Introduction to ALFA and ALFALFA

Martha Haynes
UAT09  09.01.12
ALFALFA:
A Census of Gas-bearing Galaxies

• A galaxy is a gravitationally bound object that consists of billions (and billions) of stars, gas clouds (of varying temperature and density = interstellar medium), dust clouds (mixed with the gas), and (so it seems), 90% dark matter.

• Optical surveys, like the Sloan Digital Sky Survey, detect the stellar component of galaxies.

• ALFALFA is designed to detect the cool (not hot; not cold) atomic gas in and near galaxies.

• ALFALFA is a blind survey; we observe the whole area of sky, whether or not we think/know there is an optical galaxy there.

• ALFALFA is a spectroscopic survey; not only do we detect the HI line flux, we also measure its frequency (velocity) and the width of the HI line (a measure of rotational velocity).
How and when do galaxies form?

Numerical simulations are used to trace the gravitational collapse of matter (dark+luminous) across cosmic time.
Virgo cluster movie from Ben Moore

$z=49.000$
Large scale structure formation

Simulation by Matthias Steinmetz
Evolution of a galaxy

Simulation by Matthias Steinmetz
How and when do galaxies acquire their gas?

Kereš et al. (2005)
Components of Interstellar Medium

The interstellar medium is composed of gas in different phases (temperatures, densities, species)

**Molecular clouds:** \( T \sim 3 \text{ -} 50 \text{ K}, \text{ densest, mostly } H_2 \)

**CNM = Cold Neutral Medium:** \( T \sim 80 \text{ K}, \text{ dense, mostly } HI (=H^0) \)

**WNM = Warm Neutral Medium:** \( T < 8000 \text{ K}, \text{ surrounding or between CNM, HI still an important part} \)

**WIM = Warm Ionized Medium:** \( T \sim 10000 \text{ K} (\text{HII} = H^+) \)

**HIM = Hot Ionized Medium:** \( T \sim 10^6 \text{ K} \text{ highly ionized } (H^+) \)

Diffuse \( H\alpha \) emission (allowed transition in H)
Hydrogen in the Interstellar Medium

HI is the designation often used for neutral hydrogen atoms in space. It is estimated that 4.4% of the visible matter in our galaxy is HI. That is $4.8 \times 10^9 M_\odot$.

The fraction of interstellar space filled with HI clouds is 20% to 90%.

Estimates for hydrogen molecules, $H_2$, vary - 1.2 to $3.5 \times 10^9 M_\odot$. $H_2$ tends to concentrate in a small number of giant gas clouds.
Neutral hydrogen (H I) spin-flip transition

The transition probability for spontaneous emission $\Delta E_{10}$ is

$$\Delta E_{10} \approx \frac{\Delta E_{10}}{10^{11}} \times 10^{10} = 8.5 \times 10^{-15} \text{ s}^{-1} \approx (1 \times 10^6 \text{ yr})^{-1}$$

The smallness of the spontaneous transition probability is due to

- the fact that the transition is “forbidden”
- the dependence of $A_{10}$ on $\text{freq}^3$

The “natural” halfwidth of the transition is $5 \times 10^{-16}$ Hz
21-cm Line of Atomic HI

Through Hydrogen maser measurements the frequency is:

\[ 1,420,405,751.7667 \pm 0.0010 \text{ Hz} \]

Energy \( \frac{hc}{\lambda} \sim 5 \times 10^{-6} \text{ eV} \)

Compared to energy of a visible light photon which is about 2 eV.

- Predicted 1944 by van der Hulst
- First observed 1951 by Ewen and Purcell
- Observed regularly with Arecibo telescope by ALFALFA* team members

The transition is mainly excited by other mechanisms, which make it orders of magnitude more frequent, e.g., the upper level is populated by:

- Collisions
- Excitation by stellar radiation field or Lyman-\( \alpha \) photons

- In the MW there are some \( 10^{66.5} \) HI atoms;
- At the rate \( A_{10} \), about \( 10^{52} \) atoms per sec would emit a photon.
- In reality, the transition probability is \( 10^5 \) times larger than \( A_{10} \)
- Hence the galactic HI emission is very easily detectable.
HI Gas in Galaxies

- Atomic hydrogen has two states in its ground level, split by spin-orbit coupling. Parallel spins give a slightly higher energy than antiparallel, and decays by emission of a photon at 1420.406 MHz.

