Overview of the Arecibo Observatory

ALFALFA
Undergraduate Workshop
Sabrina Stierwalt
January 12, 2009
Designed by then Cornell Professor William Gordon to study the ionosphere
Opening ceremony on November 1st 1963
Now part of NAIC (National Astronomy and Ionosphere Center)
Operated by Cornell University under cooperative agreement with NSF

Employees
- Scientific staff
- Engineering & Computer staff
- Maintenance
- Administration
- Public Outreach
Location, Location, Location

- Built in a limestone sinkhole in Arecibo, Puerto Rico
- Constructed near the equator in a place where all of the planets in our solar system are visible) so the radar used to study the ionosphere could also be used for the planetary observations
- Latitude: 18° 20’ 58” N
Zapatos para el reflector
Para poder caminar sobre el reflector se utiliza un zapato especial. Estos protegen los paneles distribuyendo el peso de la persona.

Reflector shoe
A special shoe is required to work on the reflector. These protect the panels by distributing the persons weight.
Welcome to ALFALFA!
7 January 2009 · No Comments

ALFALFA is a blind survey using the Arecibo telescope designed to detect neutral hydrogen in other galaxies. A brief overview of the survey is available in the About page. If that’s not nearly enough information for you, don’t worry! Future posts will describe various aspects of the survey, data, and follow-up observations in detail. Another goal of this blog is to share the excitement (and trials) of ALFALFA, including observing reports and summaries of new science and papers as they’re published.

We’d also love to hear from you. Do you have a general question about ALFALFA that you would like answered? Post it in the comment section of this entry, and we’ll do our best to answer it. Are you a member of the ALFALFA team and would like to contribute content to this blog? Contact Betsy and your help will be gratefully accepted.

http://alfalfasurvey.wordpress.com
Tower T8 is the tallest of the 3!
Parabolic Reflector

Spherical Reflector
430 MHz Antenna

- “Very long line feed”
- 96 feet in length
- Receives & transmits radio waves at 430 MHz
- Main instrument used in study of the ionosphere
- What popular movie features a fight between the hero and the bad guy on the long line feed?
Gregorian

- The dome is referred to as the “Gregorian”.
- A Gregorian focus means the secondary reflector is placed **behind** the focal point of the primary reflector.
- The Gregorian protects the receivers from RFI and weather.

What are some advantages of Gregorian optics over line feeds?
Advantages of Gregorian Optics

- Each line feed covers a narrow frequency band and a limited number of line feeds can be used at one time.
- With Gregorian optics, an array of receivers covering the whole 1-10 GHz range can be easily moved onto the single focal point where the incoming signal is focused.
Available Receivers: 327 MHz, 430 MHz, 610 MHz, ALFA, L-Wide, S-Low, S-Narrow, S-High, C, C-High, X

Each have different frequency ranges, sensitivities, temperatures, and beam sizes

<table>
<thead>
<tr>
<th>Receiver Name</th>
<th>Freq Range (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>327-MHz</td>
<td>0.312-0.342</td>
</tr>
<tr>
<td>430-MHz</td>
<td>0.425-0.435</td>
</tr>
<tr>
<td>610-MHz</td>
<td>0.6075-0.6115</td>
</tr>
<tr>
<td>ALFA</td>
<td>1.225-1.525</td>
</tr>
<tr>
<td>L-wide</td>
<td>1.15-1.73</td>
</tr>
<tr>
<td>S-low</td>
<td>1.8-3.1</td>
</tr>
<tr>
<td>S-narrow</td>
<td>2.33-2.43</td>
</tr>
<tr>
<td>S-high</td>
<td>3-4</td>
</tr>
<tr>
<td>C</td>
<td>3.85-6</td>
</tr>
<tr>
<td>C-high</td>
<td>5.9-8.1</td>
</tr>
<tr>
<td>X</td>
<td>7.8-10.2</td>
</tr>
</tbody>
</table>
L-Band

