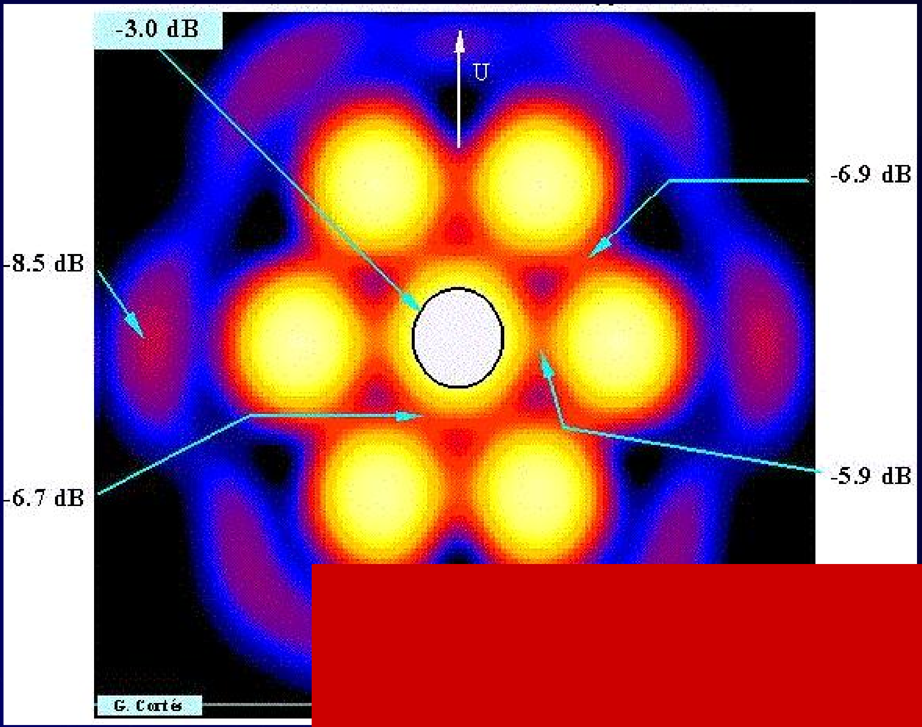


The survey vehicles of choice….

ALFALFA

Arecibo Leg

May 1933: Karl Jansky kickstarts Radio Astronomy

1940

Van de Hulst & Oort make good use of wartime

1950

1951: HI line first detected

1953: Hindman & Kerr detect HI in Magellanic Clouds

1960

Green Bank
Nancay
Effelsberg
Parkes, J.Bank

First 100 galaxies

1970

VLA and WSRT come on line
Arecibo upgraded to L band;
broad-band correlators, LNRs

1975: Roberts review
1977: Tully-Fisher

1980

Cluster deficiency, Synthesis maps,
DLA systems, interacting systems
Rotation Curves, DM,
Redshift Surveys

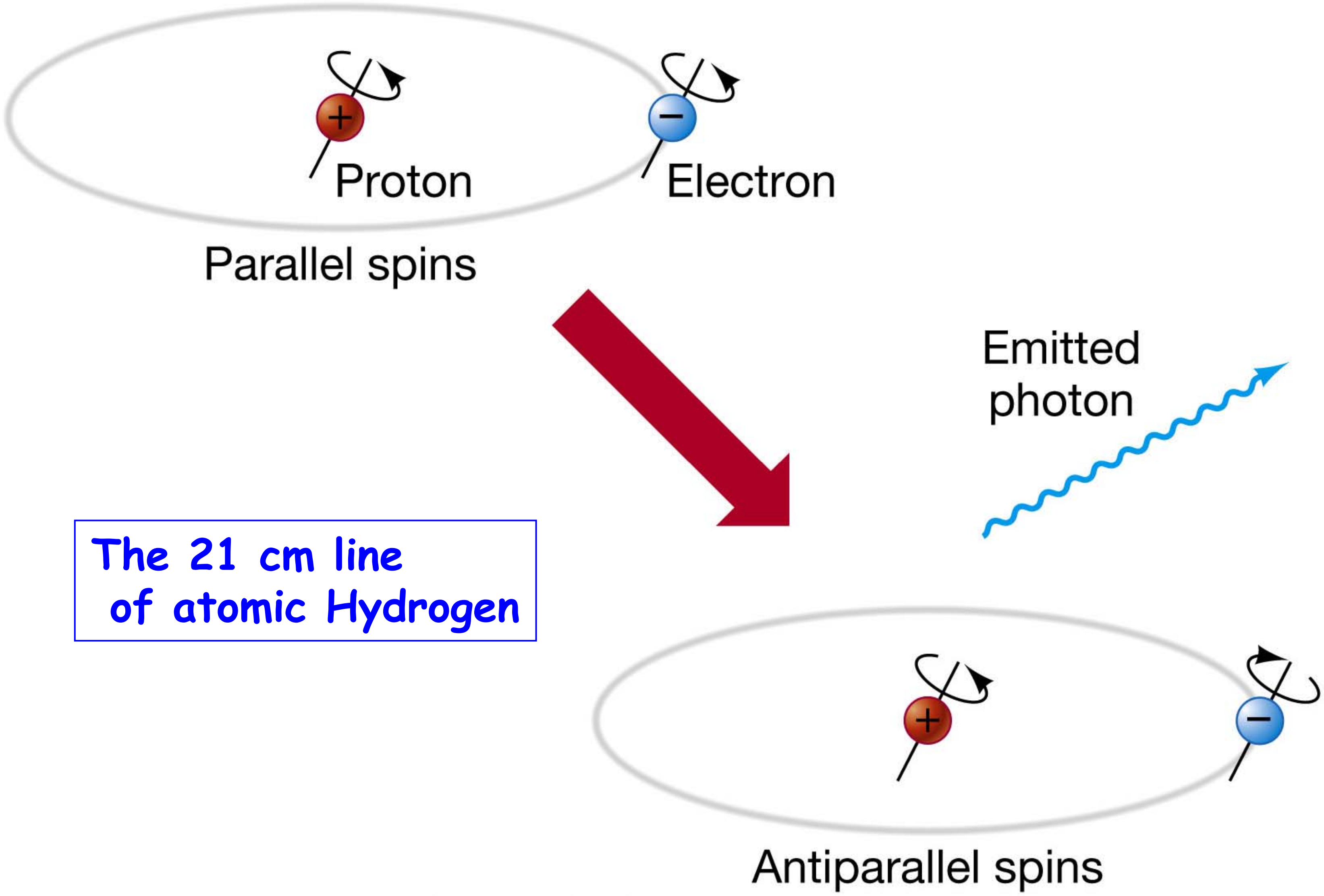
1990

Peculiar velocity surveys, deep mapping

2000

Multifeed systems : large-scale surveys

ALFALFA



The 21 cm line of atomic Hydrogen

The splitting of the ground energy state of atomic H results from the fact that the spins of the electron and the proton can be parallel or antiparallel.

HI Line: transition probability

The transition probability for spontaneous emission 1 ➔ 0 is

$$A_{10} = 2.85\times10^{-15}\,s^{-1} \simeq \left(11\times10^{6}\,yr\right)^{-1}$$

The smallness of the spontaneous transition probability is due to

- the fact that the transition is “forbidden”
- the dependence of A_{10} on ν^3

The “natural” halfwidth of the transition is 5×10^{-16} Hz

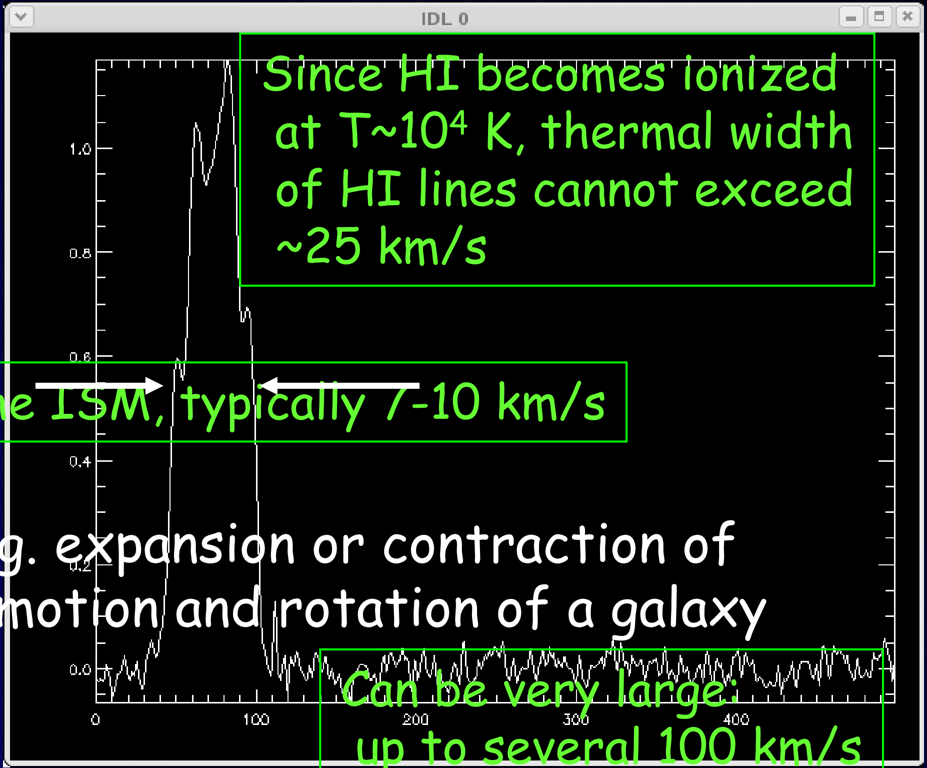
In the MW there are some $10^{66.5}$ HI atoms; at the rate A_{10}, about 10^{52} atoms per sec would emit a photon. In reality, the transition probability is 10^5 times larger than A_{10}, hence the galactic HI emission is very easily detectable.

The transition is mainly excited by other mechanisms, which make it orders of magnitude more frequent, e.g.:
-Collisions
-Excitation by RF or Lyman-α photons

ALFALFA

Since the natural width of the HI line is very small, its broadening due to motions of the emitting atoms, - Doppler broadening - can be easily measured.

