Development of a New Generation Small Radio Telescope (SRT)

Dustin Johnson

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MIT Haystack Observatory

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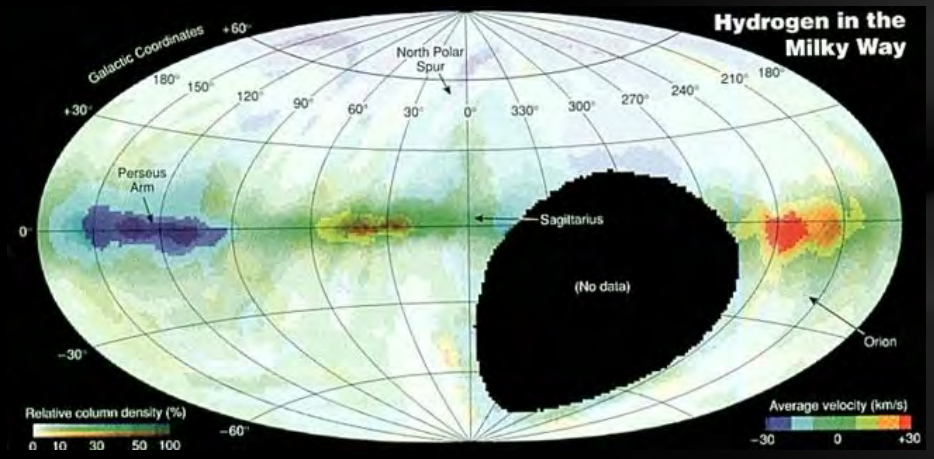
HAYSTACK
OBSERVATORY

Outline

- What is the SRT?
- Why do we need a new one?
- Design of the new SRT
- Performance
- Interference Problems
- Software
- Documentation
- Astronomy

What is the SRT?

- An inexpensive radio telescope for teaching astronomy and radio technology, operating in the 1400-1427 MHz radio astronomy band
- Developed at Haystack in 1998
- Original was based on custom equipment from CASSI, a company founded to build the SRT
- Hundreds deployed at universities around the world



Map of galactic neutral hydrogen made with the SRT

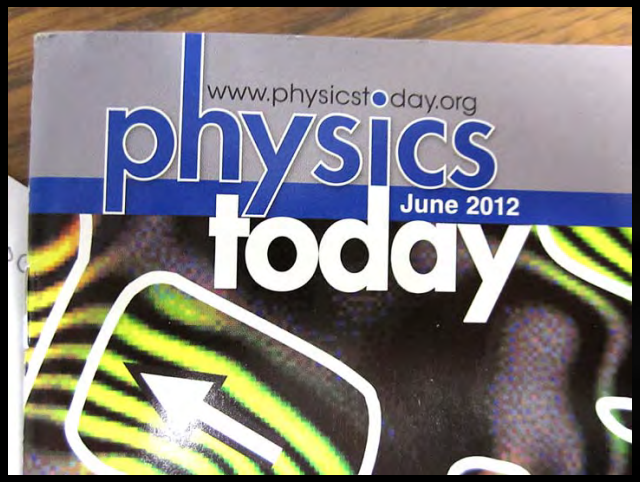
Credit: http://www.haystack.mit.edu/edu/undergrad/srt/SRT%20Projects/Hydrogen_in_Milky_Way.jpg

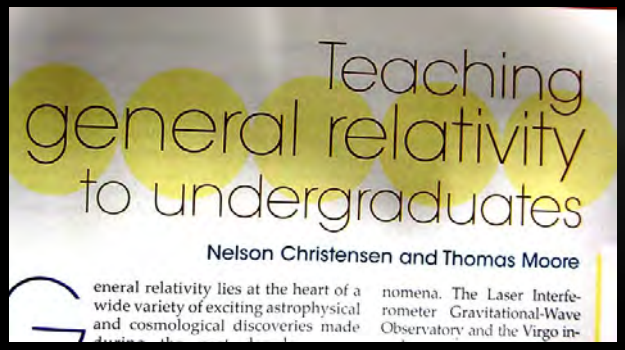
The original SRT

Credit: http://www.haystack.mit.edu/edu/undergrad/srt/srtdecember.jpg

Why do we need a new one?

- CASSI stopped offering the SRT
- Electronics have advanced significantly since the original design
- There is demand for the SRT





frame.[4] Students can use a relatively inexpensive radio telescope to actually measure the galactic rotation curve and so discover that our galaxy contains dark matter.[5] Although we are unaware of relativity experiments that use the global positioning system, the many relativistic effects underlying GPS make for interesting study and discussion.[1]

