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GIANO, the high resolution IR spectrograph of the TNG : geometry of the echellogram and strategies for the 2D reduction of the spectra

E. Oliva*[a], N. Sanna[a], M. Rainer[a], F. Massi[a], A. Tozzi[a], L. Origlia[b]

[a] INAF-Arcetri Observatory, largo E. Fermi 5, I-50125 Firenze, Italy;
[b] INAF-Osservatorio Astronomico di Bologna, via P. Gobetti 93/3, I-40129, Bologna, Italy

ABSTRACT

GIANO is the IR high resolution spectrograph of the TNG. It covers the 950-2450 nm wavelengths range in a single shot at a resolving power of R=50,000.

This document describes the first fundamental steps of the data reduction, namely eliminating the curvature of the traces and the tilt of the slit images. These effects can be accurately modeled and corrected using a physical model of the instrument. We find that the curvature and tilt parameters did not vary during the whole lifetime of the instrument. In particular, they were not affected by thermal cycles or by the works performed to mount the spectrometer on its new interface.

A similar ab-initio modeling is also applied to the wavelength calibration that can be accurately (0.03 pixel r.m.s.) defined using a minimum number of parameters to fit. This approach is particularly useful when using a calibration source with an irregular wavelengths coverage; e.g. for the U-Ne lamp that has only few lines in the 2000 nm - 2300 nm wavelengths range.

Keywords: Ground-based instruments, high resolution spectrographs, infrared spectrographs, data reduction of echelle spectra

1. INTRODUCTION

GIANO is the IR high resolution spectrograph of the TNG. It covers the 950-2450 nm wavelengths range in a single shot at a resolving power of R=50,000. It is the first IR spectrograph worldwide offering such a combination of high resolving power and broad spectral coverage.

The instrument was originally designed for direct feeding of light at the Nasmyth-B focus of the TNG via a dedicated opto-mechanical interface[1]. However, this focal station was not accessible at first light in 2012. Therefore, the spectrometer was provisionally positioned on the rotating building and connected to the only available focus via a very complex system of optical interfaces and fibers[2]. The spectrometer was then offered to the community in this preliminary and inefficient setup. In the meantime, another interface for direct light-feeding was designed and built[c]. In October 2016 the spectrometer was eventually moved to its final position and renamed GIANO-B.

This document describes the first steps for the data reduction, focusing on eliminating the curvature of the traces and the tilt of the slit images. These effects can be accurately modeled and corrected using a physical model of the instrument. We find that the curvature and tilt parameters did not vary during the whole lifetime of the instrument. In particular, they were not affected by thermal cycles or by the works performed to mount the spectrometer on its new interface.

A similar ab-initio modeling is also applied to the wavelength calibration that can be accurately (0.03 pixel r.m.s.) defined using a minimum number of parameters to fit. This approach is particularly useful when using a calibration source with an irregular wavelengths coverage; e.g. for the U-Ne lamp that has only few lines in the 2000 nm - 2300 nm wavelengths range.

*oliva@arcetri.astro.it; phone +39 0552752291

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2. DATA GEOMETRY AND 2D DATA REDUCTION

Figure **1** shows the spectrum of the atmospheric airglow[d] taken in September 2014 with GIANO looking directly to the sky. The echellogram includes 50 orders, from #32 (bottom of frame, central wavelength 2400 nm) to #81 (top of frame, central wavelength 946 nm). The traces of the orders are curved. The first aim of the 2D-reduction is to eliminate this curvature, i.e. to create a 2D image with straight and parallel traces of the orders.
The lines – i.e. the images of the slit at different wavelengths – are tilted by different amounts in different orders. The second aim of the 2D-reduction is to correct this tilt, i.e. to create slit-images that are vertical everywhere.

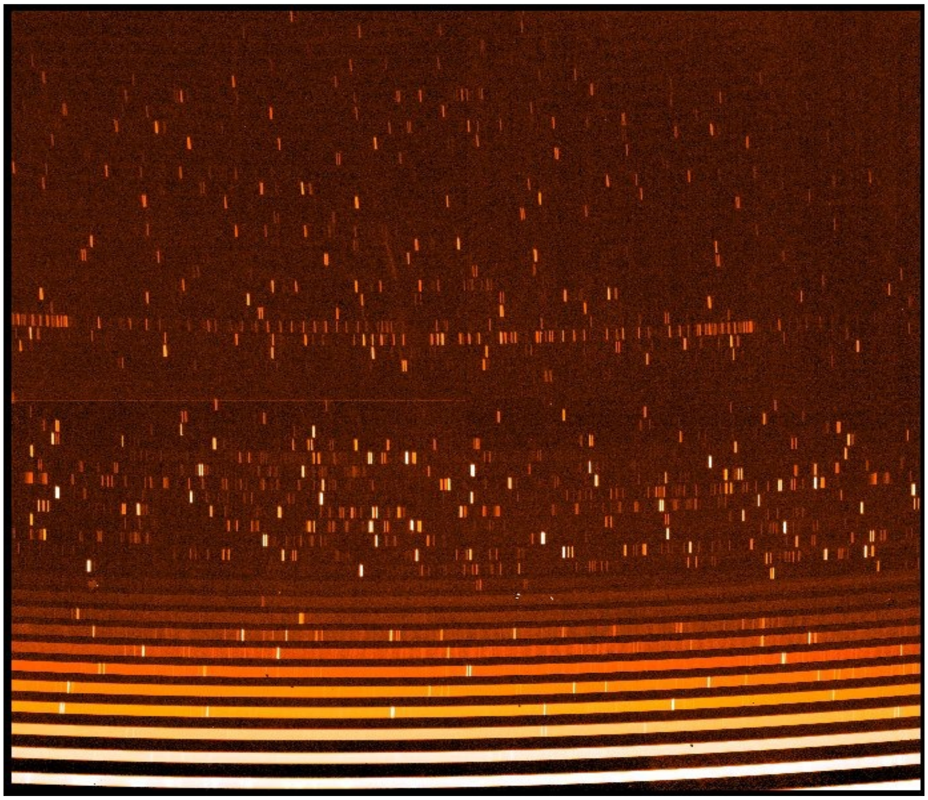

Figure 1 The 2D GIANO sky-airglow spectrum.

The first steps of the data reduction are described in details in the next sections. The dark subtraction must be applied to the flat-field and the wavelength calibration lamp spectra, while the science spectra do not require this procedure. In fact, for compact objects the observing strategy consists of nodding-on-slit, i.e. acquiring the source in two different positions (A and B) along the slit and performing the A-B subtraction of the two frames. For extended sources a separate exposure of the sky (at a TBD distance from the source) must be subtracted from the target acquired in central point (C) of the slit.

2.1 The flat-field correction

Due to the fact that GIANO is a long-slit spectrograph, the division between the science spectra (nodding A-B for compact sources and C-sky for extended objects) and the flat-field can be done directly on the 2D frames, after creating a mask that excludes the pixels of the flat-image with intensities below a given threshold (i.e. masking the dark regions in between the orders). This approach guarantees the best correction of the blaze-function and of the pixel-to-pixel response of the detector. The wavelength-calibration lamp spectra must be treated in the same way.

2.2 Correction of the orders curvature

The curvature of the orders is a direct consequence of the optical design that includes a cross-disperser before the grating-echelle. This effect can be conveniently modeled over the whole 2D image by means of simple analytical functions.