That broadening can be due to different reasons:



- thermal broadening

Since HI becomes ionized at T~10^4 K, thermal width of HI lines cannot exceed ~25 km/s

- turbulence

In the ISM, typically 7-10 km/s

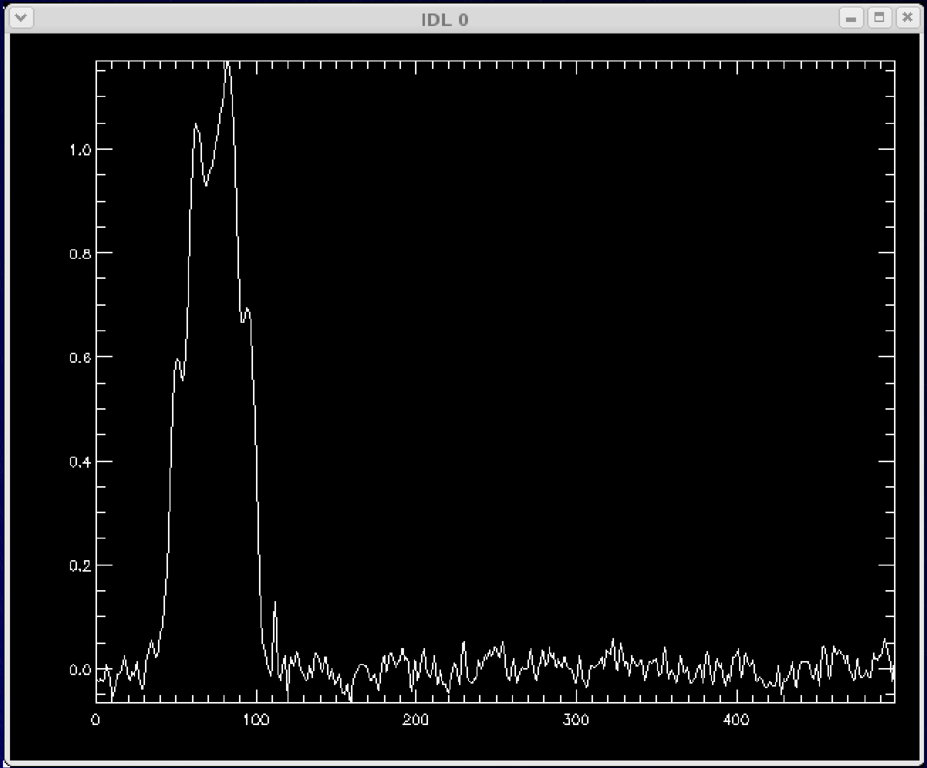
- large scale motions, e.g. expansion or contraction of a gas cloud, systemic motion and rotation of a galaxy

Can be very large: up to several 100 km/s

Because the sources of HI line emission are generally optically thin (i.e. we see the emission of ALL atoms in the source),

the integral over the line profile is proportional to the total number of emitting atoms, i.e. it is a direct indication of the source's

HI Mass



ALFALFA

- An extragalactic HI line survey covering 7000 sq deg
- with the ALFA multibeam feed at Arecibo
- 1335-1435 MHz (-2000 to + 17500 km/s) with 5 km/s res
- 2-pass, drift mode (eff. integration time per beam ~ 48 sec)
- 1.6/2.3 mJy rms per beam/pixel @ R=30,000
- 4000 hrs of telescope time, 5-6 years
- started Feb 2005

ALFALFA science goals

1 Determination of the faint end of the HI Mass Function

2 Environmental variation in the HI Mass Function

3 Blind Survey for HI tidal remants

4 HI Diameter Function

5 The low HI Column density environment of galaxies

6 The nature of HVC’s around the MW and M33

7 HI absorbers and the link to Lyman α absorbers

8 OH Megamasers at intermediate redshift

The HI Mass Function

- The HI mass function tells the number of galaxies per unit volume per bin of HI mass

$$\Phi(x) = \frac{dn}{d(\log x)} = (\ln 10)\Phi^* x^{\alpha+1} e^{-x}$$

$$x = M_{HI} / M^*$$

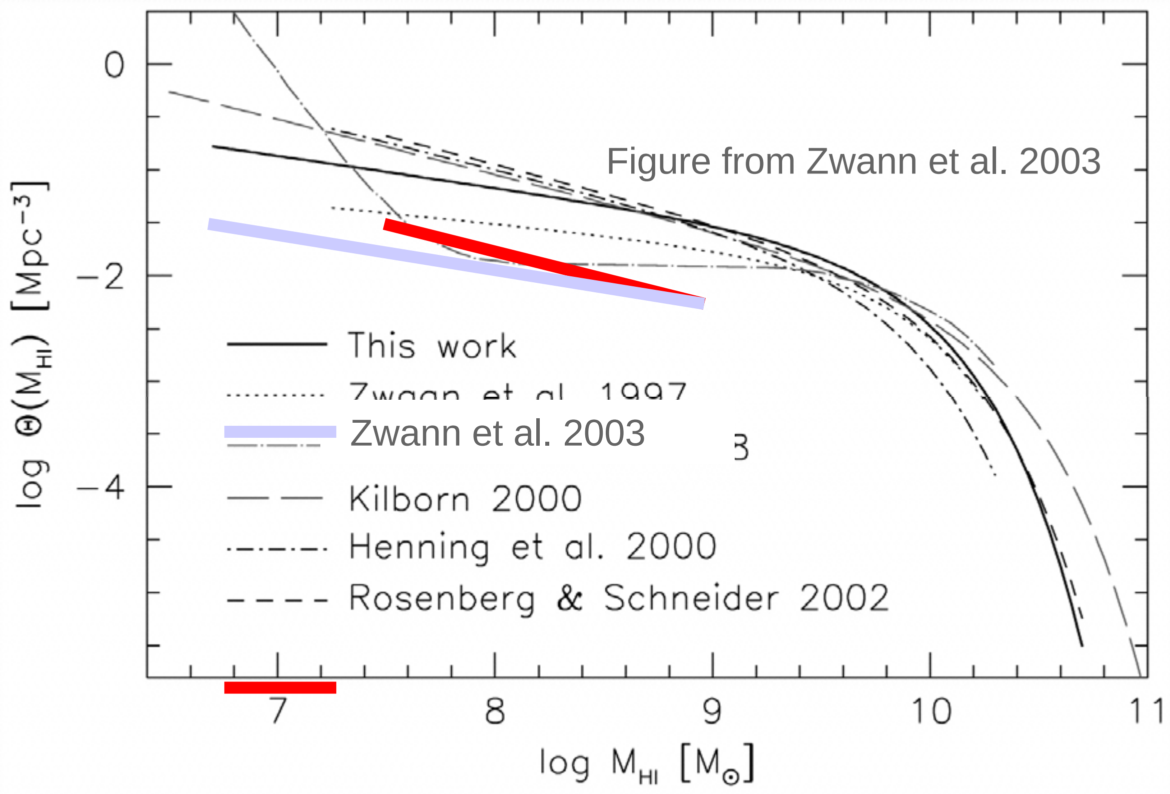


Figure from Zwann et al. 2003

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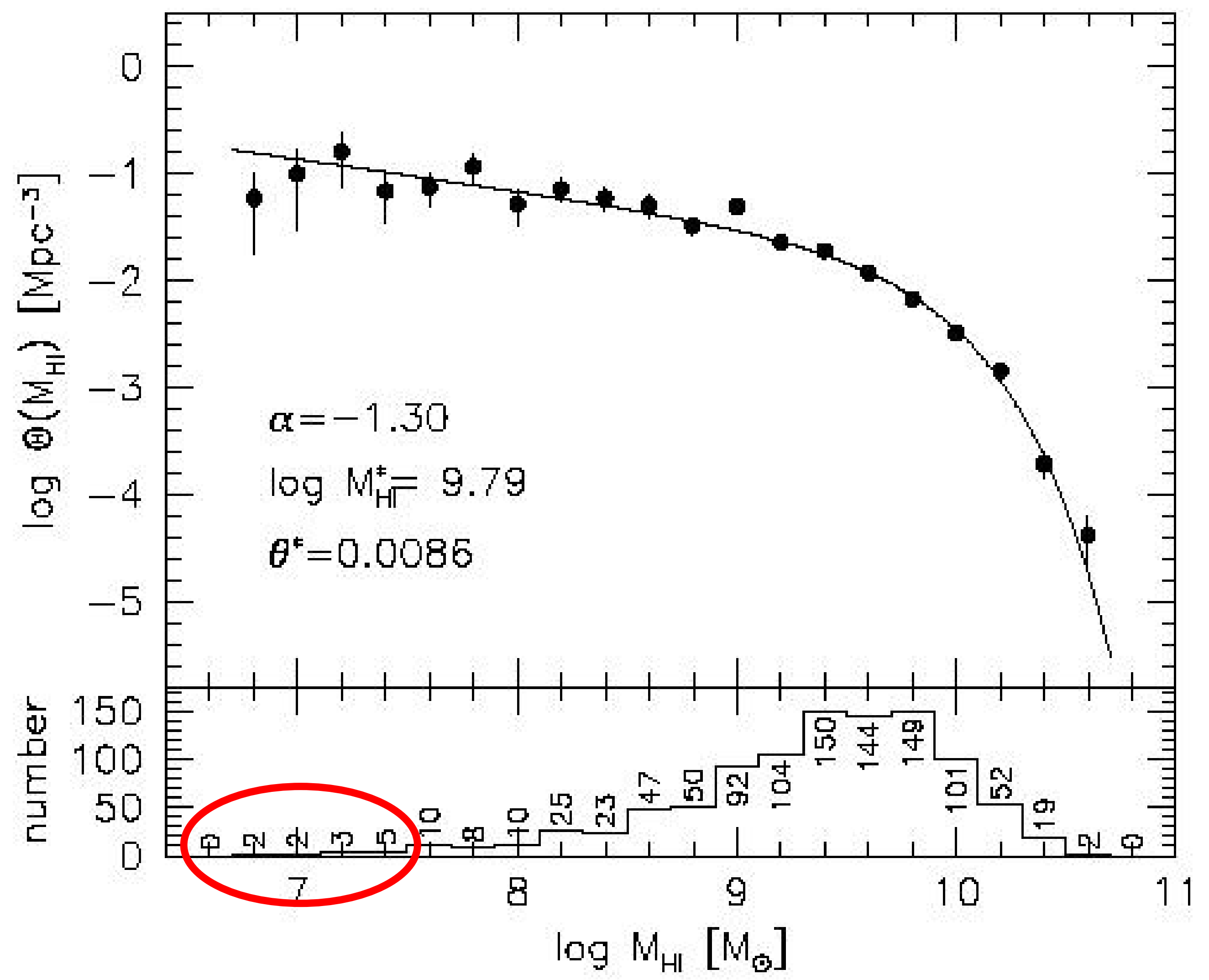
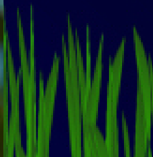
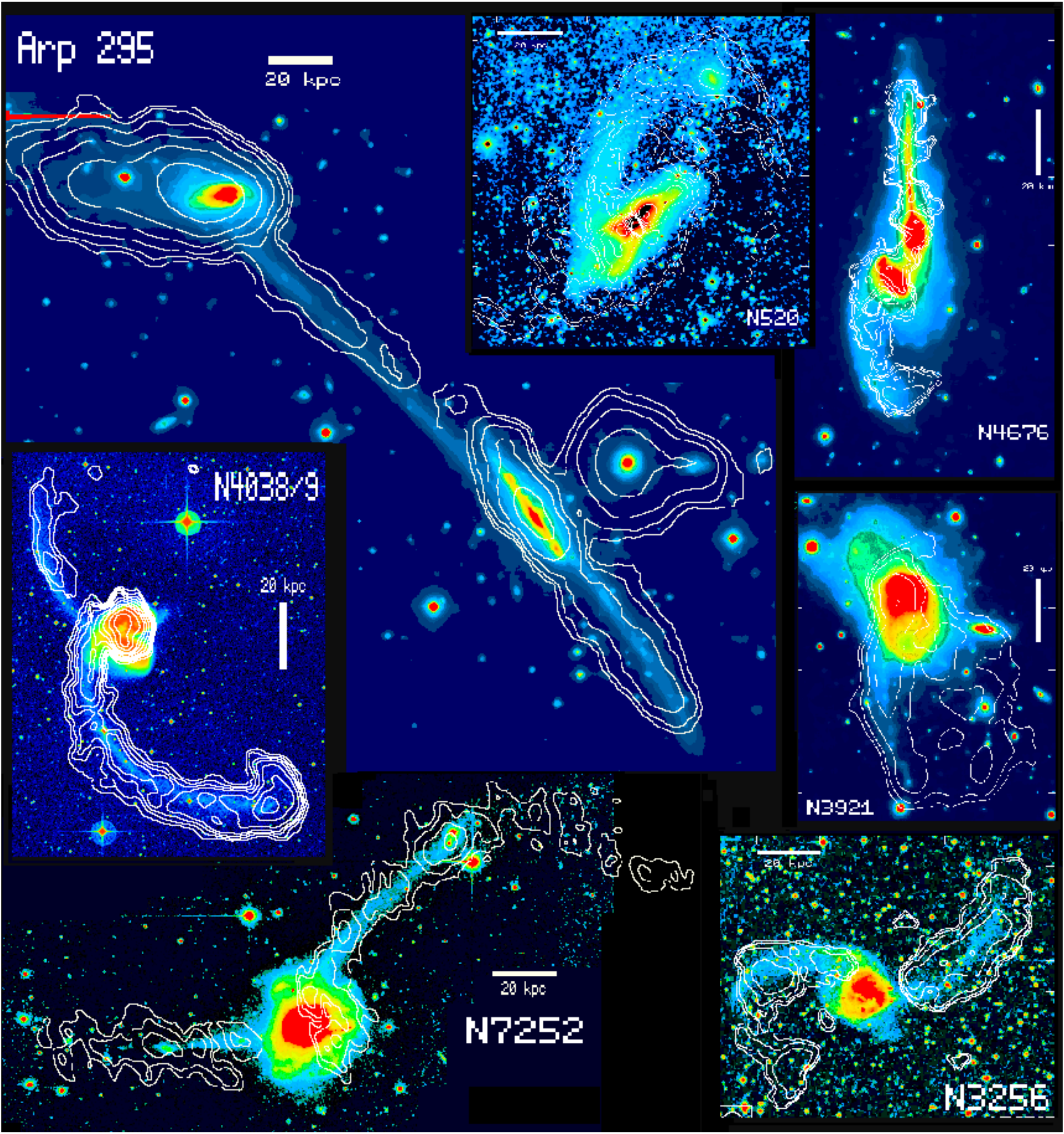


