The **Herschel** SPIRE Fourier Transform Spectrometer Spectral Feature Finder V. Rotational measurements of NGC 891

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**ABSTRACT**

The ESA **Herschel** Spectral and Photometric Imaging Receiver (SPIRE) Fourier Transform Spectrometer (FTS) Spectral Feature Finder (FF) project is an automated spectral feature fitting routine developed within the SPIRE instrument team to extract all prominent spectral features from all publicly available SPIRE FTS observations. In this letter we demonstrate the use of the FF information extracted from three observations of the edge-on spiral galaxy NGC 891 to measure the rotation of N\textsc{ii} and C\textsc{i} gas at Far-infrared frequencies in complement to radio observations of the [H\textsc{i}] 21cm line and the CO(1-0) transition. We find that measurements of both N\textsc{ii} and C\textsc{i} gas follow a similar velocity profile to that of H\textsc{i} showing a correlation between neutral and ionized regions of the interstellar medium (ISM) in the disk of NGC 891.

**Key words:** Submillimetre: galaxies – Techniques: imaging spectroscopy – Techniques: spectroscopic – Methods: data analysis – Galaxies:ISM – Galaxies: kinematics and dynamics

1 **INTRODUCTION**

The **Herschel Space Observatory** is an observatory class mission of the European Space Agency (ESA) (Pilbratt et al. 2010) that completed four years of observations exploring the far-infrared (FIR) and submillimeter (sub-mm) Universe in April 2013 with the depletion of its liquid cryogens (Schmidt & Keck 2014). The Spectral and Photometric Imaging REceiver (SPIRE) was one of three focal plane instruments on board **Herschel**, consisting of both an imaging photometric camera and an imaging Fourier Transform Spectrometer (FTS) (Griffin et al. 2010). The SPIRE FTS has two detector arrays, the Spectrometer Long Wavelength (SLW) and the Spectrometer Short Wavelength (SSW), that simultaneously cover a frequency band of 447–1546 GHz (SLW: 447–990 GHz, SSW: 958–1546 GHz). SPIRE FTS observations provide a wealth of molecular and atomic fine-structure spectral lines including the [N\textsc{ii}] 3P\textsubscript{1}–3P\textsubscript{0}, [C\textsc{i}] 3P\textsubscript{2}–3P\textsubscript{1}, and [C\textsc{i}] 3P\textsubscript{1}–3P\textsubscript{0} transitions. During **Herschel**’s mission, the SPIRE FTS instrument made three high resolution (∆ν ~ 1.2 GHz) spectral observations of the spiral galaxy NGC 891 (observation IDs 1342224765, 1342224766, and 1342213376) that are publicly available through the **Herschel Science Archive** (HSA) (SPIRE Handbook 2018). The [N\textsc{ii}] 3P\textsubscript{1}–3P\textsubscript{0} line has been measured with exceptionally high signal-to-noise ratios (SNRs) in these observations which also contain lower SNR CO and [C\textsc{i}] features.

Recently the SPIRE FTS observations have become more accessible through the SPIRE Spectral Feature Finder Catalogue, which includes a collection of significant spectral features extracted from all publicly available high resolution (HR) single-pointing and mapping observations by the automated SPIRE Feature Finder (FF) routine (Hopwood et al. 2020; Scott et al. 2020a; Benson et al. 2020; Scott et al. 2020b). Due to repeated

