Astro 233 2005 Lect #3

• The article by Hubble: *why big telescopes?*
• Optional “scavenger hunt” exercise on the web (and handout) meant to get you thinking.
• A bit about cosmology and dark matter
• Some basic astronomy
• Sources of radio radiation
• Introduction to (radio) telescope fundamentals
Dark Matter: Stuff We Cannot See

- Exerts gravitational influence on visible objects
- But is too faint for current telescopes to detect

1781 - Uranus discovered by Wm. Herschel
1830 - Slight wandering of Uranus noted.
1842 - Adams investigates cause
1845 - Adams predicts position of Neptune
1846 - Leverrier predicts similar position
1846 - Neptune discovered

Neptune was “dark matter” before its discovery.
The Cosmic Microwave Background Radiation

1965: Penzias and Wilson discover a faint radio signal coming from all over the sky.

- Current temperature is 2.725K, and uniform to better than 1 part in 100,000.
- Uniformity best described by Big Bang Cosmology.
- Small “wiggles” are seeds of galaxies (i.e. structure formation).
What WMAP Tells Us

• Precision cosmology!
• Age: 13.7 billion years since BB (1% error!)
• First stars ignited 200 million years after BB
• Light from CMB is from 379,000 years after BB

• 4% “normal” matter
• 23% dark matter
• 73% dark energy
• Looks like Universe will expand forever
Census of Low Mass Halos

- Do large numbers of low mass “halos” exist?
- If so, do they contain baryons?
- If so, could they be “starless” but gas-rich?
- If so, could they be found preferentially in some environments but not in others?

**ALFALFA**: Exploits new 7-beam array at Arecibo to conduct a blind search for HI-rich dwarfs
ALFALFA Science Goals:

1. Determination of the HI “Mass Function” (# of galaxies of given mass per unit volume), especially at lowest masses
2. Extent of HI disks: the HI “Diameter Function”
3. Blind HI Survey for tidal remnants
4. Environmental variations of the HI properties of galaxies and the HIMF (isolated versus group versus cluster)
5. Determine the population of gas-rich systems in the Local Group and the periphery of the Milky Way (“high velocity clouds”)
6. HI absorbers and the link to Lyman α absorbers (absorption lines due to neutral gas redshifted from UV to optical)
7. OH Megamasers at intermediate redshift $0.16 < z < 0.25$

Project website: http://egg.astro.cornell.edu/alfalfa
Introduction to Telescopes and Radio Astronomy

- Astronomy basics
- Radio Sources
- Radio telescope components
- Radio telescope characteristics

Useful Texts

Burke & Graham-Smith, *An Introduction to Radio Astronomy*
Rohlfs, *Tools of Radio Astronomy*
Stanimirovic et al., *Single-dish Radio Astronomy: Techniques and Applications*
Local Perspective: Ithaca

Latitude 42° N

What the Night Sky Does in Ithaca

Altitude of NCP = Latitude of observer

Celestial Equator
Meridian Altitude is
180° - 90° - 42° = 48°
Celestial Sphere Basics

- The apparent diurnal path of a star (galaxy), Sun, Moon, planets follows the line corresponding to its declination.
- The Sun’s declination changes systematically through the year due to the inclination by 23½° of the Earth’s rotational axis to its orbital plane.

![Diagram of Celestial Sphere with NCP and Arecibo Observatory highlighted.](attachment:image.png)

Altitude of the NCP = Latitude of observer + 18°21' (N)

Arecibo Observatory
Latitude +18°21’ (N)

Celestial Equator

Local meridian

NCP

N

S
Sources of Radio Emission

- **Blackbody (thermal) radiation**
  - Ionized gas in vicinity of high energy/hot sources (e.g., massive stars, black holes, etc)

- **Synchrotron (non-thermal) radiation**
  - Fast moving (relativistic) electrons spiral around magnetic field lines (most high energy sources with magnetic fields like pulsars, energetic events)

- **Continuum sources**: emit at all frequencies.

- **Spectral line sources**: emit/absorb at discrete frequencies.
**Astronomy Basics**

**Blackbody:** An object whose radiative properties depend only on its temperature.

**Planck's Law:**

\[ I(\nu) = \frac{2h\nu^3}{c^2} \frac{1}{\exp(h\nu/kT) - 1} \]

**Kirchhoff's Laws are:**

- A hot solid, liquid or gas, under high pressure, gives off a continuous spectrum.
- A hot gas under low pressure produces a bright-line or emission line spectrum.
- A dark line or absorption line spectrum is seen when a source of a continuous spectrum is viewed behind a cool gas under pressure.
Blackbody Sources