- The upper level is populated by collisions, and has a decay half-life of about $3.5 \times 10^{14}$ seconds = $1.1 \times 10^7$ years; this is detectable only because there are lots of H atoms. In the MW there are some $10^{66.5}$ HI atoms: at the rate $A_{10}$, about $10^{52}$ atoms per sec would emit a photon. In reality, the transition probability is $10^5$ times larger than $A_{10}$; hence the galactic HI emission is very easily detectable.

- Under most circumstances, the total H I mass can be derived from the integrated line profile; that is, the flux (integrated over all frequencies where there is signal) is proportional to the number of hydrogen atoms.

- The frequency (velocity) spread of the line reflects the velocities of the gas atoms, not quantum mechanics => hence the width of the line tells about the motions of the gas (rotation within the galaxy or turbulence, expansion, etc)
HI emission from galaxies

- Under most circumstances, the total H I mass can be derived from the integrated line profile; that is, the flux (integrated over all frequencies where there is signal) is proportional to the number of hydrogen atoms.

- The frequency (velocity) spread of the line reflects the velocities of the gas atoms, not quantum mechanics => hence the width of the line tells about the motions of the gas (rotation within the galaxy or turbulence, expansion, etc).

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

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

\[ \Delta V \rightarrow \text{Mass} \]

Rest frequency 1420.4058 MHz
Clues from the HI line

- HI mass and distribution (for extended objects)
  - Normal, star-forming disks
  - Low mass, LSB dwarfs
  - Potential for future star formation (HI content)
  - HI deficiency in clusters
  - History of tidal events
- Redshifts
- Rotational velocities
  - Dark matter
  - Redshift-independent distances via Tully-Fisher relation
- HI absorption: optical depth
  - Link to Ly-$\alpha$ absorbers
  - Fundamental constant evolution
HI: The Fuel for Star Formation

**M33 – Spiral Galaxy (Type Sc)**

Distance: 3,000,000 light-years (1 Mpc)  
Image Size = 42 x 42 arcmin  
Visual Magnitude = 5.7

- **X-Ray:** ROSAT
- **Ultraviolet:** ASTRO-1
- **Visible:** DSS
- **Visible:** IAC/RGO/Malin
- **Near-Infrared:** 2MASS
- **Mid-Infrared:** IRAS
- **Far-Infrared:** IRAS
- **Radio:** NRAO

---

**ALFALFA**
M33

CO GMC's
(Engargiola et al. 2004)

superposed on HI
(Deul & van der Hulst 1987)
In some cases, the HI reveals interaction where the optical does not: M81/M82 system

TIDAL INTERACTIONS IN M81 GROUP

Stellar Light Distribution  21 cm HI Distribution

Credit: NRAO, Yun et al.
Tidal Dwarf Galaxies

Hibbard et al. 1994

- Expected to form in dynamically cool, gas-rich tidal tails
- Should be a mix of pre-existing stars from tidally disrupted material and a “new generation” of young stars produced as HI gas condenses => fall off the metallicity-luminosity relation
- Should contain little dark matter (assuming no DM in galaxy disks)
- Although young TDGs may be prominent due to the burst of star formation, their long-term fate remains unclear
HI: Probing Dark Matter

NGC 5055 Optical (left); HI (right)
Tom Osterloo
Are there totally “dark” galaxies?

Are recibo map outer extent [Hoffman et al. 1993]

$M_H = 2.5 \times 10^8 M_\odot$

$M_{\text{stars}} = 5.0 \times 10^7 M_\odot$

$M_{\text{Dyn}} = 3.0 \times 10^9 M_\odot$

DDO154

Extent of Optical image

Carignan & Beaulieu 1989

VLA D HI
The HI 21 cm line @ 1.42 GHz

HI: Why do we care?

