Introduction

After a brief presentation of Richard Prestage's talk on

Open Source Radio Telescope

John Makous will give a longer presentation on

Digital Signal Processing in Radio Astronomy – a Research Experience for Teachers

Open Source Radio Telescope

- http://opensourceradiotelescopes.org/
- a resource for radio astronomy telescope construction at any level, from simple feed horns to phased-array feeds and interferometers.
- Discussion Forums
- Telescope Designs
- LightWork Memo Series
- Additional Resources:
  - Larger Scale Home Built Radio Telescope, Radio Astronomy Supplies
  - Canadian Centre for Experimental Radio Astronomy (CCERA)
  - Digital Signal Processing in Radio Astronomy (DSPIRA)
  - Society of Amateur Radio Astronomers (SARA)
  - Such A Lovely Small Antenna (SALSA)

Digital Signal Processing in Radio Astronomy – a Research Experience for Teachers

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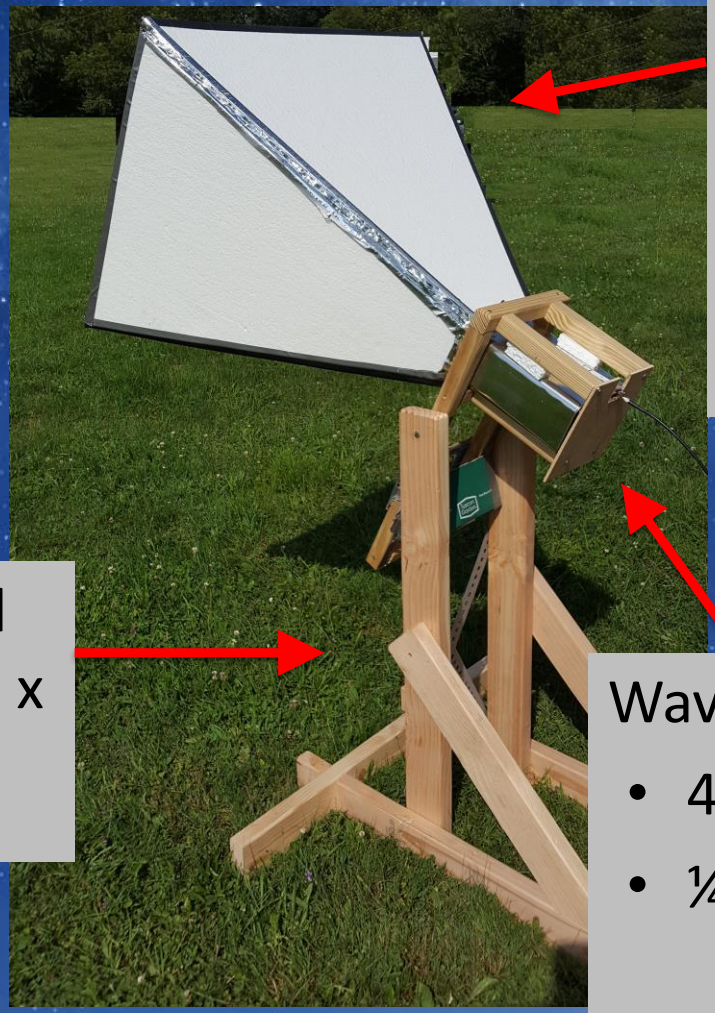
Outline

- Introduction
- Design and construction
- Operation and capabilities

Introduction – Horn Telescopes

- This talk is the result of 2 summers attending the RET DSPIRA program at WVU and GBO.
- The horn telescopes described here are designed to detect the 21 cm radio waves transmitted by neutral atomic hydrogen (HI) emitted by interstellar hydrogen in the galaxy.

Horn Telescope Design



Horn

- aluminized insulation board
- 60 cm x 75 cm horn opening

Stand - constructed from 2” x 2” and 2” x 4” wood

Waveguide & Antenna

- 4 ½ ” x 6 ½ ” metal can
- ¼ wave antenna: 5.25 cm


POLYPRO™ BOARD 1.44 1.93 2.69
FOIL FACING with AIR SPACE 2.8 2.6 2.8
SYSTEM R-VALUE
**To obtain the System R-Value there must b
between the foil facing and the exterior claddin
R- means the resistance to heat flow.
The higher the R value the greater the insulating power.
Notice: This insulation sheathing board meets or exceeds the
properties of the American Society of Testing Methods (AST
Installation: Install over exterior studs using a 7/16" crow
plastic cap nail fasteners. Fasteners should be 8" apart a
edge and center of sheathing penetrating the stud at le
the seams of the sheathing will help keep air from infi
structure. Do not use as a nailing base. Corner bracin
Warning: Although this product contains a fire re
it is combustible. Keep away from open flame
heat and ignition. It may burn rapidly. If used
inadequately protected for a long period of time
your local building official for specific use.
Manufactured by:
PERMA R PRODUCTS
EPS INSUL
Manufactured by:
PERMA R PRODUCTS

Low noise amplifier:

- optimized for 21 cm radio waves at 1420.4 MHz
- gain = 50 db
- Stabilized for operation in urban environments