RADIO FREQUENCY SPECTRUM

Frequency bands and wavelengths:
- L-Band: 21 cm

RADIO WAVES → MICROWAVES

Wavelengths and frequency ranges:
- Radio waves: 100 m to 1 mm
- Microwaves: 1 mm to 1 cm

Frequency bands and technologies:
- FM Broadcast
- AM Broadcast
- High Frequency
- Ultra High Frequency
- Super High Frequency
- Extra High Frequency

Frequency ranges:
- 30 Hz to 3 MHz
- 3 MHz to 30 GHz
- 30 GHz to 300 GHz
Diagram courtesy of José Alonso
Impedance of transmission lines increases with frequency so signals are down-converted to lower frequencies before traveling away from the telescope.

- Conversion done with a mixer which requires an oscillating signal of a specific frequency.
- **IF** stands for Intermediate Frequency (the lower frequency the signal is converted to).
- **LO** stands for Local Oscillator (the locally-produced signal being mixed with the cosmic signal).
The components of the telescope the signal enters after having been down-converted

Several different backends are available at Arecibo with different frequency spans

Tonight we will use the 4 WAPPs (Wideband Arecibo Pulsar Processor)
Control Interface Module for Arecibo: a graphical interface that makes observing as easy as clicking buttons (more on this later...)
Arecibo Stats

- Covers 6m - 3cm (47 MHz - 10 GHz)
- Slew rate of 25°/min in azimuth
- Slew rate of 2.5°/min in zenith
- Pointing accuracy of 5 arcseconds
- 3 pairs of cables that lead under dish for mm precision placement of platform
- Can view objects within ~40° cone about local zenith (0 to 36 degrees in dec)
Equatorial Coordinates

- **Right Ascension**
  - Measured in hours (0 to 24)
  - Zero-point toward constellation Pisces (increases to the east)
  - Similar to longitude

- **Declination**
  - Measured in degrees
  - Zero-point is the equator
  - Similar to latitude

- They are the same for every observer location!
Azimuth & Zenith

- **Azimuth Angle**
  - Measured in degrees
  - Tells how far east of north the source is located

- **Zenith Angle**
  - Measured in degrees
  - Tells how far below zenith a source is located

- They depend on the observer’s location!
The altitude of the North Celestial pole (as measured up from the horizon) is equal to the latitude of the observer.
The altitude of the intersection of the Celestial Equator with the meridian is $\theta = 180^\circ - 18^\circ - 90^\circ = 72^\circ$. 

*Note: The diagram illustrates the altitude calculation with the given coordinates. The altitude is marked by the angle $\theta$.*
Local Perspective: **North Pole**

At the North or South Pole:
Half of the stars are above the horizon all of the time. The other half of the stars are never visible.
Local Perspective: Equator

All of the stars are visible above the horizon but only half of the time

Star Paths at LAT = 0°

(i.e. the equator on earth)
The Sun’s Apparent Path

- The Sun’s apparent position among the stars changes throughout the year with an eastward annual drift.
- Unlike a star, the Sun (Moon and planets) moves with respect to the (much more distant) stars.
- Right Ascension & Declination of Sun (Moon & planets) change throughout the year.
- The path the Sun (Moon and planets) takes across the sky on any given day depends on its Declination on that day.
- Noon-time altitude (above horizon) varies
- Length of time to cross from East to West along the path on a given day varies.
The Sun’s Path Throughout the Year

- The Sun’s Declination changes throughout the year due to the inclination of the Earth on its axis.
- On Sep 20\textsuperscript{th} and Mar 20\textsuperscript{th}, the Sun’s Declination is 0°.
  - The Sun’s path follows the Celestial Equator.
  - These are called the \textit{autumnal} and \textit{vernal} equinoxes.
- On Dec 21\textsuperscript{st}, the Sun’s Declination is -23½°.
  - At noon, the Sun crosses the meridian south of the Celestial Equator.
  - \textbf{Winter} in the northern hemisphere; summer in the South.
- On Jun 21\textsuperscript{st}, the Sun’s Declination is +23½°.
  - At noon, the Sun crosses the meridian north of the Celestial Equator.
  - \textbf{Summer} in the northern hemisphere; winter in the South.
Sun’s Path: June 21st