- Easy to detect, simply physics \(\rightarrow\) cold gas mass
- Good index of SF fertility \(\rightarrow\) future SF
- Comparative HI content \(\Rightarrow\) HI deficiency
- Excellent tracer of host dynamics \(\rightarrow\) dark matter
- Useful Cosmology tool \(\Rightarrow\) TF relation, HIMF, BAO
- Interaction/tidal/merger tracer
- Can be dominant baryon form in low mass galaxies

- ALFALFA: A census of HI in the local universe
The HI Mass Function

• How many HI sources are there?

• Previous surveys have included few (if any) objects with HI masses less than $10^8 M_\odot$.

• At lowest masses, differ by 10X:
  Rosenberg & Schneider (2000)
  versus
  Zwaan et al. (1997)

Parkes HIPASS survey: Zwaan et al. 2003
Dwarf galaxies

- dE, dSph, dIrr
- Low mass: detected only nearby
- Dark matter dominated
- Low abundances
- Stellar mass: \(10^6-10^8 \, M_\odot\)
- Blue Luminosity: \(10^6-10^8 \, L_\odot\) (\(M_B > -15\))
- Dynamical mass: \(10^7-10^9 \, M_\odot\)

Where they are gas-rich:
- HI mass: \(10^6-10^8 \, M_\odot\)
  - Sometimes, extensive HI
  - Evidence for dark matter

"Dwarf galaxies of the Local Group" Mateo 1998 ARAA
Where are the low HI mass galaxies?

- Galaxies mainly clustered around the two principal galaxies MW & M31

- Morphological segregation evident
  - dE/dSph near large galaxies
  - dI at larger distances

Diagram from Grebel 1999
The Search for 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: A 2\textsuperscript{nd} generation HI survey

- In comparison with opt/IR, the HI view is largely immature
- HIMF based on only few thousand objects (HIPASS)

ALFALFA:
- Designed to explore the HI mass function over a cosmologically significant volume
  - Higher sensitivity than previous surveys
  - Higher spectral resolution $\Rightarrow$ low mass halos
  - Higher angular resolution $\Rightarrow$ most probable optical (stellar) counterparts
  - Deeper: 3X HIPASS median redshift $\Rightarrow$ volume
  - Wider area than surveys (other than HIPASS) $\Rightarrow$ nearby volumes for lowest $M_{\text{HI}}$
ALFALFA Science Goals

1. Census of HI in the Local Universe over cosmologically significant volume
2. Determination of the faint end of the HI Mass Function and the abundance of low mass gas rich halos
3. Environmental variation in the HI Mass Function
4. Blind survey for HI tidal remnants
5. Determination of the HI Diameter Function
6. The low HI column density environment of galaxies
7. The nature of HVC’s around the MW (and beyond?)
8. HI absorbers and the link to Ly $\alpha$ absorbers
9. OH Megamasers at intermediate redshift $0.16 < z < 0.25$
# Comparison of blind HI surveys

<table>
<thead>
<tr>
<th>Survey</th>
<th>Beam arcmin</th>
<th>Area sq. deg.</th>
<th>rms (mJy @ 18 km/s)</th>
<th>min $M_{HI}$ @ 10 Mpc</th>
<th>$N_{det}$</th>
<th>$t_s$ sec</th>
<th>$N_{los}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHISS</td>
<td>3.3</td>
<td>13</td>
<td>0.7</td>
<td>2.0$x10^6$</td>
<td>65</td>
<td>var</td>
<td>17,000</td>
</tr>
<tr>
<td>ADBS</td>
<td>3.3</td>
<td>430</td>
<td>3.3</td>
<td>9.6$x10^6$</td>
<td>265</td>
<td>12</td>
<td>500,000</td>
</tr>
<tr>
<td>HIPASS</td>
<td>15.9</td>
<td>30,000</td>
<td>13</td>
<td>3.6$x10^7$</td>
<td>5300</td>
<td>460</td>
<td>1.9$x10^6$</td>
</tr>
<tr>
<td>HIJASS</td>
<td>12.0</td>
<td>(TBD)</td>
<td>13</td>
<td>3.6$x10^7$ (TBD)</td>
<td>3500</td>
<td>(TBD)</td>
<td>3200</td>
</tr>
<tr>
<td>J-Virgo</td>
<td>12.0</td>
<td>32</td>
<td>4</td>
<td>1.1$x10^7$</td>
<td>31</td>
<td>3500</td>
<td>3200</td>
</tr>
<tr>
<td>HIDEEP</td>
<td>15.0</td>
<td>32</td>
<td>3.2</td>
<td>8.8$x10^6$</td>
<td>129</td>
<td>9000</td>
<td>2000</td>
</tr>
<tr>
<td>ALFALFA</td>
<td>3.5</td>
<td>7,000</td>
<td>1.7</td>
<td>4.4$x10^6$</td>
<td>25,000+</td>
<td>40</td>
<td>7$x10^6$</td>
</tr>
</tbody>
</table>

