How to Observe Hydrogen Line Spectra of Galaxies Outside of the Milky Way

By Jason Burnfield 24 September 2024

A Brief Introduction to the Hydrogen Line

The hydrogen line is an emission line of neutral atomic hydrogen caused by a "spin flip" of the electron in the ground state.





The hydrogen line was first observed in 1951 by Harold Ewen and Edward Purcell at Harvard University using the horn antenna shown here.



• Map of neutral atomic hydrogen (21- cm line) published by Jan Oort (1958); figure taken from the text book Scheffler & Elsässer (1992). The Sun is in the upper part of the plot at 8 kpc.

- This was produced using the doppler shift observed in 21 cm emissions along various lines of sight within the galactic plane.
- The reason for the "blind spots' toward and away from the center of the galaxy are due to geometry. For angles close to 180 or 0 degrees, the relative motion is entirely tangential and there is no doppler shift.

When observing hydrogen spectra from spiral galaxies outside the milky way, the single hydrogen peak gets split in two by doppler shift due to the spinning motion of the disc.

The distance between the peaks indicates the orientation of the disc from our vantage point.

The more "edge-on" the further apart the peaks, the more "face-on" the closer to together they are.









Drift Scanning with a Small Dish (I suggest at least 2.5 meters or larger)

Planning Your Observation



Observatio	on data (J2000 epoch)
Pronunciation	/traɪˈæŋɡjʊləm/
Constellation	Triangulum
Right ascension	01 ^h 33 ^m 50.02 ^{s[1]}
Declination	+30° 39′ 36.7″ ^[1]
Redshift	-0.000607 ± 0.000010 ^[1]
Heliocentric radial velocity	-179 ± 3 km/s ^[2]
Galactocentric velocity	-44 ± 6 km/s ^[2]
Distance	970 kpc (3.2 Mly) ^[3]
Apparent magnitude (V)	5.72 ^[1]

Gather information on your target galaxy from credible sources (including RA/Dec coordinates, reference profile, and/or average radial velocity).

Calculate Radial velocities at the GBT

Calculate

UT date	UT time	Right Ascension	Declination	V-Helio	V_LSRK	V_GAL
2024/09/07	12:00:00	01:35:00	31:00:00	-20.338 km/sec	-19.734 km/sec	154.962 km/sec

This gives the velocity in the direction (RA,Dec) from the point of view of Positive means it is receding from us (redshift); negative, it is approaching

V Helio is the velocity due to the rotation of the Earth and the motion of the

Look up the VLSR correction for the target galaxy coordinates on the observation date (see references at the end of this presentation for the url for this site).

Use the Stellarium phone app to identify the start and end times of the main transit by setting the field of view equal to the HPBW of your dish and incrementing the clock until the galaxy just enters and exits the screen.



07

05

Choose a pre-transit start time and posttransit end time such that each is half the length of the main transit duration.

Select a center frequency that corresponds to the average velocity of the galaxy you want to observe.

M33 Plan GF: 1421.26 MHZ VLSR: -19.734 8/7/24 AZ 180° ER 82° pre 330 main 352)44 436)44 post 506

Fo = Fs
$$\left[\frac{1}{(1 + V/C)}\right]$$
 = 1420.406 $\left[\frac{1}{(1 - 180/300,000)}\right]$

Fo = 1421.26 MHz

Collecting Observation Data

Set up your dish with the proper Azimuth/Elevation setting to do a transit scan of the target galaxy.



Set the center frequency of Airspy SDR# software to the center frequency that is recorded in your observation plan.



I recommend using the following settings for IF Averaging:

- FFT Resolution 128
- Intermediate Averaging 1000
- Dynamic Averaging 7659000

Set the default filename and path to suit your needs.



Connect your SDR, feed, LNA and Band-Pass Filter and then press "play" on SDR# to begin recording data.



Launch IF Averaging and enable "Multiple Save". Make sure you start at least 30 minutes before your pre-transit start time to allow the system to stabilize before collecting meaningful data.



Analyzing Observation Data

Look at the time stamps on your data files and record which ones correspond to the pre main and post transit times in your plan.

350 item

Home Share View			
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dish and system tests	^ Name	Date modified	
ezRABase	7Sep24 0013.txt	9/7/2024 5:05 AN	
galaxy survey	7Sep24_0012.txt	9/7/2014 4:51 AM	
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Hydrogen Line	7Sep24_0010.txt	9/7/21 24 4:25 AM	
IC10 Observations	7Sep24_0009.txt	9/7/2024 4:12 AM	
M31 Observations	7Sep24_0008.txt	9/7/2014 3:59 AM	
M33 Observations	7Sep24_0007.txt	9/7/2021 3:46 AM	
M74 Observations	28Aug24_0063.txt	8/28/2024 529 AM	
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Open a copy of my data analysis spreadsheet and paste the data from these files into the appropriate columns in a new copy of the "Raw Data" sheet and rename the tab to the observation date.

