Introduction to Radio Astronomy
The Visible Sky, Sagittarius Region
The Radio Sky
Optical and Radio can be done from the ground!
Outline

The Discovery of Radio Waves
Maxwell, Hertz and Marconi

The Birth of Radio Astronomy
Jansky and Reber

Tools of Radio Astronomy
What we use to detect radio

Sources of Radio Emission
Everything!
James Clerk Maxwell

Tied together theories of electricity and magnetism (Maxwell’s equations) to derive the electromagnetic theory of light
• Electric and magnetic fields oscillate together with the same frequency and period

• Electromagnetic waves do not require a medium!

• The velocity and wavelength spectrum are defined:

\[ c = \lambda f \]
Heinrich Hertz

Constructed a circuit to induce electric and magnetic field oscillations. This circuit transmitted *electromagnetic waves* to a nearby capacitive loop receiver

Heinrich Hertz's first transmitter, 1886
Karl Guthe Jansky

Founder of Radio Astronomy

Hired by Bell Labs in the late 1920’s, Jansky’s mission was to find sources of radio interference
• Jansky constructed a directional 20.5 MHz antenna on a turntable to locate radio noise source positions

• Sources of noise
  – Nearby storms
  – Distant storms
  – A faint hiss that returned every 23 hours 56 minutes
In 1933, Jansky identified this source of noise as the center of our galaxy, in Sagittarius.
Grote Reber
Radio Astronomy Pioneer

• After Jansky’s project ended, Bell Labs was not interested in studying radio astronomy

• Reber continued Jansky’s original work, by constructing his own radio telescope in 1937

• Provided the first maps of the radio sky at 160 and 480 MHz
Reber’s 31.4 ft parabolic reflector
Reber’s contour maps of the Milky Way, at 160 and 480 MHz
Radio Continuum (408 MHz)  

Bonn, Jodrell Bank, and Parkes
Colors of light we can’t see…

• Ionizing Radiation
  – UV
  – X-Rays
  – Gamma Rays

• Non-Ionizing Radiation
  – IR
  – Microwave
  – Radio
# Multi-wavelength Astronomy

<table>
<thead>
<tr>
<th>Type of Radiation</th>
<th>Wavelength Range (nanometers $[10^{-9} \text{ m}]$)</th>
<th>Radiated by Objects at this Temperature</th>
<th>Typical Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma rays</td>
<td>Less than 0.01</td>
<td>More than $10^8$ K</td>
<td>Few astronomical sources this hot; some gamma rays produced in nuclear reactions</td>
</tr>
<tr>
<td>X-rays</td>
<td>0.01 - 20</td>
<td>$10^6$ - $10^8$ K</td>
<td>Gas in clusters of galaxies; supernova remnants, solar corona</td>
</tr>
<tr>
<td>Ultraviolet</td>
<td>20 - 400</td>
<td>$10^5$ - $10^6$ K</td>
<td>Supernova remnants, very hot stars</td>
</tr>
<tr>
<td>Visible</td>
<td>400 - 700</td>
<td>$10^3$ - $10^5$ K</td>
<td>Exterior of stars</td>
</tr>
<tr>
<td>Infrared</td>
<td>$10^3$ - $10^6$</td>
<td>$10$ - $10^3$ K</td>
<td>Cool clouds of dust and gas; planets, satellites</td>
</tr>
<tr>
<td>Radio</td>
<td>More than $10^6$</td>
<td>Less than 10 K</td>
<td>Dark dust clouds</td>
</tr>
</tbody>
</table>
Astronomy expands to the entire spectrum.

- **Radio Continuum**: 408 MHz Bonn, Jodrell Banks, & Parkes
- **Atomic Hydrogen**: 21 cm Leiden-Dwingeloo, Maryland-Parkes
- **Radio Continuum**: 2.4-2.7 GHz Bonn & Parkes
- **Molecular Hydrogen**: 115 GHz Columbia-GISS
- **Infrared**: 12, 60, 100 μm IRAS
- **Near Infrared**: 1.25, 2.2, 3.5 μm COBE/DIRBE
- **Optical**: Laustsen et al. Photomosaic
- **X-Ray**: 0.25, 0.75, 1.5 keV ROSAT/PSPC
- **Gamma Ray**: >100 MeV CGRO/EGRET
FCC allotment of Radio Spectrum
Tools of Radio Astronomy

• Your car radio is an example of a simple antenna and receiver

• Radio waves actually cause free electrons in metals to oscillate!

• Radio receivers amplify these oscillations, so, radio telescopes measure the voltage on the sky
Formation of Radio Waves

• Thermal Radiation

• Synchrotron Radiation
  – Relativistic $e^-$ in magnetic fields

• Bremstrahlung
  – “Breaking Radiation” $e^-$/ion collisions

• Maser
  – Microwave Laser $e^-$ oscillations in molecular clouds

• Atomic Transitions (emission spectra)
  – Hydrogen $e^-$ spin flip
Formation of 21cm Radio waves
(1420 MHz)

Formation of the 21-cm Line of Neutral Hydrogen

Higher energy state: Proton and electron spins aligned

Emission of 21-cm photon

Lower energy state: Proton and electron have opposite spins.
Reception of Radio Waves

• Radio waves cause oscillation of free e\textsuperscript{-} in metals

• Dish reflector antennas localize the source and exclude background noise

• Radio signal intensity is measured as voltage
Telescopes for visible light

Type: Compound Telescope (catadioptric)*

Advantages: Long focal length in short tube; can make use of compact “fork” style equatorial mount

Disadvantages: Narrow field of view; long cooldown time; susceptible to dewing

*Most commonly a Schmidt-Cassegrain or Maksutov
The 140 Foot Telescope
Green Bank, WV
Reception of Radio Waves
Reception of Radio Waves
Example signal path of a radio telescope
Spectrometer Output

- Spectrum: brightness vs. radio frequency
- Continuum: total brightness over all frequencies

![Sample Hydrogen Spectrum](image)
• Radio waves are VERY weak!

• Radio brightness measured in units of Janskys
  \[1 \text{ Jansky (Jy)} = 10^{-26} \text{ W/m}^2/\text{Hz}\]

• Typical sources:
  – Sun: 10,000’s of Jy
  – Brightest Supernova Remnant: 1000’s of Jy
  – Active Galactic Nuclei: 10-100 Jy
The Ideal Radio Telescope

- Directional antennae, such as those with reflectors, isolate the radio power from single sources to reduce confusing radiation from others

- Low temperature receivers are more sensitive

- Large collecting areas increase gain and resolution

- Resolution: roughly $57.3 \frac{\lambda}{D}$ degrees ($\lambda$: observing wavelength, $D$: diameter of aperture)
• Optical telescopes have an advantage on radio telescopes in angular resolution

• A one meter optical telescope has a resolution of 0.1 seconds of arc.

• Since radio telescopes cannot be built large enough to match optical resolution, they can be combined as an interferometer to emulate a large single dish
At 21-cm wavelengths, PARI’s 26-m and Smiley (4.6 m) have resolutions of 0.5 and 2.5 degrees respectively.
Greenbank (WV) 100-m telescope has a resolution of 7 arc-minutes.
300-m telescope in Arecibo, Puerto Rico
(resolution – 2.4 arcminutes)
Very Large Array, resolution – 1.4 arc seconds
10 Antennas of the Very Long Baseline Array
(resolution – 5 milli-arcseconds)
Time for Radio Astronomy Observing...