**ALFALFA will be ~ 1 order of magnitude more sensitive than HIPASS with 4X better angular resolution.**

Median cz for HIPASS ~ 2800 km/s  
For ALFALFA ~ 7500 km/s
Arecibo Legacy Fast ALFA Survey

- One of several major surveys currently ongoing at Arecibo, exploiting its new multibeam capability

- An extragalactic spectral line survey
- Covers 7000 sq deg of high galactic latitude sky
- 1345-1435 MHz (-2000 to +17500 km/s for HI line)
- 5 km/s resolution
- 2-pass, drift mode (total int. time per beam ~ 40 sec)
- 1.5-2 mJy rms
- 4400 hrs of telescope time, 5 (6,7...) years
- started Feb 4, 2005; ~3000 hrs to date

http://egg.astro.cornell.edu/alfalfa
Total Incoherent Multi Beam Pattern

TE_{11} Mode Horn 25.0 cm \times 26.0 cm

Sky Area 25' \times 25' at 1.375 GHz
It is a radio "camera"

Arecibo L-band Feed Array
Drift scanning

7 elliptical beams
Avg(HPBW)=3.5′
on elliptical pattern
of axial ratio ~1.2
Array rotation

The individual feed horns move along an elliptical ring oriented in Az, ZA.

Note: The beams are actually elliptical, NOT circular.
Fig. 2.— Sketch of the geometry of the ALFA footprint, with the array located along the local meridian and rotated by an angle of 19° about its axis. The outer boundary of each beam corresponds to the -3 dB level. The dashed horizontal lines represent the tracks at constant Declination of the seven ALFA beams, as data is acquired in drift mode.
ALFALFA schedule notation

- "Master list" of drift declinations preassigned, starting at 0° and moving northward to +36° ⇒ DriftN, N = 1, 148
- Two passes: p1 and p2

<table>
<thead>
<tr>
<th>107p1</th>
<th>+255454</th>
</tr>
</thead>
<tbody>
<tr>
<td>107p2</td>
<td>+260212</td>
</tr>
<tr>
<td>108p2</td>
<td>+261648</td>
</tr>
</tbody>
</table>

7.3 arcmin
14.6 arcmin
**ALFALFA drift mode**

- "Almost" fixed azimuth drifts
  - Track in J2000 Declination
  - Declination of all survey drifts specified, except for $+16^\circ < \text{DecJ} < +20^\circ$ (zenith "Zone of Avoidance")

- Specify observing "block" according to date/time at start, specified as yy.mm.dd
  - 09.01.12a: This (early) morning’s block
  - 09.01.12p: This afternoon’s block