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Update the VLSR correction value in cell "A2" to whatever is listed in your plan.

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	4	171 6881	1419 687	0.002991	0.002991	0.003019	0.0
	5	166,4027	1419.712	0.003034	0.003034	0.003072	0.0
	6	161,1174	1419.737	0.003102	0.003103	0.003151	0.0
	7	155.8324	1419.762	0.003194	0.003194	0.003255	0.0
	8	150.5475	1419.787	0.003307	0.003308	0.003385	0.0
	9	145.2628	1419.812	0.003444	0.003443	0.003538	0.0
	10	139.9783	1419.837	0.003602	0.003602	0.003715	0.0
	11	134.694	1419.862	0.003781	0.003781	0.003912	0.0

Edit the "Pre", "Main", and "Post" cells for each category on the "Analysis" sheet to select the correct columns of data from the "Raw Data" Sheet.

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171	0.041	0.051	1.00471157		0.002991	0.003022	0.003024	
166	0.056	0.058	1.006488008		0.003034	0.003075	0.003077	
161	0.071	0.071	1.008156351		0.003102	0.003156	0.003158	
156	0.084	0.087	1.009724884		0.003194	0.003261	0.003266	
150	0.104	0.104	1.012028126		0.003307	0.003393	0.003398	
145	0.122	0.121	1.01414896		0.003444	0.008548	0.003554	

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3	176.9738	1419.662	0.00297	0.00297
4	171.6881	1419.687	0.002991	0.002991
5	166.4027	1419.712	0.003034	0.003034
6	161.1174	1419.737	0.003102	0.003103
7	155 8324	1419 762	0 003194	0 003194

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If necessary, edit the Center Frequency in cell "B1" until the Velocities in column "B" closely match column "A" on the "Raw Data" sheet.

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	3	176.9	9738	1419	.662	0.00297	0.00297	0
	4	171.6	5881	1419	.687	0.002991	0.002991	0
	5	166.4	1027	1419	.712	0.003034	0.003034	0
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Edit the formula in the "Main vs Ref" column to point to the appropriate "Pre", "Main", and "Post" cells.

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$\times \checkmark f_x$	=H3/(AVERAGE(G	53,I3))				
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177	0.037	0.037	1.004221646		0.00297	0.002996	0.002997
171	0.041	0.051	1.00471157		0.002991	0.003022	0.003024
166	0.056	0.058	1.006488008		0.003034	0.003075	0.003077
161	0.071	0.071	1.008156351		0.003102	0.003156	0.003158
450	0.004	0.007	4 000704004		-	-	-

Edit the "Combined" cells to average all "Main vs Ref" Columns. This column also converts the raw amplitude ratios to dB using 20 Log.

Drav	v Page La	yout For	mulas Data	Review Vie	ew Help					
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r Vel	Combined	Smoothed	Main vs Ref 1	Main vs Ref 2	Main vs Ref 3	Main vs Ref 4	Main vs Ref 5	Main vs Ref 6		Pre
132	-0.007	-0.007	0.999760561	0.999856718	0.999721286	0.998265157	0.99790468	0.99989207	>	0.0
127	-0.006	-0.007	0.999858173	0.999985144	0.999602024	0.998012924	0.997899011	1.000370921		0.0
122	-0.007	-0.007	1.000201645	1.000144846	0.99934798	0.997807557	0.997433137	1.000456338		0.0
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111	-0.008	-0.008	1.000673193	0.999993091	0.998587325	0.997606112	0.997045122	1.000797738		0.0
106	-0.008	-0.008	1.000124073	1.000079859	0.998645164	0.99737912	0.997122839	1.000826148		0.
101	-0.008	-0.008	1.000360034	1.000263174	0.998296484	0.997291833	0.997012146	1.001227191		0.0
95	-0.009	-0.008	1.000466452	1.000192683	0.998159503	0.997297007	0.996874546	1.001135139		0.0
90	-0.008	-0.008	1.000615649	1.000231571	0.998014457	0.997299551	0.996967974	1.001628581		0.0
85	-0.009	-0.008	1.000199537	1.000236357	0.998150478	0.996909541	0.99684339	1.001446642		0.0
79	-0.008	-0.008	1.000786899	0.999993059	0.997946857	0.997221423	0.996805309	1.001632171		0.0
74	-0.009	-0.009	1.000762919	1.000056379	0.998145943	0.997075499	0.996440511	1.001468704		0.
69	-0.009	-0.009	1.000463363	1.000090463	0.997874731	0.99672368	0.996723676	1.002006931		0.0
64	-0.009	-0.009	1.00058217	1.000326438	0.997756564	0.996953108	0.996688744	1.001597935		0.0
58	-0.009	-0.009	1.000725199	1.000042168	0.997468513	0.996849836	0.996561963	1.002050472		0.
53	-0.009	-0.009	1.000840428	1.000186535	0.997610654	0.996952401	0.996601353	1.001863743		0.0