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1 [http://archives.esac.esa.int/hsa/whsa/](http://archives.esac.esa.int/hsa/whsa/)
2 [https://www.cosmos.esa.int/web/herschel/spire-spectral-feature-catalogue](https://www.cosmos.esa.int/web/herschel/spire-spectral-feature-catalogue)
referred to as M) corresponding to four jiggle positions of the SPIRE FTS Beam Steering Mirror (BSM). Mapping observations of the SPIRE FTS are projected onto hyper-spectral cubes and the FF extracts lines from the spectra for each pixel separately (see Paper I). This observation was taken on 2011-01-28 (operational day 625) with an integration time at each jiggle position corresponding to 32 FTS HR scans. The FF has catalogued lines from both the extended and point source calibrations of the SPIRE FTS for these observation and the extended source calibration minimizes the gap in the SLV–SSW overlap region (see SPIRE Handbook 2018; Wu et al. 2013). The third observation of NGC 891 is an intermediate sampled mapping observation (1342224766 and 1342224765, hereafter referred to as North and South, respectively). These observations were taken on 2011-07-26 (operational day 804) and both have an integration time corresponding to 55 FTS HR scans. The FF has catalogued lines from both the extended and point source calibrations of the SPIRE FTS for these observation and the extended source calibration minimizes the gap in the SLV–SSW overlap region (see SPIRE Handbook 2018; Wu et al. 2013). The third observation of NGC 891 is an intermediate sampled mapping observation (1342213376, hereafter referred to as M) corresponding to four jiggle positions of the SPIRE FTS Beam Steering Mirror (BSM). Mapping observations of the SPIRE FTS are projected onto hyper-spectral cubes and the FF extracts lines from the spectra for each pixel separately (see Paper I). This observation was taken on 2011-01-28 (operational day 625) with an integration time at each jiggle position corresponding to 32 FTS HR scans. The FF only extracts lines from an extended source calibration for mapping observations (Paper I). All three observations have been reduced by the SPIRE calibration tree spire_cal_14_3 and the emission from NGC 891 does not fill the entirety of the SPIRE beam for each detector (Hughes et al. 2015). Since emission from the galaxy is also not uniformly point-like for each detector, a proper determination of line-flux values requires semi-extended considerations outlined in Wu et al. (2013).

The footprint of each SSW detector in observations N and S are shown with that of the SSW cube from observation M in Fig. 1. It is important to note that the full extent of observation M is not perfectly rectangular (see Fig. 2) and that immediately sampled mapping observations only provide 16 arcsecond (∼ 1 beamwidth) sampling rather than Nyquist resolved spatial sampling of the observed region (SPIRE Handbook 2018). Sparse observations have a 32 arcsecond sampling determined by the detector spacing of the FTS (SPIRE Handbook 2018). In Fig. 1 the spatial resolution of each observation is shown by the FWHM of the SSW beam for each detector in observations N and S. The pixel size of the hyperspectral cube in observation M is shown by the inset rectangle in the lower left of its footprint. Each pixel is only spatially sampled by the SPIRE beam once.

In all three observations, the prominent [N ii] $^3P_1$–$^3P_0$ feature is readily detected by the SSW array. SLW detectors measure a number of neutral carbon fine-structure lines and the occasional CO rotational feature albeit at a much lower SNR. The full results from the FF line fitting are provided in the accompanying appendix material (Tables A1 and A2) along with their molecular and atomic transitions determined by template matching in the FF’s line identification routine (see Benson et al. 2020). Some lines extracted by the FF remain unidentified by the FF routine, often due to highly uncertain velocity estimates for their respective detector/pixel (see Paper II) or the lines being absent from

**Figure 1.** The SSW array of the FTS for each sparse observation (N and S) is shown with the footprint of the SSW cube from the mapping observation (M). These are imposed on a SPIRE photometer short wavelength (PSW) map of NGC 891 centered at 250µm. Each circle shows the full width at half maximum (FWHM) of the SPIRE FTS beam (Makiwa et al. 2013) and detectors that have observed the [N ii] feature have a thicker outline with colours assigned to each unique detector. The central rectangle indicates the extent of observation M with the small inset rectangle and circle showing the on-sky size of a pixel in the associated hyperspectral cube and SPIRE SSW beam.
the identification template (see Paper III). A few of these have been manually identified in this letter.

Neutral carbon (see Paper IV) and ionized nitrogen provide complementary measurements to CO and [H\textsc{i}] measurements of NGC 891 that probe different energy regimes within the galaxy. Neutral carbon will ionize at 11.26 eV (Haynes 2003) but will be readily bonded into CO at energies of 11.1 eV (Dyson & Williams 1997; Darwent 1970) thus [C\textsc{i}] features originate from a very narrow energy range separating the ionized and molecular phases of the ISM. The first ionization energy of nitrogen is 14.52 eV (Haynes 2003) thus the [N\textsc{ii}] 3\textit{P}_1 – 3\textit{P}_0 feature provides a method to trace ionization regions (Haffner et al. 2009).