HI Mass Function in the local Universe

Parkes HIPASS survey: Zwaan et al. 2003

Credit: Virgo collaboration (MPIfAp)

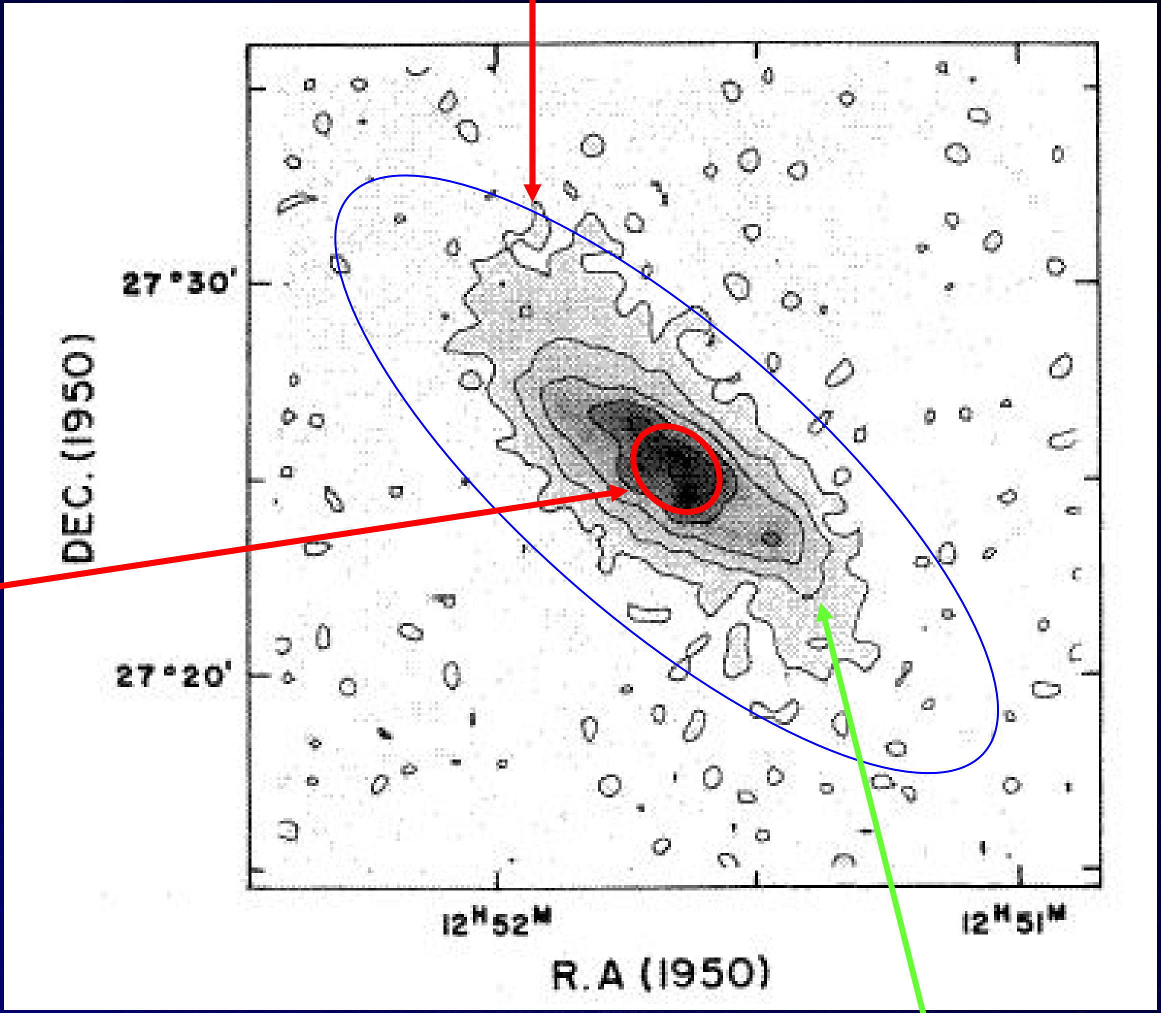




From John Hibbard's Gallery of HI Rogues

DDO 154

Arecibo map outer extent [Hoffman et al. 1993]

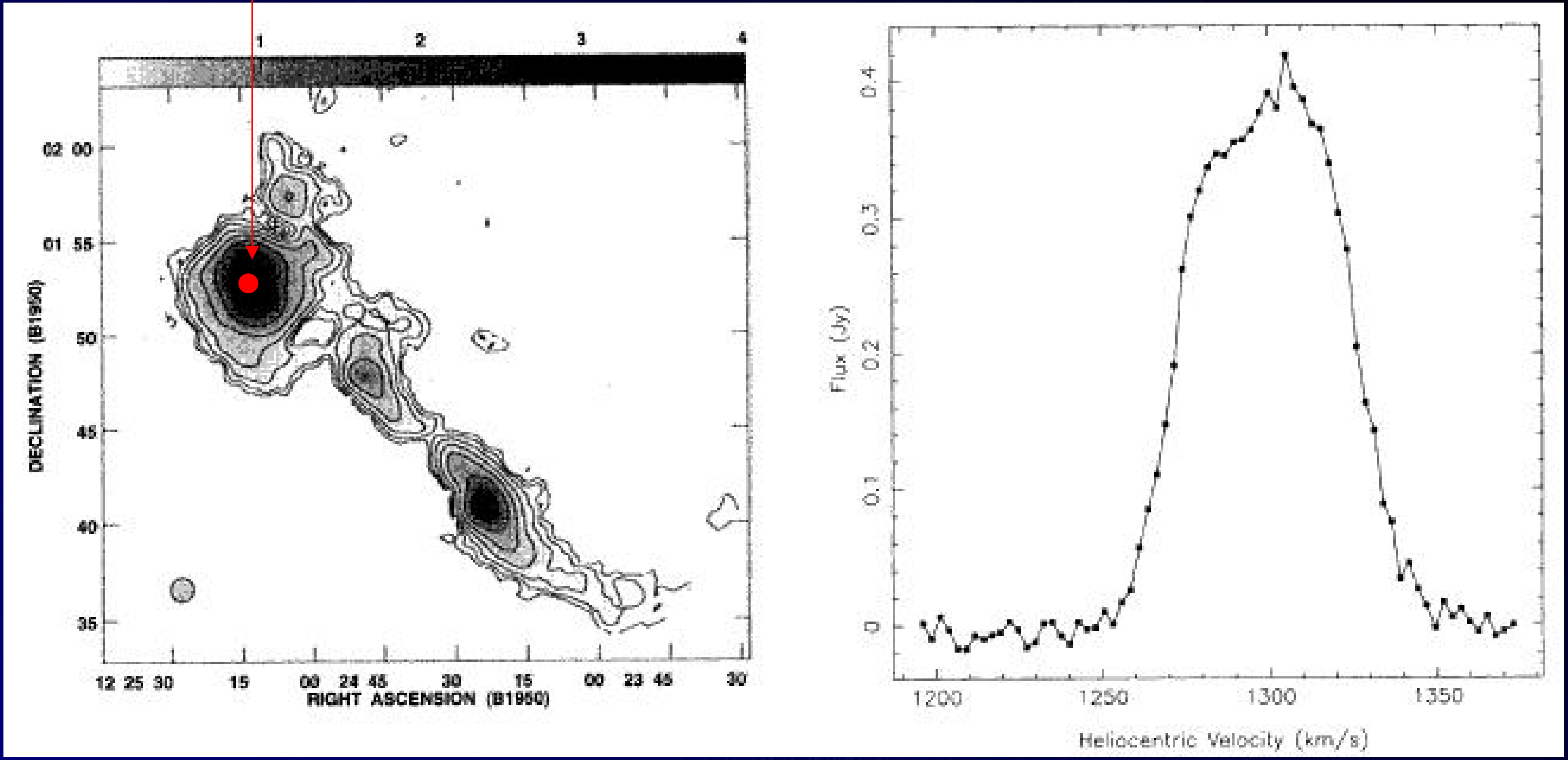


Extent of optical image

Carignan & Beaulieu 1989 : VLA D-array HI column density contours

ALFALFA

HI 1225+01



Optical galaxy

Chengalur, Giovanelli & Haynes 1991 VLA data
[discovered by Giovanelli, Williams & Haynes 1989 at Arecibo]

So, what is ALFALFA?