Edit the flattening polynomial coefficients on the "Flattened" sheet until the background on either side of the expected profile region in the orange plot is reasonably flat and at zero.



Adjust the horizontal and vertical scales on the "Compare" and "Final" Plots as desired to display the spectral profile as nicely as possible.



Observing with the Green Bank 20 Meter Dish



Observation Settings

- L-Band
- High Resolution
- Center Frequency set to 1420.4 MHz
- 1 second "ON"
- 1 second "OFF"
- 10 repetitions for a total of 10 seconds for each
- 1.5 degrees Az and El offset for "OFF"

Open your browser and go to <u>https://www.skynet.unc.</u> <u>edu</u>.

Log-in using the SARA username and password which you can get by emailing Stephen Tzikas at:

Tzikas@alum.rpi.edu.



Click on the menu icon in the top left. Select the "My Observatory" tab and select the "Radio Observing" option.



You will see a list of observations that are pending or recently completed.

Scroll down to the bottom of the page and select "+ Add New Observation".





Scroll down the page until you see the "keywords:" box and type in the designation or name of the galaxy you want to observe.

You can also enter coordinates exactly instead of using the keyword search.



Scroll up to the top and you should see the coordinates already populated for the object you entered.

Edit the Observation Name to add your initials.

You can change the Min Sun Separation and Min Target Elevation as desired.

A chart will show when the object will be in range of the observation settings you selected.

Hit "Save and Continue" to go to the next screen.

XM Wi-Fi 奈 5:55 PM	54% 🗲	💵 XM Wi-Fi 奈	5:55 PM	54% 🛃
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🔒 skynet.unc.edu			🔒 skynet.unc.edu	

Select "High Resolution Mode".

Set both the center frequency and secondary frequency to 1420.4 MHz.

Current Receiver: L-Band 1300.0MHz-1800.0MHz
Current Receiver: L-Band 1300.0MHz-1800.0MHz
L-Band 1300.0MHz-1800.0MHz
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High Resolution Mode
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15.625 MHz
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1420.4
Secondary Frequency (MHz):
1420.4
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Make the following selections: Path Type "On/Off" Duration "1" RA[Lng]Az Offset "1.5" Dec[Lat]El Offset "1.5" Repeat "10" Integration time "1"

Hit "Save and Continue".

IM WI-FI 춗	5:56 PM	;	00% [7]'		5:57 PM	56
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1.5				seconds (22	credits)	
1.0				38		

Double-check all of your selections and if they look correct, hit "Submit".

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Submit 🔨



Select "Skynet Live" to see the status of the Green-Bank 20 telescope.



From here, you can watch the observation status in progress.

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Select "Radio Observing" again and you will see that the status is "archived" which means your observation results are now ready to view and/or download.

When you click on the ID of the observation you will see a link to view and download your data.

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ID	Name	Мар Туре	Target	State
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120787	ngc3521 100 sec JLB	onoff	11:05:48.4 -00:02:09.1	archive <mark>d</mark>
120738	ngc7331 100 JLB	onoff	22:37:04 34:24:56.8	archived
120737	ngc2903 50 sec JLB	onoff	09:32:10.1 21:30:02.8	archived
120736	ngc3198 50 sec JLB ⋒ skvn	onoff et unc e	10:19:54.8 45:32:58 9 du	ard



Continuum Spectra		2024-08-23 21:42:32 (UT)	Latest	20m Info	
Raw data Calibrated Calibrated off-source Calibration Info On/Off Cal	Observer: socamrad_21318				
	HIRES onoff; filter 1355_1435; 243 secs	Log	20m Skynet		
Data File Description.			<u>Skynet: my obs</u>		

{Raw data at 20m-data:/raid/scratch/cyborg/SkynetData/Skynet_60545_messier_101_10_sec_JLB_120655/Cyborg }

If you click on that link, you will see power vs time and spectral plots of your observation data.