<table>
<thead>
<tr>
<th>Block</th>
<th>Date</th>
<th>AST</th>
<th>LST</th>
<th>#</th>
<th>DecJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>09.01.12p</td>
<td>M 12Jan</td>
<td>16h00-17h00</td>
<td>23h02-00h02</td>
<td>14p2</td>
<td>+032424</td>
</tr>
<tr>
<td>09.01.13a</td>
<td>T 13Jan</td>
<td>00h15-07h15</td>
<td>07h04-14h05</td>
<td>14p2</td>
<td>+032424</td>
</tr>
<tr>
<td>09.01.13p</td>
<td>T 13Jan</td>
<td>18h30-20h15</td>
<td>01h37-03h22</td>
<td>49p2</td>
<td>+115524</td>
</tr>
<tr>
<td>09.01.14</td>
<td>W 14Jan</td>
<td>18h15-20h15</td>
<td>01h41-03h26</td>
<td>41p1</td>
<td>+095118</td>
</tr>
</tbody>
</table>
ALFA spectra:
- 16 x 4096 frequency channels (2 not used)
- 7 beams x 2 polarizations/beam
- 100 MHz wide
- Centered at 1385 MHz
Radio Frequency Interference

- Man-made signals are much stronger than cosmic ones!
- Some are always present; others come and go.
- Radars (e.g. FAA at San Juan airport) occur with some regular period (e.g. 12 sec)
- Some RFI is so strong that it “saturates” the front end.

We have to live with it (but we don’t have to like it!).
<table>
<thead>
<tr>
<th>Frequency</th>
<th>Range</th>
<th>Active</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1214.75</td>
<td></td>
<td></td>
<td><strong>Aerostat</strong> radar balloon in jaicas, dual freq or quad freq modes.</td>
</tr>
<tr>
<td>1244.6</td>
<td></td>
<td></td>
<td>160 usec per pulse, chirped. Rotation rate 11.59 secs. Blanks toward</td>
</tr>
<tr>
<td>1256.5</td>
<td></td>
<td></td>
<td>A0 (see <a href="#">radar info</a>)</td>
</tr>
<tr>
<td>1261.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1273/1290</td>
<td></td>
<td>2</td>
<td><strong>Remy Radar</strong> at the end of the runway. (fps20-931). 12 sec rotation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>rate, single ipi of 2781. Runs in 1270 or 1290 mode (not simultaneously).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(see <a href="#">radar info</a>)</td>
</tr>
<tr>
<td>1287.5/1299.84</td>
<td>1300/1309</td>
<td>&lt;0.25</td>
<td><strong>Dista</strong> birdies. Occur every 2 minutes for a few seconds. Az dependent.</td>
</tr>
<tr>
<td>1400</td>
<td>1411.52</td>
<td></td>
<td>Dista have a 27 Mhz clock.</td>
</tr>
<tr>
<td>1412.5</td>
<td></td>
<td></td>
<td>Data was measured in jan01 (<a href="#">before shielding work</a>).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Data was remeasured in apr02 (<a href="#">after some shielding work</a>).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>The window was changed</td>
</tr>
<tr>
<td>1313/1350</td>
<td></td>
<td>2</td>
<td><strong>FAA airport radar</strong>. 12 sec rotation, 5 ipps about 2.5 ms. 5 usec</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>pulse. 1350 then 1330 pulse sent each ipi. (<a href="#">radar info</a>)</td>
</tr>
<tr>
<td>1366.2/1382.66</td>
<td>1324/1340</td>
<td></td>
<td><strong>Raders with 1.94 sec rotation</strong> rates. (<a href="#">more info</a>). These radar</td>
</tr>
<tr>
<td>1387.3/1371.0</td>
<td></td>
<td></td>
<td>were probably associated with military ship practices. First rotating</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>radars are needed when objects move far within 1 rotation (planes near</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>aircraft carriers, etc.,)</td>
</tr>
<tr>
<td>1381.05</td>
<td>1</td>
<td></td>
<td><strong>GPS L2 downlink.</strong> (<a href="#">more info</a>)</td>
</tr>
<tr>
<td>1388.55</td>
<td>0.24</td>
<td>98</td>
<td><strong>beeper</strong> harmonic (3rd of 462.85)</td>
</tr>
<tr>
<td>1388.6</td>
<td>0.24</td>
<td>93</td>
<td><strong>beeper</strong> harmonic (3rd of 462.875) (horituous beepers)</td>
</tr>
<tr>
<td>1388.858</td>
<td>&lt;190</td>
<td></td>
<td><strong>done camera</strong> birdies. Part of a comb of 14.385 Mhz. (<a href="#">more info</a>).</td>
</tr>
<tr>
<td>1417.495</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1390.8</td>
<td>0.24</td>
<td>fc93</td>
<td><strong>beeper</strong> harmonic (3rd of 463.6 (nr. beeper))</td>
</tr>
<tr>
<td>1407</td>
<td>3</td>
<td></td>
<td><strong>tvChan20</strong> arecibo. Drifted around with time. They were having trouble</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>with their transmitter. (<a href="#">more info</a>)</td>
</tr>
<tr>
<td>1422.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1525-1545</td>
<td></td>
<td>aug03</td>
<td><strong>Inmarsat stdC</strong> ship, portable earth downlinks.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Inmarsat stdM</strong> ship downlinks</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inmarsat status is unknown.</td>
</tr>
</tbody>
</table>
RFI is ugly