Sun’s declination is $+23\frac{1}{2}^\circ$
Sun’s path is $||$ Cel. Eq. but $23\frac{1}{2}^\circ$ N of it

Sun at noon on June 21st in Arecibo

The altitude of the Cel. Eq. when it crosses the meridian is $72^\circ$ in Arecibo. The Sun’s altitude at noon then is $95\frac{1}{2}^\circ = 72^\circ + 23\frac{1}{2}^\circ$
Sun’s Path: Dec 21st

Sun’s declination is $-23\frac{1}{2}^\circ$
Sun’s path is || Cel. Eq. but $23\frac{1}{2}^\circ$ S of it

Sun at noon on Dec 21st in Arecibo

The altitude of the Cel. Eq. when it crosses the meridian is $72^\circ$ in Arecibo. The Sun’s altitude at noon then is $48\frac{1}{2}^\circ = 72^\circ - 23\frac{1}{2}^\circ$

The Celestial Equator
Sun’s Path: Jan 13th

Sun’s declination somewhere between its declinations at the summer and winter solstices, but closer its path on Dec 21st.

18°
Zenith Angle of a Drift 14p2 ($\delta = +03^\circ 24' 24''$)

$ZA = 18^\circ 20' 58'' - \delta = 14^\circ 56' 34''$

Azimuth = $360^\circ$ (source is S of zenith)
### How long is a source “up”?

<table>
<thead>
<tr>
<th>Dec (deg)</th>
<th>-1</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (h:mm)</td>
<td>0:30</td>
<td>0:58</td>
<td>2:18</td>
<td>2:27</td>
<td>2:42</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dec (deg)</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>38</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (h:mm)</td>
<td>2:46</td>
<td>2:40</td>
<td>2:20</td>
<td>1:35</td>
<td>0:10</td>
</tr>
</tbody>
</table>
$\delta = +03^\circ 24' 24''$
How do I get time on the telescope?

- Telescope operates 24 hours a day
- Submit a proposal which is judged by a panel of referees
- Deadlines are February 1\(^{st}\), June 1\(^{st}\), and October 1\(^{st}\)
For More Information...

www.naic.edu
Areas of Study at Arecibo

- Atmospheric Science (20%)
  - Measures composition, temperature, and density of upper atmosphere
  - Measures the growth and decay of disturbances in the ionosphere
- Radio Astronomy (80%)
Radio Astronomy: *Radar*

- Radio energy is transmitted, reflected and then collected.
- Studies surface features, composition, size, shape, rotation and path of target.
- Studies objects within our solar system.

Asteroid Kleopatra 216
Radio Astronomy: Continuum Observations

- Radio frequency observations over a wide range of frequencies
- Example: studying synchrotron emission in our own galaxy
Radio Astronomy: **Pulsars**

- Neutron stars were a purely theoretical concept until observations of the 33-ms pulsar in the Crab Nebula in 1968.
- Proved connection proposed by Baade & Zwicky that neutron stars are connected to supernova remnants and the end stages of stellar life.

Crab Nebula
Radio Astronomy: *Pulsars II*

- First detection of an extrasolar planet EVER
- Discovered by Alex Wolszczan & Dale Frail through pulsar timing
- At least 3 bodies of Earth-like masses around PSR B1257+12
VLBI - Very Long Baseline Interferometry

- Joined the VLBI network in the late 1990s
- NAIC commits 4% of AO’s telescope time to VLBI
- Broad bandwidth video recorders record signals and are then replayed later in the same location
The Seyfert 2 - NGC 7674

Contour Plot courtesy of E. Momjian

**Figure 1**
Spectral Line Observations

- Discrete radio emission
- When we search for the 21-cm line, we cannot be sure where to look due to a galaxy's redshift
- Could be emission or absorption
- Lines could be narrow or broad and have Gaussian shape or double-horned structure

Spectra from Haynes & Giovanelli, 1981

NGC 5363