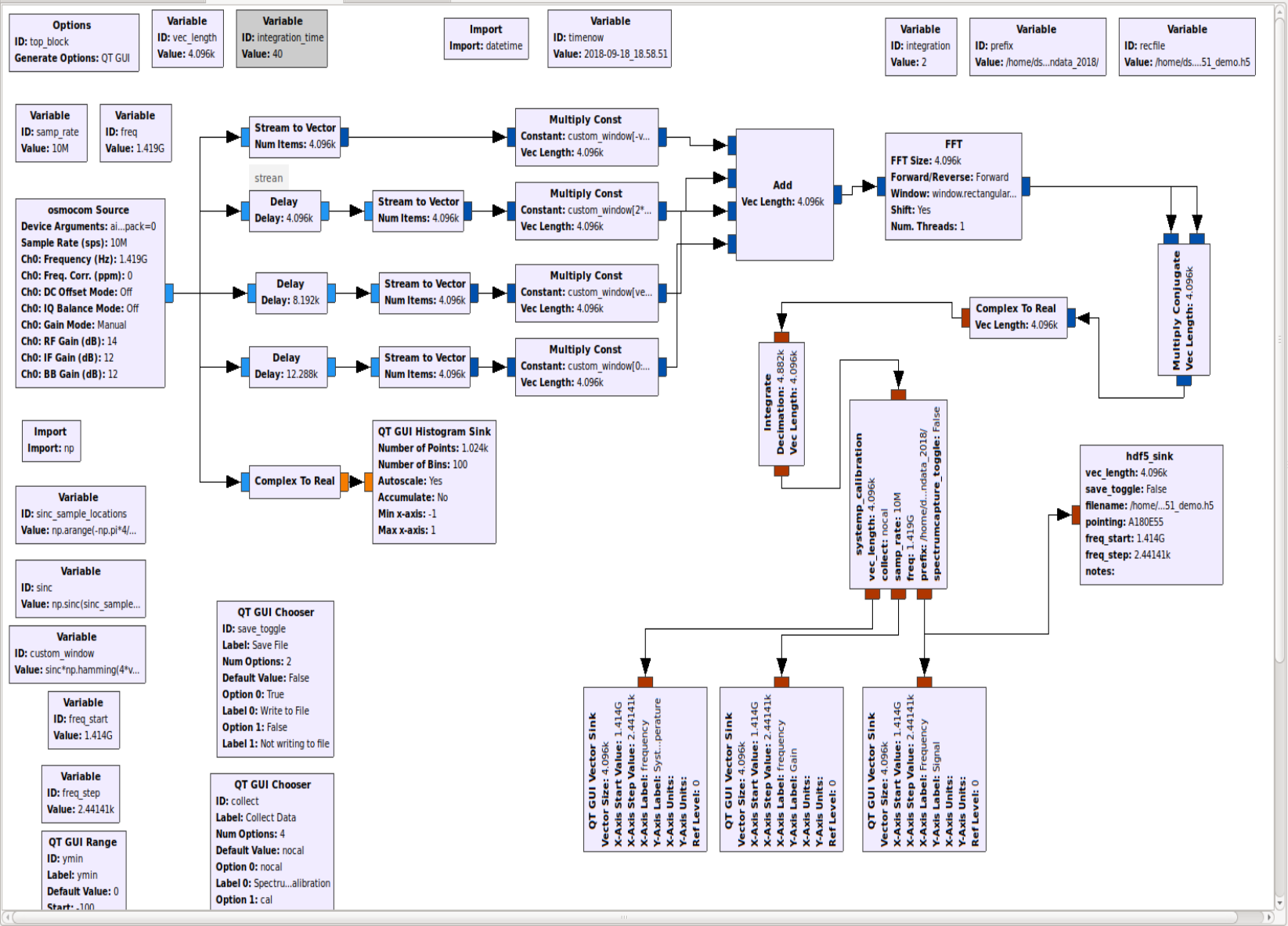
Horn Telescope Operation

Software Defined Radio (SDR)

- Airspy radio
  - 24 MHz – 1800 MHz range
  - 10 MHz bandwidth
- Gnuradio program:
  - used to perform the signal processing
  - free & open source