ALFALFA is a partnership of 43 scientists from 11 countries and 29 different institutions, who plan to carry out

- an extragalactic HI line survey covering 7000 sq deg
- with the ALFA multibeam feed at Arecibo
- 1335-1435 MHz (-2000 to + 17500 km/s) with 5 km/s res
- 2-pass, drift mode (eff. integration time per beam ~ 48 sec)
- 1.6/2.3 mJy rms per beam/pixel @ R=30,000
- 4000 hrs of telescope time, 5-6 years
- started Feb 2005

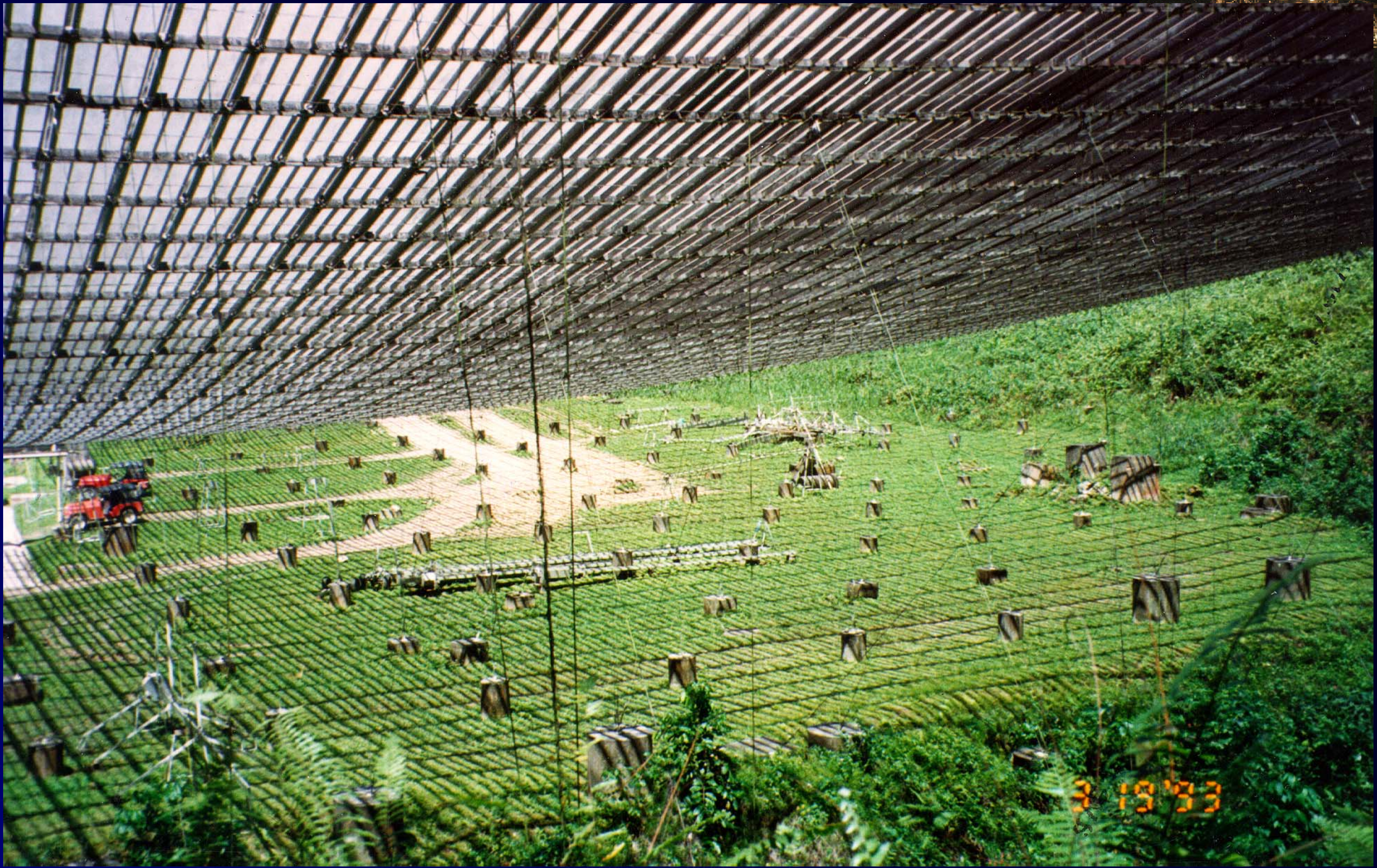
The Radio Telescope of Arecibo

With a diameter of 305 meters, it is
the largest cm wave telescope on Earth,.
Built in 1963 by Cornell University, it underwent
major upgrades in the 1970s and the 1990s.

It is currently operated by Cornell University,
under a cooperative agreement with the U.S.
National Science Foundation.

While the primary reflector (the "dish") is suspended just above ground level over a network of steel cables, the focal structure with all the receiving equipment – which weighs 900 tons - is suspended 150 meters above the ground, and can be steered to point at cosmic sources within 20 degrees of zenith.

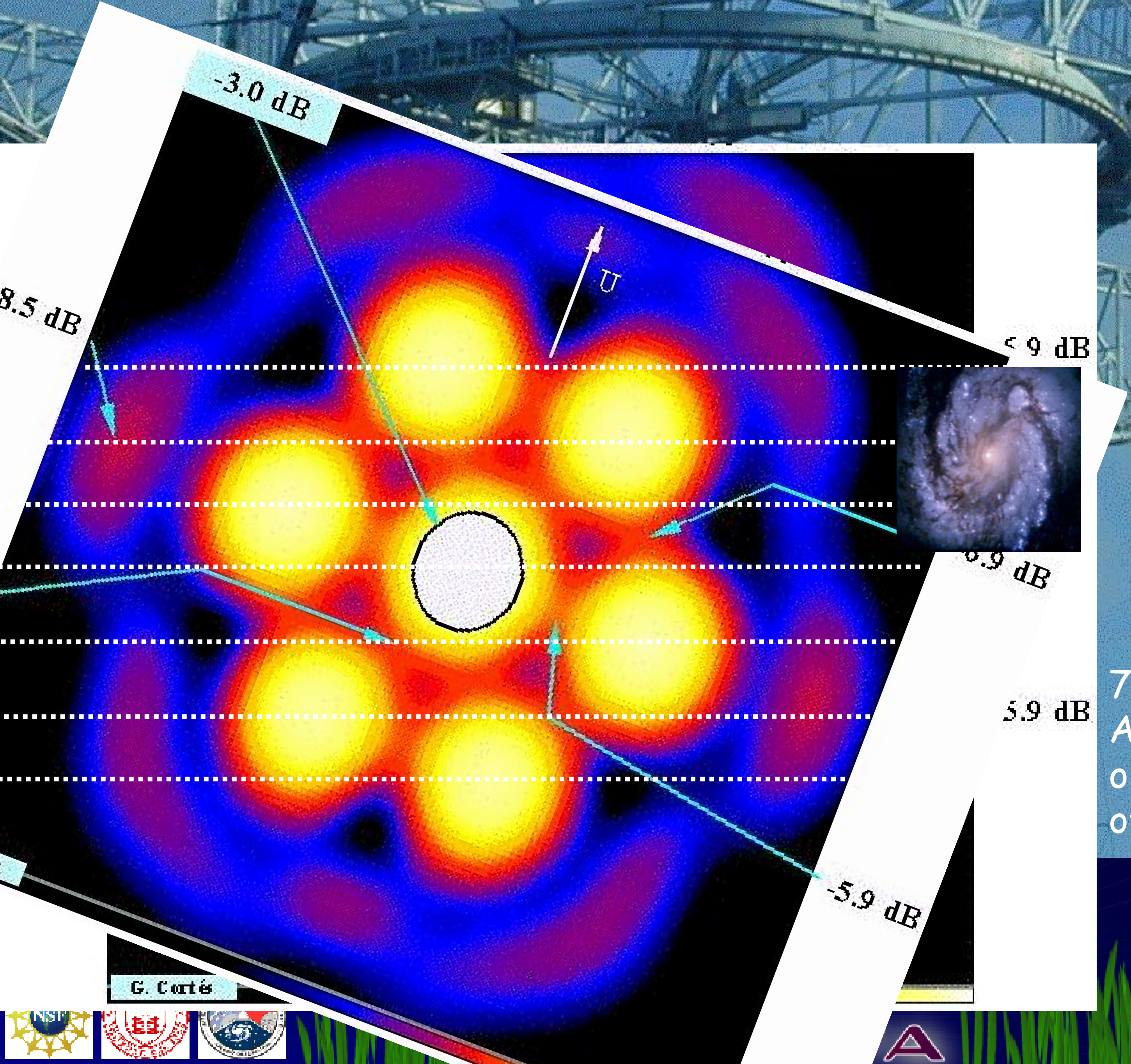
ALFALFA



Under the Arecibo dish, roads snake around among a network of support and tension cables, amidst lush tropical vegetation.

The Arecibo telescope was built at this site in order to take advantage of the vicinity to the Equator and of the topography of the terrain, which provided a nearly spherical valley and minimized excavation.

ALFALFA



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

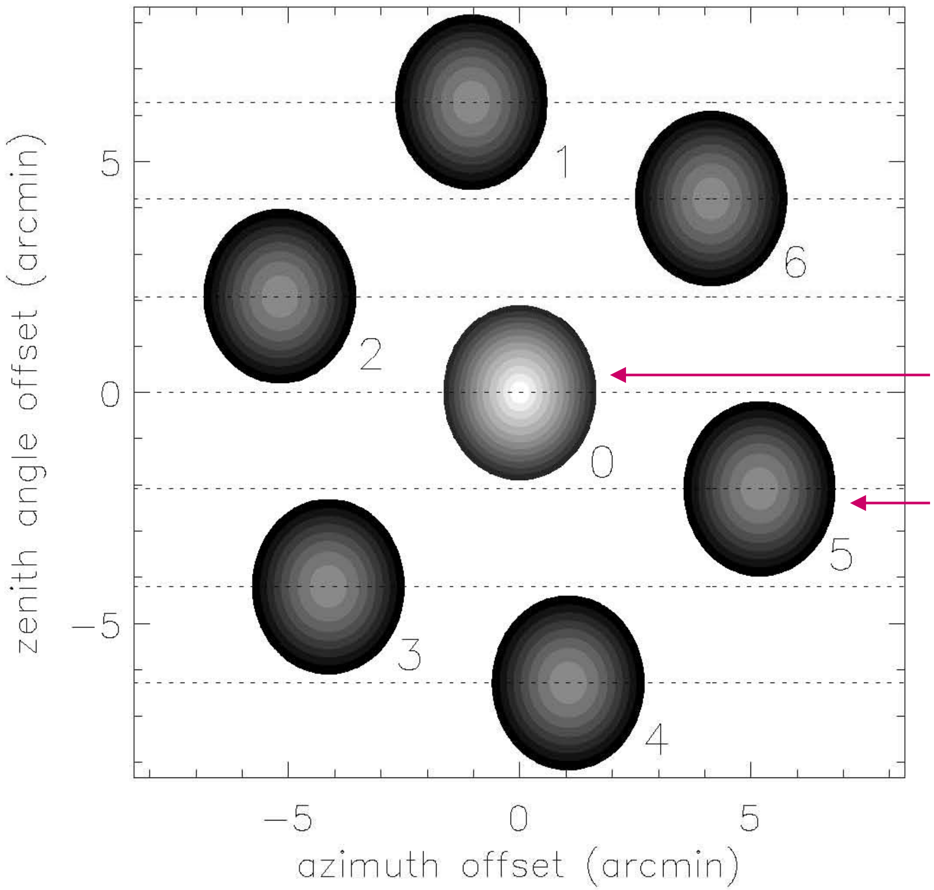


Fig. 2.— Sketch of the geometry of the ALFA footprint, with the array located along the local meridian and rotated by an angle of 19° about its axis. The outer boundary of each beam corresponds to the -3 dB level. The dashed horizontal lines represent the tracks at constant Declination of the seven ALFA beams, as data is acquired in drift mode.

