The Story of Galaxy Evolution in the Cosmos

Dr. Brian R. Kent
National Radio Astronomy Observatory
http://www.cv.nrao.edu/~bkent/
We begin our story...

...at the end!
The Local Group
What makes a "galaxy"?

Now, to the beginning of the story...
A BIG BANG!

Very **HOT**

Very **DENSE**
Baryon – Photon Decoupling

- Temperature and Density of the Universe drops as it expands
- Ionization stops, neutral atoms form.
- Photons are free to move about without colliding!
- The imprint of the photons “escaping” is called…
The Surface of Last Scattering

Guess what?

We can see it!
A note on distances and time!

1 pc = 3.26 light years
1 kpc = 3260 light years
1 Mpc = 3,260,000 light years
$z = 11.9$

800 x 600 physical kpc

Diemand, Kuhlen, Madau 2006
Data from 2dF, map by Brian Kent
Anatomy of a Galaxy

- $R_0 \sim 8 \text{ kpc}$
- 200 billion stars
- $5 \times 10^{11} M_{\odot}$
- SFR $\sim 3 M_{\odot}/\text{yr}$
- Bulge $\sim 3 \text{ kpc}$ in diameter
M101

Mean distance $\sim 7$ Mpc
M33

Mean distance \(~1\ Mpc\)
M87 (Virgo Cluster)
Mean distance ~16.7 Mpc
I Zwicky 18
Mean distance $\sim 14.3$ Mpc
Large Magellanic Cloud
Mean distance $\sim 51$ kpc
Where are the missing satellites…

…and how can we find them?
**Makeup of the Universe**

Most of the baryons are in the IGM…

*Data compiled from Fukugita and Peebles 2004*
Diameter: 1000 foot dish

460 foot platform

Frequency range:
300 MHz to 10 GHz
Arecibo L-band Feed Array

- 7 element receiver
- Rotated at 19° (depending on the area of sky observed) and each beam tracks constant J2000 declination
$n = 2, \, ^2P$

$n = 1, \, ^2S$

$J = 1/2$

$I = 1/2$

$F = 2$

$F = 1$

$F = 0$

1420.4058 MHz
Why study neutral hydrogen?

It’s EVERYWHERE!
What does neutral hydrogen tell us?

- **NGC 4611**
  - Flux Density [mJy]
  - Mass: $2.5 \times 10^{10} \, M_\odot$
  - Distance: 89.4 Mpc

- **NGC 4501**
  - Flux Density [mJy]
  - Mass: $1.6 \times 10^9 \, M_\odot$
  - Distance: 16.7 Mpc

- **VCC 132**
  - Flux Density [mJy]
  - Mass: $1.7 \times 10^8 \, M_\odot$
  - Distance: 16.7 Mpc

- **AGC 225880**
  - Flux Density [mJy]
  - Mass: $4.3 \times 10^7 \, M_\odot$
  - Distance: 16.7 Mpc
HI Surveys: A Status Snapshot

**ALFALFA**
- 8539

**HIPASS**
- 5315

**HIDEEP**
- 173

**HIJASS**
- 222

**WSRT**
- 146

**ADBS**
- 265
VLA mapping of HI1208+115

$M_{HI} \sim 4 \times 10^7 M_{\odot}$
The Future of Radio Astronomy

Bigger distances, more molecules
You can explore too!

Radio astronomy on your computer
**ALFALFA**

**NEW DISCOVERIES IN EXTRAGALACTIC HI**

Arecibo is the world's most sensitive radio telescope at L-band. In addition to that all-important sensitivity advantage, Arecibo equipped with ALFA offers important and significant improvements in angular and spectral resolution over the available major wide area extragalactic HI line surveys such as HIPASS and HJUASS. To break ground into new science areas, extragalactic HI surveys with ALFA must exploit those capabilities to explore new higher volumes with greater sensitivity, than have the previous surveys. ALFA has the power to detect more objects than ever before in a short time, as well as to open up new areas of the galaxy to study.