3 RESULTS AND DISCUSSION

The [N\textsc{ii}] 3\textit{P}_1 – 3\textit{P}_0 is detected at exceptionally high SNR in most spectra (detected at an average FF calculated SNR of 30, see Paper I; Paper III) making it an excellent tool to measure the rotation of ionized gas in the galaxy at FIR frequencies. Fig. 3 shows the [N\textsc{ii}] feature from each detector that observed it in observations N and S. The continuum has been extracted using the fitted continuum parameters provided by the FF. This figure also demonstrates the sinc-like line profile of the SPIRE FTS (see SPIRE Handbook 2018, Naylor et al. 2016). Due to this line shape, it can often prove difficult to extract low SNR lines via visual inspection which is one of the motivations for the FF project.

Fig. 4 shows the heliocentric radial velocity of the galaxy along its major axis from all three observations (N,S,M). Each point represents a radial velocity measurement from a [N\textsc{ii}] 3\textit{P}_1 – 3\textit{P}_0, [C\textsc{i}] 3\textit{P}_1 – 3\textit{P}_0, or [C\textsc{i}] 3\textit{P}_2 – 3\textit{P}_1 feature. Measurements corresponding to each observation are shown by the insets in the lower panel. The SPIRE resolution is shown in position-velocity space at the rest frequency of the [N\textsc{ii}] 3\textit{P}_1 – 3\textit{P}_0 feature determined by the FWHM of the SPIRE SSW beam (Makiwa et al. 2013) and the 1.2 GHz frequency resolution of the spectrometer (SPIRE Handbook 2018). In reality, the frequency calibration of the SPIRE FTS has been shown to allow the accurate measurement of line centers up to a factor of 1/50 the resolution of the FTS (Swinyard et al. 2014; Spencer et al. 2015); however the spectral resolution of the SPIRE FTS does not allow for the study of the internal structure of detected [N\textsc{ii}] lines. Velocity error is determined by the error in the central line frequency determined by the
line fitting of the FF. [C\textsc{i}] features are detected by the SLW array which has a beam that is 14–25 arcseconds greater than the SSW array. The axis of the galaxy is defined by a linear fit of all points in the SPIRE PSW map (see Fig. 1) that are at least 2.5\% of the peak intensity. This cutoff was chosen based upon visual inspection of the photometer data. Error in these positional measurements based upon this axis was estimated using a Monte-Carlo simulation varying the 2.5\% intensity cutoff 5000 times with a standard deviation of 0.3\% and again with a cutoff centered at 20\% of the peak intensity with a standard deviation of 1\%. Both simulations provided statistically equivalent results. We have defined the FIR center of the galaxy by taking the median coordinates of all pixels in the SPIRE PSW map that have \geq 70\% of the flux of the pixel with the greatest flux (the median coordinates of pixels containing the bulge). This places the center at coordinates α = 2h22m33.189\ s \ δ = 42° 20′ 52.383″, \sim 8 arcseconds from the radio center reported by Yim et al. (2011) (see the top panel of Fig. 4).

The halo of NGC 891 is known to contain slower rotating H\textsc{i} gas and diffuse ionized gas up to altitudes greater than 4 kpc from the disk (Swaters et al. 1997; Rand et al. 1990) and thus there is potential for slower rotating [N\textsc{ii}] emission that can contaminate SPIRE observations of the disk. Swaters et al. (1997) have shown a significant decrease in the rotational speeds of H\textsc{i} gas at 30 < |z| < 60 arcseconds. With the 16.6 arcsecond FWHM SPIRE beam at the rest frequency of the [N\textsc{ii}] 3\textsc{P}_1–3\textsc{P}_0 line, any observations with an elevation (\mid z\mid) greater than \sim 20 arcseconds is likely subject to a significant amount of contamination from slow-moving halo gas. Based upon 16 SPIRE [N\textsc{ii}] measurements that are within 20 arcseconds of the galaxy’s disk and are less then a beam-width apart we have found that their radial velocities may disagree by 22–64 km s\textsuperscript{−1}. Fig. 4 demonstrates that a single spectral resolution element of the FTS is large in velocity space; this coupled with the spatial resolution of the instrument may result in the FF reported line centers being subject to line-blending from [N\textsc{ii}] features at multiple velocities. Keppel et al. (1991) have studied the kinematics of ionized hydrogen perpendicular to the major axis of NGC 891 and have shown that radial velocities measured by H\alpha emission may decrease by as much as \sim 55 km s\textsuperscript{−1} within perpendicular distances as wide as the SPIRE SSW beam.