The curved-shape of the order traces can be accurately represented by a simple parabolic function

$$Y(X,N) - Y_0(N) = C2(N) * [(X - X_0(N)) / 2048]^2 \quad (1.1)$$

Where

N	is the index referring to the order (from 32 to 81)
X	is the pixel coordinate along the horizontal axis (from 1 to 2048)
$Y(X,N)$	is the pixel coordinate of the bottom of the trace at the given X-coordinate
$Y_0(N)$	is the pixel coordinate of the trace at its minimum, defined in table 1
$X_0(N)$	is the *X*-position of the minimum, defined in Eq. (1.2)
$C2(N)$	is the curvature parameter, defined in Eq. (1.3)

The above parameters can be approximated as follows

$$X_0(N) = 833.2 – 24.51*N + 230.3*sqrt(N-25) \quad (1.2)$$
$$C2(N) = 120.5 + 0.765*N \quad (1.3)$$

The geometry of the orders is an intrinsic property of the GIANO spectrometer, i.e. it is always the same; this is confirmed by an analysis of spectra during the whole life-time of GIANO at TNG (see Figure 4).
The geometry may only change after a major maintenance that requires dis-mounting the spectrometer.
However, a shift of the spectral image of a few pixels could be produced by spurious instrumental effects (e.g. temperature variations produced by accumulation of liquid-oxygen in the cryogenic tank). This effect was noticed in the analysis of GIANO spectra taken in the past years. It can be easily corrected by shifting the image in the Y-direction, i.e. by applying a constant shift to the values of $Y_0(N)$. The values reported in Table 1 are matched to frames taken on Nov 18th 2016 during the commissioning of GIANO-B.

Table 1 Y-coordinates (pixels) of the minimum value of each order-trace

$Y_0(32)$	$Y_0(33)$	$Y_0(34)$	$Y_0(35)$	$Y_0(36)$	$Y_0(37)$	$Y_0(38)$	$Y_0(39)$	$Y_0(40)$	$Y_0(41)$
4	66	132	190	244	296	345	392	437	480
$Y_0(42)$	$Y_0(43)$	$Y_0(44)$	$Y_0(45)$	$Y_0(46)$	$Y_0(47)$	$Y_0(48)$	$Y_0(49)$	$Y_0(50)$	$Y_0(51)$
522	563	602	641	678	715	752	788	823	859
$Y_0(52)$	$Y_0(53)$	$Y_0(54)$	$Y_0(55)$	$Y_0(56)$	$Y_0(57)$	$Y_0(58)$	$Y_0(59)$	$Y_0(60)$	$Y_0(61)$
893	928	962	996	1031	1065	1099	1134	1169	1203
$Y_0(62)$	$Y_0(63)$	$Y_0(64)$	$Y_0(65)$	$Y_0(66)$	$Y_0(67)$	$Y_0(68)$	$Y_0(69)$	$Y_0(70)$	$Y_0(71)$
1238	1273	1309	1345	1380	1416	1453	1490	1528	1566
$Y_0(72)$	$Y_0(73)$	$Y_0(74)$	$Y_0(75)$	$Y_0(76)$	$Y_0(77)$	$Y_0(78)$	$Y_0(79)$	$Y_0(80)$	$Y_0(81)$
1605	1644	1683	1723	1764	1805	1847	1889	1932	1976

2.1 Correction of the slit tilt

The slit images are tilted and the tilt angle varies in different positions of the echellogram. This is a direct consequence of the optical design that includes a cross-disperser before the grating-echelle. This effect can be accurately modeled over the whole 2D image using simple analytical functions.

The tilt of the slit is constant within each order within <0.1 pixels. In other words, the images of the slit within a given order are parallel to each-others within a tenth of a pixel. The tilt-angle of the slit varies linearly with the position of the order along the Y-axis i.e.

$$Tilt(N) = -0.0240 - 0.137 * [\ Y_0(N) / 2048\ ] \qquad (1.4)$$

where

- N is the index referring to the order (from 32 to 81)
- $Tilt(N)$ is the tilt-angle measures in radians
- $Y_0(N)$ is the Y-position of the order, defined in Eq. (1.1) and Table 1.

The variation of the tilt with orders is an intrinsic property of the spectrometer, i.e. the slope parameter in Eq. (1.4) is always the same. However, the actual tilt of the slit in a given order – i.e. the constant in Eq. (1.4) – may vary if the cryogenic slit is repositioned or changed after a major maintenance operation. This effect can be corrected by simply modifying the value of the constant in Eq. (1.4).

3. THE STRAIGHT-GIANO-2D PROGRAM

The above relationships have been implemented inside a dedicated “straight-giano-2D program” that creates 2D-frames with straight orders and vertical slit images. The program can operate with or without linear-interpolation between pixels-values. The default mode does not use interpolation, i.e. it only re-organizes the positions of the pixels inside the 2D frame, without modifying their values. The option with interpolation may be useful to study the effect of pixels-interpolation on the final spectra. Indeed, interpolation creates spurious correlation of the pixel-to-pixel noise and smearing of the hot/bad pixels (see Figure 2). Therefore, it is much safer to preserve the identity of the pixels during the various phases of data-reduction.

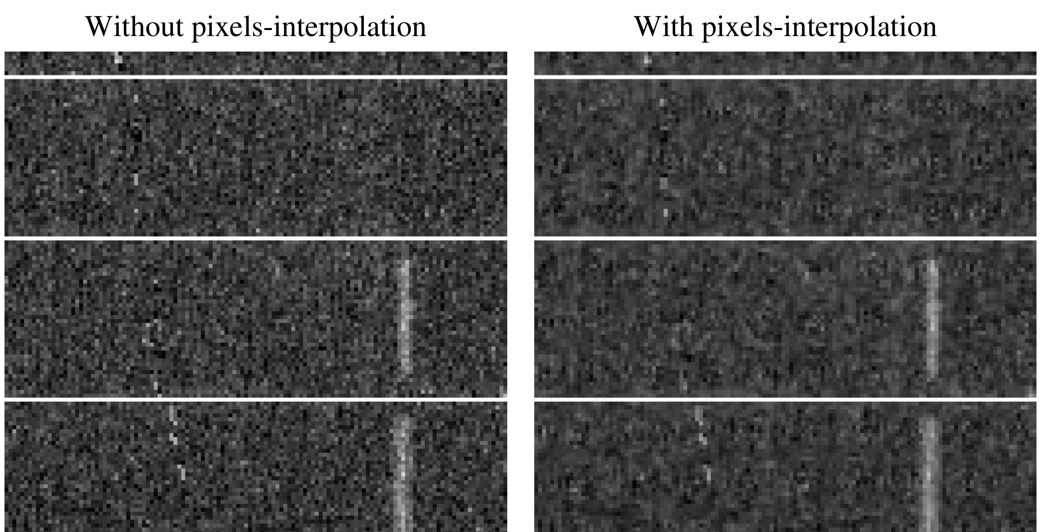

Figure 2 Detail of the sky spectrum highlighting the pixel-to-pixel noise and a vertical stripe of warm/bad pixels. The detailed structure of the image is fully preserved in the straightened spectrum without interpolation (left panel). The right-hand panel shows the smearing effect of interpolation.