Computer advances have made it possible for

References

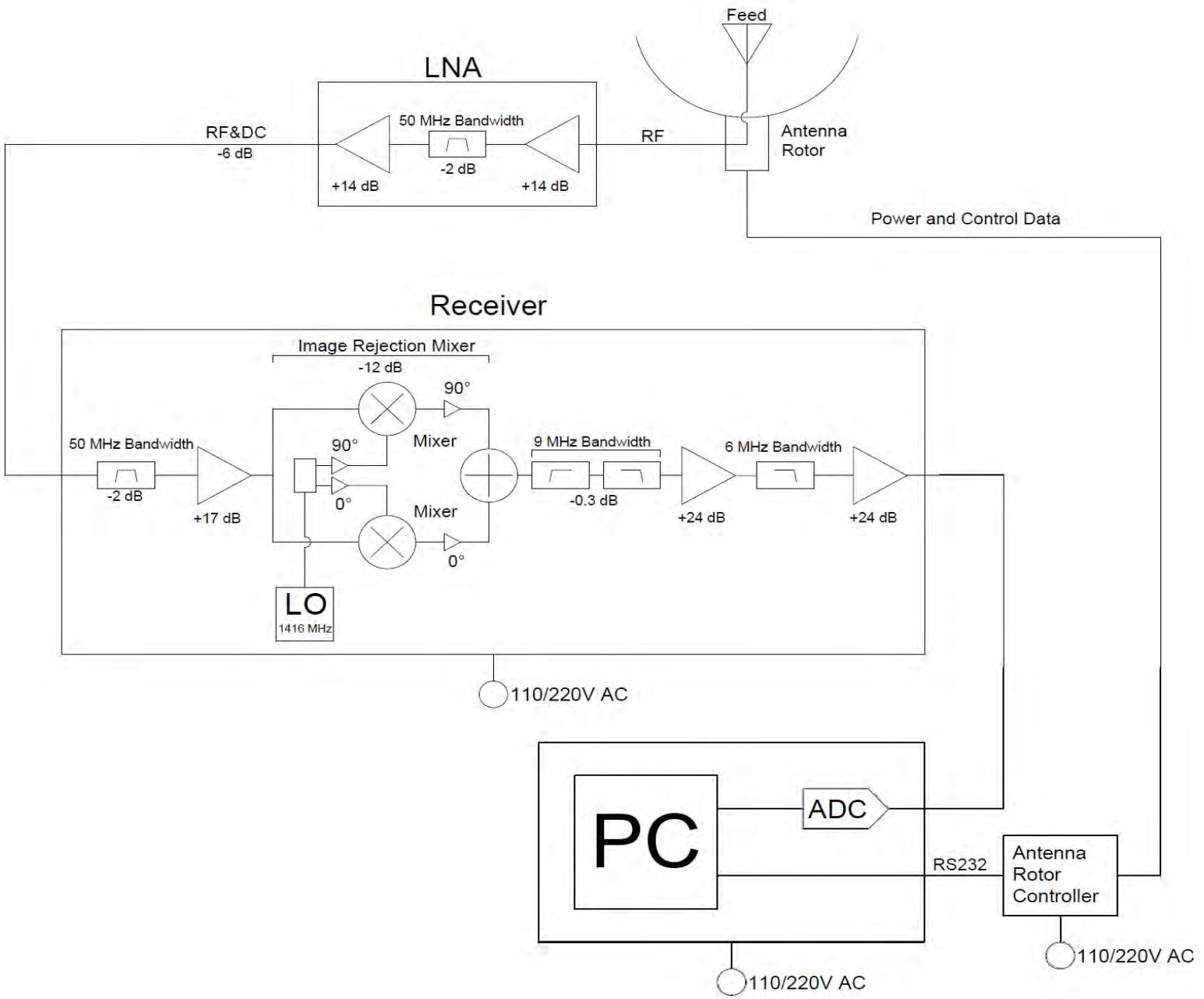
1. H. F. Fliegel, R. S. DiEsposti, "GPS and relativity: An engineering overview" (1996), http://tycho.usno.navy.mil/ptti/1996/Vol%2028_16.pdf.
2. E. F. Taylor, J. A. Wheeler, *Spacetime Physics: Introduction to Special Relativity*, 2nd ed., W. H. Freeman, New York (1992).
3. J. B. Hartle, *Gravity: An Introduction to Einstein's General Relativity*, Addison-Wesley, San Francisco (2003); *Am. J. Phys.* **74**, 14 (2006).
4. P. Wogt, J. Kuhn, *Phys. Teach.* **50**, 182 (2012).
5. MIT Haystack Observatory, Undergraduate Research, SRT, http://www.haystack.mit.edu/edu/undergrad/srt.
6. J. B. Hartle, *Mathematica Notebooks*, http://wps.aw.com/aw_hartle_gravity_1/0,6533,512496,00.html. See also K. Lake, http://arxiv.org/abs/physics/0509108.
7. T. Moore, *A General Relativity Workbook*, http://pages.pomona.edu/~tmoore/grw/download.html.
8. Open Source Physics, http://www.opensourcephysics.org.
9. Rotation Curves, http://burro.astr.cwru.edu/JavaLab/RotcurveWeb/main.html.
10. R. Hake, *Am. J. Phys.* **66**, 64 (1998).

The SRT is referenced in *Physics Today*

Design of the new SRT

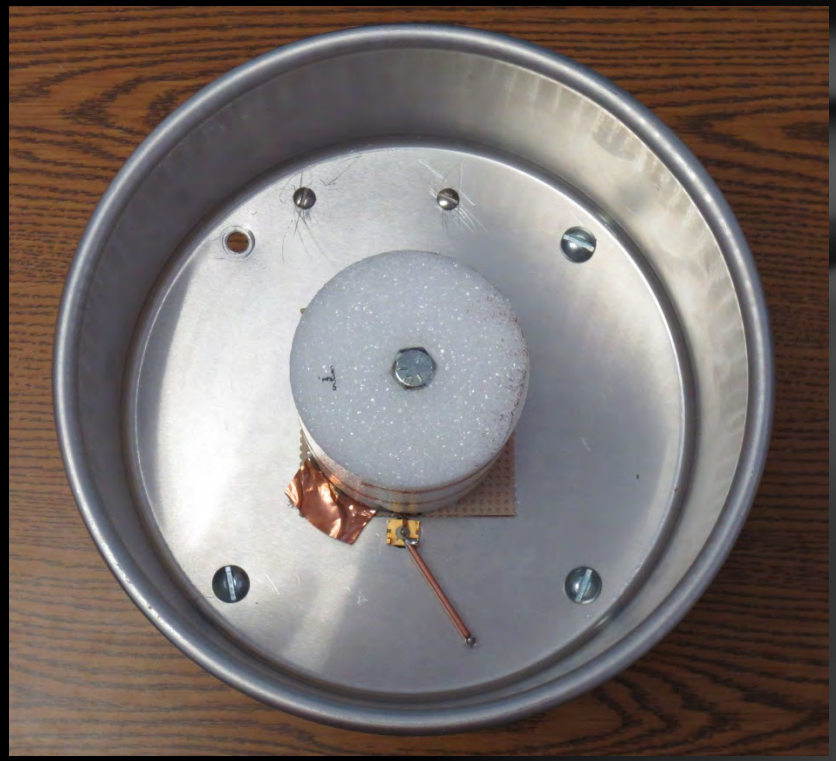
- Design philosophy: build it yourself
  - Haystack provides instructions, a list of parts, and software
  - Universities buy the components from commercial retailers and build the telescope themselves
- Components of the SRT:
  - 2.3m satellite dish on fully steerable elevation-azimuth mount
  - Helical antenna and cavity feed
  - Low-noise amplifier
  - Super-heterodyne receiver with a 1416 MHz local oscillator and amplification
  - A/D conversion on a PCI card
  - Software to control the telescope and process and plot data
  - Antenna rotor controller

- Highlighted components were the focus of this project


Feed
LNA
RF&DC
-6 dB
50 MHz Bandwidth
-2 dB
+14 dB
+14 dB
RF
Antenna
Rotor
Power and Control Data
Receiver
Image Rejection Mixer
-12 dB
90°
Mixer
90°
0°
Mixer
0°
50 MHz Bandwidth
-2 dB
+17 dB
9 MHz Bandwidth
-0.3 dB
6 MHz Bandwidth
+24 dB
+24 dB
LO
1416 MHz
110/220V AC
PC
ADC
RS232
Antenna
Rotor
Controller
110/220V AC
110/220V AC

Helical Antenna and Cavity Feed

- The SRT uses a cavity backed low-profile helix feed based on designs from the literature, modified from that used on the original SRT
- Changes made:
  - Placing LNA in enclosure on back of the feed
  - Changed method of impedance matching for better performance