Our measurements of the galactic rotation from the [N\textsc{ii}] 3\textsc{P}_1–3\textsc{P}_0 feature follow a similar trend to the higher
spatially resolved [H I] measurements presented in Sancisi & Allen (1979) and Yim et al. (2011) showing no major deviations from these within SPIRE’s limited spatial resolution. Keplerian rotation is seen within the extent of SPIRE observations with the furthest points beginning to show the flattening of the rotation curve due to dark matter. The limited extent of the SPIRE FTS observations ($R < 11.5$ kpc) does not allow us to determine if the [N II] emission experiences the same asymmetry as [H I] emission that occurs at $R > 14$ kpc for the south end of the galaxy (Sancisi & Allen 1979).

Measurements of [C I] features near the center of the galaxy do not show the characteristic profile of the rapidly rotating molecular disk near the galactic nucleus (García-Burillo et al. 1992; Sofue 1996) and are instead more in agreement with [H I] measurements. This provides further evidence that this central disk is completely molecular. It should be noted that SPIRE measurements of [C I] features in the galaxy tend to be of much lower SNR than measurements of the [N II] $^3P_1-^3P_0$ feature and thus are subject to a much higher degree of uncertainty. These lines are also detected in the SLW band and their spatial resolution is significantly worse than measurements of the [N II] $^3P_1-^3P_0$ feature.

The rotation curve in Fig. 5 is calculated from spectra containing the [N II] $^3P_1-^3P_0$ feature that are within a half beam-width of the galaxy’s major axis. Radial velocity has been corrected for the slight inclination of the galaxy. Within the extent of near-disk SPIRE observations, the motion is Keplerian and in agreement with the rotation curve for neutral hydrogen measured by Sancisi & Allen (1979). The large uncertainty in velocity values is indicative of the maximum velocity discrepancy ($64 \text{ km/s}$) between complementary measurement of [N II] emission within one beam-width of each other.

The agreement between our measurements of [N II] and [C I] with measurements of [H I] suggest a correlation between the Warm Neutral Medium (WNM) associated with [H I] 21 cm emission and the Warm Ionized Medium (WIM) probed by the [N II] feature (see Haffner et al. 2009). Correlations between these two phases of the ISM have been shown qualitatively at high altitudes from the galactic plane in spiral galaxies (see Haffner et al. 2009; Hartmann & Burton 1997) and for intermediate to high velocity clouds that are not co-rotating with the disk of the galaxy (Tufte et al. 1998; Haffner et al. 2001). Our results suggest that such a correlation exists within the disk of NGC 891. This result is consistent with a clumpy model of the ISM in which neutral condensations exist within a [H II] region with complex interfaces between neutral and ionized regions (Hollenbach & Tielens 1999; Haffner et al. 2009).

4 CONCLUSION

The Herschel SPIRE FF includes provision of line frequencies, signal-to-noise ratios, velocity information, and an initial line identification estimate for three HR spectral observations of the edge-on galaxy NGC 891. Using these catalogued measurements we have made rotational measurements of the ionized gas in NGC 891 with [N II] $^3P_1-^3P_0$ fine-structure lines that are detected at high SNR in these observations. We have also included measurements of the narrow neutral carbon energy regime with measurements of the [C I] $^3P_1-^3P_0$ and [C I] $^3P_2-^3P_1$ fine-structure lines.