This program must be applied to the flat-field corrected spectra (see Sect. 2.1).

The traces of the orders are conveniently organized in rectangles of 2048 x 41 pixels. The 41st row of each rectangle is used as separator: all pixels in this row are set to a constant value selectable by the program (see option *V* below).

The synopsis of the program is as follows

straight_giano_2D FILE_IN FILE_OUT [options]

where

FILE_IN is the name of the input file, including extension (e.g. flat01.fts)
FILE_OUT is the name of the output file, including extension (e.g. flat01_straight.fts)

the options are

I=0 does not interpolate pixels-values (default)
I=1 interpolate pixels-values
DY=nn vertically shift the frame by "*nn*" pixels (default *nn=0)*
DT=tt add the constant *"tt"* to the tilt parameter of Eq. (1.4) (default *tt=0)*
V=xx set to "*xx*" the value of the separator pixels between orders (default *xx=0)*

Figure 3 shows an example of the results of 2D-reduction and includes details showing the effects of linear interpolation between the pixels-values.

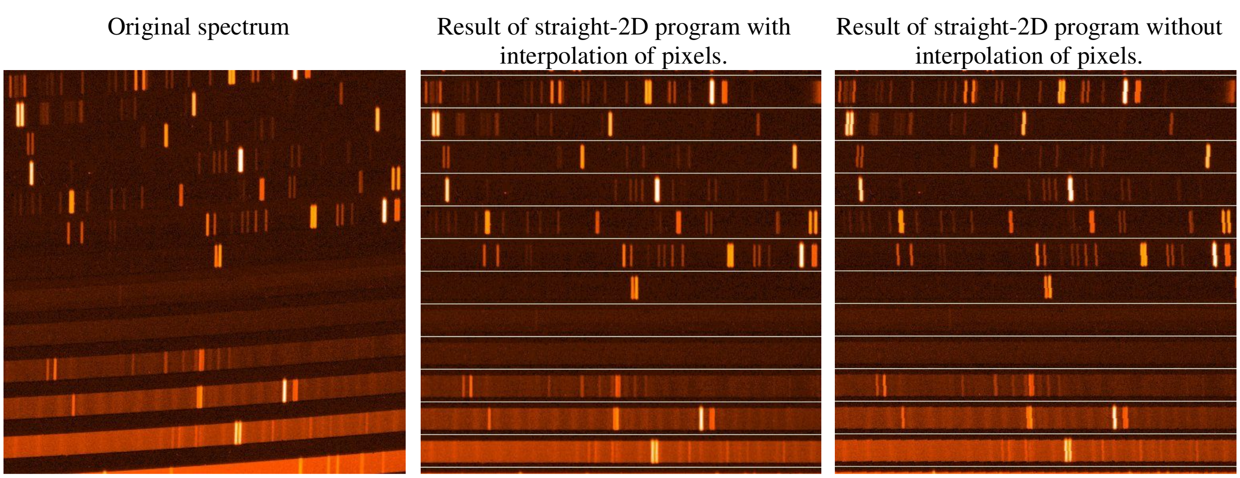

Figure 3 Portions of the sky spectrum. The original spectrum is displayed in the left panel. The spectra generated by giano-straight-2D are shown in the second and third panels. The "zig-zag" behaviour of the traces and lines in the last panel is the consequence of maintaining the identity of the pixels (i.e. no interpolation). The maximum peak to valley variation is half a pixel

The program can also be used on all frames taken with GIANO in the provisional fibers-fed mode; that was used up to September 2016. A few examples are shown in Figure 4. The results confirm that the geometry of the echellogram remained the same at all epochs.

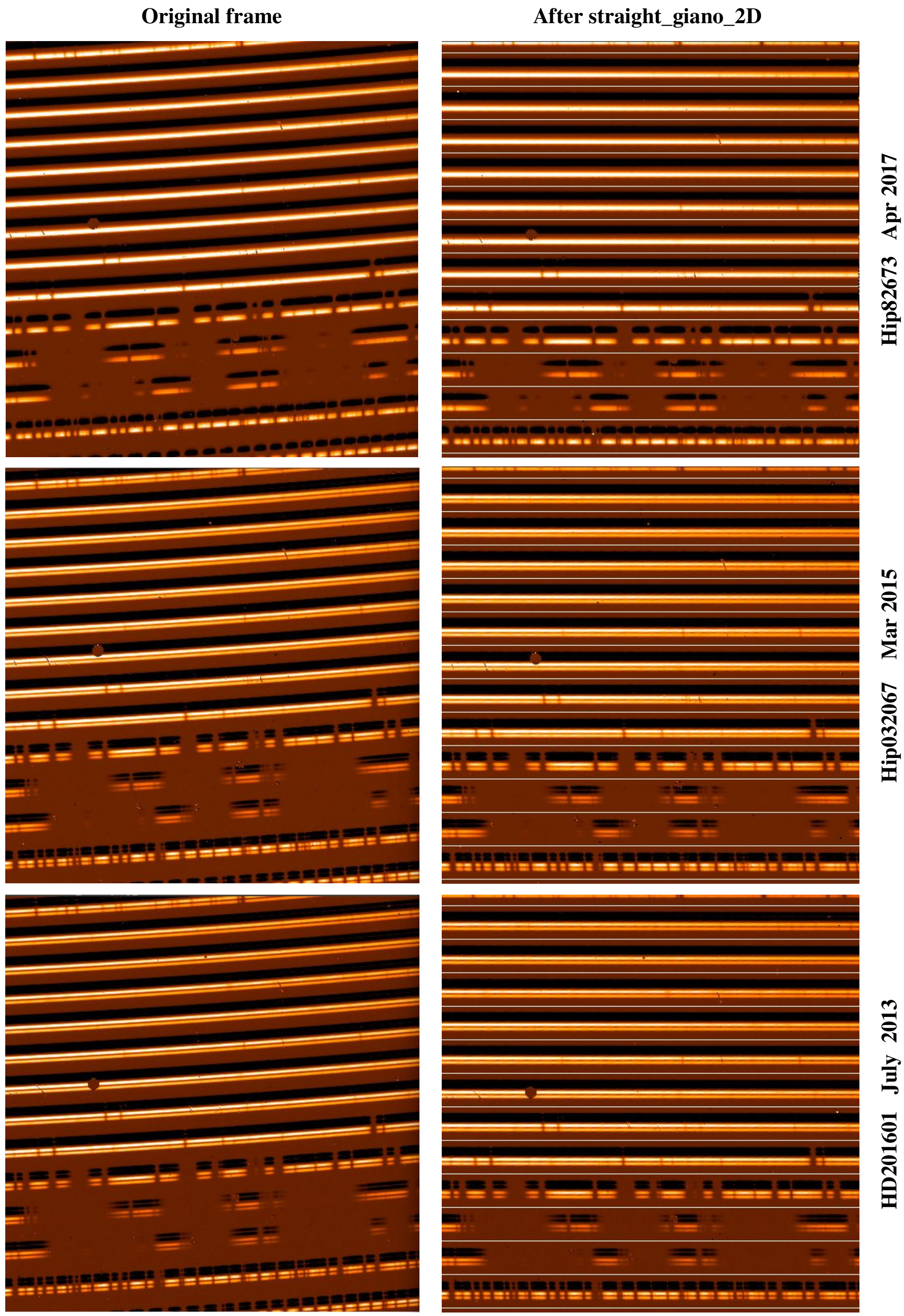

Figure 4 Portions of scientific frames taken with GIANO at various epochs. The quality of the straightening (i.e. the geometry of the echellogram) is the same for all frames.