File Edit View Run Tools Help

spectrometer&continuum_w_cal | spectrometer_w_cal | fm_radio_JLM

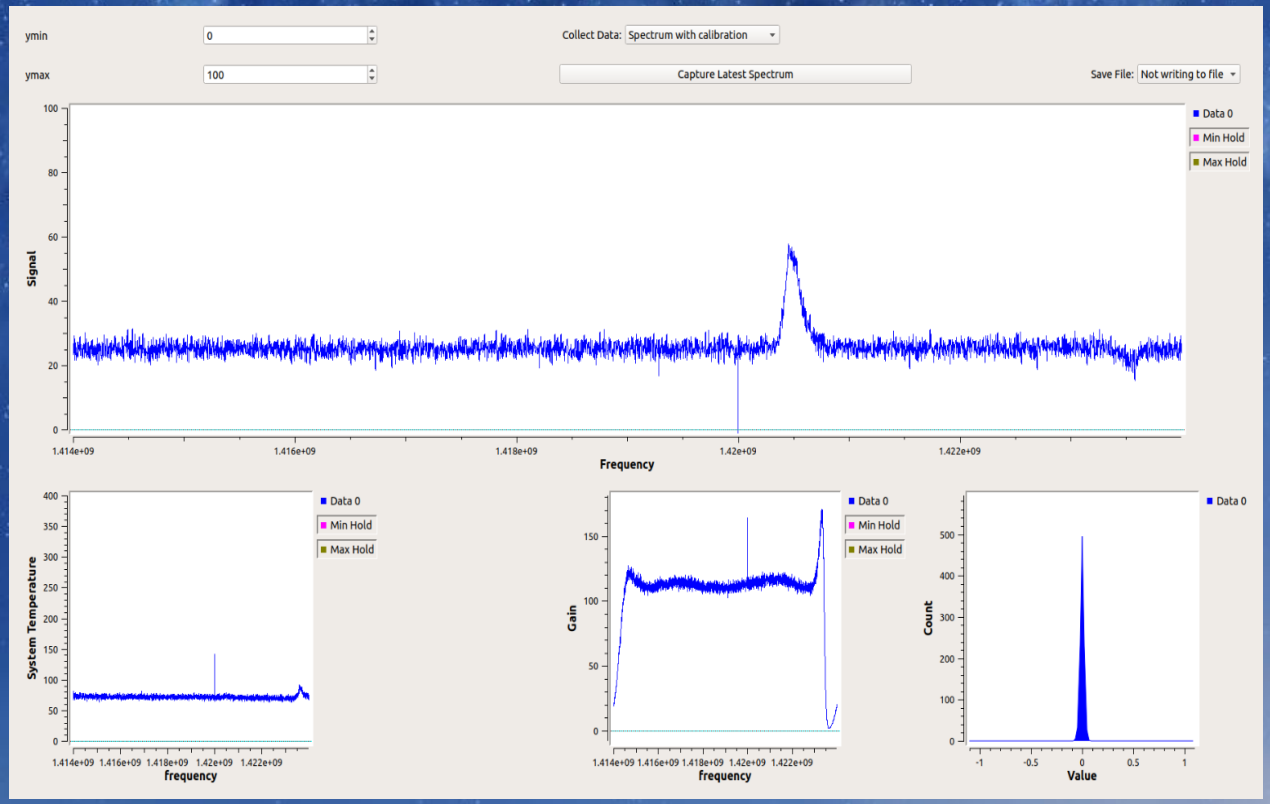


Id | Value

- calibration
- Core
  - Audio
  - Boolean Operators
  - Byte Operators
  - Channelizers
  - Channel Models
  - Coding
  - Control Port
  - Debug Tools
  - Deprecated
  - Digital Television
  - Equalizers
  - Error Coding
  - FCD
  - File Operators
  - Filters
  - Fourier Analysis
  - GUI Widgets
  - Impairment Models
  - Instrumentation
  - Level Controllers
  - Math Operators
  - Measurement Tools
  - Message Tools
  - Misc
  - Modulators
  - Networking Tools
  - NOAA
  - OFDM
  - Packet Operators
  - Pager
  - Peak Detectors
  - Resamplers
  - Stream Operators
  - Stream Tag Tools
  - Symbol Coding
  - Synchronizers
  - Trellis Coding
  - Type Converters
  - UHD
  - Variables

Horn Telescope Calibration

Calibrated Scans on the Run



Horn Calibration

- Signals detected include inputs from extraneous sources

$$P_{measured} = G \times (T_{object} + T_{system})$$

$P_{measured}$ = detected signal
G = gain
T_{object} = signal from object of interest (galaxy, pulsar, etc.)
T_{system} = signal from extraneous sources

These are all functions of frequency

- Calibration involves measuring spectra of 2 known temperatures
- "T_{hot}" = temperature of ground = 300 K (assumed)
- "T_{cold}" = temperature of empty sky = 10 K (assumed)

Horn Calibration

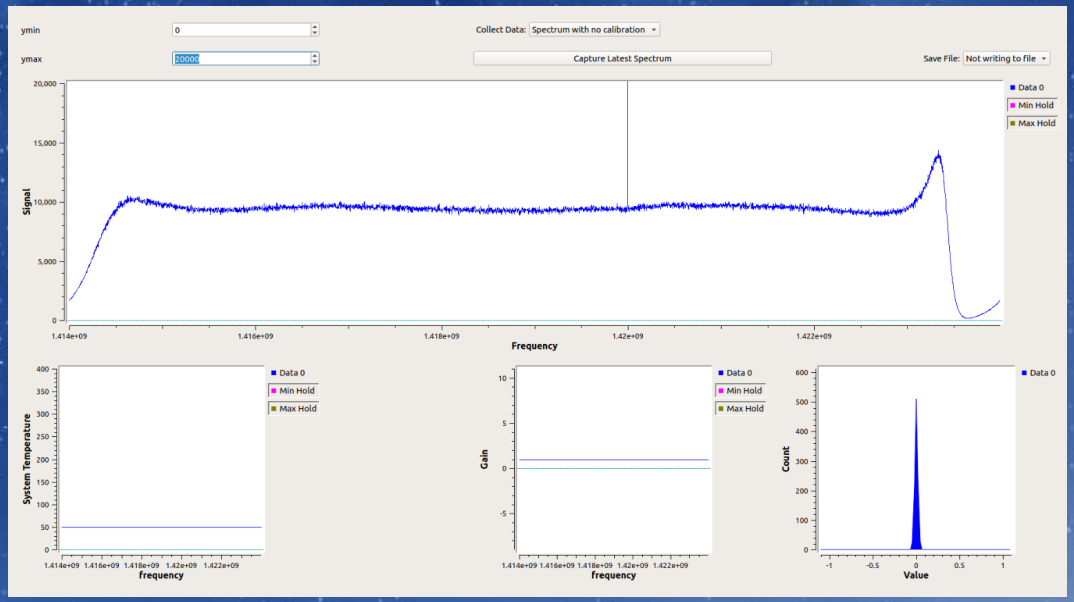
- By collecting spectra of the ground and empty sky, the gain and system temperature can be determined:

$$G = \frac{P_{hot} - P_{cold}}{T_{hot} - T_{cold}}$$

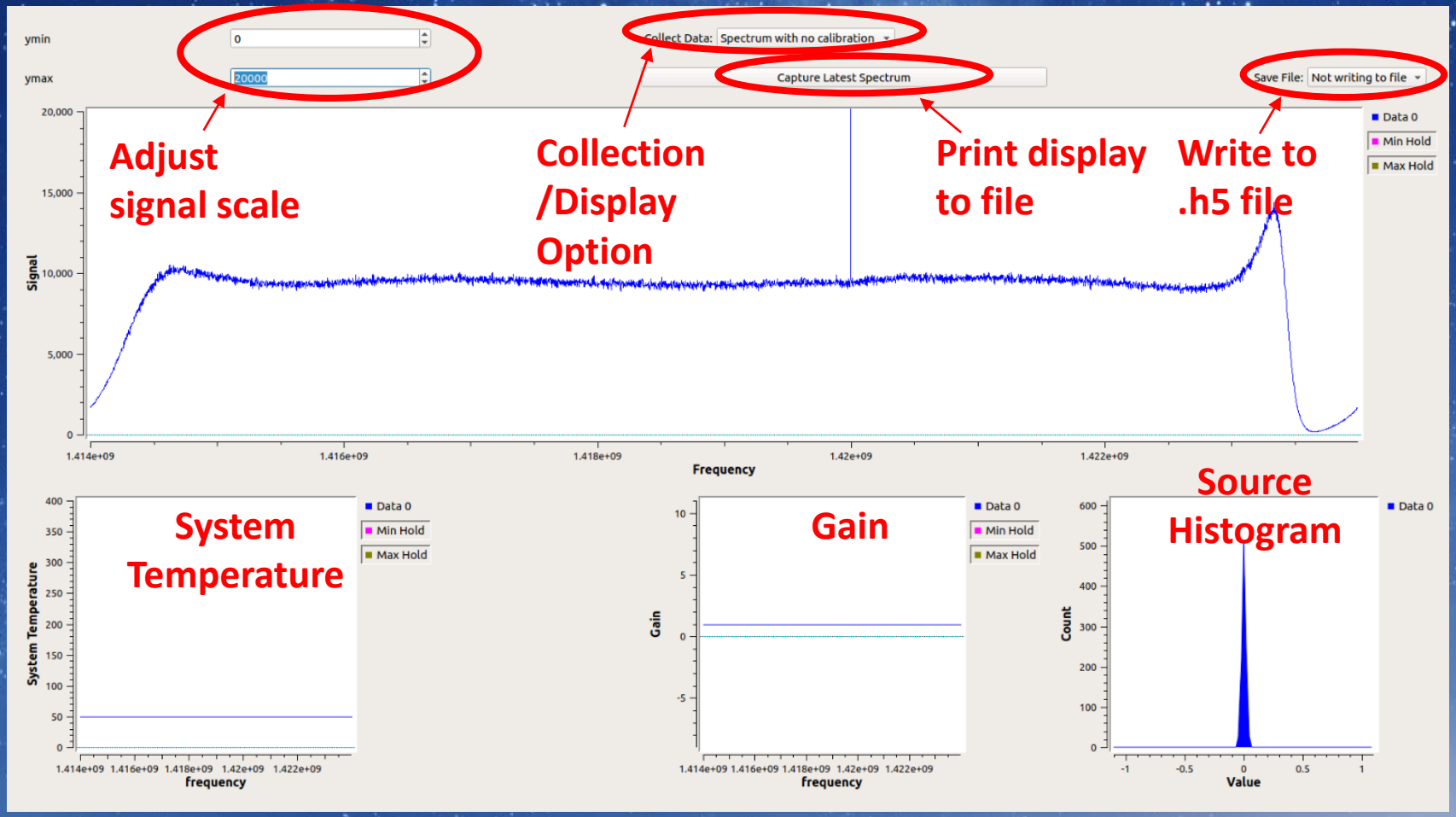
$$T_{system} = \frac{T_{hot} - T_{cold}(P_{hot}/P_{cold})}{(P_{hot}/P_{cold}) - 1}$$

Calibration on the Fly

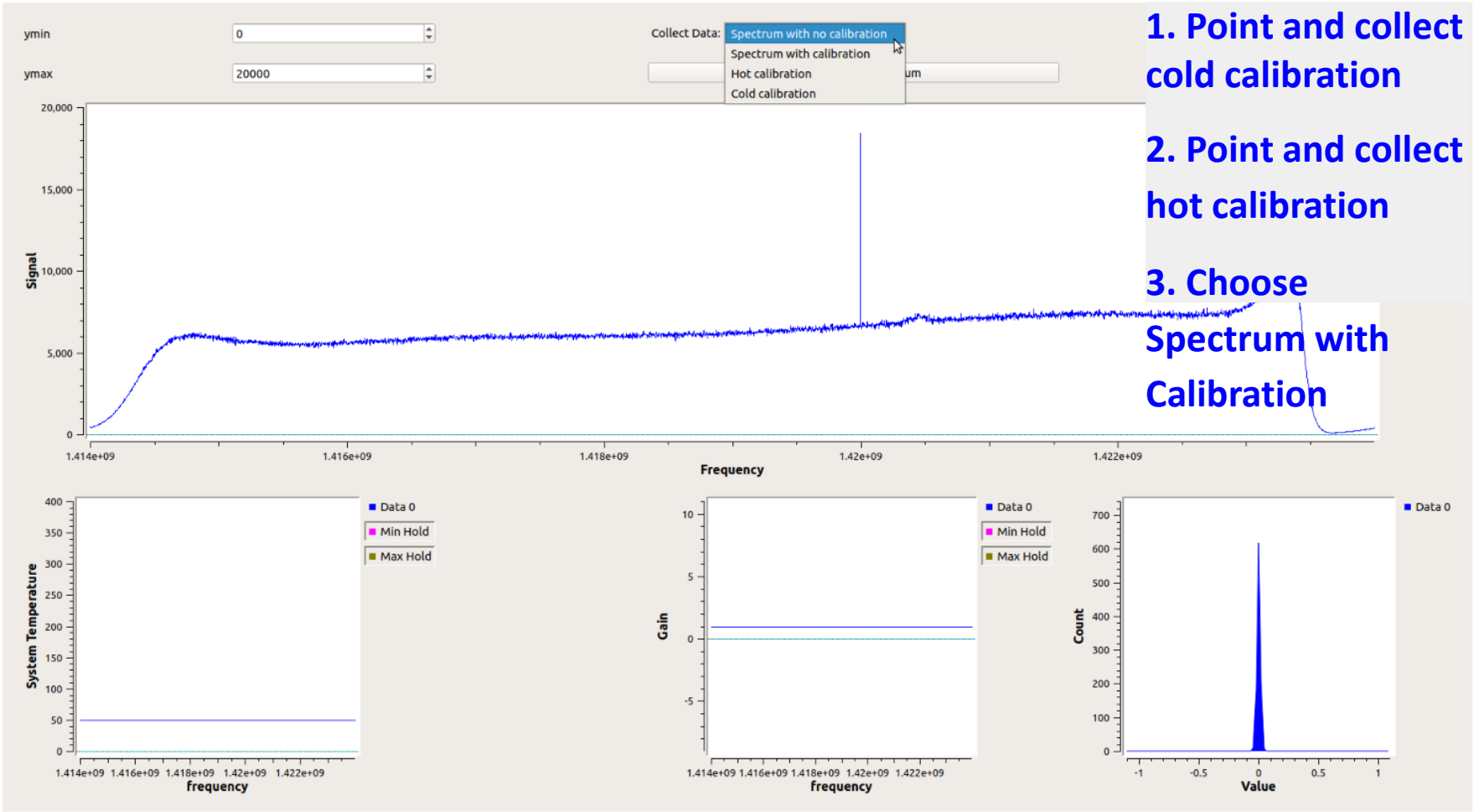
- We built a gnuradio block to accommodate calibration runs that can be incorporated into the live display during a run