We present our results in complement to radio measurements of CO and [H I] presented in García-Burillo et al. (1992); Scoville et al. (1993); Sofue (1996) and Yim et al. (2011). In spite of the limited spatial and velocity resolution of the SPIRE FTS We have found that the position-velocity profile of [N II] and [C I] lines closely match that of atomic hydrogen in NGC 891. This result evidences the formation of ionization interfaces on the exterior of neutral clumps in ionization regions within the disk of NGC 891.

This letter demonstrates through this simple example that the information collected by the FF and made available through SAFECAT greatly aids the exploitation of observations made with the Herschel SPIRE FTS and enhances the legacy value of the instrument and associated data archive. The wealth of FIR data contained in SAFECAT aids in interpreting a large portion of the highest resolution and most sensitive observations of the FIR universe to date.

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This research has made use of the SciPy (www.scipy.org) and Astropy (www.astropy.org) Python packages.

DATA AVAILABILITY

The Herschel SPIRE Spectral Feature Catalogue has been assigned an ESA Digital Object Identifier (DOI) and is available at: doi.org/10.5270/esa-lys2yi. The FF code and all FF products are publicly available via the Herschel Science Archive.

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APPENDIX A: FEATURE FINDER RESULTS

This paper has been typeset from a TeX/LaTeX file prepared by the author.
Table A1. FF results from both sparsely sampled SPIRE FTS observations of NGC 891 (N and S). ν is the central frequency of the FF fitted line. For information on line identification and quantum number format see Benson et al. 2020.

| Detector | ν [GHz] | SNR | Transition | Detector | ν [GHz] | SNR | Transition |
|----------|---------|-----|------------|----------|---------|-----|------------|
| SSWC3    | 460.182(61) | 6.0 | CO(4–3)    | SSWD3    | 460.349(50) | 14.8 | CO(4–3)    |
| SSWC3    | 491.196(49) | 6.9 | [C i] 3P₁–3P₀   | SSWC3    | 491.470(61) | 7.5 | [C i] 3P₁–3P₀ OR \ p-H₂CO 7(1.7)–6(1.6) |
| SSWC3    | 574.55(10)  | 3.0 | CO(5–4)    | SSWC3    | 575.566(63) | 7.2 | CO(5–4)    |
| SSWC3    | 689.72(11)  | 5.3 | CO(6–5)    | SSWC3    | 690.521(76) | 10.4 | CO(6–5)    |