4. 2D-CONSTRAINED WAVELENGTH CALIBRATION

The wavelength calibration of the echellogram is intrinsically a 2D function set by the optical design of the spectrograph. Therefore, the parameters of the calibration of a single order are constrained to the coefficients of the neighboring orders. Moreover, since the spectrometer works in a fixed configuration, the long-term variation of the calibration – caused e.g. by thermo-mechanical drifts – can only affect the low-orders terms of the parameters. In other words, echellograms taken at different time may be shifted and stretched, while their overall geometry and higher order deformations remain unchanged.

A stable algorithm for wavelength calibration was therefore derived by the analysis of synthetic spectra, generated from the optical design (i.e. rays tracing) and varying the parameters of the optics to match the observed echellogram at a given epoch. The results are as follows.

The calibration within a single order can be very accurately (<0.03 pixels r.m.s.) represented by a third degree polynomial, i.e.

$$\lambda = \lambda_C(N) + K_1(N)\cdot[X-X_C(N)] + K_2(N)\cdot[X-X_C(N)]^2 + K_3(N)\,[X-X_C(N)]^3 \qquad (4.1)$$

Where

- λ is the wavelength in nm
- X is the pixel coordinate along the horizontal axis (from 1 to 2048)
- N is the index referring to the order (from 32 to 81)

The coefficients $K_1(N)$, $K_2(N)$ and $K_3(N)$ are simple functions of the order N

$$K_3(N) = 1.780E\text{-}9/N \qquad (4.2)$$
$$K_2(N) = -3.560E\text{-}5/N \qquad (4.3)$$
$$K_1(N) = -0.8490\,(1/N - 1/2150) \qquad (4.4)$$

The additive term in Eq. (4.4) represents the geometrical distortion of the GIANO camera that produces a variation of the pixel scale between different orders. This variation is also visible in the Y-direction where the length of the slit increases from about 29 pixels (at order 32) to about 31 pixels (at order 81).
The only parameters that must be fit are $\lambda_C(N)$ and $X_C(N)$. The fit should be separately done for each order starting from the first-guess (and indeed already quite accurate) values listed in Table 2. Values of $X_C(N)$ far from the first-guess should be rejected by the fitting procedure because there is no physical reason that the spectrum should shift by more than a few pixels. In other words, the fitted value of $X_C(N)$ should be used as a sanity check of the calibration: values of $X_C(N)$ that deviate more than a few pixels from the first-guess indicate that something went wrong with the calibration.

Appendix 1 lists a subset of relatively bright and isolated lines of UI and NeI lines that can be used as convenient starting point for the calibration of U-Ne lamp spectra.

Table 2 First-guess values of $X_C(N)$ (pixels) for wavelength calibration

N (#order)	$X_C(N)$	*N* (#order)	$X_C(N)$	*N* (#order)	$X_C(N)$	*N* (#order)	$X_C(N)$	*N* (#order)	$X_C(N)$
32	987	42	965	52	937	62	904	72	874
33	984	43	963	53	933	62	901	73	871
34	982	44	960	54	930	64	898	74	868
35	980	45	957	55	927	65	895	75	865
36	978	46	955	56	924	66	892	76	862
37	976	47	952	57	921	67	889	77	859
38	974	48	949	58	918	68	886	78	857
39	972	49	946	59	914	69	883	79	855
40	970	50	943	60	910	70	880	80	853
41	968	51	940	61	907	71	877	81	851

5. APPENDIX 1: SUBSET OF U-NE LINES

Below is a list of relatively bright and isolated lines of UI and NeI lines that could be conveniently used as starting point for the calibration of U-Ne lamp spectra. The lines wavelengths (in vacuum) and identifications are taken from the published list (Redman et al. 2011); hence the entries marked with "?" are non-identified lines that were already reported and wavelength calibrated in the above paper. The centroids (in pixel) and Peak intensities (in ADU) were measured in a calibration spectrum taken with GIANO on November 18th 2016.

Selected lines: reasonably bright, isolated and with verified identification in frames taken on Nov 18 2016

#

#Ord	wl-line-vac	iden	ADU-peak	Xcen	Ord	wl-line-vac	iden	ADU-peak	Xcen
#	(nm)		(in 30s)	(pix)					
32	2422.5535	NeI	120	17.5	32	2416.8025	NeI	2400	255.9
32	2415.6486	NeI	250	303.0	32	2410.5148	NeI	1100	510.1
32	2409.8982	NeI	70	534.7	32	2409.3528	NeI	300	556.5
32	2398.4701	NeI	7400	980.8	32	2397.8372	NeI	350	1004.9
32	2396.2964	NeI	10200	1063.9	32	2391.8541	NeI	250	1231.4
32	2371.5599	NeI	7000	1971.3	32	2370.8130	NeI	1300	1997.7
33	2337.9343	NeI	9900	488.1	33	2326.6619	NeI	5400	943.6
33	2316.3073	UI	50	1346.8	33	2310.6784	NeI	6000	1560.8
33	2306.1369	UI	30	1731.2	33	2305.5006	UI	40	1754.7
34	2269.3959	NeI	300	475.2	34	2266.7971	NeI	1800	585.5
34	2253.6528	NeI	14300	1126.4	34	2247.292	NeI	700	1379.3
34	2243.4265	NeI	2100	1530.6	35	2211.6752	UI	110	155.0
35	2206.6706	UI	30	379.1	35	2193.8562	UI	50	931.8
35	2191.6194	UI	760	1025.6	35	2185.941	UI	40	1260.4
35	2181.7791	UI	30	1430.0	35	2171.4039	NeI	9600	1842.7
35	2169.9301	UI	130	1900.4	35	2168.0435	UI	20	1973.9
36	2150.9615	NeI	120	118.2	36	2146.4337	NeI	30	327.7
36	2142.7883	NeI	70	493.4	36	2142.0939	NeI	60	524.5
36	2138.2102	UI	20	697.7	36	2115.1352	UI	20	1676.2
36	2111.7899	UI	60	1812.0	36	2110.5746	UI	160	1861.1
37	2091.0236	NeI	50	201.2	37	2085.4446	NeI	20	463.8
37	2077.7859	UI	100	813.9	37	2075.1251	UI	20	932.9
37	2070.9371	UI	40	1117.9	37	2069.6294	UI	270	1175.1
37	2059.2439	UI	20	1620.1	37	2058.4225	UI	30	1654.8
37	2057.2657	UI	10	1703.4	37	2052.2892	UI	140	1910.3
38	2037.9683	UI	50	101.3	38	2035.9404	NeI	100	201.1
38	2035.5771	NeI	1400	218.9	38	2027.6944	UI	50	597.2
38	2021.4879	UI	30	885.7	38	2020.665	UI	30	923.5
38	2016.1633	UI	15	1127.6	38	2007.0852	UI	30	1529.6
38	2002.9148	UI	30	1710.2	39	1980.8026	UI	170	344.5
39	1977.786	NeI	90	493.0	39	1977.5676	UI	70	503.7
39	1972.2301	UI	30	761.1	39	1967.8788	UI	20	966.4
39	1958.2455	NeI	2100	1409.4	39	1957.9094	NeI	630	1424.5
39	1956.6699	UI	50	1480.2	40	1936.6173	UI	60	66.5
40	1932.331	?	60	288.2	40	1930.3572	UI	15	388.6
40	1918.7326	UI	20	961.4	40	1911.8452	UI	30	1287.9
40	1903.4591	UI	230	1674.4	41	1888.0055	UI	100	137.1
41	1886.0817	UI	280	239.0	41	1883.945	UI	20	351.0
41	1872.0499	UI	150	953.3	41	1869.2468	UI	50	1090.7
41	1868.7339	NeI	200	1115.7	41	1868.1179	NeI	130	1145.6
41	1863.9514	UI	730	1346.0	41	1863.0245	NeI	3800	1390.3
41	1862.3992	NeI	2800	1420.0	41	1861.8291	UI	130	1446.9
41	1860.2776	NeI	16400	1520.3	41	1859.6617	NeI	9400	1549.3
41	1854.1083	UI	50	1807.7	42	1842.7432	NeI	10000	151.1
42	1840.78607	NeI	6400	257.1	42	1839.49582	NeI	14500	326.4
42	1838.98458	NeI	11300	353.7	42	1837.1974	UI	450	448.6
42	1836.41077	NeI	450	490.2	42	1830.89656	NeI	11800	776.8
42	1828.76064	NeI	19800	885.8	42	1828.16323	NeI	22000	916.2
42	1825.83042	NeI	100	1033.8	42	1825.24309	NeI	120	1063.2
42	1823.19929	NeI	2300	1165.0	42	1822.60624	NeI	3000	1194.4
42	1821.8659	UI	40	1230.9	42	1821.52793	UI	1000	1247.7