Features of the Calibration Block & Display

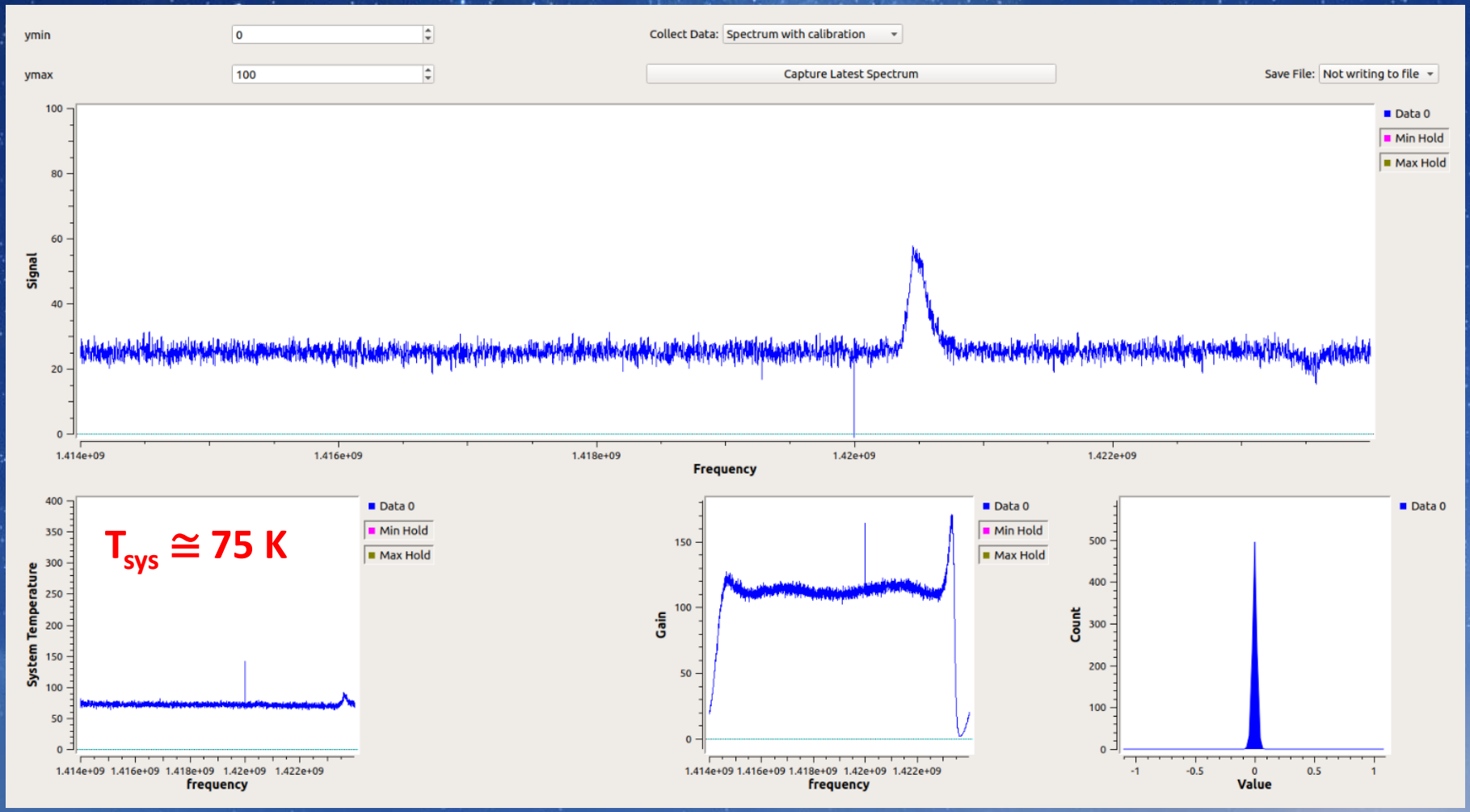


Calibration Procedure

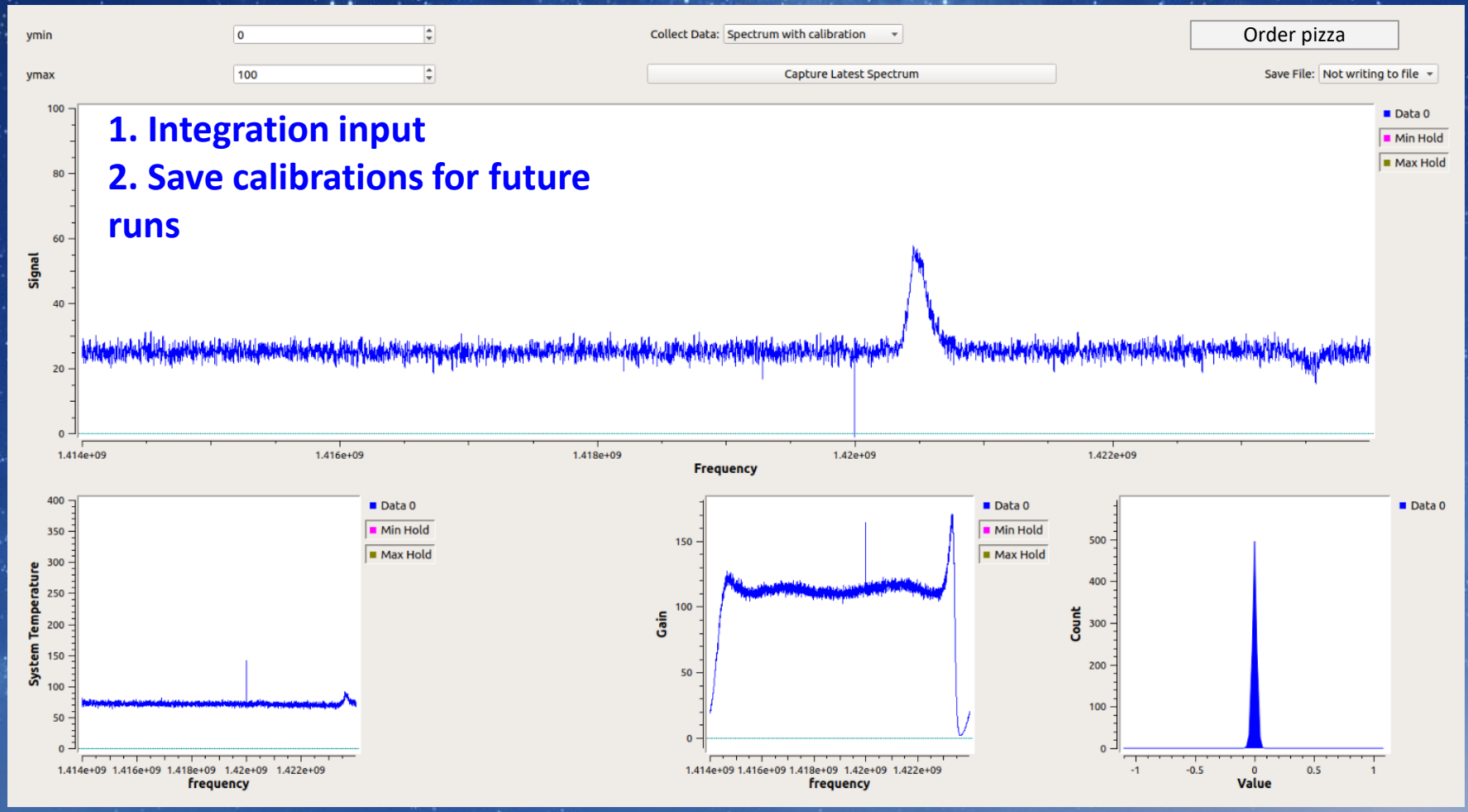


1. Point and collect cold calibration
2. Point and collect hot calibration
3. Choose Spectrum with Calibration

Calibrated Spectrum Displayed

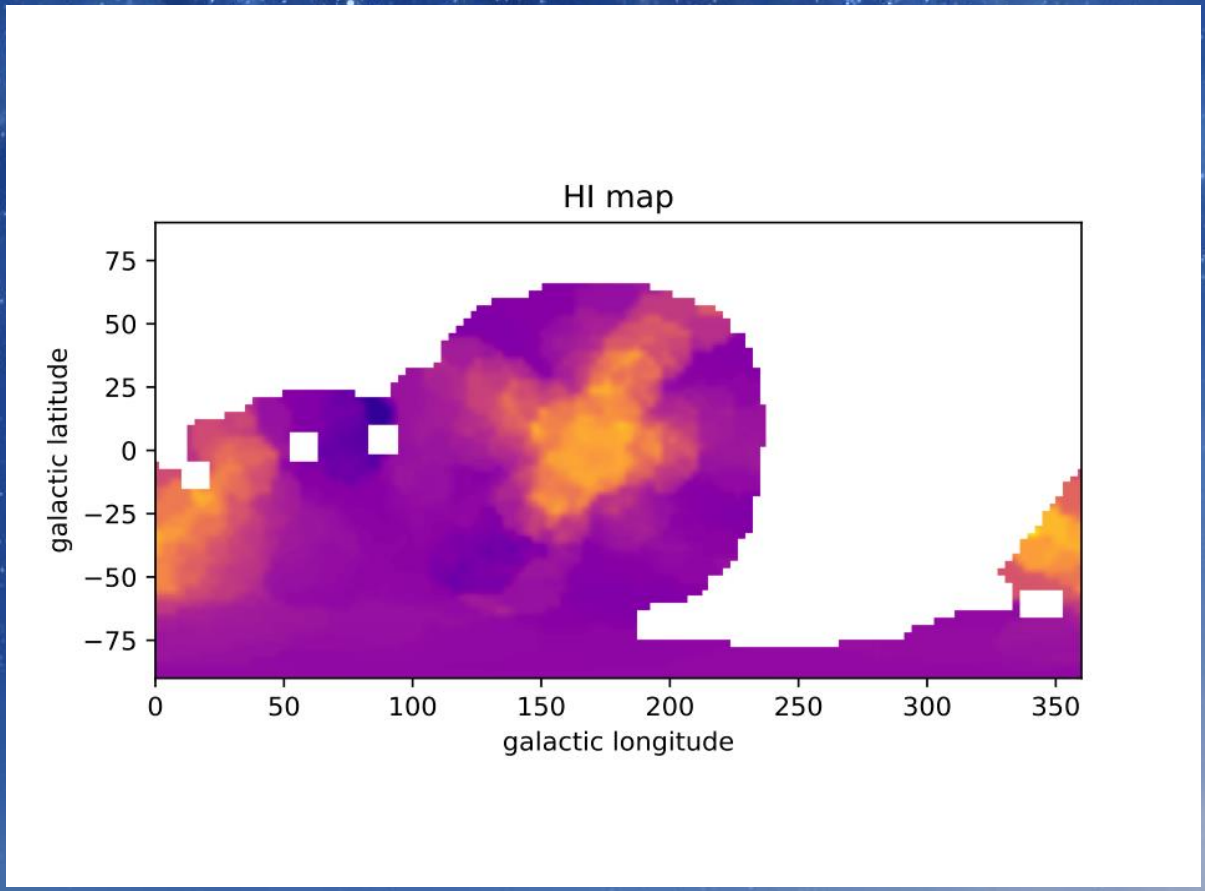


Future Modifications



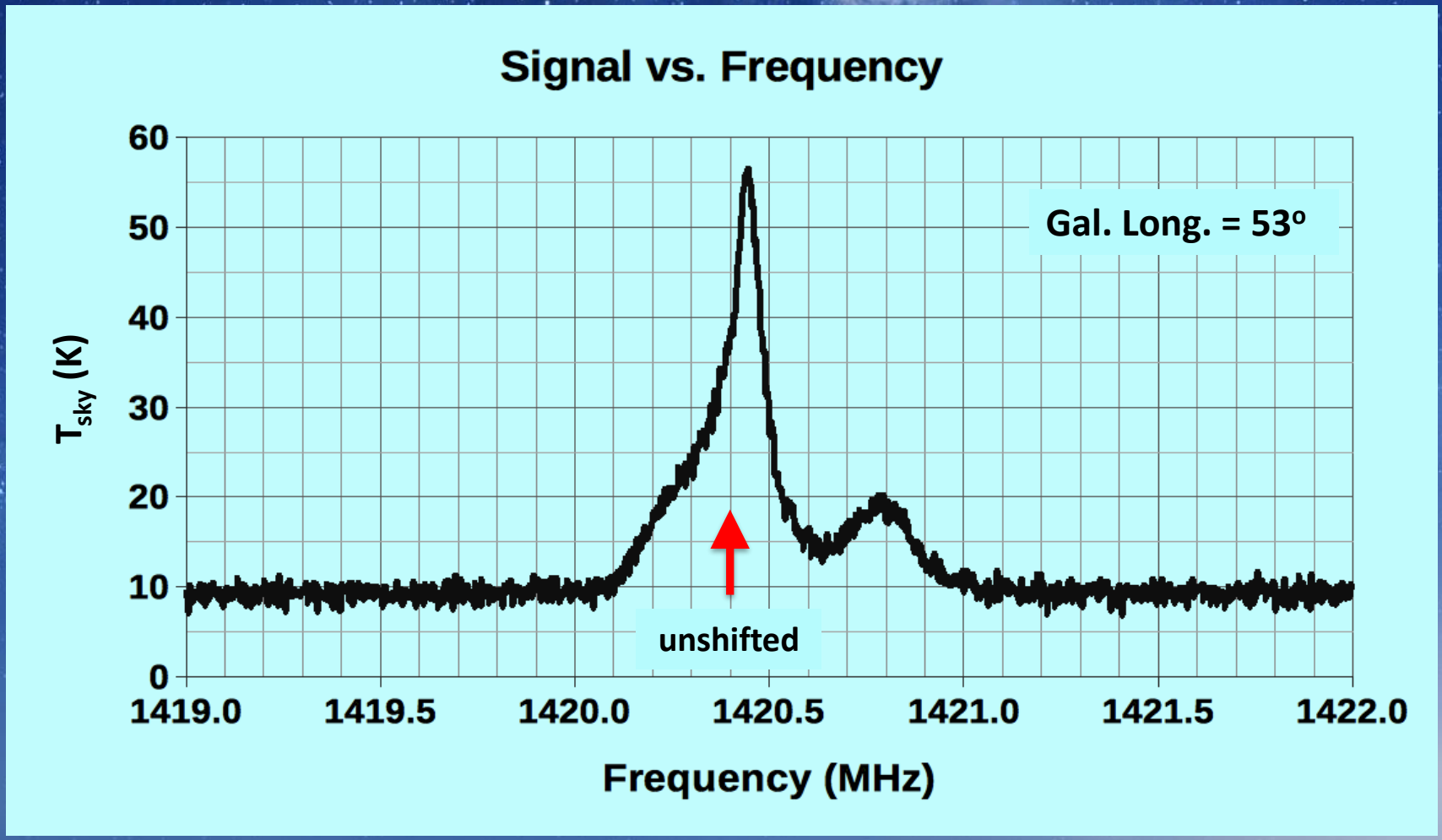
Horn Telescope Performance

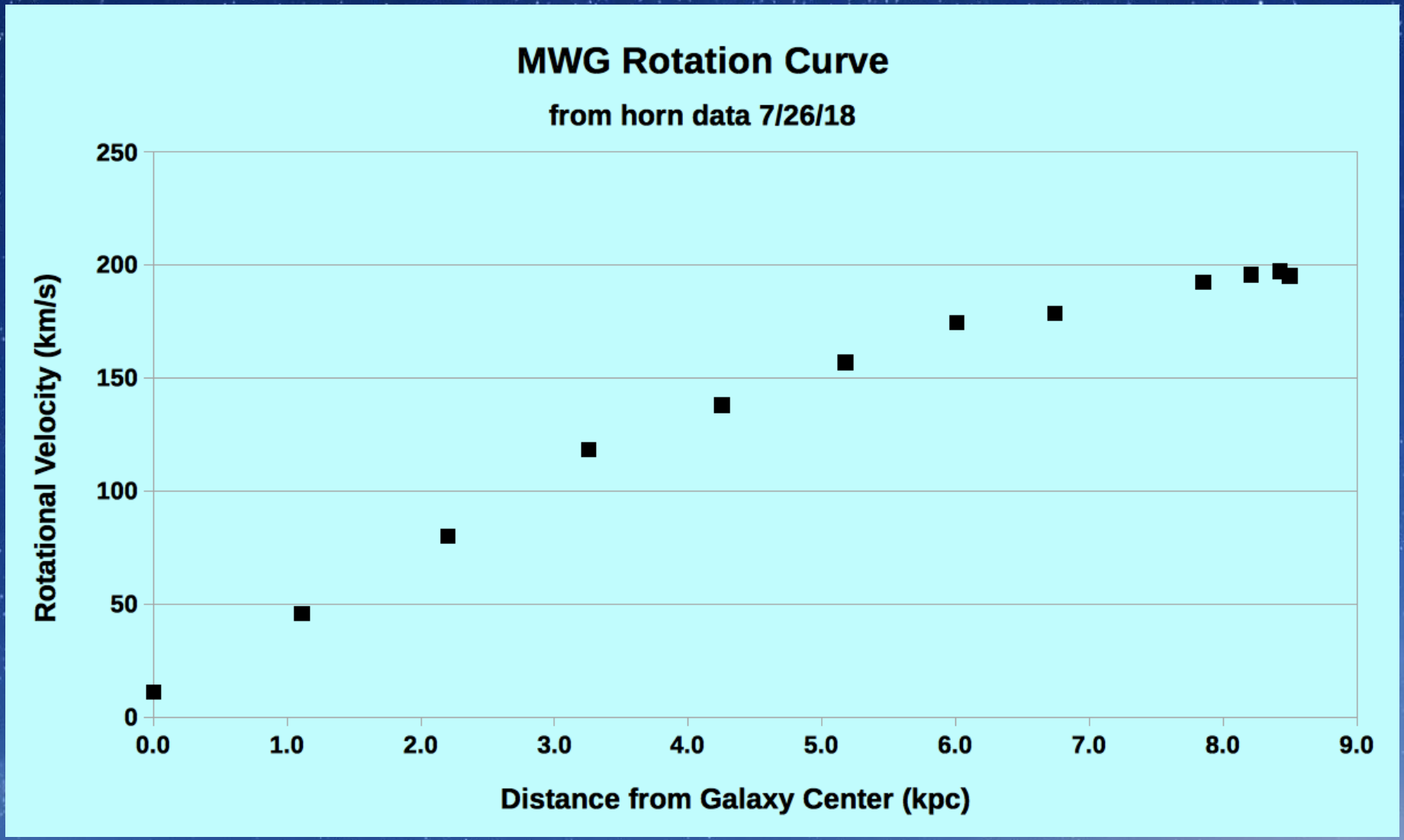
- Can detect neutral hydrogen (HI) from the Milky Way Galaxy.



Students can measure the Doppler shift of the hydrogen signal from the expected 1420.4 MHz