FAA radar

Galaxy!

Galactic hydrogen

Channel number/frequency →
Two-pass strategy

We want to drift across each stop on the sky TWICE
  • Double integration time
  • Helps to discriminate cosmic sources from
    1. Noise
    2. RFI

We offset the 2nd drift by half of the beam spacing.
  • Helps with position centroiding
  • Evens out the gain scalloping

We conduct the 2nd pass 3-9 months after the first.
  • Cosmic sources will have shifted in frequency due to the Earth’s motion around the Sun, but terrestrial ones won’t have.
  • Some interference comes and goes.
Final coverage for 2 pass strategy

- For the 2\textsuperscript{nd} pass, Beam 0, which has higher gain than the others, is offset by 7.3 arcmin from its 1\textsuperscript{st} pass position.

- Some smoothing of gain scalloping.

- 2-pass sampling thus at 1.05 arcmin

- 2\textsuperscript{nd} pass occurs 3-9 months after the 1\textsuperscript{st} pass (vs. RFI)
ALFALFA Scheduling Strategy

• ALFALFA aims to survey 7000 square degrees of high galactic latitude sky.

• “Fixed azimuth drift” mode: the telescope moves only slightly, to maintain constant Dec (J2000); Drifts offset by 14.6 arcmin.

• A “tile” of data will contain all beam positions within a box of 20 min in RA by 4 degrees in Dec.

• Within a single observing block, the data taking sequence consists of a series of 600 second (10 min) drifts at constant Dec J.

• Over a season, we try to “complete” sets of drifts within a tile: 16 drifts/tile/pass.

• The second pass occurs 3-9 months after the 1st pass (to aid RFI identification and signal confirmation).
ALFALFA Survey 2005-8

- Commensal with TOGS HI
- Does not compete with galactic plane surveys

High galactic latitude sky visible from AO

Supergalactic plane

Virgo cluster

Leo Group
A Drift scan, before bandpass correction (bpd)
After BPD

A Drift scan, after bandpass correction (bpd)
Maximizing Observing Efficiency

- Telescope time is precious and competition is stiff.
- Our science goals demand high quality data.
- The legacy nature of ALFALFA raises the standards for data product generation and delivery.
- Arecibo and ALFA are complex instruments to use.
- RFI is nasty and inevitable.
- ALFALFA uses a lot of telescope time and generates a lot of data!
- The A2010 proposal was approved pending periodic reviews of our ability to perform the survey.
  - We got an A+ last year.
ALFALFA observing sequence

- Set dome at transit (360° or 180°)
- Rotate ALFA to 19°
- Setup spectrometer
- Start 600 sec drift scan
  - Record spectra every 1 sec
    (actually 14 = 7 beams X 2 polarizations/beam)

......

- Terminate drift scan
- Fire noise diode for 1 sec
- Close/open FITS data file
- Start next drift

...........
Repeat until end of observing block

Calibration:
1. Noise diode
2. Radio continuum sources of known flux
3. Galactic Hydrogen
Scavenger Hunt #1

http://egg.astro.cornell.edu/alfalfa/ugradteam/hunt09/hunt2_09.htm

- Think about using ALFA for ALFALFA
- Start thinking about what we can learn about galaxies
So, enough talk; let's eat...!