Gain:

11 K/Jy

8.6 K/Jy

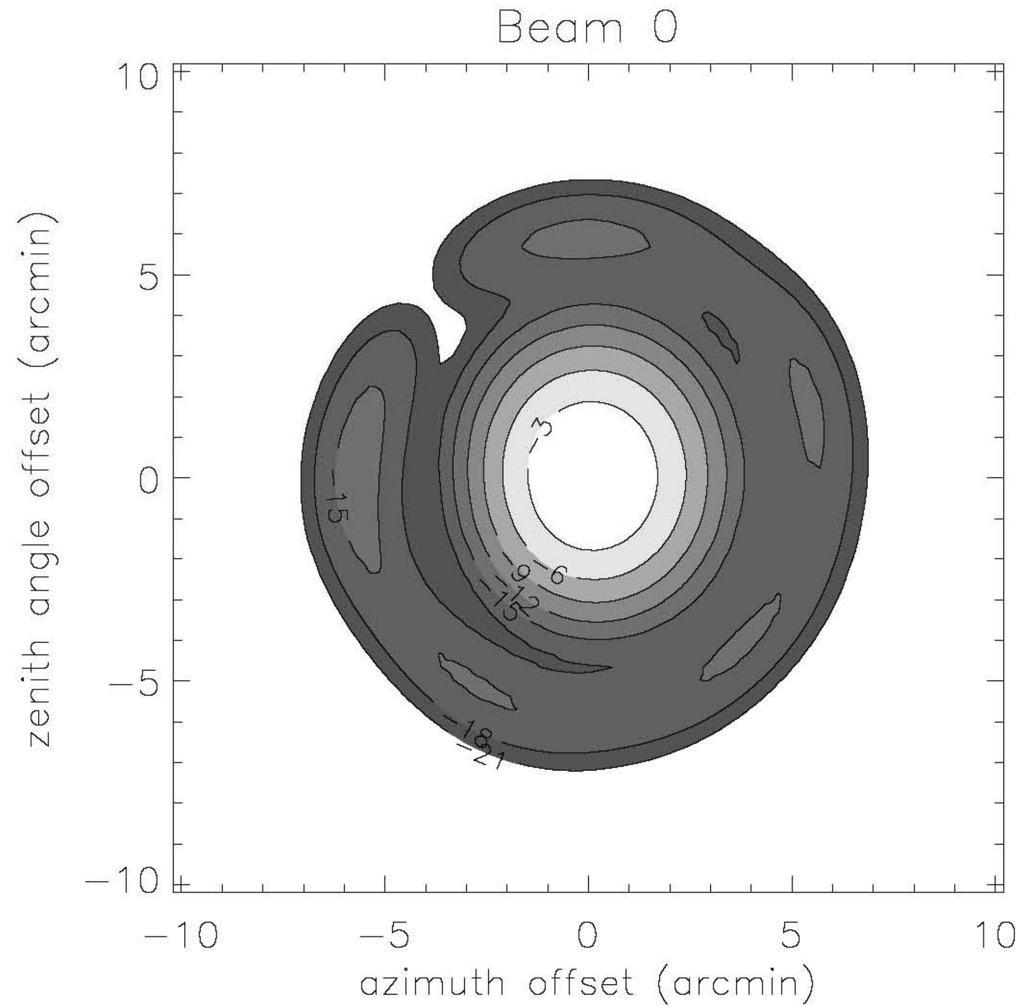
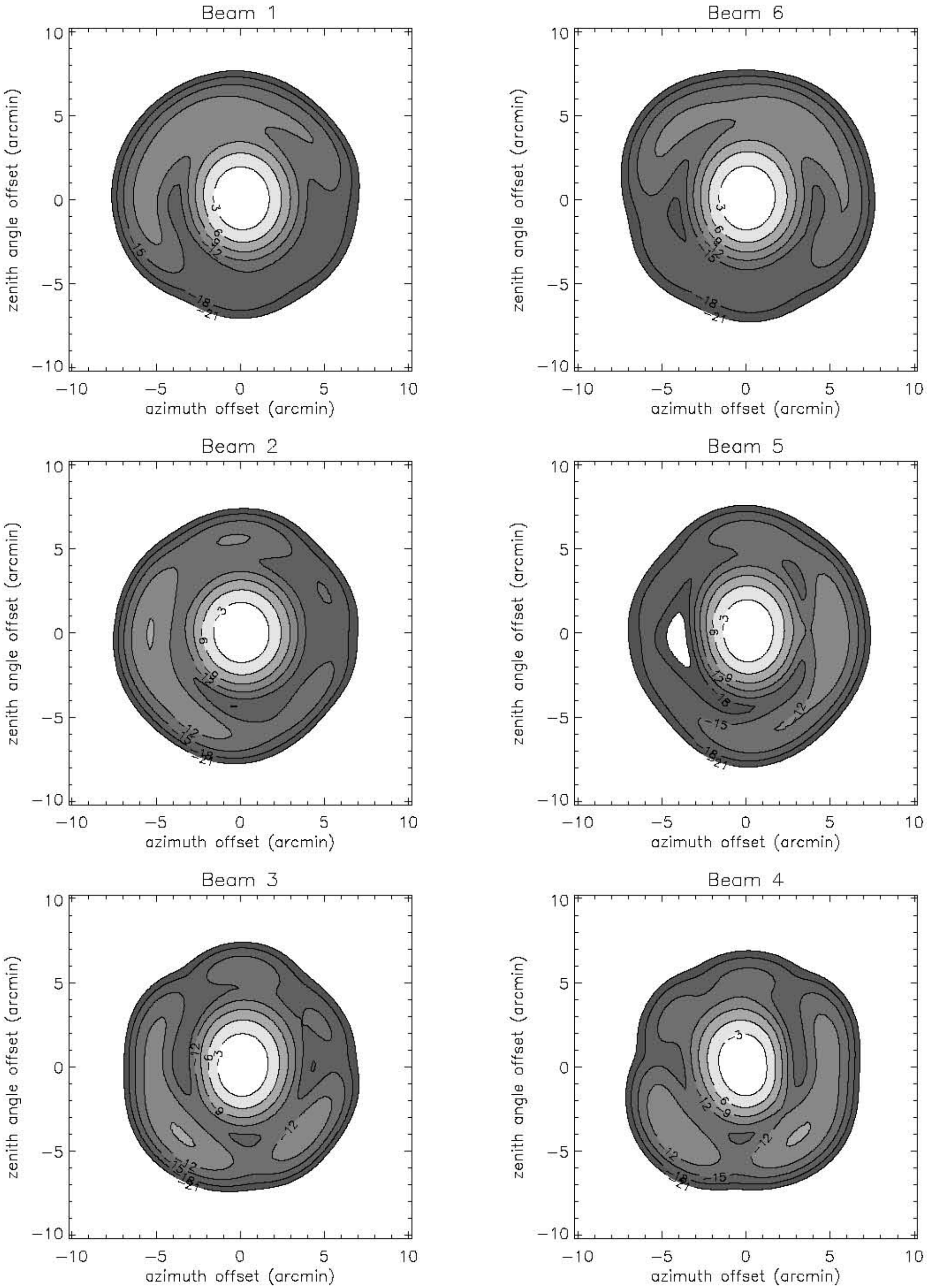


Fig. 3.— Beam pattern of beam 0. Contour lines and shading intervals are plotted at intervals of 3 dB below peak response (the highest contour is at half the peak power). The first sidelobe ring, with a diameter near 12’, is at approximately -15 dB.


Beam 1
Beam 6
Beam 2
Beam 5
Beam 3
Beam 4
zenith angle offset (arcmin)
azimuth offset (arcmin)
10
5
0
−5
−10
−10
−5
0
5
10
−3
−6
−9
−12
−15
−18
−21

Each of the seven ALFA beams has two receivers, each of which detects radiation of two polarization components;

each of the signals of the 14 receivers is separately analyzed, delivering a spectrum of 4096 channels,

once per second.

The data rate is about 1 Gbyte per hour.

How do we choose the main parameters of the survey, e.g.

- how long to integrate per beam position
- how large a section of sky to map
- how many times to revisit a given sky position?

A few useful scaling laws come to aid…

▷ The minimum integration time t_s required for ALFA to detect a source of HI mass M_{HI} and width W_{kms} at the distance D_{Mpc} is

$$t_s = \frac{1}{4}\underset{\uparrow}{f_\beta^{-2}}\left(\frac{M_{HI}}{10^6 M_\odot}\right)^{-2}(D_{Mpc})^4\left(\frac{W_{kms}}{100}\right)^{-2\gamma}$$

Beam dilution

where

$$\gamma = \begin{cases} -3/4 & \text{if } W_{kms} \leq 100 \\ -1 & \text{if } W_{kms} > 100 \end{cases}$$

i.e. $\boxed{\textbf{the depth of a survey increases only as } t_s^{1/4}}$

▷ Alternatively, the minimum detectable HI mass at distance D_{Mpc} is

$$\left(\frac{M_{HI}}{10^6 M_\odot}\right)_{min} \simeq 0.5 f_\beta^{-1} t_s^{-1/2} (D_{Mpc})^2 \left(\frac{W_{kms}}{100}\right)^{-\gamma}$$

[by comparison, HIPASS detects 1 million solar masses at 1 Mpc in 460 sec…]

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Is it better to cover a large solid angle of sky, with a short integration per beam area

or

To cover a small area of sky, increasing the sensitivity per beam area by using long integration times?

It depends. Once the integration time is sufficient to detect a given HI mass at a distance of astrophysical interest …

▷ For a given HI mass, the volume sampled by a survey

$$V_{survey}(M_{HI}) = \Omega\, D_{max}^3/3$$

can be increased by either (a) surveying a larger solid angle Ω or (b) integrating longer and increasing D_{max}.