42	1819.5008	UI	15	1347.2	42	1818.9969	UI	15	1371.8
42	1816.0600	UI	20	1514.3	42	1814.1603	UI	430	1605.7
42	1810.4524	UI	430	1782.5	42	1809.5308	UI	430	1826.0
42	1808.8119	UI	6800	1859.9	43	1799.4234	UI	170	173.9
43	1796.9793	UI	300	309.2	43	1796.6073	NeI	40	329.5
43	1795.5938	UI	200	384.9	43	1794.891	UI	10	423.3
43	1793.0662	UI	10	521.7	43	1791.7478	UI	20	592.2
43	1789.1183	UI	30	731.9	43	1782.9342	UI	15	1053.3
43	1778.517	UI	60	1278.0	43	1773.1598	UI	300	1544.9
43	1771.1613	UI	10	1643.1	43	1767.8857	UI	10	1802.6
43	1763.5729	UI	5	2010.1	44	1759.0602	UI	20	140.7
44	1757.1628	UI	40	248.5	44	1752.7147	UI	40	497.0
44	1750.2035	UI	10	634.6	44	1745.5877	UI	510	883.2
44	1743.2584	UI	40	1006.5	44	1743.078	UI	230	1016.0
44	1741.9952	UI	50	1072.8	45	1720.918	UI	40	82.2
45	1716.66222	NeI	4200	329.4	45	1715.3101	UI	15	406.6
45	1709.7903	UI	15	716.2	45	1708.8475	UI	90	768.3
45	1698.86133	NeI	90	1305.4	45	1693.6004	UI	270	1579.3
45	1692.1864	UI	25	1651.8	45	1691.2466	UI	50	1700.0
45	1691.062	UI	210	1709.4	45	1688.877	UI	25	1820.4
45	1686.62554	NeI	70	1934.0	46	1682.8867	UI	30	115.6
46	1680.5965	UI	10	251.8	46	1679.3378	NeI	140	325.8
46	1678.0042	UI	10	403.8	46	1677.6275	UI	20	425.7
46	1677.2286	UI	20	449.0	46	1677.0881	UI	50	457.0
46	1676.8234	UI	15	472.4	46	1676.1414	UI	10	511.6
46	1673.881	UI	20	641.2	46	1673.5147	UI	20	662.0
46	1672.1545	UI	10	739.0	46	1671.4981	UI	20	776.1
46	1671.1866	UI	15	793.4	46	1666.4933	UI	20	1054.1
46	1665.1687	UI	15	1126.5	46	1663.85935	NeI	45	1197.5
46	1661.39757	NeI	220	1330.5	46	1661.1556	NeI	80	1343.5
46	1660.5071	UI	25	1378.3	46	1657.4696	UI	30	1539.7
46	1653.26019	UI	40	1760.3	46	1648.8733	UI	10	1986.7
46	1647.92536	NeI	170	2035.1	47	1647.92536	NeI	170	60.6
47	1647.3492	NeI	40	96.0	47	1646.7184	UI	15	134.5
47	1645.8211	UI	10	189.4	47	1643.9581	UI	35	302.0
47	1643.2431	UI	15	344.9	47	1642.8149	NeI	20	370.6
47	1642.1369	UI	10	410.9	47	1641.3996	UI	8	454.6
47	1640.97373	NeI	270	479.7	47	1636.537	UI	15	738.6
47	1636.3782	UI	20	747.7	47	1635.7614	UI	10	783.3
47	1635.13887	NeI	50	818.8	47	1634.7493	UI	30	841.3
47	1632.3383	UI	40	978.3	47	1630.9986	UI	10	1053.7
47	1628.0998	UI	60	1215.2	47	1627.34004	UI	110	1257.3
47	1626.86908	NeI	70	1283.2	47	1625.7112	NeI	10	1346.7
47	1625.2439	UI	10	1372.3	48	1610.2884	NeI	65	263.5
48	1604.9882	NeI	10	585.1	48	1602.71469	NeI	220	720.0
48	1601.2891	UI	70	803.7	48	1598.9095	UI	30	942.3
48	1598.2501	UI	8	980.3	48	1596.9969	UI	40	1052.4
48	1593.9931	UI	70	1223.4	48	1593.6238	UI	120	1244.3
48	1592.8081	UI	10	1290.3	48	1590.7387	?	310	1406.0
48	1589.7806	UI	15	1459.4	48	1589.4346	UI	10	1478.4
48	1587.152	UI	10	1604.3	48	1586.6087	UI	10	1634.1
48	1584.9179	UI	20	1726.4	49	1574.9334	UI	50	416.3
49	1574.5669	UI	50	439.1	49	1572.4578	UI	10	568.6
49	1572.0513	UI	20	593.4	49	1568.7982	UI	20	789.8
49	1567.8433	UI	20	846.9	49	1563.8812	UI	20	1080.5
49	1560.84777	NeI	100	1256.3	49	1560.3996	UI	30	1282.1
49	1560.0038	UI	210	1304.9	49	1558.7407	UI	30	1377.0
49	1555.8605	UI	20	1540.2	49	1553.6168	UI	20	1666.0
49	1553.4966	UI	20	1672.7	49	1551.9072	UI	8	1761.2
49	1550.5133	NeI	20	1838.0	49	1550.3719	NeI	20	1845.8
49	1550.1815	UI	20	1856.4	49	1547.4479	UI	5	2006.2
49	1547.04528	NeI	10	2027.9	50	1547.4479	UI	10	156.4
50	1547.04528	NeI	20	182.2	50	1546.7245	UI	7	203.3
50	1545.8507	UI	15	259.5	50	1541.18032	NeI	260	555.0
50	1540.7342	UI	8	582.9	50	1539.4233	NeI	20	664.2
50	1538.9882	UI	30	691.2	50	1538.8214	UI	50	701.5
50	1538.5953	UI	15	715.4	50	1537.7524	UI	15	767.1
50	1536.7934	UI	15	825.6	50	1534.3187	UI	7	975.5