| SSWC3    | 807.43(70)  | 13.8 | [C i] 3P₂–3P₁ | SSWC3    | 705.80(12)  | 5.3 | –          |
| SSWB3    | 807.329(70) | 10.1 | [C i] 3P₂–3P₁ | SSWC3    | 805.60(22)  | 4.3 | CO(7–6)    |
| SSWD1    | 460.081(62) | 11.2 | CO(4–3)*   | SSWC3    | 808.373(45) | 18.2 | [C i] 3P₂–3P₁ |
| SSWD1    | 491.096(57) | 11.3 | HC₃N(6–5)  | SSWA3    | 460.009(81) | 6.8  | CO(4–3)    |
| SSWD1    | 577.17(19)  | 2.8  | o-H₂CO 8(1,7)–7(1,6) | SSWB3    | 460.317(72) | 5.6  | CO(4–3)    |
| SSWD1    | 807.512(50) | 17.1 | o-H₂CO 12(1,12)–11(1,11) | SSWB3    | 491.576(45) | 9.2  | [C i] 3P₁–3P₀ OR \ p-H₂CO 7(1.7)–6(1.6) |
| SSWD2    | 460.177(49) | 6.7  | CO(4–3)    | SSWB3    | 575.392(74) | 5.5  | CO(5–4)    |
| SSWD2    | 491.088(51) | 7.2  | [C i] 3P₁–3P₀ OR \ p-H₂CO 7(1.7)–6(1.6) | SSWB3    | 600.54(11)  | 7.2  | CO(6–5)    |
| SSWD2    | 574.893(60) | 6.1  | CO(5–4)    | SSWB3    | 806.26(15)  | 6.8  | CO(7–6)    |
| SSWD2    | 690.380(98) | 7.0  | CO(6–5)    | SSWB3    | 808.322(41) | 25.1 | [C i] 3P₂–3P₁ |
| SSWD2    | 807.685(53) | 17.6 | [C i] 3P₂–3P₁ | SSWB4    | 808.17(12)  | 6.6  | –          |
| SSWD4    | 1457.754(81) | 55.4 | [N ii] 3P₁–3P₀ | SSWC2    | 460.132(72) | 6.7  | CO(4–3)    |
| SSWD4    | 1461.989(68) | 6.2  | –          | SSWD2    | 808.91(11)  | 7.0  | –          |
| SSWB5    | 1455.892(71) | 6.7  | –          | SSWD4    | 1459.3982(45) | 54.9 | [N ii] 3P₁–3P₀ |
| SSWB5    | 1457.523(22) | 15.0 | [N ii] 3P₁–3P₀ | SSWA4    | 1459.109(40) | 8.2  | [N ii] 3P₁–3P₀ |
| SSWC4    | 1457.686(10) | 36.6 | [N ii] 3P₁–3P₀ | SSWB5    | 1458.7231(70) | 60.2 | [N ii] 3P₁–3P₀ |
| SSWC5    | 1457.246(43) | 7.6  | [N ii] 3P₁–3P₀* | SSWB5    | 1465.9(4.4) | -28.1 |            |
| SSWD3    | 1458.010(30) | 12.5 | [N ii] 3P₁–3P₀ | SSWC3    | 1459.713(34) | 9.5  | [N ii] 3P₁–3P₀ |
| SSWE2    | 1458.354(14) | 24.5 | [N ii] 3P₁–3P₀ | SSWC4    | 1459.3070(72) | 50.8 | [N ii] 3P₁–3P₀ |
| SSWE3    | 1457.6126(40) | 73.2 | [N ii] 3P₁–3P₀ | SSWC5    | 1459.121(14) | 27.7 | [N ii] 3P₁–3P₀ |
| SSWE4    | 1457.791(44) | 7.9  | [N ii] 3P₁–3P₀ | SSWC5    | 1557.465(52) | 6.5  | –          |
| SSWF1    | 1458.634(13) | 27.8 | [N ii] 3P₁–3P₀ | SSWD3    | 1459.652(46) | 7.7  | [N ii] 3P₁–3P₀ |
| SSWF2    | 1457.8871(97) | 42.0 | [N ii] 3P₁–3P₀ | SSWE3    | 1459.396(71) | 53.1 | [N ii] 3P₁–3P₀ |
| SSWG1    | 1458.120(14) | 24.1 | [N ii] 3P₁–3P₀* | SSWF2    | 1459.532(22) | 16.4 | [N ii] 3P₁–3P₀ |