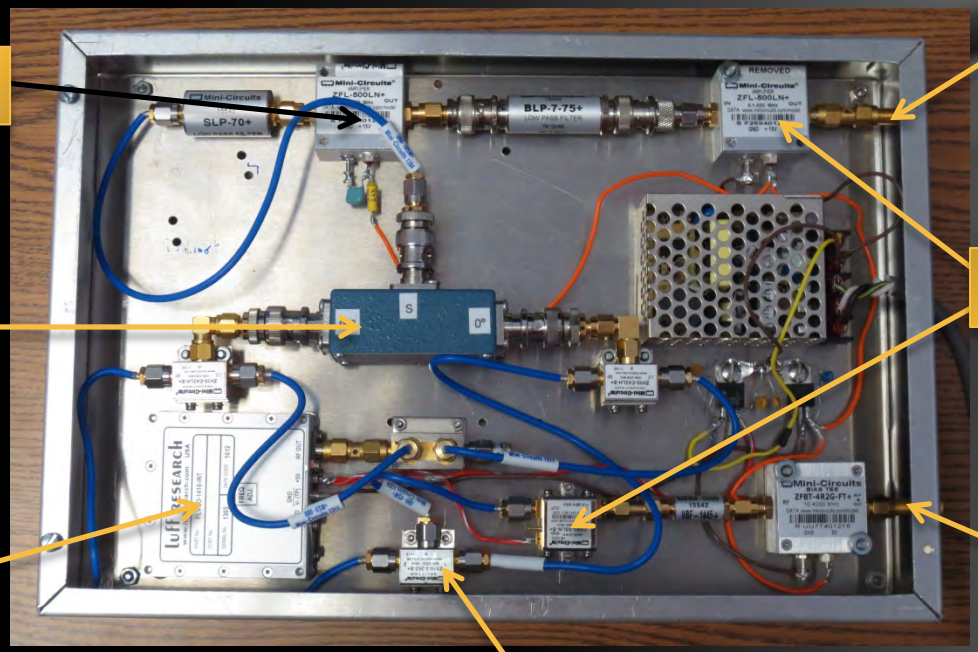


Low-Noise Amplifier

- Two-stage amplification with band pass filtering
- Powered over the coaxial cable using a bias-tee
- Changes made:
  - Made from commercially available modules that can be simply assembled in a waterproof enclosure
  - Mounted on back of feed instead of underneath helical antenna

Receiver

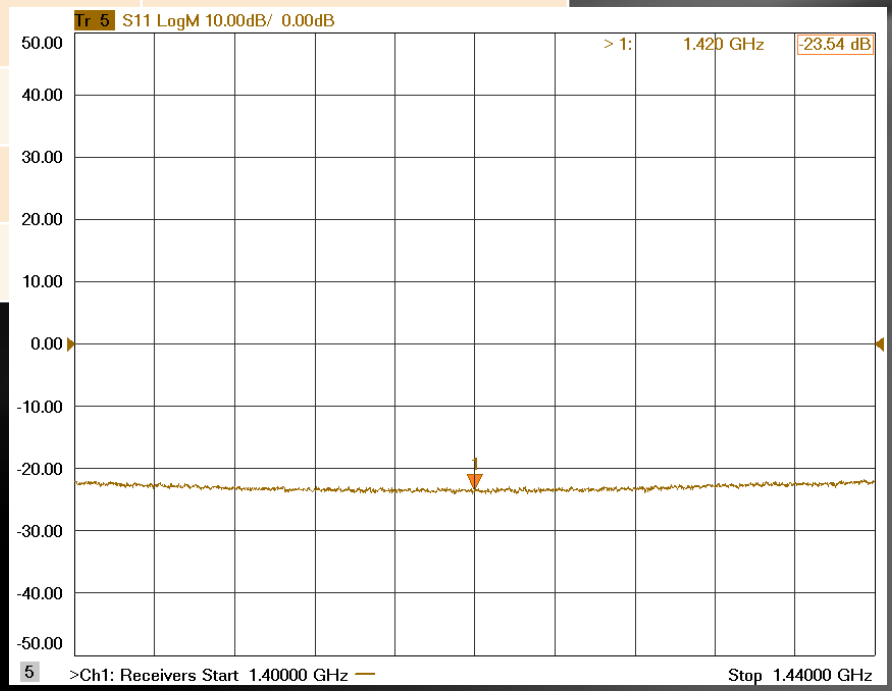
- Super-heterodyne receiver with fixed 1416 MHz local oscillator with amplification
- Three amplifiers: one RF and two IF
- Changes made:
  - Accurate but non-tunable local oscillator for the 21-cm hydrogen line
  - All components are available commercially and most can be simply connected with standard SMA cables
  - Moves A/D conversion to a PCI card



Performance

- Two 1420-1470 MHz filters remove RFI
- Two low pass and one high pass IF filters
- Filtering on the power supply

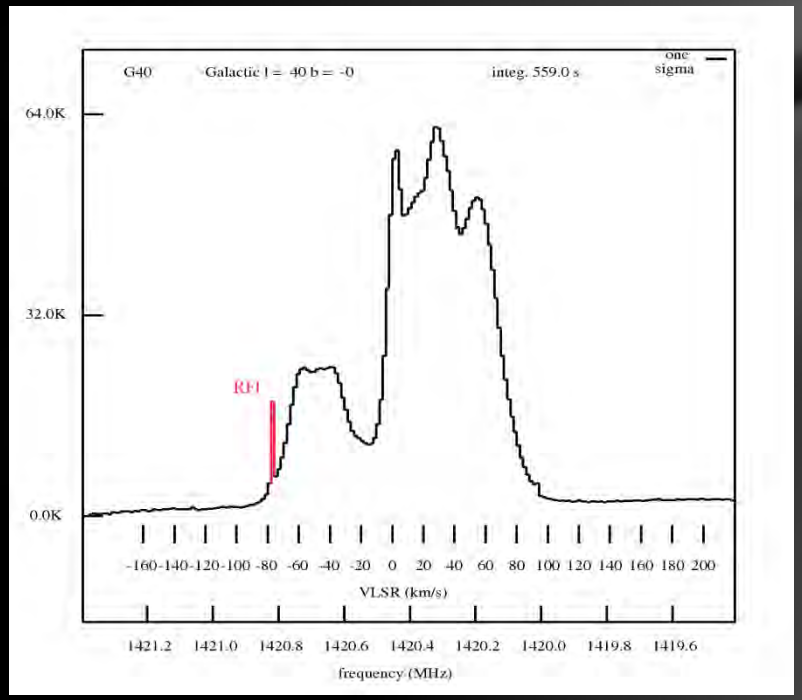
Parameter	Measured	Theoretical
Gain	71.5 dB	71 dB
Image rejection	-34 dB	
S11: old feed	-13.2 dB	
S11: new feed	-23.5 dB	
Beamwidth	6.5°	
System temp.	171 K	



Network analyzer trace of the feed's S11

Interference Problems

- Millstone Hill radar: broadcasts at 1295 MHz at very high power
  - Stub filter in RF stage, 2.4 dB attenuation at 1420 MHz
  - Not a problem at other SRTs
- Computers: RFI at several frequencies
  - Keep the SRT away from computers, remove signals in software
- Local Oscillator
  - LO in prototype produces spur at 1420 MHz
  - Company who makes the LO will remove this for future SRTs