- Since the time required to complete the survey is $t_{survey} \propto (\Omega/\Omega_b)\, t^s$,
- and $D_{max} \propto t_s^{1/4}$,
- then $V_{survey}(M_{HI}) \propto \Omega[D_{max}]^3 \propto \Omega\, t_s^{3/4} \propto t_{survey}\, t_s^{-1/4}$
- Inverting: $t_{survey} \propto V_{survey}\, t_s^{1/4}$

Hence, once t_s is large enough to make M_{HI} detectable,

it is more advantageous to maximize Ω than to increase the survey depth.

One pass maximizes volume sampled at any HI mass limit.

… however

Two-pass strategy increases signal detection reliability, allows for continuum variability and transient detection, identification of transient rfi, avoidance of having blank coverage in case of single amplifier failure

… at the expense of sacrificing ~17% of volume sampled.

Comparison of blind HI surveys

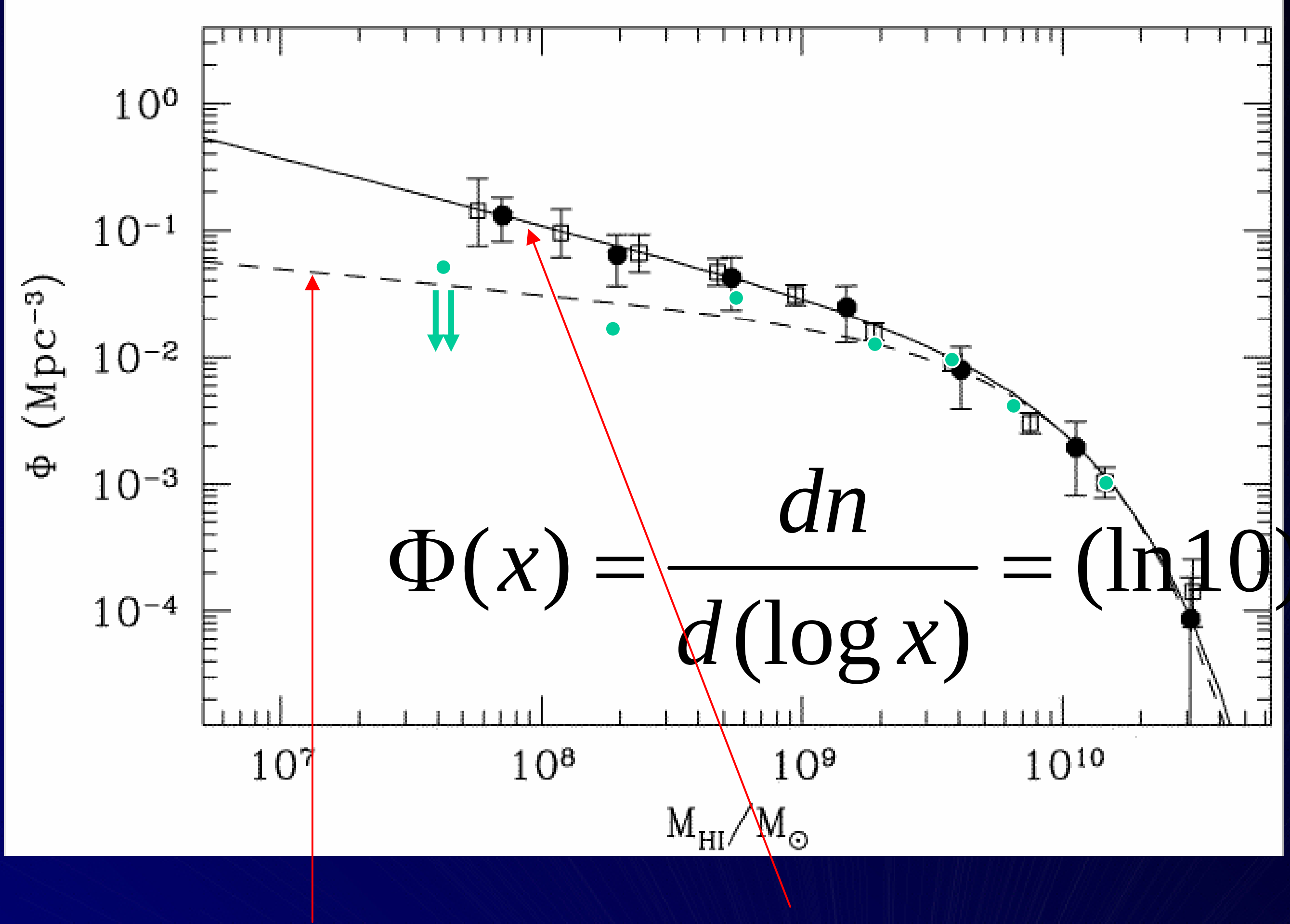
Survey	Beam arcmin	Area sq. deg.	rms (mJy @ 18 km/s)	min M_{HI} @ 10 Mpc	N_{det}	t_s sec	N_{los}
AHISS	3.3	13	0.7	2.0×10^6	65	var	17,000
ADBS	3.3	430	3.3	9.6×10^6	265	12	500,000
HIPASS	15.	30,000	13	3.6×10^7	4315	460	1.9×10^6
HIJASS	12.	(TBD)	13	3.6×10^7	(?)	3500	(TBD)
J-Virgo	12	32	4	1.1×10^7	31	3500	3200
HIDEEP	15	32	3.2	8.8×10^6	129	9000	2000
ALFALFA	3.5	7,000	1.7	4.4×10^6	16,000?	30	7×10^6

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

ALFALFA

Survey simulations…

HIMF



$$\Phi(x) = \frac{dn}{d(\log x)} = (\ln 10)\Phi^* x^{\alpha+1} e^{-x}$$

where

$$x = M_{HI} / M^*$$

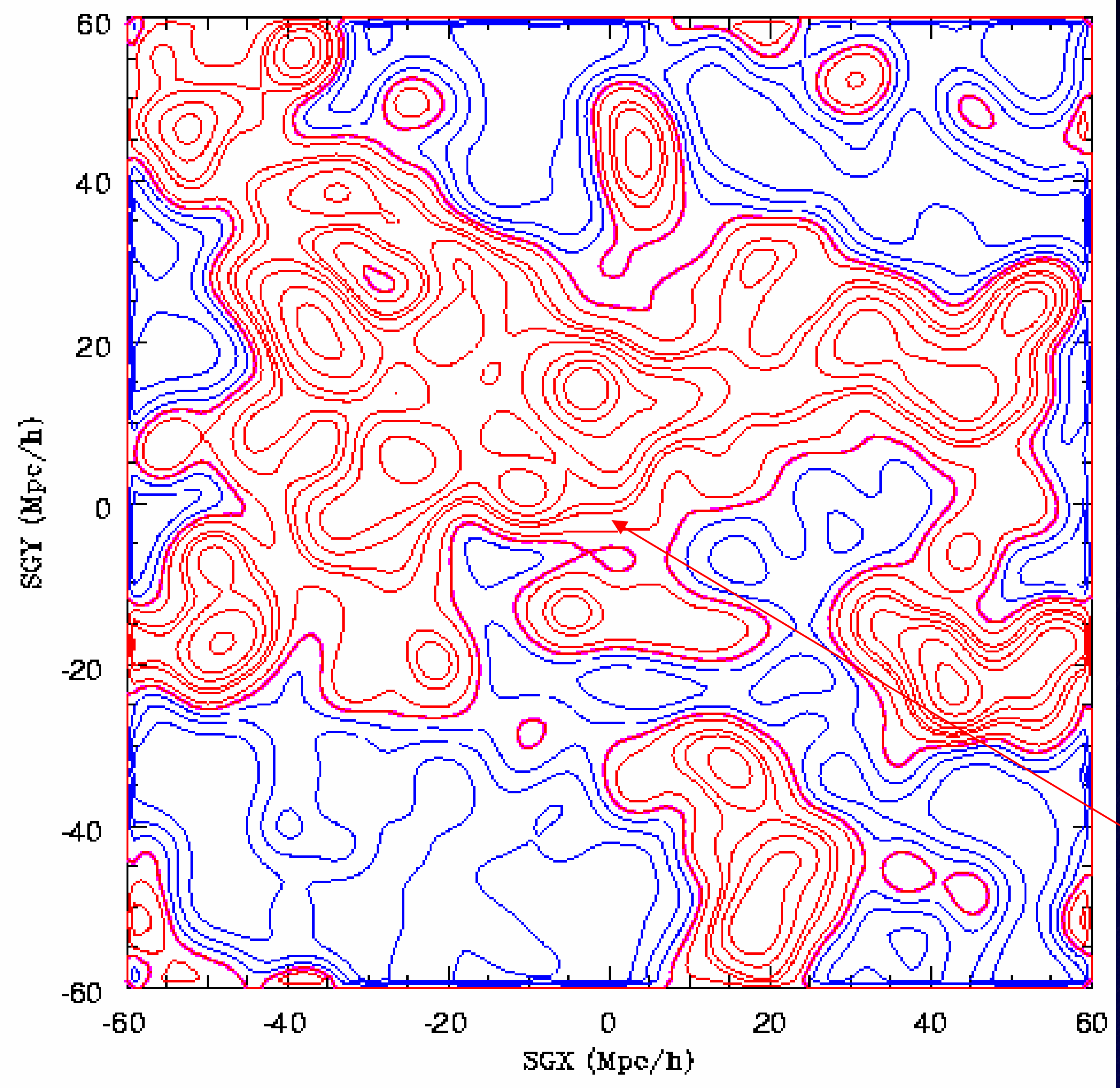
Zwaan et al. 97:

$$\Phi^* = 0.0048 h_{70}^3$$
$$\log M^* / M_{sun} = 9.86 - 2 \times \log h_{70}$$
$$\alpha = -1.20$$

Rosenberg & Schneider 02:

$$\Phi^* = 0.0041 h_{70}^3$$
$$\log M^* / M_{sun} = 9.94 - 2 \times \log h_{70}$$
$$\alpha = -1.53$$