➔ the MW galaxy is rotating!




MWG Rotation Curve
from horn data 7/26/18
Rotational Velocity (km/s)
250
200
150
100
50
0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
Distance from Galaxy Center (kpc)

Possible Projects

- Interferometry
- Pulsar detection
- Fast Radio Burst detection

Implementation in the classroom

Utilizing a horn telescope covers many STEM standards:

- Math – in all phases of use
- Engineering & Technology – build/design horns, test/modify cycle
- Computer programming – gnuradio, python
- Astronomy
  - radio waves, EM spectrum, signals, energy
  - telescopes: purpose & design, astronomical measurements
  - structure and motion of galaxies
- Physics
  - Kepler's laws, motions of galaxies, dark matter

Rich in Science Standards

NGSS HS.Space Systems			
Horn Telescope Activity	**Science & Engineering Practices**	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Measuring H1 spectrum; determining rotation curve	Developing and using models	ESS1.B – Kepler's laws, orbits, etc.	Scale, Proportion, and Quantity
	Using mathematical and computational thinking	PS4.B – EM Radiation	Interdependence of Science, Engineering, and Technology
	Constructing Explanations and Designing Solutions		Scientific Knowledge Assumes an Order and Consistency in Natural Systems
	Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena		

SUMMARY

Horn telescopes offer:

- Rich STEM experience for students
- Hands-on science – learn by doing
- Ability for students to develop and/or test models of nature
- Ability for students to experience a part of the world of digital signals

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RET DSPIRA PROGRAM

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