50	1532.7743	UI	40	1067.8	50	1531.507	UI	40	1143.2
50	1530.2332	UI	7	1218.4	50	1529.379	UI	60	1268.7
50	1528.0911	UI	130	1344.0	50	1527.8142	UI	80	1360.2
50	1527.2079	UI	20	1395.4	50	1525.6781	UI	15	1484.1
50	1524.0762	UI	30	1576.2	50	1523.8023	UI	10	1591.9
50	1523.48765	NeI	13000	1609.8	50	1520.4895	UI	50	1780.3
50	1519.67882	NeI	30	1825.9	50	1519.50832	NeI	160	1835.7
51	1517.84581	NeI	20	103.9	51	1515.6639	UI	30	248.5
51	1514.42356	UI	300	329.2	51	1513.6818	UI	8	377.6
51	1511.7742	UI	15	500.5	51	1511.0523	UI	50	546.4
51	1510.862	UI	10	558.6	51	1510.4132	UI	10	587.3
51	1509.6371	UI	5	636.5	51	1508.94329	NeI	90	680.0
51	1508.1663	UI	10	728.9	51	1507.91629	NeI	50	744.4
51	1507.82883	NeI	130	749.8	51	1507.7223	UI	20	756.7
51	1507.3015	UI	15	783.0	51	1506.31048	NeI	20	844.4
51	1505.7655	UI	45	878.6	51	1505.1811	UI	20	914.4
51	1504.8071	UI	20	937.5	51	1504.1493	UI	25	977.9
51	1503.5602	UI	75	1014.1	51	1501.5064	UI	8	1139.0
51	1500.8876	UI	10	1176.3	51	1500.4341	UI	20	1203.6
51	1500.0522	UI	50	1226.6	51	1499.04149	NeI	460	1287.0
51	1498.1815	UI	10	1338.5	51	1496.4705	UI	10	1439.9
51	1493.38864	NeI	70	1620.6	51	1491.9276	UI	10	1705.8
51	1487.4478	UI	5	1962.7	52	1488.7371	UI	20	95.5
52	1487.4478	UI	10	183.0	52	1485.5799	UI	10	307.9
52	1482.3575	UI	10	520.0	52	1481.4642	UI	75	578.1
52	1481.168	UI	30	597.3	52	1479.1304	UI	30	728.3
52	1476.3729	UI	330	903.2	52	1476.1374	UI	7	918.1
52	1474.5239	UI	30	1019.0	52	1473.8157	UI	10	1063.0
52	1471.3334	UI	110	1216.2	52	1467.8877	UI	80	1425.7
52	1467.7421	UI	20	1434.6	52	1467.0733	UI	10	1474.7
52	1466.1262	UI	15	1531.6	52	1465.6387	UI	15	1560.7
52	1464.5006	?	120	1628.5	52	1460.3178	UI	65	1874.8
52	1460.1252	UI	110	1886.1	52	1459.076	UI	10	1947.3
53	1460.3178	UI	90	115.4	53	1460.1252	UI	170	128.7
53	1459.076	UI	20	200.9	53	1454.8793	UI	30	484.6
53	1452.6461	UI	10	632.4	53	1451.4761	UI	40	708.9
53	1449.9949	UI	20	805.4	53	1446.9322	UI	50	1001.7
53	1445.7723	?	80	1075.4	53	1444.3881	UI	10	1162.5
53	1444.111	UI	80	1179.9	53	1442.394	UI	30	1287.1
53	1441.9633	UI	35	1313.8	53	1439.6121	UI	100	1458.8
53	1437.3976	UI	40	1594.0	53	1435.72729	NeI	30	1694.8
53	1434.60814	NeI	70	1762.2	53	1433.2302	UI	20	1844.8
53	1431.0923	UI	7	1971.8	53	1430.47431	NeI	30	2008.1
54	1434.60814	NeI	70	17.7	54	1434.3658	UI	15	35.2
54	1433.2302	UI	30	115.5	54	1431.0923	UI	20	265.0
54	1430.47431	NeI	90	307.6	54	1428.3082	UI	620	456.5
54	1427.9479	UI	110	480.9	54	1420.2694	UI	25	990.6
54	1418.2241	UI	10	1122.5	54	1417.0104	UI	50	1200.3
54	1416.0322	UI	70	1262.5	54	1415.023	UI	15	1326.4
54	1414.5251	UI	15	1357.7	54	1413.6988	UI	80	1409.7
54	1411.932	UI	7	1520.0	54	1410.6343	UI	10	1600.7
54	1409.8051	UI	25	1651.7	54	1407.8305	UI	65	1772.8
54	1405.6313	UI	15	1906.5	54	1404.9657	UI	20	1946.8
55	1407.8305	UI	80	64.9	55	1405.6313	UI	30	222.3
55	1404.9657	UI	50	269.6	55	1403.5537	UI	15	368.9
55	1398.8387	UI	30	693.8	55	1396.5395	UI	1400	848.6
55	1396.215	UI	100	870.4	55	1394.4251	UI	15	989.3
55	1392.3728	?	140	1124.3	55	1389.7053	UI	10	1297.5
55	1388.4532	UI	10	1377.9	55	1385.6533	UI	280	1556.0
55	1384.2376	UI	30	1645.2	55	1379.2756	UI	5	1953.3
56	1379.2756	UI	15	309.6	56	1376.8035	UI	65	485.3
56	1376.4604	UI	40	509.4	56	1375.3691	UI	35	585.6
56	1373.7477	UI	15	698.4	56	1372.0212	UI	120	817.1
56	1371.2313	UI	120	870.9	56	1368.7094	UI	35	1041.3
56	1367.7344	UI	250	1106.5	56	1366.5407	UI	40	1185.8
56	1364.0161	UI	100	1351.9	56	1362.075	UI	15	1478.2
56	1360.3345	UI	20	1590.4	56	1359.6698	UI	20	1633.1
56	1358.2185	UI	100	1725.6	56	1357.5774	UI	30	1766.4

