TECHNICAL MEMORANDUM

Title: Analysis of using NIRSpec to meet JWST Requirement L1-2		TM: STScI-JWST-TM-2004-0020 A Date: 29 November 2004 Rev.:
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1.0 Abstract

The JWST Level 1 requirement #2 states that 2500 galaxies need to be observed in both R=1000 mode and R=100 mode for the mission to be successful. In this memorandum we determine how long it will take the NIRSpec instrument on JWST to fulfill this requirement. After making several assumptions about the science program, sources, and available time to observe with NIRSpec, we determine that it will take 234 days of on-source integration time. Given the system overheads this will require 275 days devoted to NIRSpec observing. Assuming time for the other instruments to observe, meeting this requirement will take 4.7 years of on-orbit JWST time.

2.0 Introduction

In this document we perform an analysis of the observations that will be performed to meet the NIRSpec L1-2 requirement:

> L1-2 Measure the spectra of at least 2500 galaxies with spectral resolutions of approximately 100 (over 0.6 to 5 micrometers) and 1000 (over 1 to 5 micrometers) and to a 2 micrometer emission line flux limit of 5.2×10^{-22} W m^{-2} to enable determination of their redshift, metallicity, star formation rate, and ionization state of the intergalactic medium.

This analysis is based on the baselined NIRSpec performance requirements and what we consider to be realistic assumptions about the nature of the project that would make the observations and the distribution of sources as a function of redshift and brightness.

3.0 Assumptions

Several assumptions are needed to perform the analysis of this requirement.

A. We assume that 2500 galaxies must be observed in both the R=100 and R=1000 resolutions.
B. We assume that only galaxies at redshifts > 2 will be scientifically interesting by the time JWST is operational.

C. We will observe all targets with a shutter open on each side of the target to observe the background. Therefore, each target requires us to open three adjacent shutters. Although this may seem overly conservative, there are several reasons for this:
   a. This is the assumption that was used in determining the sensitivity of the NIRSpec. Thus, to be consistent we should use the same observing mode in all calculations.
   b. Incorrect background subtraction leads to systematic rather than random errors. Therefore, even at the low background levels of R=1000 mode, the background must be accurately removed.
   c. Using non-local background for subtraction can only be done after calibration because instrument response must be removed before the subtraction. This would place a much harder to meet requirement on the instrument calibration than the current calibration requirement (which is already hard to meet). By using a local background the subtraction can be done before calibration avoiding a major source of error.

D. Our R=100 observations will be to detect continuum emission from Z > 2 targets found in a NIRCam deep field. This will be both to confirm their red-shift and to do astrophysics on the faintest/youngest/smallest observable objects.

E. Our R=1000 observations will be a follow-up of the R=100 observations and we will observe each of these to the line limit in the requirement.

F. At our sensitivity limit we require a signal-to-noise ratio of at least 10 per resolution element.

G. All sensitivity limits are based on the Near Infrared Spectrograph Systems Requirement Document ESA-JWST-RQ-322 Issue 1.

H. Due to the overlap of second order light, only one target per row can be observed in R=1000 mode.

I. In R=100 mode two targets can be observed in each row due to the shorter spectra and the lack of second order light.

J. To avoid a large loss of light and an uncertainty in the flux of the targets, targets must be in the central 100x350 mas region of a shutter.

K. Our goal is observe galaxies at the limit of what can be done in imaging today (the Hubble Ultra Deep Field (UDF). This is approximately AB=27.5 or 35 nJy at 2 microns.

L. The contrast of the microshutters is high enough that targets will not be rejected because light from a bright source behind a closed shutter contaminates the target. With a contrast that meets the requirement of 2000 a star of with an AB magnitude of 19.2 would contribute the same amount of light as our faintest galaxies. At this brightness level there are about 4 stars in the UDF. Using the logic detailed below this yields a 1% chance that the light from a star brighter than AB=19 will overlap one of our target galaxies. Even so, some care will need to be taken to avoid the light from these interlopers and fainter ones by selecting roll angles that prevent their attenuated light from overlapping our target galaxies.

4.0 Multiplexing Factor

A key number that is needed to determine how long it will take to observe the 2500 galaxies in each mode is the number of targets that can be observed at the same time or the multiplexing factor. The baselined microshutter array consists of four 175x384