- **Cosmic Microwave Background** is about the only relevant blackbody source but nearly constant over sky.
- Peak in cm-wave radio requires very low temperature (2.7 K).
- Ignored in most work - essentially constant source of static (same in all directions) and much weaker than static produced by instrumentation itself.
Non-thermal Continuum Sources

Due to relativistic electrons:
- Synchrotron radiation
- Bremsstrahlung

- Quasars, Active Galactic Nuclei, Pulsars, Supernova Remnants, etc.
- Used by ALFALFA for calibration(!)
Spectral Line Sources

• Neutral hydrogen (H I ) spin-flip transition
• Recombination lines (between high-lying atomic states)
• Molecular lines (CO, OH, H₂O, H₂CO, etc)
HI line: rest frequency is 1420.4058 MHz

Because of Hubble’s Law $V = H_0D$, we observe the HI line from distant galaxies redshifted to lower frequencies.

In frequency units, we write the redshift

$$z = \frac{f_{\text{rest}}}{f_{\text{obs}}} - 1$$

The ALFALFA survey setup covers a frequency range that covers 100 MHz centered at 1385 MHz, corresponding to HI lines with velocities from -2000 to +18000 km/s.
• HI spectral line from galaxy shifted by expansion of universe ("recession velocity") and broadened by rotation

Rest frequency 1420.4058 MHz

\[ \int SdV \rightarrow \text{HI mass} \]

\[ V \rightarrow \text{Distance} \]

\[ \Delta V \rightarrow \text{Mass} \]
What is the purpose of a telescope?

- The main purpose of a telescope is to gather light, i.e. to collect and focus photons.

- We can think of a telescope then as a "light bucket" - the bigger the bucket, the more photons a telescope can collect.

In addition, telescopes show us the detailed structure of objects that emit light. Thus, telescopes help to produce sharp (rather than blurry) images of faint, distance objects.
For a telescope of a given aperture diameter, operating at a given wavelength, the minimum angular distance (or "angular resolution") between two objects that can be identified as separate depends on

- The wavelength of light (in centimeters)
- The diameter of the telescope (in centimeters)

This is called the diffraction limit of the telescope.

\[ \Theta = \frac{1.22 \times \text{wavelength (cm)}}{\text{diameter of telescope (cm)}} \]
Unlike most optical telescopes which are atmospheric seeing limited (and telescope arrays), “single dish” radio telescopes like Arecibo are diffraction limited. At L-band (1.4 GHz, 20 cm), resolution ~ 3.5 arcmin.
Radio Telescope Components

- Reflector(s)
- Feed horn(s)
- Low-noise amplifier
- Filter
- Downconverter
- IF Amplifier
- Spectrometer
**ALFA: 7 feed array**

**Feedhorns**

**Typical cm-wave feedhorn**
Beam & sidelobes

- Essentially diffraction pattern of telescope functioning as transmitter
- Uniformly illuminated circular aperture: central beam & sidelobe rings
• Obstructions, non-uniform illumination by feedhorn \( \rightarrow \) asymmetry and alter strengths of sidelobes vs. central beam
• Emission received from pattern outside first sidelobe ring often called *stray radiation*
• Beamwidth FWHM or HPBW refers to the radial distance at which the sensitivity of the beam falls to half its central value.
  - ALFA beams are elliptical.
  - The central beam is more sensitive (higher gain) than the outer beams.
  - The side/coma lobes are pretty ugly. (the price we pay for all those photons)

This diagram shows the illumination pattern of the ALFA instrument with its 7 pixels (feed horns)
Sensitivity

- Limited by noise - mostly thermal noise within electronics but also from ground reflected off telescope structure into feedhorn and CMB
- **System temperature**: temperature of blackbody producing same power as telescope + instrumentation produces when there is no source in beam
- **Brightness temperature**: brightness of source in temperature units; difference in effective blackbody temperature when source is in beam vs. when no source is in beam - even when source is spectral line or synchrotron radiation and brightness has little to do with actual temperature of the source
- Preferred unit (requires calibration) is the **Jansky**:  
  \[ 1\text{Jy} = 10^{-26} \text{W m}^{-2} \text{Hz}^{-1} \]
Signal Path

- Low-Noise Amplifier
- Filter
- Down-converter
- IF Amplifier
- Spectrometer
- Local Oscillator
Research Impact of New Instruments

“The 200-inch Telescope and Some Problems It May Solve

Three specific problems Hubble discusses:
1. Canals on Mars (telescope angular resolution)
2. Relative abundance of chemical elements in stars
   (spectroscopic dispersion)
3. Nature of the redshift (sensitivity/space penetration)

Arecibo + ALFA gets us (2) and (3) plus
4. Volume sampled nearby (speed of sky coverage)