56	1353.6965	UI	20	2010.4	57	1358.2185	UI	100	74.5
57	1357.5774	UI	40	122.4	57	1353.6965	UI	80	406.8
57	1352.9300	UI	30	462.1	57	1351.9396	UI	10	533.0
57	1349.221	UI	15	725.4	57	1348.4375	UI	20	780.2
57	1347.0085	UI	30	879.6	57	1345.0895	UI	30	1011.6
57	1344.8115	UI	120	1030.7	57	1341.0734	UI	30	1283.4
57	1339.7122	UI	15	1374.2	57	1331.5565	UI	15	1905.5
57	1330.987	UI	170	1941.8	57	1329.8344	UI	40	2015.2
58	1331.5565	UI	35	315.2	58	1330.987	UI	490	357.3
58	1329.8344	UI	160	442.2	58	1328.6472	UI	15	528.8
58	1326.1036	UI	170	712.2	58	1324.5032	UI	20	825.9
58	1322.28579	NeI	6900	981.8	58	1321.9201	UI	50	1007.4
58	1318.8764	UI	4000	1217.6	58	1310.7947	UI	20	1759.5
58	1310.0961	UI	20	1805.3	58	1306.7447	UI	15	2023.2
59	1310.0961	UI	35	227.9	59	1306.7447	UI	60	479.9
59	1306.5388	UI	15	495.3	59	1304.8665	UI	30	618.6
59	1301.046	UI	25	895.4	59	1298.4799	UI	55	1077.6
59	1298.0483	UI	50	1108.0	59	1297.2441	UI	15	1164.6
59	1293.6866	UI	30	1411.1	59	1291.55459	NeI	7100	1556.3
59	1290.0144	UI	35	1660.4	59	1288.621	UI	20	1754.0
59	1286.3124	UI	60	1907.6	60	1290.0144	UI	35	87.7
60	1288.621	UI	25	196.5	60	1286.3124	UI	190	374.4
60	1282.4134	UI	20	668.0	60	1279.9433	UI	310	850.0
60	1279.5787	UI	35	876.6	60	1277.6059	UI	140	1019.6
60	1277.30181	NeI	2070	1041.5	60	1273.6139	UI	60	1303.7
60	1271.1878	UI	30	1473.4	60	1269.7517	UI	45	1572.7
60	1269.26745	NeI	8100	1606.1	60	1266.6738	?	65	1783.3
60	1266.18089	NeI	120	1816.6	60	1264.61981	NeI	130	1922.0
61	1269.7517	UI	35	13.3	61	1269.26745	NeI	7050	52.3
61	1266.6738	?	125	258.1	61	1264.61981	NeI	410	418.0
61	1262.7293	UI	130	563.4	61	1262.11211	NeI	310	610.2
61	1261.0487	UI	80	690.7	61	1259.84506	NeI	3400	781.1
61	1259.08693	NeI	690	837.5	61	1257.4452	UI	550	959.2
61	1255.4532	UI	40	1105.0	61	1254.3659	UI	20	1183.7
61	1253.5241	UI	40	1244.4	61	1250.9661	UI	30	1427.0
61	1249.2364	UI	60	1548.9	61	1249.01478	NeI	190	1564.4
61	1246.75265	NeI	50	1722.1	61	1246.27992	NeI	3400	1755.0
61	1244.5243	UI	12	1876.0	61	1243.1148	UI	5	1972.5
62	1249.2364	UI	45	12.7	62	1249.01478	NeI	170	30.6
62	1247.3889	UI	20	162.8	62	1246.27992	NeI	5700	251.8
62	1244.5243	UI	35	391.2	62	1243.1148	UI	40	501.6
62	1239.9122	UI	45	748.5	62	1237.6894	UI	220	916.6
62	1236.2006	UI	30	1028.0	62	1234.3653	UI	30	1163.8
62	1231.3785	UI	20	1381.5	62	1228.8798	UI	15	1561.0
62	1226.4715	UI	50	1731.7	62	1225.3815	UI	260	1808.3
62	1224.418	UI	650	1875.6	62	1222.1717	UI	15	2031.6
63	1228.8798	UI	15	52.9	63	1227.3868	UI	35	175.8
63	1226.4715	UI	75	250.5	63	1225.3815	UI	600	338.5
63	1224.418	UI	2200	415.8	63	1222.1717	UI	110	593.8
63	1221.7932	UI	280	623.5	63	1218.5338	UI	80	876.0
63	1217.0754	UI	40	987.2	63	1214.415	UI	35	1187.4
63	1213.3018	UI	40	1270.2	63	1212.0623	UI	50	1361.7
63	1206.96364	NeI	11800	1731.7	63	1203.764	UI	20	1959.2
63	1203.0441	UI	20	2009.8	64	1206.96364	NeI	21000	275.3
64	1203.764	UI	100	535.3	64	1203.0441	UI	180	592.9
64	1201.5821	UI	165	709.1	64	1198.81939	NeI	11500	925.2
64	1196.3634	UI	15	1114.2	64	1196.2051	UI	45	1126.2
64	1194.3911	UI	65	1263.6	64	1193.9262	UI	30	1298.6
64	1191.2084	UI	3200	1501.3	64	1187.4994	UI	25	1772.9
64	1186.2662	UI	360	1862.2	65	1191.2084	UI	2300	33.5
65	1187.4994	UI	55	346.4	65	1186.2662	UI	1300	448.3
65	1185.0062	UI	50	551.3	65	1183.1709	UI	300	699.6
65	1181.7157	UI	35	816.0	65	1180.228	UI	30	933.6
65	1179.31165	NeI	3800	1005.5	65	1179.22713	NeI	21000	1012.1
65	1177.00137	NeI	21000	1184.8	65	1174.4167	UI	230	1382.3
65	1170.4193	UI	50	1682.2	65	1169.12022	NeI	1150	1778.2
65	1168.8247	UI	30	1800.0	65	1166.8375	UI	7	1945.5
66	1170.4193	UI	75	265.5	66	1169.12022	NeI	2900	375.3