Software

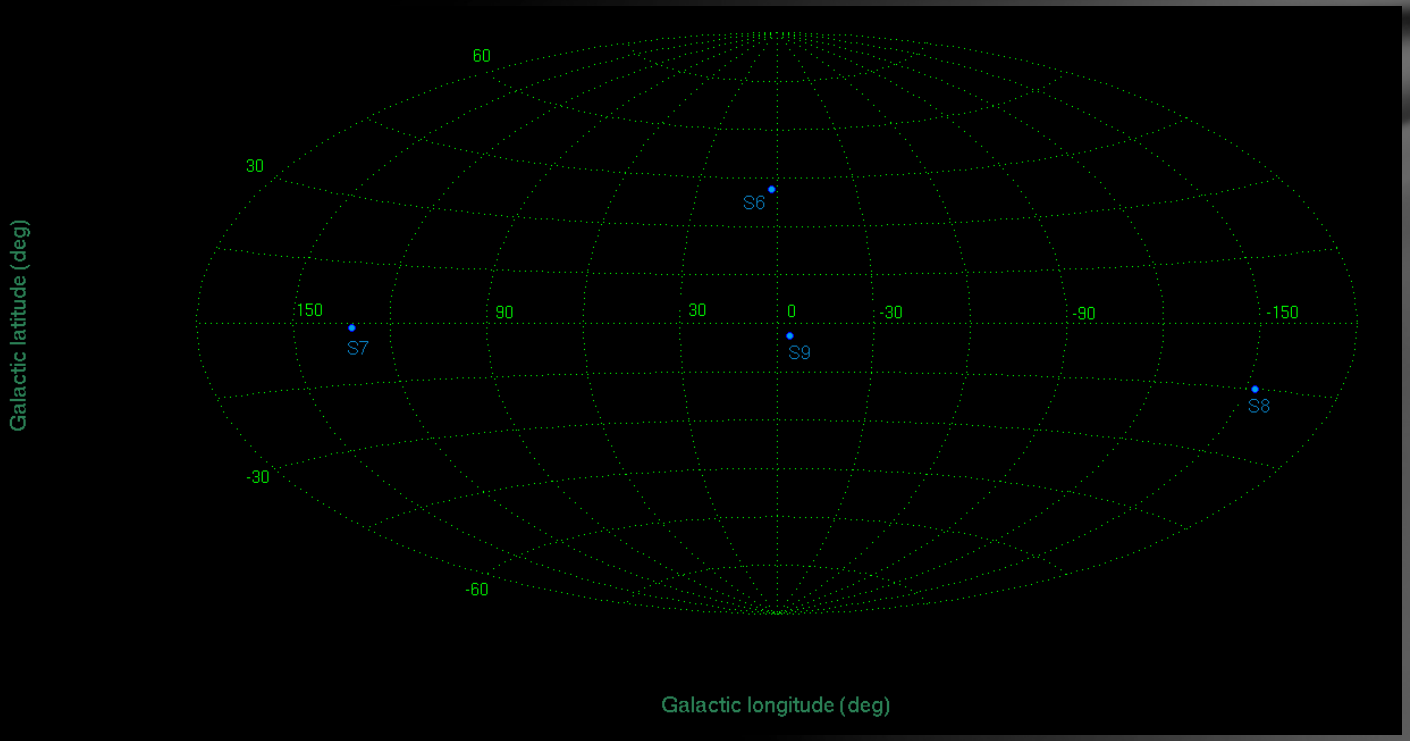
- Two pieces of software developed for this project
- Pswriter:
  - In current program, spectra can only be plotted in real time
  - Pswriter allows spectra to be plotted from data files
- Updated rotor control:
  - Two commercial controllers available, but need new control routine
  - Code for communication protocol developed
  - Insufficient time to develop control routine

Documentation

- Developed a full assembly manual for the SRT hardware
  - Dish selection and installation
  - Step-by-step construction of feed, LNA, and receiver
  - Installation and alignment of rotor
- Complete set of technical drawings
  - Mechanical: dimensions of components, locations of features
  - Electrical: schematic and block diagram of system
- Parts list of all components

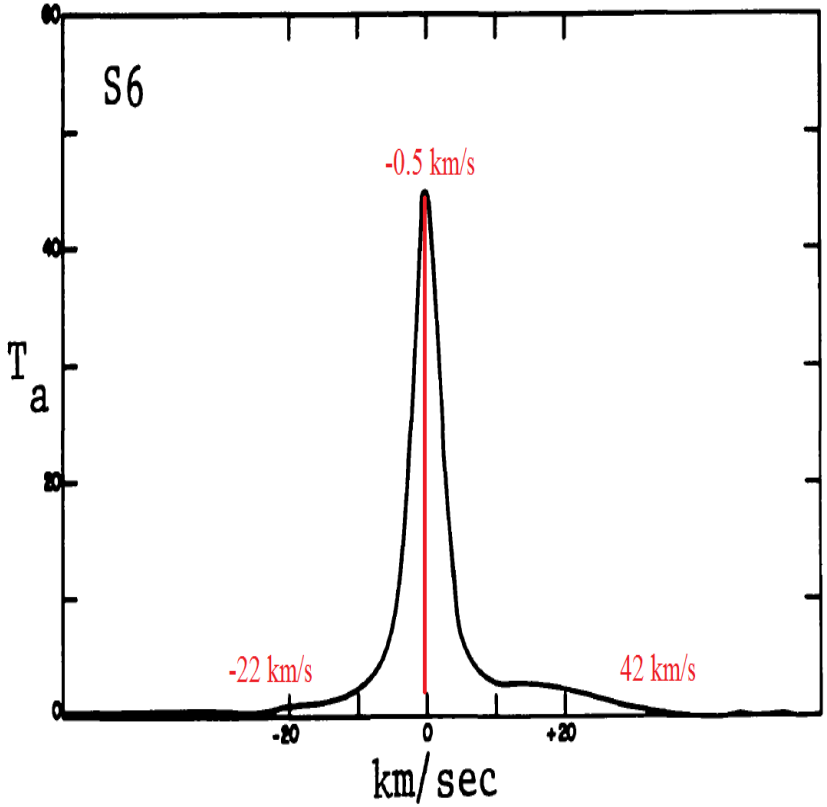
Astronomy: Standard Regions

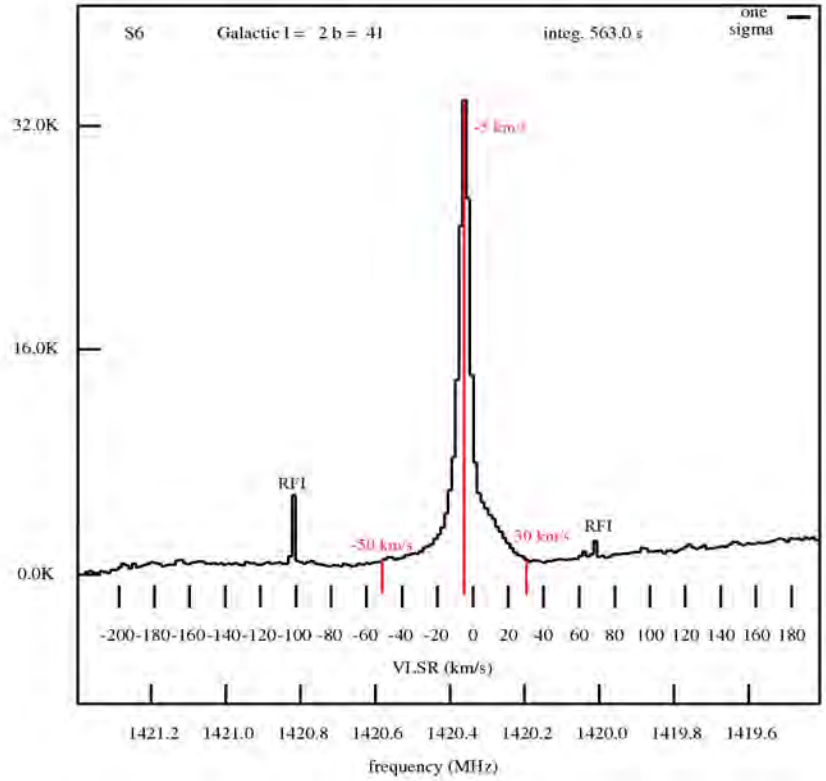
- Four regions of hydrogen emission recommended for equipment calibration and establishing brightness temperature scales for comparison of HI surveys
- Spectra of these regions from Williams[1] compared to spectra of these regions taken with the new SRT
- Position of features of spectra correspond well
- Differences probably due to the different beamwidths of the telescopes used



1. Williams, D.R.W. "Studies of four regions for use as standards in 21-cm observations." Astronomy and Astrophysics Supplement, Vol. 8 pp. 505-516.

