, + 30 minutes overhead), totalling 3.5 hours of NIFS + Altair on May 8 to observe our two star-forming galaxies.

In the event that only one of our two targets may be executed (i.e. part of the time requested is lost to weather or technical concerns), we would like to focus all available time on target 125792 to boost the signal-to-noise. We believe that even the results for one target alone will lead to publications and will be a prime case for future related studies (though the two proposed targets probe the evolution of the Hubble sequence at two different redshift references).

Special Note on Usable Guide Star for 6496

For some reason when we input 6496 as a target in the Observations Section of the Phase I Tool, its Guiding shows up as 0%. However, we have checked that a guide star within the requirements ($R < 17$ and distance $< 25''$) is indeed available – please see Table 2. We have found this star in the USNOB catalog, and double checked with SIMBAD that it is indeed a star. As it is within the range of the FT call (RA $\sim$ 10 hrs), it is confusing why PIT would miss this guide star. Private communication with NIFS specialists Andreea Petric and Jenny Shih reveals that this target would be accepted by the Phase II Tool. Therefore, we hope this is only a bug with PIT that may be resolved.

Band 3 Plan

This program is not suitable for band 3.

Classical Backup Program

This is not a classical request. However, given that the only combination of NIFS availability + FT window + observability of the COSMOS field (+ LGS nights) is the first $\sim$4 hours on the night of May 8, we identified it as the only plausible observing time for this program.

Justify Target Duplications

The GSA search revealed no duplicate observations.

Publications

Hemmati et al. 2014, ApJ, 797, 108
Miller et al. 2011, ApJ, 741, 115
Mobasher et al. 2009, ApJ, 690, 1074
Scoville et al. 2014, ApJ, 783, 84
U et al. 2013, ApJ, 775, 115

Use of Other Facilities or Resources

This program is based on other existing or archival observations.

HST: The COSMOS and CANDELS *HST* legacy surveys provide multi-band high-resolution images for SED fitting pixel-by-pixel. These form the basis of the resolved property maps to which we will compare the Hα maps from NIFS. The NIFS observations will provide important constraints on the instantenous SFR and dynamics of the star-forming clumps we wish to study.

Keck: The selection of sources for the current proposal depends heavily on the use of MOSFIRE spectra from Keck, since these allow us to pre-select the best candidates with strong Hα detection. The 1D dynamics from MOSFIRE spectra could set expectations for the NIFS observations, which are important because they provide 2D information that is otherwise missing.

ALMA: The selection of sources for the current proposal came from a successful ALMA cycle, so our proposed targets have ALMA detection and ISM gas masses. This facilitates the computation of gas and star mass fractions when total mass is computed from the NIFS observations, addressing the question of the star-forming nature in these clumpy systems.