66	1166.8375	UI	40	565.5	66	1164.6405	UI	80	745.5
66	1162.7683	UI	30	896.5	66	1161.7260	NeI	18700	979.7
66	1160.47129	NeI	6600	1079.3	66	1159.2428	UI	70	1175.9
66	1158.3683	UI	60	1244.2	66	1157.1976	UI	420	1334.9
66	1153.95029	NeI	6400	1583.6	66	1152.81755	NeI	13500	1669.3
66	1152.5900	NeI	22000	1686.5	67	1153.95029	NeI	7700	175.2
67	1152.81755	NeI	20500	273.3	67	1152.5900	NeI	2900	292.9
67	1150.6532	UI	560	458.3	67	1147.6051	UI	90	713.4
67	1146.2269	UI	120	826.8	67	1145.1365	UI	220	915.7
67	1143.7099	UI	120	1031.2	67	1141.3550	UI	610	1219.1
67	1141.22575	NeI	17100	1229.4	67	1139.3552	NeI	12200	1376.5
67	1138.7248	UI	1250	1425.7	67	1137.6958	UI	60	1505.7
67	1135.9438	UI	70	1640.7	67	1133.2728	NeI	10	1844.3
67	1130.7641	NeI	8	2032.8	68	1138.7248	NeI	7700	15.7
68	1137.9822	UI	65	82.3	68	1137.6958	NeI	60	107.8
68	1135.9438	UI	105	262.5	68	1132.9386	UI	20	522.5
68	1131.3390	UI	50	658.4	68	1129.7221	UI	1350	794.0
68	1126.7230	UI	110	1041.4	68	1126.5356	UI	160	1056.7
68	1124.6981	UI	40	1205.4	68	1123.8574	UI	40	1273.0
68	1121.2368	UI	90	1481.2	68	1118.05855	NeI	21600	1729.3
68	1117.0894	UI	350	1804.1	68	1116.3270	NeI	50	1862.7
68	1114.6072	NeI	4900	1994.0	69	1121.2368	UI	90	101.2
69	1118.05855	NeI	21000	384.3	69	1117.0894	UI	1350	469.3
69	1116.3270	NeI	250	535.6	69	1114.6072	NeI	21000	683.4
69	1113.1007	UI	170	811.5	69	1111.6694	UI	1350	931.7
69	1109.8814	UI	540	1080.3	69	1108.8922	UI	340	1161.7
69	1105.6341	UI	100	1426.1	69	1104.70248	NeI	110	1500.6
69	1103.0766	UI	100	1629.7	69	1102.5842	UI	30	1668.7
69	1100.0890	UI	55	1864.3	70	1105.6341	UI	80	58.9
70	1104.70248	NeI	110	144.4	70	1103.0766	UI	180	291.8
70	1102.5842	UI	65	336.0	70	1100.089	UI	340	557.2
70	1098.7693	UI	60	672.3	70	1097.5296	UI	240	779.4
70	1093.8891	UI	280	1088.3	70	1092.5097	UI	40	1203.2
70	1091.0168	UI	45	1326.4	70	1089.311	UI	100	1465.6
70	1086.1762	UI	15	1718.0	70	1084.74479	NeI	3700	1831.7
70	1083.893	UI	8	1898.9	70	1082.6898	UI	35	1993.5
71	1090.3326	UI	20	29.4	71	1089.311	UI	90	124.7
71	1086.1762	UI	45	411.6	71	1084.74479	NeI	20000	539.9
71	1083.893	UI	100	615.5	71	1082.6898	UI	650	721.5
71	1081.8693	UI	50	793.3	71	1080.274	UI	1400	931.4
71	1080.10009	NeI	8300	946.3	71	1077.8828	UI	75	1135.5
71	1076.6022	UI	270	1243.3	71	1075.0912	UI	75	1369.4
71	1073.2394	UI	15	1522.3	71	1070.2021	UI	70	1769.3
72	1075.0912	UI	50	34.4	72	1073.2394	UI	20	208.6
72	1070.2021	UI	300	488.4	72	1065.8804	UI	540	874.2
72	1065.7772	UI	110	883.2	72	1065.038	UI	650	947.8
72	1063.9854	UI	70	1039.2	72	1063.4371	UI	180	1086.6
72	1063.1251	UI	30	1113.5	72	1063.0216	UI	60	1122.4
72	1062.3576	NeI	1600	1179.3	72	1062.2416	UI	60	1189.2
72	1061.6728	UI	25	1237.6	72	1061.2974	UI	20	1269.6
72	1060.1162	UI	130	1369.5	72	1059.6173	UI	20	1411.5
72	1059.2772	UI	20	1440.0	72	1058.698	UI	20	1488.2
72	1057.9356	UI	20	1551.8	72	1056.53029	NeI	3400	1668.0
72	1055.7822	UI	810	1729.5	72	1054.811	UI	10	1809.0
72	1052.0399	UI	10	2033.5	73	1060.1162	UI	90	53.7
73	1058.698	UI	25	189.3	73	1057.9356	UI	25	261.4
73	1056.53029	NeI	8500	392.8	73	1055.7822	UI	3400	462.2
73	1054.811	UI	90	551.5	73	1054.1726	UI	95	609.8
73	1052.6052	UI	150	751.6	73	1052.0399	UI	360	802.3
73	1049.5012	UI	35	1027.4	73	1047.9821	UI	40	1160.1
73	1044.4664	UI	190	1461.7	73	1043.2897	UI	20	1561.2
73	1042.9646	UI	20	1588.6	73	1041.2321	UI	20	1733.3
74	1045.1936	UI	10	107.4	74	1044.4664	UI	200	177.7
74	1043.2897	UI	35	290.4	74	1042.9646	UI	40	321.3
74	1041.2321	UI	90	484.5	74	1038.1124	UI	170	772.1
74	1037.5625	UI	180	822.0	74	1035.6222	UI	130	996.5
74	1035.1121	UI	210	1042.0	74	1033.5291	UI	30	1181.9
74	1031.6595	UI	90	1345.3	74	1031.1183	UI	60	1392.1

74	1029.82378	NeI	420	1503.5	74	1029.4254	UI	30	1537.6
74	1026.2358	UI	220	1807.7	74	1024.9751	UI	15	1913.2
75	1031.6595	UI	60	63.3	75	1031.1183	UI	50	116.6
75	1029.82378	NeI	620	242.9	75	1029.4254	UI	55	281.5
75	1026.2358	UI	1680	585.1	75	1024.9751	UI	330	702.7
75	1023.4655	UI	20	842.0	75	1016.0697	UI	1140	1501.8
75	1015.9393	?	160	1513.1	75	1015.3144	UI	20	1567.2
75	1015.2185	UI	15	1575.6	76	1016.0697	UI	1500	258.3
76	1015.9393	?	230	271.1	76	1012.5263	UI	75	600.3
76	1010.6265	UI	170	779.3	76	1009.8038	UI	80	855.9
76	1008.8800	UI	170	941.4	76	1007.6354	UI	360	1055.6
76	1004.3273	UI	140	1353.8	76	1004.1571	UI	80	1368.9
76	1002.5237	UI	15	1513.5	76	999.6211	UI	30	1766.7
77	1004.3273	UI	110	108.0	77	1004.1571	UI	55	125.2
77	1001.357	UI	180	403.5	77	999.6211	UI	210	572.3
77	998.7824	UI	90	652.9	77	996.6842	UI	340	852.1
77	995.5216	UI	70	961.0	77	995.3023	UI	45	981.5
77	993.5484	UI	390	1143.6	77	991.9931	UI	170	1285.6
77	990.8607	UI	100	1387.9	77	988.4181	UI	35	1606.1
77	988.1539	UI	30	1629.6	77	987.1067	UI	40	1721.8
77	986.9820	UI	20	1732.8	78	991.9931	UI	90	47.5
78	990.8607	UI	85	163.3	78	988.4181	UI	90	408.7
78	988.1539	UI	100	435.0	78	987.1067	UI	220	538.3
78	983.3281	UI	30	902.7	78	982.7135	UI	80	961.0
78	982.1688	UI	690	1012.3	78	981.6335	UI	70	1062.6
78	976.3327	UI	30	1549.4	78	974.9685	UI	10	1671.8
79	976.3327	UI	80	361.1	79	976.2380	UI	15	370.5
79	974.9685	UI	50	498.0	79	973.4038	UI	20	653.0
79	972.9988	UI	75	692.7	79	970.0059	UI	90	982.2
79	968.5206	UI	10	1123.2	79	966.80709	NeI	9300	1284.0
79	965.1822	UI	65	1434.5	79	962.8053	UI	10	1651.8
79	961.9690	UI	20	1727.4	79	959.7705	UI	10	1924.3
80	966.80709	NeI	5600	78.1	80	965.5902	UI	130	205.3
80	965.1822	UI	85	247.6	80	962.8053	UI	45	490.8
80	961.9690	UI	150	574.9	80	961.0884	UI	35	662.8
80	959.7705	UI	280	793.4	80	958.8470	UI	70	883.7
80	956.8693	UI	20	1075.3	80	956.0555	UI	25	1153.1
80	955.3605	UI	35	1219.2	80	955.00241	NeI	1080	1253.1
80	954.3909	NeI	25	1310.8	80	953.67793	NeI	1930	1377.8
81	955.00241	NeI	520	58.6	81	953.67793	NeI	1720	199.2
81	948.9285	NeI	3500	687.7	81	946.1806	NeI	990	960.6
81	944.4719	UI	170	1127.3					

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