ALFALFA is a comparison major blind HI surveys and ALFALFA is presented in Table 3. It will deliver 1.6 mJy/channel sensitivity (at 10 km/s), 0.5° better than HIPASS and with 0.2° better angular resolution (FWHM). In addition to its broad applications, such a wide area HI survey will also serve as a strategic approach to a number of focused E-ALFA science objectives. In coordination with this survey, deeper studies of selected regions, such as some of which will be the second generation E-ALFA spectrometer, will address all other critical E-ALFA science goals that are not discussed herein.

**UPDATE: Catalog 3 Released: Second Virgo Catalog**

Kent et al. 2008. AJ, in press (link)

We present the third installment of HI sources extracted from the Arecibo Legacy Fast ALFA extragalactic survey. This dataset continues the work of the Virgo ALFALFA catalog. The catalogs and spectra published here consist of data obtained during the 2005 and 2006 observing sessions of the survey. The catalog consists of 578 HI detections within the range 11.36m < R.A. (J2000) < 13h 52m and +08 deg < Dec. (J2000) < +12 deg, and cz_sun < 10,000 km/s. The catalog entries are identified with optical counterparts where possible through the examination of digitized optical images. The catalog can be divided into three categories: (a) direction of high reliability with SN > 85; (b) high velocity clouds in the Milky Way or its vicinity; and (c) sources of lower SN which coincide spatially with an optical object and known redshift. 75% of the sources are newly published HI detections. Of particular note is a complex of HI clouds projected between M87 and M84 that do not coincide with any optical counterparts. Candidate objects without optical counterparts are few. The median redshift for this sample is 6500 km/s and thecz distribution exhibits the local large scale structure consisting of Virgo and the background void and the Alcubierre-Corwin supercluster regime at cz_sun ~7000 km/s. Position corrections for telescope pointing errors are applied to the dataset by comparing ALFALFA continuum centroid with those cataloged in the NRAO VLA Sky Survey. The unperturbed positional accuracy averages 27 arcsec (21 arcsec) for all sources with SN > 5 and is of order 21 arcsec (16 arcsec) for signals with SN > 12. Uncertainties in distances toward the Virgo cluster can affect the calculated HI mass distribution.

The catalog contents can be accessed by using the Search tools.

**Catalog 2 Released: +/27 degree region**
Exploring the Radio Universe

As a Jansky Fellow at the National Radio Astronomy Observatory (NRAO), I study galaxies in the Universe at radio frequencies. In particular, I work on studies of gas-rich galaxies in the Virgo Cluster. I use the 305-m Arecibo, 100-m Green Bank, and Very Large Array radio telescopes (above) to study the dynamics of these galaxies near and far.

In addition, I'm fascinated by the current revolution in astronomy dealing with large datasets. I write lots of software (web based server and client) dealing with the visualization and mining of these datasets at radio frequencies. The animation above is a 3D volume rendering of the velocity field based on data from the PSCz catalog (Saunders et al. 2000 and Schmidt et al. 1999).

I earned my Ph.D. in Astronomy and Space Sciences from Cornell University. Read here about what I study and visit my NRAO Wiki Page!

Selected Talks

- EVLA Vision Dec. 2008
- Jansky Talk Oct. 2008
- NRAO Lunch Talk and PSCz movie!

Events

- Assembly, Gas Content and Star Formation History of Galaxies
- AstroStatistics 2002
- 2009 NRAO Symposium
- Space Terahertz Technology
- ALMA: Birth of Massive Stars
- EVLA Vision: Galaxies throughout cosmic time
Credits

• Credits: Priscilla Frisch (2000) for the Local Interstellar Cloud
• Voyager, NASA
• Cassini, NASA
• Milky Way Image: Benjamin R.A. 2008
• 2dF survey
• Copyright Robert Gendler and Josch Hambsch 2005 for the LMC
• Nieten et al. (M31 CO), Tautenburg Observatory (optical)
• WMAP/NASA
• Hubble Heritage
• Moore et al. 1996
• SkyView/Digital Sky Survey
• Virtual Observatory
• Google Sky

• NRAO: An NSF facility operated by AUI
• NAIC: An NSF facility operated by Cornell

Digital Sky Survey Blue images of gas-rich ALFALFA galaxies

http://www.cv.nrao.edu/~bkent/
bkent@nrao.edu