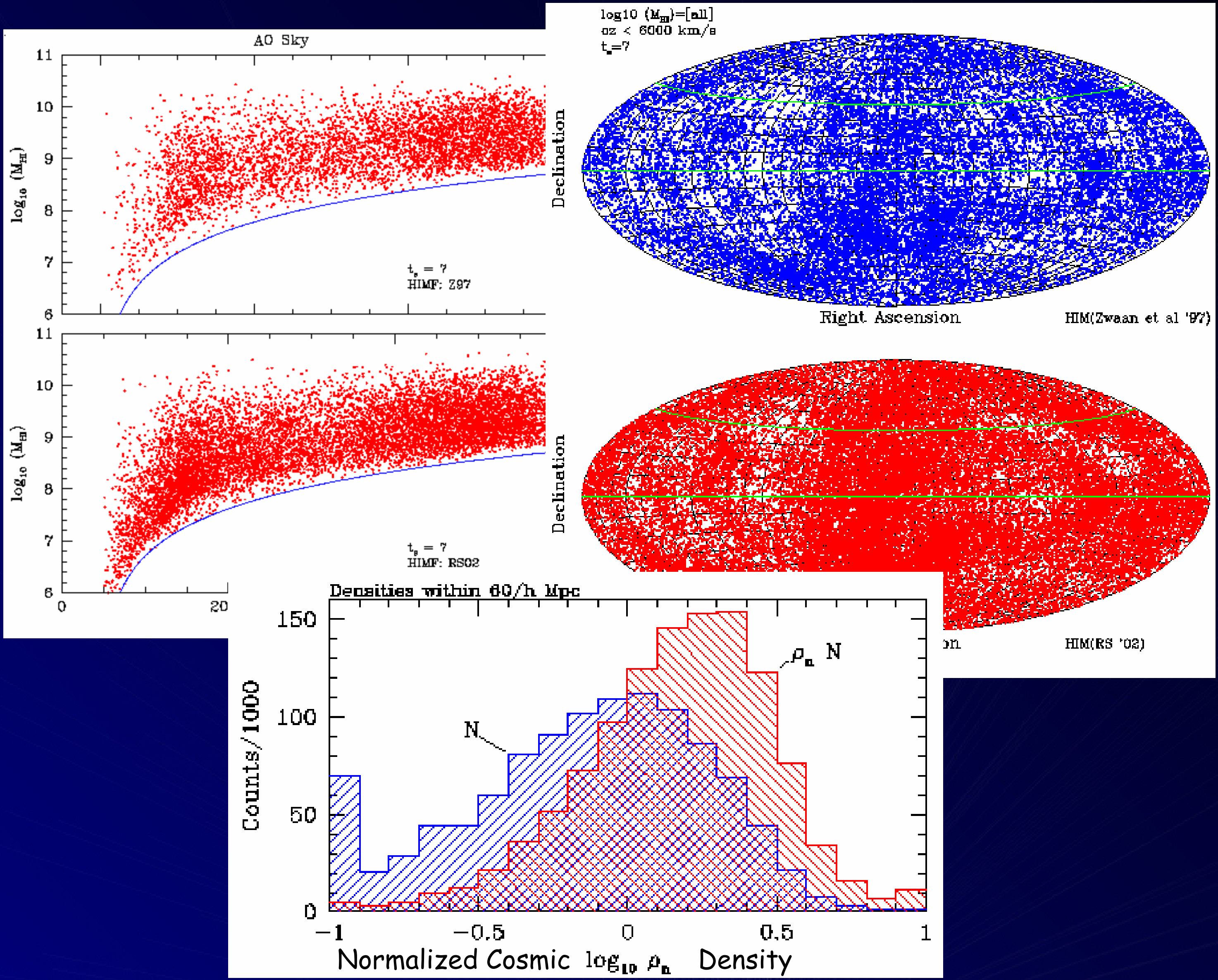
[$\mathrm{Mpc}^{-3}\ \mathrm{dex}^{-1}$]



Slice of the cosmic Density field along The Supergalactic Plane

You are here

ALFALFA


AO Sky
11
10
9
8
7
6
$\log_{10}(M_{HI})$
$t_s = 7$
HIMF: Z97
$t_s = 7$
HIMF: RS02
0
20
$\log10\ (M_{HI})$=[all]
cz < 6000 km/s
t_s=7
Declination
Right Ascension
HIM(Zwaan et al '97)
HIM(RS '02)
Densities within 60/h Mpc
150
100
50
0
Counts/1000
N
ρ_n N
−1
−0.5
0
0.5
1
Normalized Cosmic $\log_{10}\rho_n$ Density

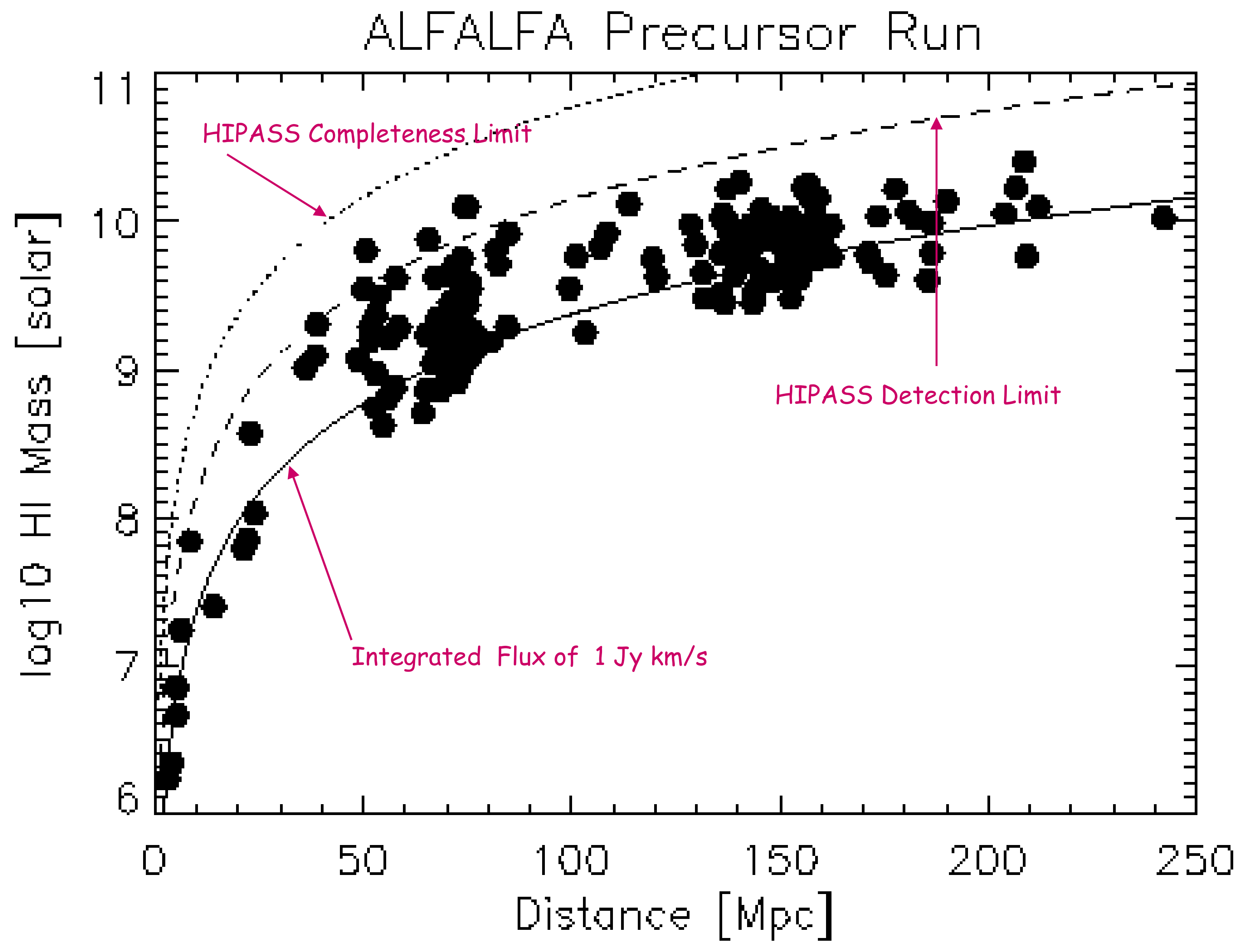
ALFALFA

ALFALFA Precursor Run: A1946

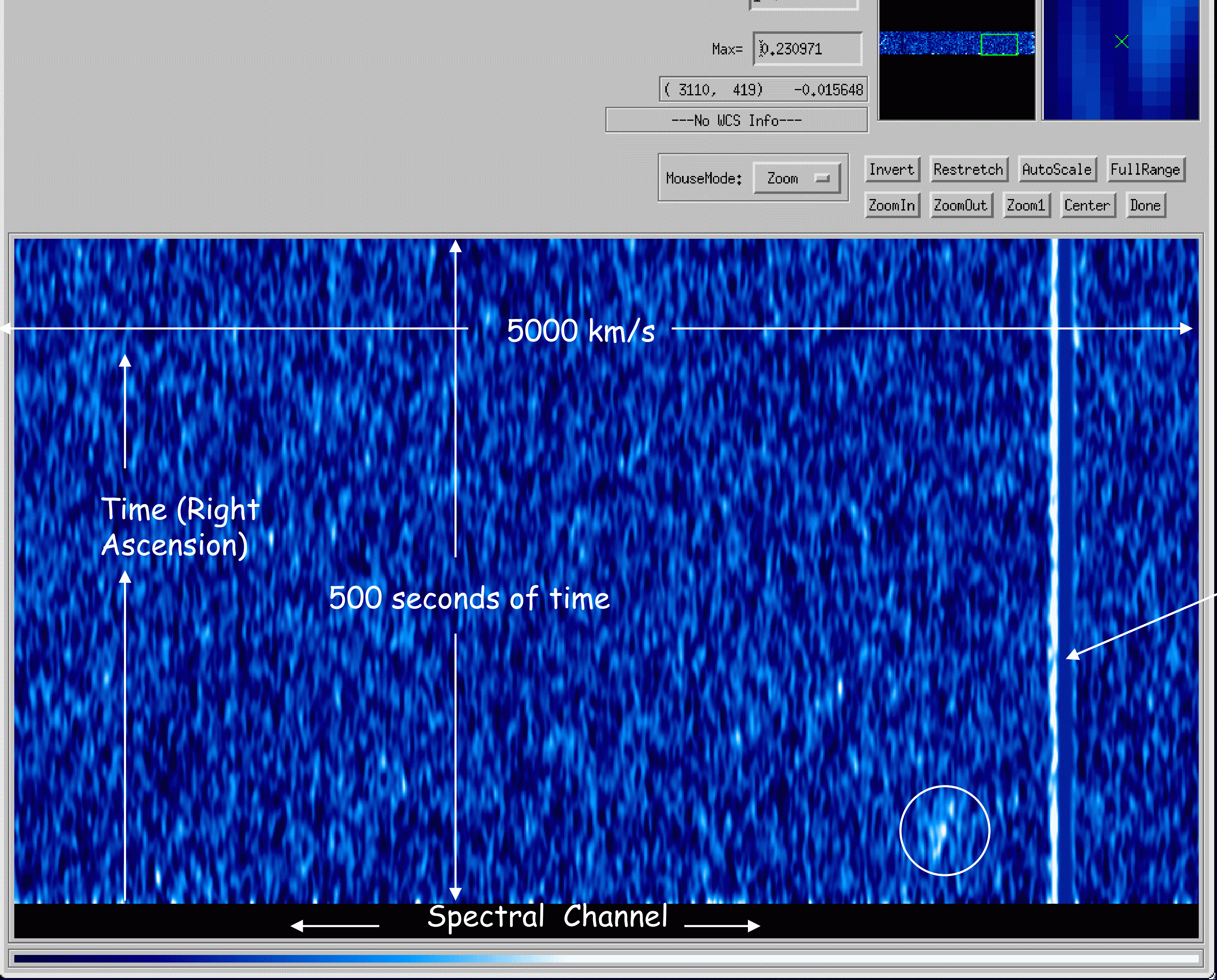
- * Aug-Sep 2004
- * Candidate Detections Confirmation Run Jan-Feb 2005
- * 36 hours of ALFA data

166 confirmed HI sources :
- 25 with HI mass > 10^{10} Msun
- 4 with HI mass < 10^{7} Msun (twice as many as all of HIPASS)
- high positional accuracy:
  we can centroid with a median accuracy of 34"
  virtually all optical counterparts ID'd; median difference position between HI centroid and optical source 33"
- slightly better detection rate than expected (high side),
  i.e. our ability to reliably dig in low S/N territory is high
- system hardware performance, "hands-off" bandpass
  calibration and baselining (IDL processing pipeline) gave excellent results.