Region S6

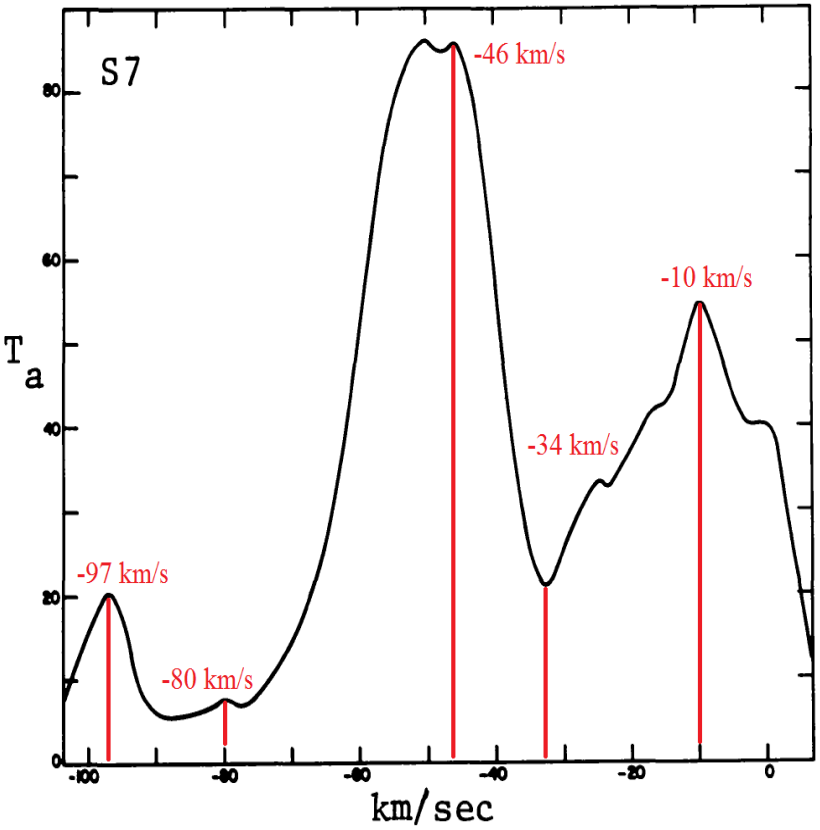


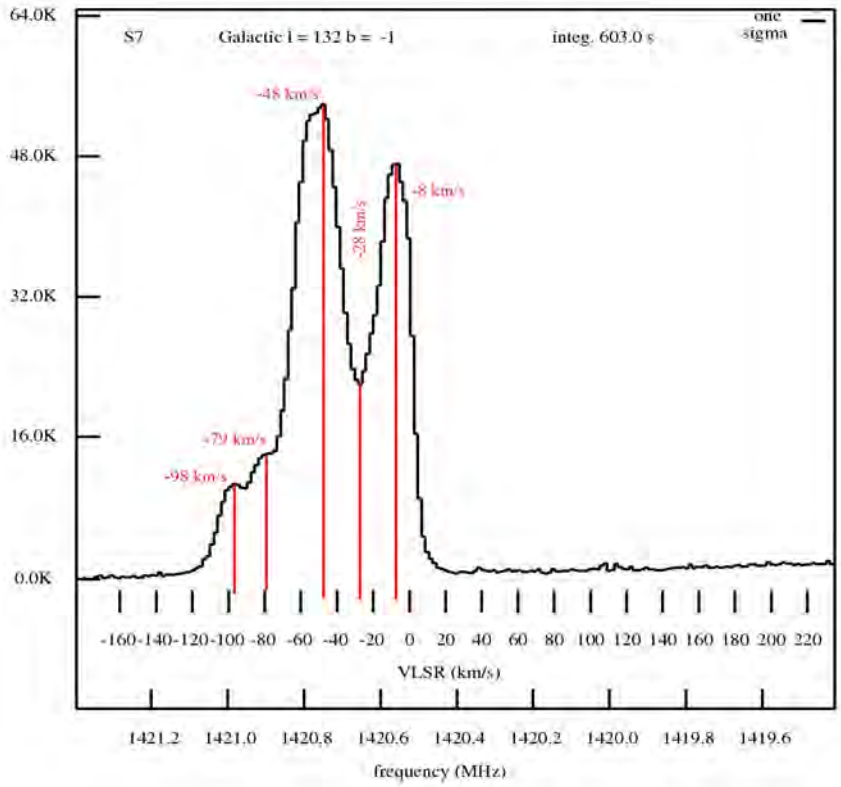


Spectrum from Williams

Spectrum from the SRT

Region S7

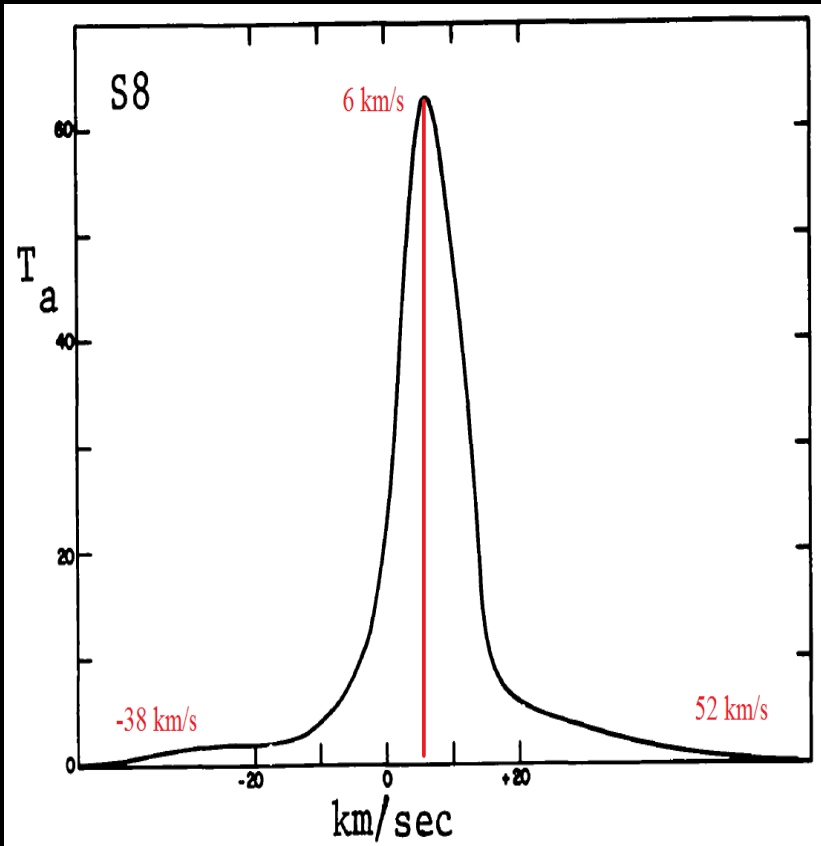




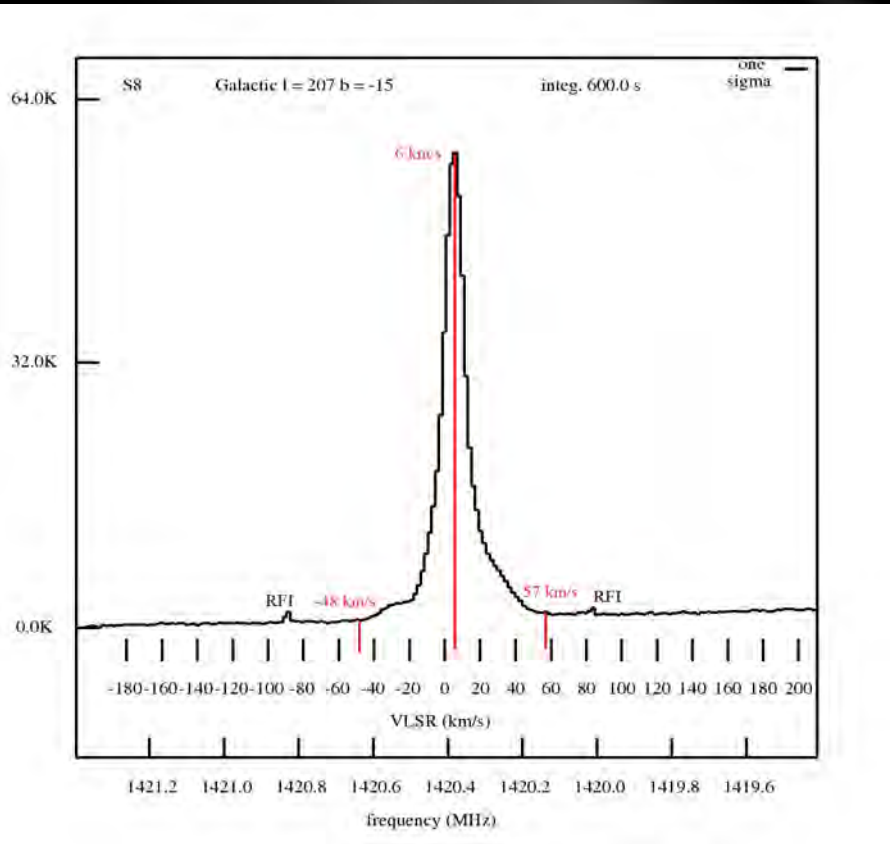
Spectrum from Williams

Spectrum from the SRT

Region S8

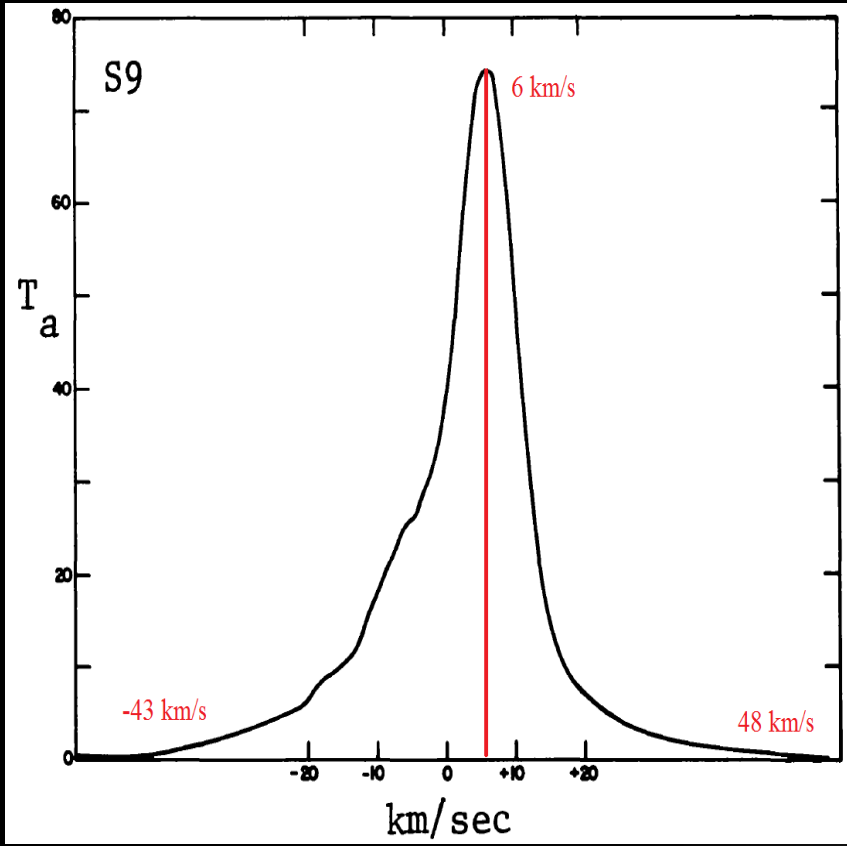


Spectrum from Williams