(spatial x spectral) subarrays. To obtain good background measurements we assume that we will open one shutter on each side of the shutter that is observing the source. This means that for the R=1000 mode we have 2x175/3 or 117 slitlets to work with. So for a given target density we need to find out the average number of targets visible in one of the 117 slitlets. Therefore, the acceptable solid angle that a target must be found in for each row is: Ω_{slit} = 2 x 384 x 100 mas x 350 mas = 7.47x10^{-3} arc minute^2.
Now the chance that there will be no target available in a row depends only on the target density, N_g, and the acceptable solid angle, Ω_{slit}. The chance there will be no target in a row is a Poisson probability p(0;μ) where μ is Ω_{slit} N_g. This can be expanded to be $e^{-\mu}$. Once we know the chance there will be zero targets in a slit we can easily find the probability that there is at least one target in each row and that is just p=(1- $e^{-\mu}$).
Because we are using two slitlets per row for R=100 mode, the acceptable solid angle of that a target must be found in, Ω_{slit}, is a factor of two smaller but we have twice as many slitlets. The solid angle is 384 x 100 mas x 350 mas = 3.74x10^{-3} arc minute^2 (1/2 the area of the R=1000 slitlet).
Now for a given probability that a row will have at least one target, p, the average number μ=p(Number_of_rows). Using 117 slitlets we get the number of targets per field for R=1000, N_f = 117(1- $e^{-\mu}$). Meanwhile for R=100 and 234 slitlets this yields: N_f = 234(1- $e^{-\mu}$).

5.0 Target Density

Given our limit of galaxies with red-shifts greater than 2, all of our interesting targets will be at least U-band dropouts in the UDF. From Bouwens et al. 2004 we find that there were 197 U-band dropouts in the 9 square arc minute field of the UDF. This works out to 22/square arc minute. The UDF cutoff was AB=26.9 or 65 nJy. If we do a simplistic conversion using Euclidian geometry, then the increase in the surface density when surveying to our 35 nJy limit is just $(65/35)^{1.5}$ = 2.5. So, the expected surface density of U-band dropouts at a sensitivity limit of 35 nJy is 55/square arc minute. We can estimate the B, V, and I dropout surface densities directly from the Table 1 in Bouwens et al. (2004) as 11, 5, and 2 per square arc minute, respectively. This yields a total surface density of interesting galaxies of 73 per square arc minute. Multiplying this by the acceptable solid angle of a slit at R=1000 yields an average number of targets per slitlet of 0.42. Thus, the average number targets per field at R=1000 is 117(0.42)= 49. For R=100 mode we get an average number of targets per slitlet of 0.24 which gives a total number of targets per field of 234(0.24)=56.

6.0 Total Observing Time

The NIRSpec SRD (ESA-JWST-RQ-322 Issue 1) states that for a source with a line flux of 5.2x10^{-22} erg s^{-1} m^{-2} NIRSpec shall be able to reach a signal to noise of 10 per resolution element in 10^5 seconds. If we convert from erg s^{-1} m^{-2} to W m^2 (the units of the L1-2 requirement) this becomes 5.2x10^{-19} W m^2. Therefore, it will take 100,000 seconds to observe each galaxy in R=1000 mode. For R=100 mode the NIRSpec SRD states that for a source with a continuum source flux of 1.18 x 10^{-30} erg s^{-1} cm^{-2} Hz^{-1} NIRSpec shall reach a signal to noise of 10 per resolution element in 10^4 seconds. Converting this to Janskys this becomes 118 nJy. To reach a flux limit of 35 nJy requires sqrt(118/35) more time or a total of 110,000 seconds. Another consideration is that the R=1000 observations require a total of three different grating settings to cover the full 1-5 mm range. The ISM diagnostic lines of interest range in wavelength from [OII]3727 to [SII]6731 or a factor of

1.8 in wavelength. Thus, to get the OII line at z=2 requires grating 1, while to get the SII line at z=5 requires grating 3. Therefore, it takes all three grating settings to observe the needed spectral lines for each R=1000 setting. So the total time is $(2500/56)*1.1x10^5 +3*(2500/49)*10^5= 2.02x10^7$ seconds= 234 days of on-source integration time.

7.0 Total Calendar Time Required

The 234 days of on-source integration time needs to be corrected to clock time by dividing by the efficiency of JWST. The efficiency requirement of JWST is that 70% of the time be spent in science observations. The single largest term in the overhead is the slews between targets. Because we are observing at one location for at least 10^5 seconds, we will assume that we have a higher than average efficiency and use 85%. This yields a total calendar time for the NIRSpec observations of 275 days. Now if we assume that NIRSpec will only be the primary instrument 30% of the time, we get a total calendar time to compete the observations of 917 days.

8.0 Years to complete the Observations

JWST is not able to observe most points on the sky continuously. If we assume that the region that NIRSpec is surveying is a contiguous area, then we will be limited in how many days a year it can be observed. At this point in time it seems like we would pick a well-studied region that has deep ground-based and space-based observations at non-JWST wavelengths. Therefore, we have assumed that the field is the Hubble Ultra Deep Field (HUDF). JWST can observe the HUDF for 195 days per year. Therefore, it will take 4.7 years to make the required observations to meet the L1-2 requirement.

9.0 References

Bouwens, R.~J., Illingworth, G.~D., Blakeslee, J.~P., Broadhurst, T.~J., \& Franx, M.\

2004, ApJ, 611, L1

Near Infrared Spectrograph Systems Requirement Document ESA-JWST-RQ-322 Issue 1

JWST Mission Requirements Document JWST-RQMT-000634-Revision J

JWST Project Plan JWST-PLAN-000633