ALFALFA


ALFALFA Precursor Run
log10 HI Mass [solar]
Distance [Mpc]
6
7
8
9
10
11
0
50
100
150
200
250
HIPASS Completeness Limit
HIPASS Detection Limit
Integrated Flux of 1 Jy km/s

ALFALFA



Max= 0.230971

(3110, 419) -0.015648

---No WCS Info---

MouseMode: Zoom

5000 km/s

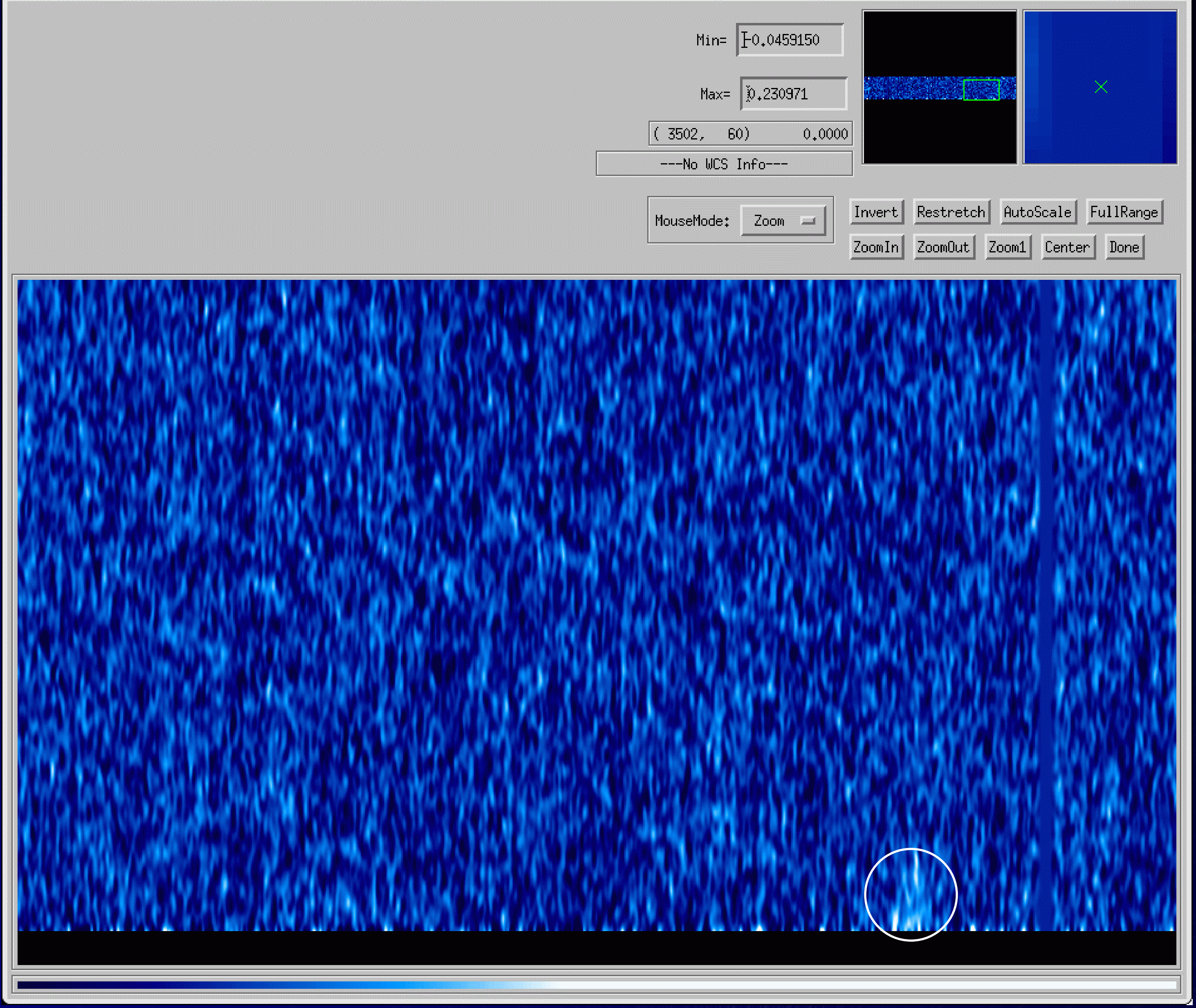
Time (Right Ascension)

500 seconds of time

Spectral Channel

Galactic HI (clipped)

ALFALFA



Min= -0.0459150

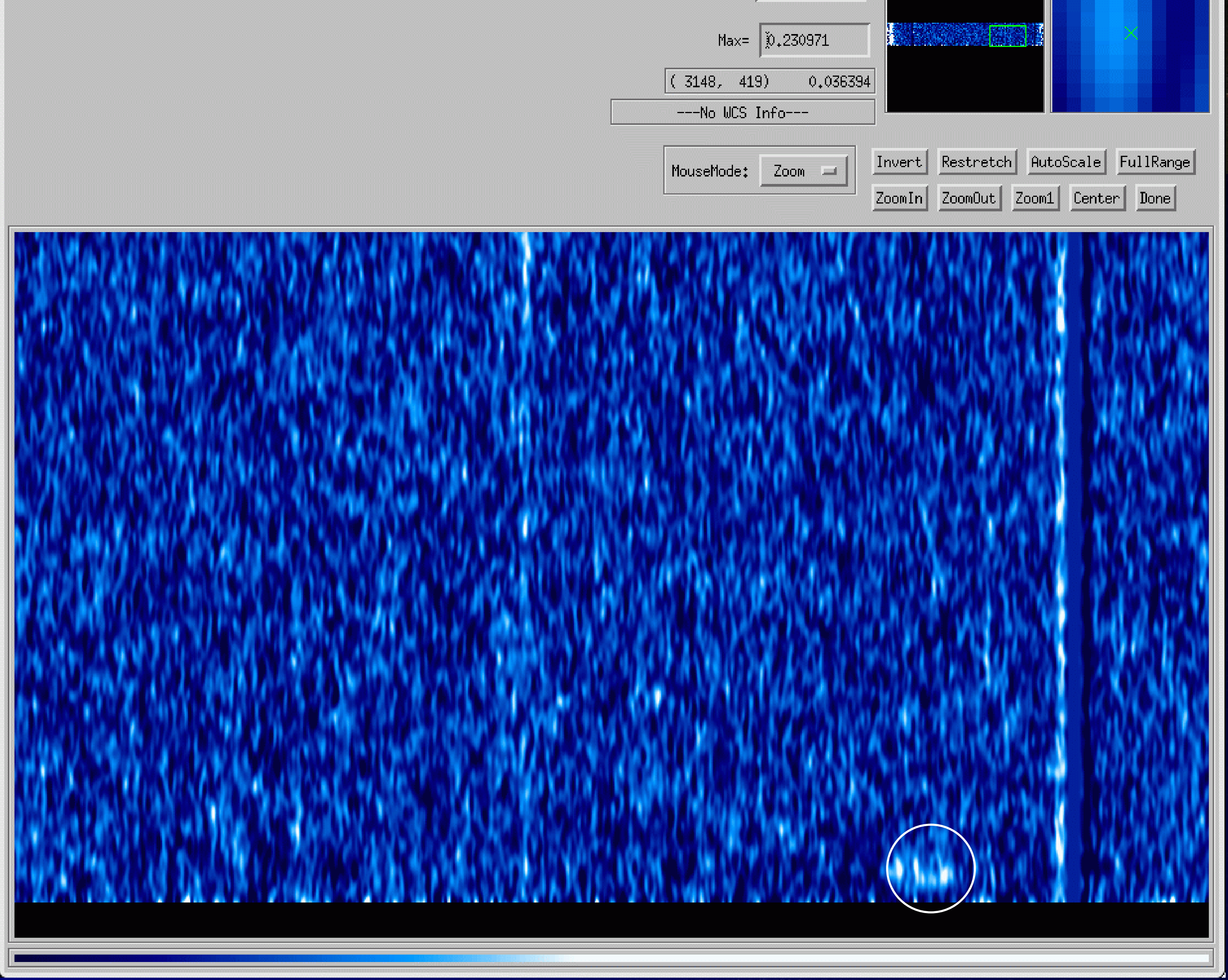
Max= 0.230971

(3502, 60) 0.0000

---No WCS Info---

MouseMode: Zoom

ALFALFA



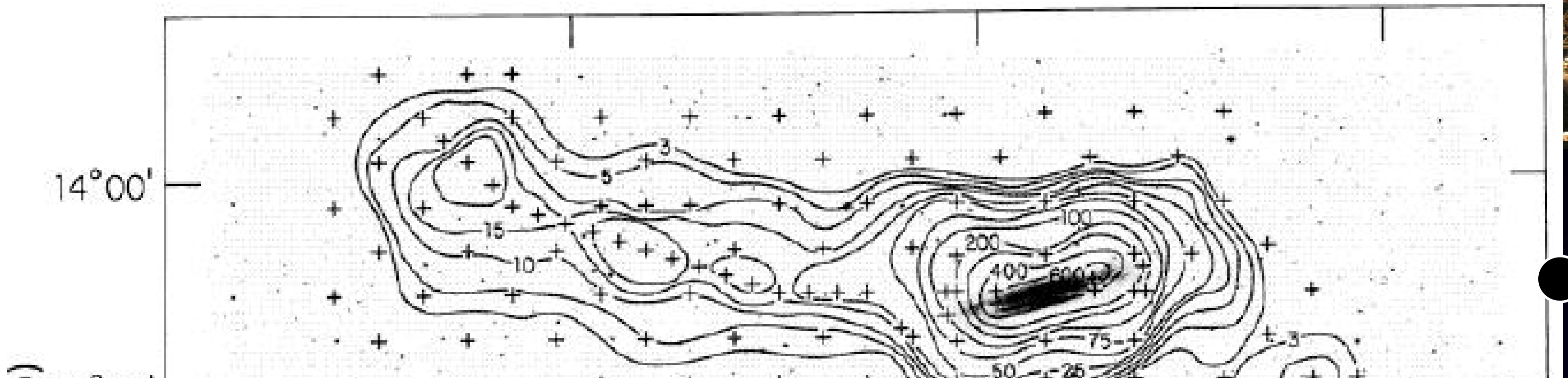
Max= 0.230971

(3148, 419) 0.036394

---No WCS Info---

MouseMode: Zoom

ALFALFA



← Right Ascension

cz ↓