*Denotes lines that have been manually identified.
| Array | Pixel | $\nu$ [GHz] | SNR | Transition | Array | Pixel | $\nu$ [GHz] | SNR | Transition |
|-------|-------|------------|-----|------------|-------|-------|------------|-----|------------|
| SLW 0.2 | 1003.658(78) | 7.7 | – | SSW | SLW 0.4 | 807.496(90) | 7.5 | [C i] $^3P_2$–$^3P_1$ | SSW |
| SLW 1.2 | 578.310(74) | 5.1 | – | SSW | SLW 1.3 | 807.267(97) | 8.1 | [C i] $^3P_2$–$^3P_1$ | SSW |
| SLW 1.4 | 575.038(71) | 5.1 | CO(5–4) | SSW | SLW 1.4 | 807.531(57) | 12.0 | [C i] $^3P_2$–$^3P_1$ | SSW |
| SLW 2.3 | 491.082(50) | 5.7 | – | SSW | SLW 2.3 | 807.772(49) | 13.9 | [C i] $^3P_2$–$^3P_1$ | SSW |
| SLW 2.4 | 491.064(53) | 5.4 | [C i] $^3P_2$–$^3P_0$ | SSW | SLW 2.4 | 491.064(53) | 5.4 | [C i] $^3P_2$–$^3P_0$ | SSW |
| SLW 3.2 | 808.004(91) | 8.7 | CO(4–3) | SSW | SLW 3.2 | 808.004(91) | 8.7 | CO(4–3) | SSW |
| SLW 3.3 | 460.205(63) | 5.2 | p-H$_2$CO (1,1)–(0,0) | SSW | SLW 3.3 | 491.200(49) | 7.4 | [C i] $^3P_2$–$^3P_0$ | SSW |
| SLW 3.5 | 575.227(50) | 6.8 | CO(5–4) | SSW | SLW 3.5 | 575.227(50) | 6.8 | CO(5–4) | SSW |
| SLW 3.3 | 690.157(70) | 8.2 | CO(6–5) | SSW | SLW 3.3 | 690.157(70) | 8.2 | CO(6–5) | SSW |
| SLW 3.5 | 807.538(17) | 25.3 | [C i] $^3P_2$–$^3P_1$ | SSW | SLW 3.5 | 807.538(17) | 25.3 | [C i] $^3P_2$–$^3P_1$ | SSW |
| SLW 3.4 | 807.694(71) | 12.7 | [C i] $^3P_2$–$^3P_1$ | SSW | SLW 3.4 | 807.694(71) | 12.7 | [C i] $^3P_2$–$^3P_1$ | SSW |
| SSW 0.7 | 1457.487(45) | 6.4 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 0.7 | 1457.487(45) | 6.4 | [N ii] $^3P_2$–$^3P_0$ | SSW |
| SSW 0.8 | 1457.501(48) | 6.1 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 0.8 | 1457.501(48) | 6.1 | [N ii] $^3P_2$–$^3P_0$ | SSW |
| SSW 1.6 | 1457.448(37) | 8.7 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 1.6 | 1457.448(37) | 8.7 | [N ii] $^3P_2$–$^3P_0$ | SSW |
| SSW 1.7 | 1457.522(25) | 12.0 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 1.7 | 1457.522(25) | 12.0 | [N ii] $^3P_2$–$^3P_0$ | SSW |
| SSW 1.8 | 1457.864(35) | 8.7 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 1.8 | 1457.864(35) | 8.7 | [N ii] $^3P_2$–$^3P_0$ | SSW |
| SSW 2.6 | 1457.521(13) | 24.3 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 2.6 | 1457.521(13) | 24.3 | [N ii] $^3P_2$–$^3P_0$ | SSW |
| SSW 2.7 | 1457.652(94) | 37.1 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 2.7 | 1457.652(94) | 37.1 | [N ii] $^3P_2$–$^3P_0$ | SSW |
| SSW 2.8 | 1457.977(20) | 17.7 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 2.8 | 1457.977(20) | 17.7 | [N ii] $^3P_2$–$^3P_0$ | SSW |
| SSW 2.9 | 1458.057(56) | 6.4 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 2.9 | 1458.057(56) | 6.4 | [N ii] $^3P_2$–$^3P_0$ | SSW |
| SSW 3.5 | 1457.646(35) | 8.9 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 3.5 | 1457.646(35) | 8.9 | [N ii] $^3P_2$–$^3P_0$ | SSW |
| SSW 3.6 | 1457.661(57) | 56.5 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 3.6 | 1457.661(57) | 56.5 | [N ii] $^3P_2$–$^3P_0$ | SSW |
| SSW 3.7 | 1457.798(46) | 58.6 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 3.7 | 1457.798(46) | 58.6 | [N ii] $^3P_2$–$^3P_0$ | SSW |
| SSW 3.8 | 1458.043(16) | 18.9 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 3.8 | 1458.043(16) | 18.9 | [N ii] $^3P_2$–$^3P_0$ | SSW |
| SSW 4.4 | 1458.103(65) | 5.2 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 4.4 | 1458.103(65) | 5.2 | [N ii] $^3P_2$–$^3P_0$ | SSW |
| SSW 4.5 | 1458.925(16) | 20.6 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 4.5 | 1458.925(16) | 20.6 | [N ii] $^3P_2$–$^3P_0$ | SSW |
| SSW 4.6 | 1457.881(43) | 63.5 | [N ii] $^3P_2$–$^3P_0$ | SSW | SSW 4.6 | 1457.881(43) | 63.5 | [N ii] $^3P_2$–$^3P_0$ | SSW |

*Denotes lines that have been manually identified.