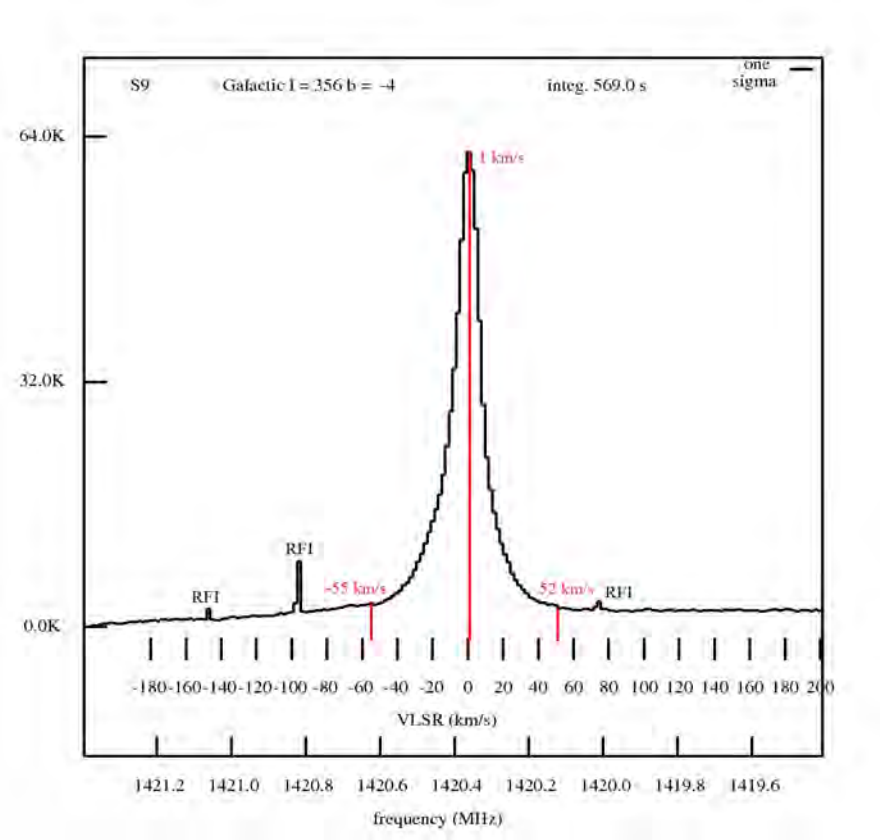


Spectrum from the SRT

Region S9



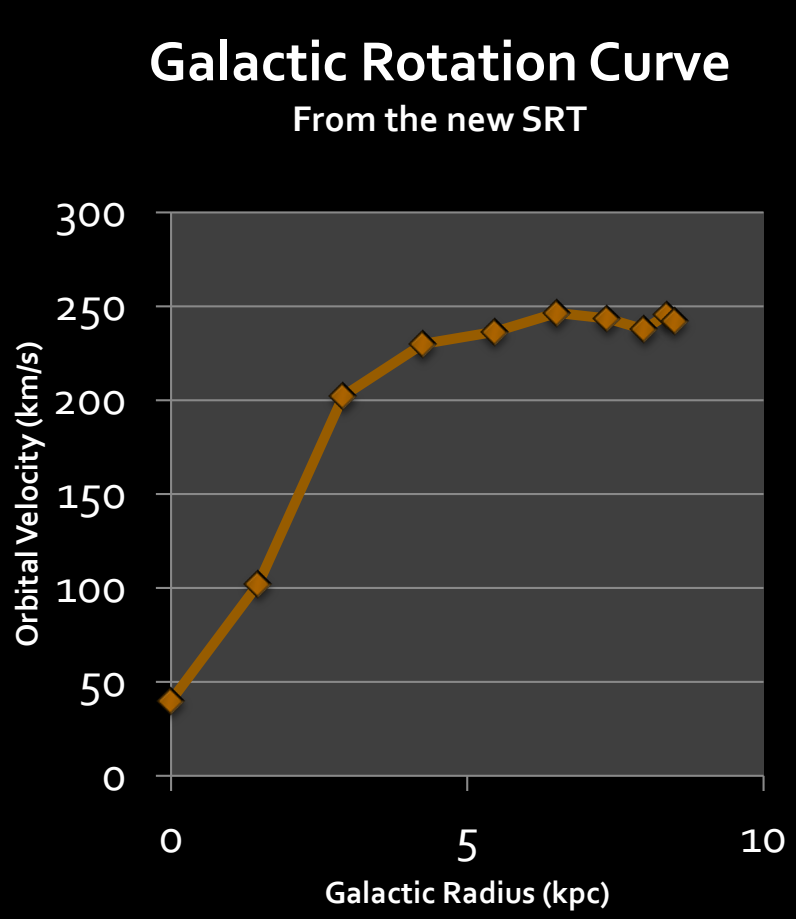
Spectrum from Williams

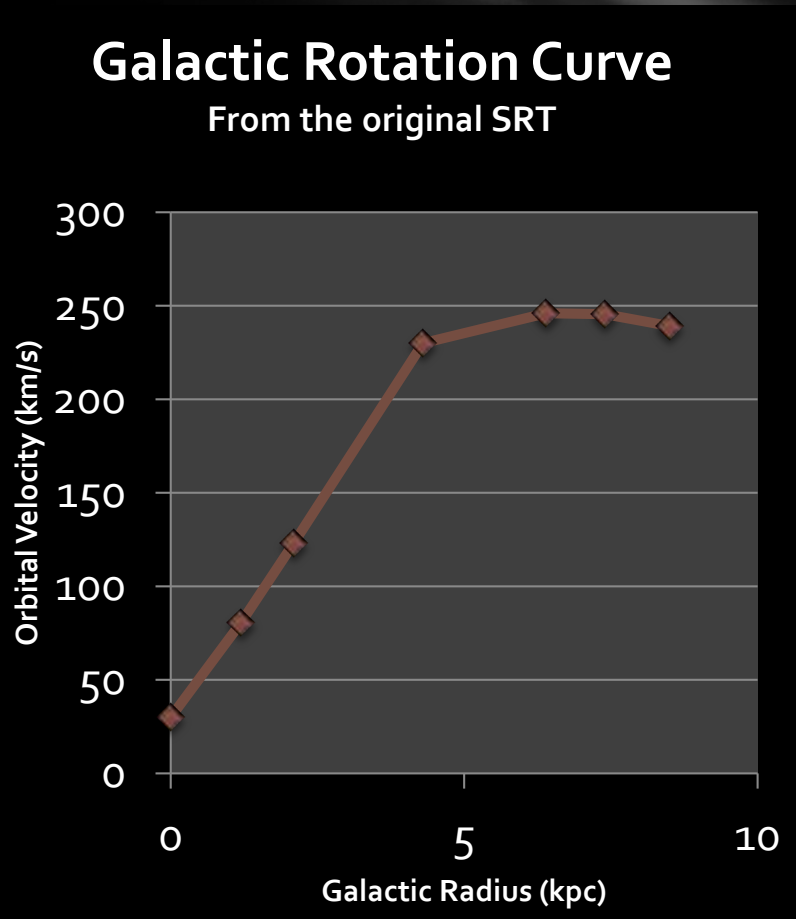


Spectrum from the SRT

Galactic Rotation Curve

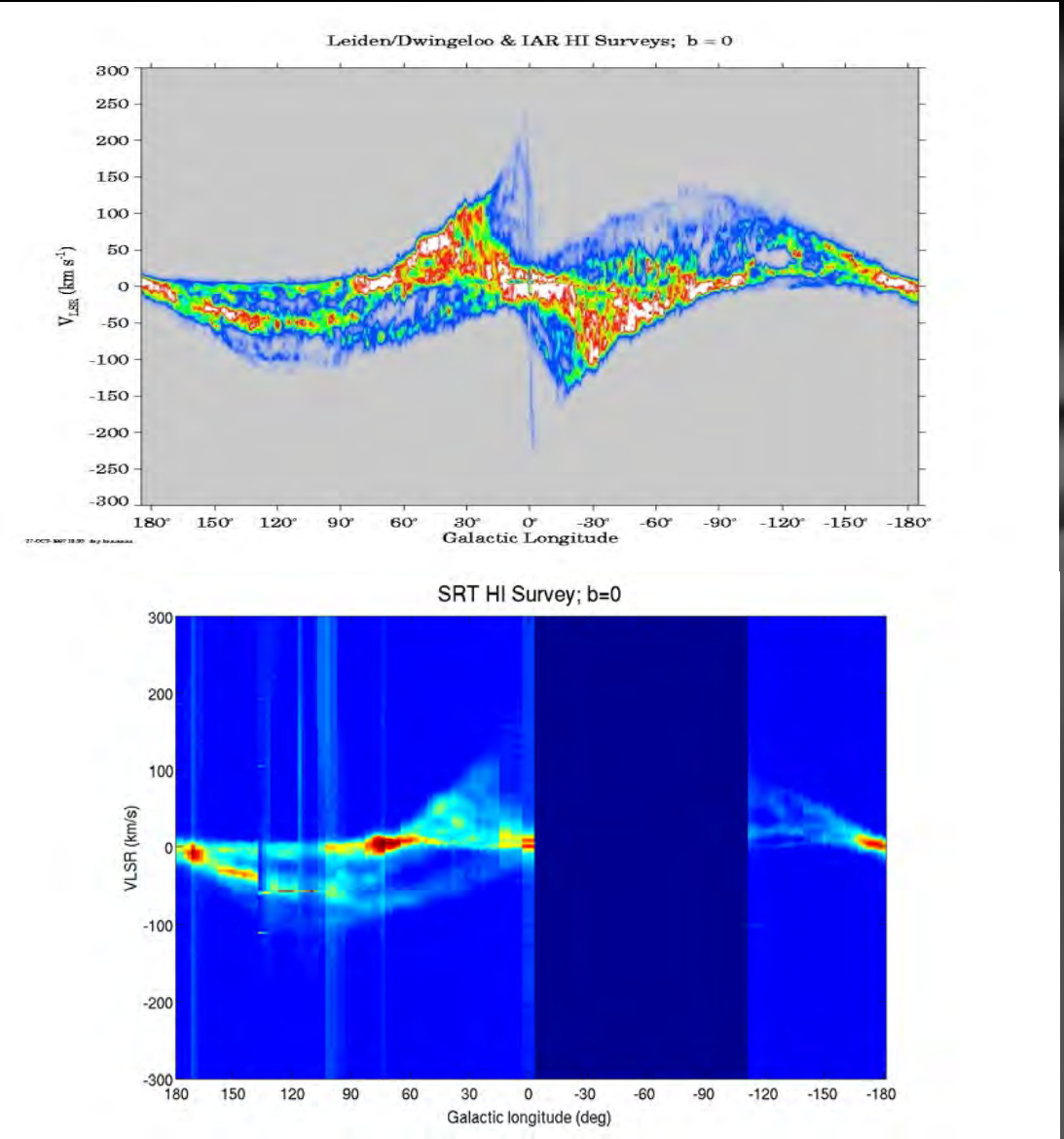
- This experiment can easily be carried out with the SRT to explore galactic