On-Off/Off spectrum :



Live Spectrum





If you click on the link in the cell marked "Spectra" it will bring up a text file with the data which you can download.

#	BASENAME=Skynet 60545 messier 101					
#	CONTROL=SKYNET					
#	PROJCODE=Skynet 60545 messier 101 10 sec JLB 12065					
#	DATAROOT=/raid/scratch/cyborg/Sky	netData				
#	DATADIR=/raid/scratch/cyborg					
#	DATADIR2=/raid/scratch/cyborg/Sky	netData/Skynet 60				
#	SCANNAME=2024 08 07 15	. , _				
#	SRC NAME=messier 101 10 sec JLB					
#	OBSERVER=socamrad 21318					
#	DATE OBS=2024-08-23T21:42:32.000					
#	OBSID=120655	# TSY	S=XX1.61 61 YY	1.64 52		
#	SCANNUM=70550	# TSV	$S = XX2 \cdot 61 \cdot 64 VV$	2.64 51		
#	MJD=60545.904537	# тса	$1 = XX1 \cdot 9 \ 17 \ VV1$	10 07		
#	UTC=78152	# TCA	$1 = XX2 \cdot 9 \ 17 \ VV2$	10.07		
#	SCANTYPE=onoff	# Calibrated	spectra: Tsvs*(ON-OFF)		
#	DATAMODE=HIRES	#	speceru. Toyo (
#	RECEIVER=Rx1 2	#				
#	OBSFRE0=1395.0000	#Ereal(MHz)	XX1	VV1		
#	Actual FRE01=1419.0000.	1426 03430	-0 4742	-0		
#	Actual FRE02=1419.0000	1426,01904	-0.4654	-0.5		
#	L01Tuning=6869.0000	1426,00378	-0.4724	-0.5		
#	RFFILTER=1355 1435	1425,98853	-0.6686	-0.5		
#	OBSBW=-15.6250	1425.97327	-0.5241	-0.6		
#	EFFBANDW=15.6250	1425.95801	-0.5196	-0.6		
#	NCHAN=1024	1425,94275	-0.5562	-0.6		
#	STARTCHAN=51	1425.92749	-0.7655	-0.4		
		1425,91223	-0.5528	-0.2		
		1425.89697	-0.7900	-0.6		
		1425.88171	-0.8184	-0.6		
		1425,86646	-0.5768	-0.4		
		1425.85120	-0.6430	-0.1		
		1425.83594	-0.9532	-0.5		
		1425.82068	-0.5565	-0.5		
		1425.80542	-0.7361	-0.8		
		1425.79016	-0.4358	-0.7		
		1 435 37 400	0 4000			

FILENAME=Skynet 60545 messier 101 10 sec JLB 12065



TCAL=X	X1:9.17, YY1:	10.07			
TCAL=X	X2:9.17, YY2:	10.07			
alibrated spe	ctra: Tsys*(O	N-OFF)/OFF			
eq1(MHz)	XX1	YY1 Fr	eq2(MHz)	XX2	
1426.03430	-0.4742	-0.3980	1426.03430	-0.4	
1426.01904	-0.4654	-0.5037	1426.01904	-0.4	
1426.00378	-0.4724	-0.5247	1426.00378	-0.4	
1425.98853	-0.6686	-0.5503	1425.98853	-0.6	
1425.97327	-0.5241	-0.0985	1425.97327	-0.5	
1425.95801	-0.5196	-0.6789	1425.95801	-0.5	
1425.94275	-0.5562	-0.6868	1425.94275	-0. <u>5</u>	
1425.92749	-0.7655	-0.4898	1425.92749	-0.7	
1425.91223	-0.5528	-0.2995	1425.91223	-0.5	
1425.89697	-0.7900	-0.6677	1425.89697	-0.7	
1425.88171	-0.8184	-0.6903	1425.88171	-0.8	
1425.86646	-0.5768	-0.4041	1425.86646	-0.5	
1425.85120	-0.6430	-0.1667	1425.85120	-0.6	
1425.83594	-0.9532	-0.5836	1425.83594	-0.9	
1425.82068	-0.5565	-0.5983	1425.82068	-0.5	
1425.80542	-0.7361	-0.8664	1425.80542	-0.7	
1425.79016	-0.4358	-0.7937	1425.79016	-0.4	
1425.77490	-0.4988	-0.5952	1425.77490	-0.4	
1425.75964	-0.6343	-0.5919	1425.75964	-0.6	
_					



I dump my data results into an excel spreadsheet to flatten the background and display the resulting spectrum in a nice plot with velocity on the x-axis instead of frequency.

There are templates and user guides for my analysis spreadsheets available.



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