Previous Use of Gemini

Reference	Allocation	% Useful	Status of previous data

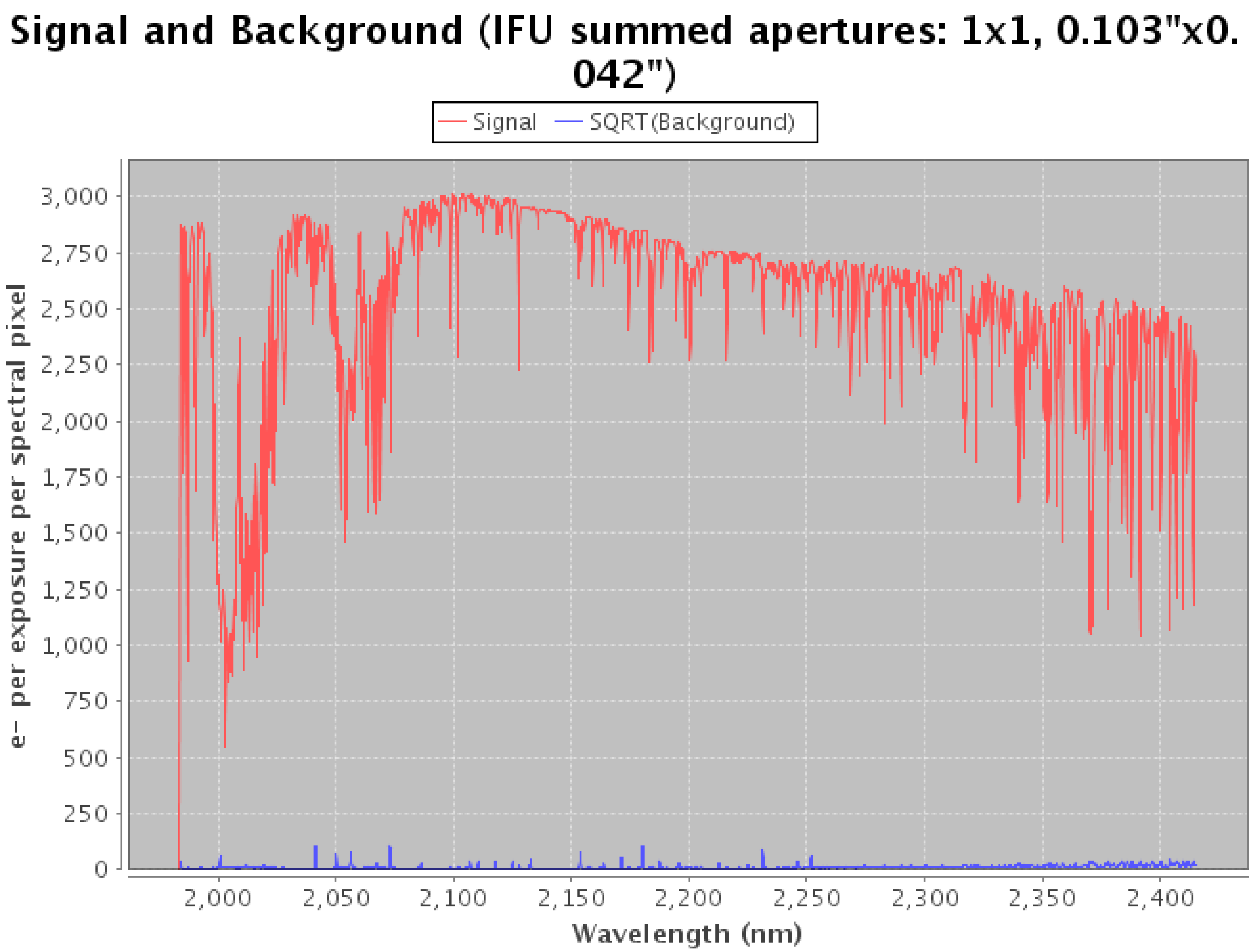
ITC Examples

Gemini Integration Time Calculator
NIFS version 4.2

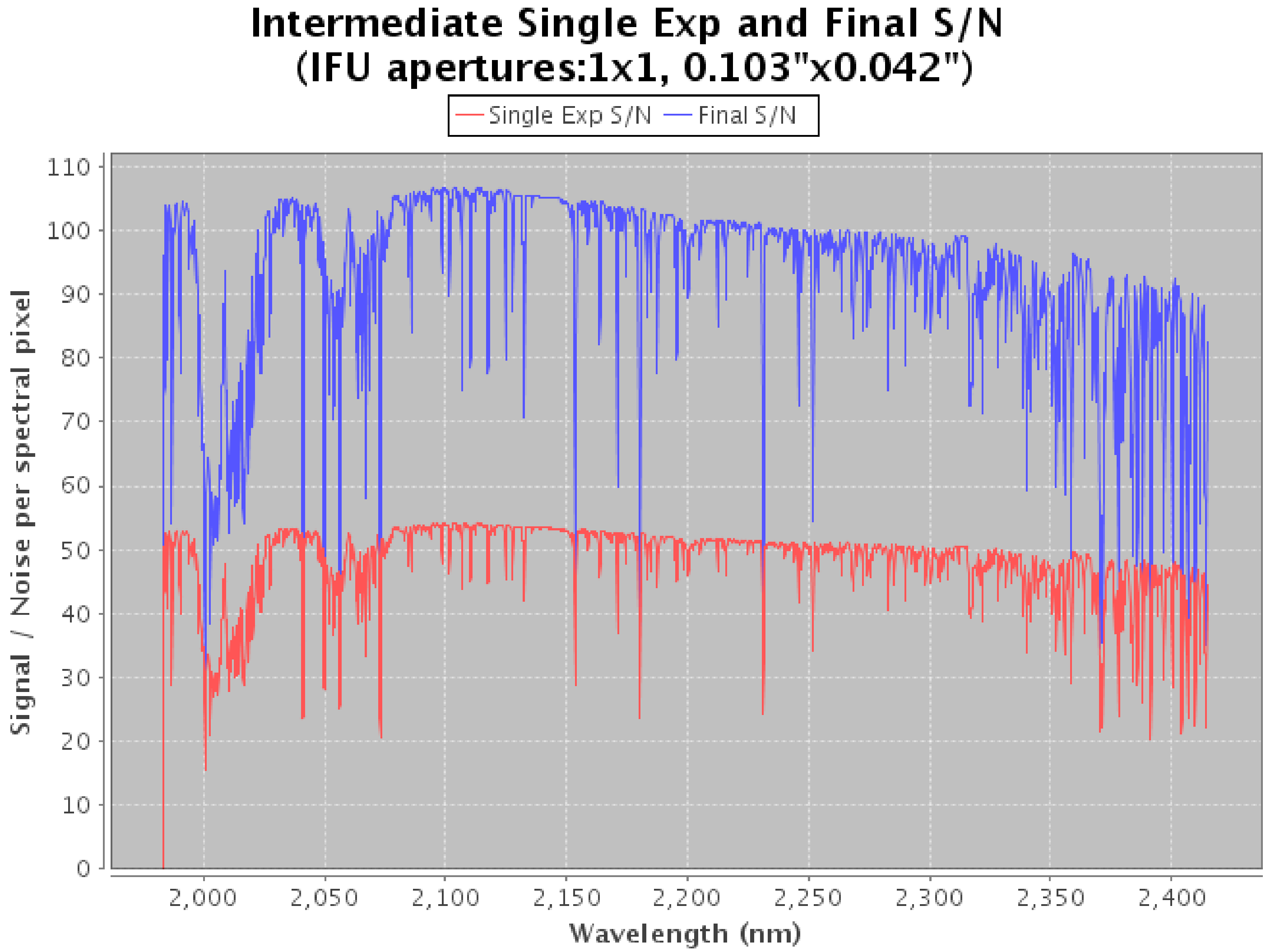
Click here for help with the results page.
SED Int: 27171.845275958523 Sky Int: 1125830.2146321565
r0(2200.0nm) = 6.101 m
Strehl = 0.477
FWHM of an AO-corrected core = 0.062 arcsec

derived image halo size (FWHM) for a point source = 0.10arcsec

Requested total integration time = 3600.00 secs, of which 3600.00 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.

Input Parameters:
Instrument: NIFS

Source spatial profile, brightness, and spectral distribution:
The z = 2.193 extended source is an emission line, at a wavelength of 2.0960 microns, and with a width of 300.00 km/s.
It's total flux is 1.0E-16 ergs_flux on a flat continuum of flux density 3.0E-17 ergs_fd_wavelength.

Instrument configuration:
Optical Components:
- Filter: hk_G0603
- Fixed Optics
- IFU Transmission
- Grating Optics: k_G5605
- Detector - 2K x 2K HgCdTe HAWAII-2 CCD
- Focal Plane Mask: ifu
- Read Noise: 8.1
- Well Depth: 90000.0

Central Wavelength: 2200.0 nm
Pixel Size in Spatial Direction: 0.0658arcsec
Pixel Size in Spectral Direction: 0.211nm
IFU is selected,with multiple summed IFU elements arranged in a 1x1 (0.103"x0.042") grid.

Altair Guide Star properties:
- Laser Guide Star Mode

Telescope configuration:
- silver mirror coating.
- up 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: 100.00%
- Airmass: 1.50

Frequency of occurrence of these conditions: 35.00%

Calculation and analysis methods:
- mode: spectroscopy
- Calculation of S/N ratio with 4 exposures of 900.00 secs, and 100.00 % of them were on source.
- Analysis performed for aperture of diameter 2.00 and a sky aperture that is 1.00 times the target aperture.

Output:
- Spectra autoscaled.