structure, mass distribution, and the presence of dark matter





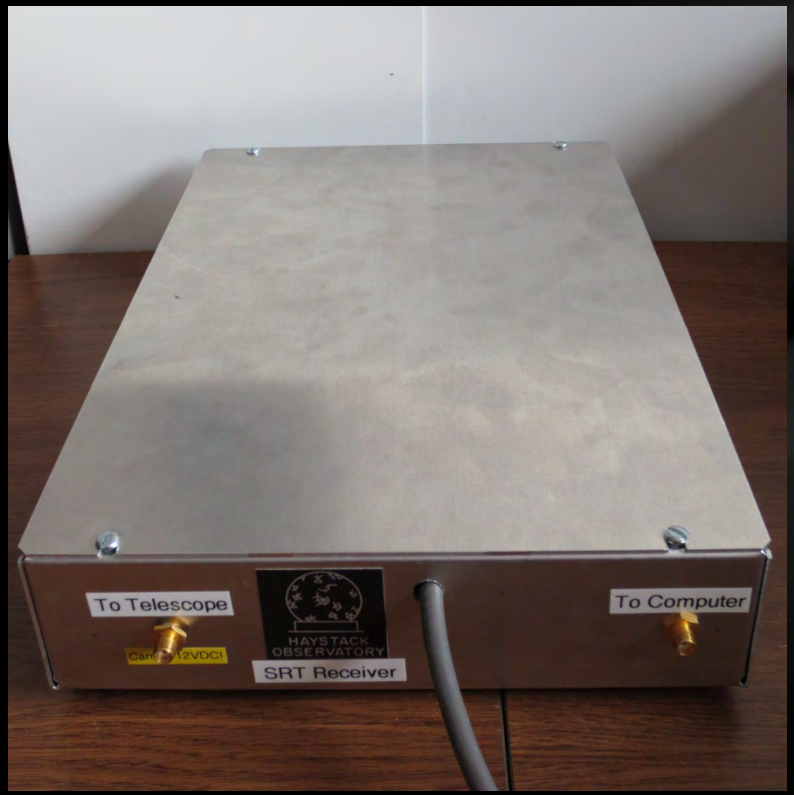
Credit: http://www.haystack.mit.edu/edu/undergrad/srt/SRT%20Projects/sample_rotcurve.jpg

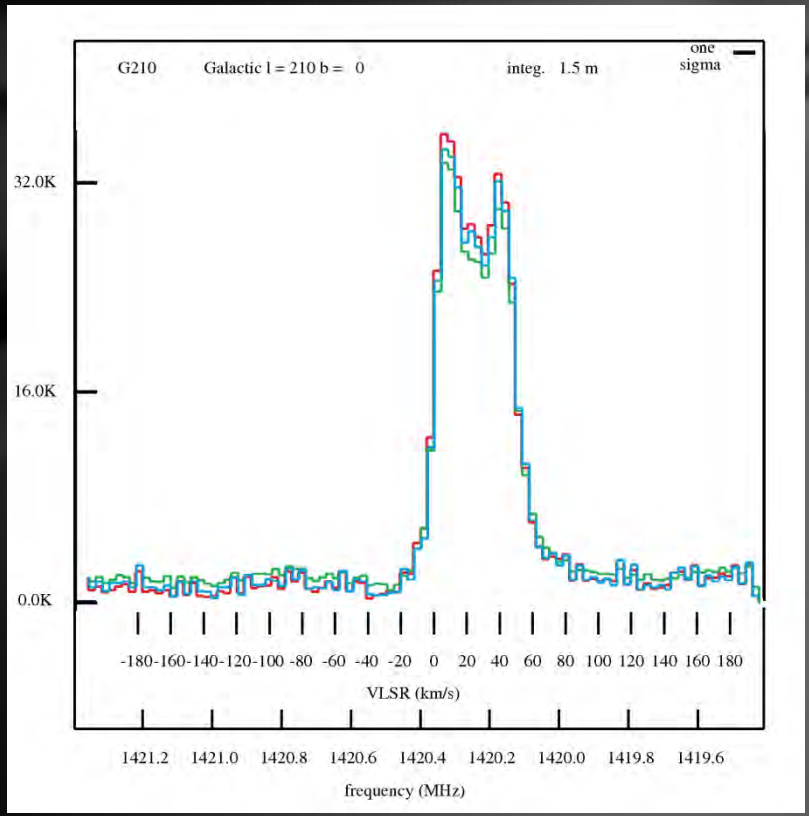
Galactic Plane Velocity-Longitude Plot



Conclusion

- The new generation Small Radio Telescope is a versatile and powerful educational tool for astronomy and radio technology
- Its design based on readily available commercial parts allows universities and other users to easily build and modify their own SRTs
- Advances in electronics since the design of the original SRT make the new SRT a more capable and sensitive instrument





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