neutral hydrogen observations

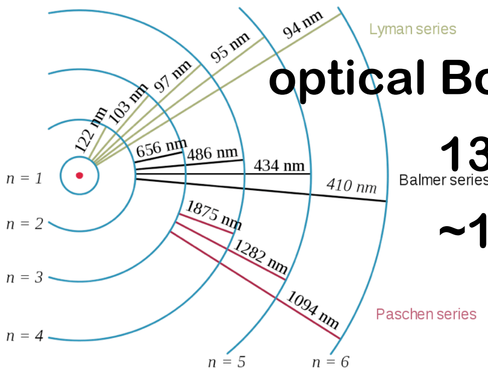
biased overview of HI measurements

basics to proceed with an idea to a proposal

Hans-Rainer Klöckner

Max-Planck-Institut
für Radioastronomie

Hydrogen (lightest element, ~76% baryons of the Universe)

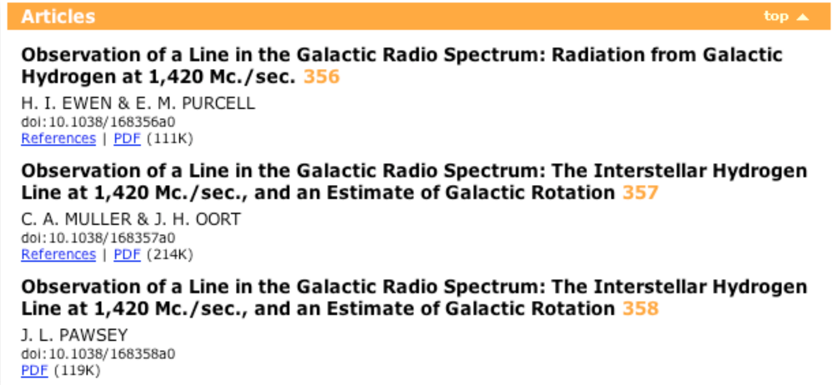


optical Bohr model

13.6 eV

~10⁵ K

Nature 1951



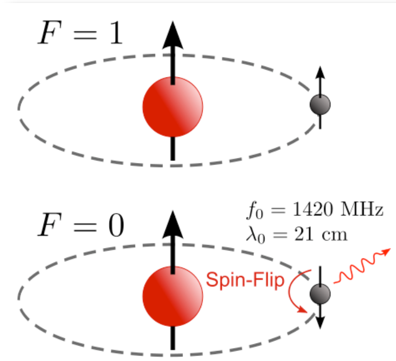
Articles top

Observation of a Line in the Galactic Radio Spectrum: Radiation from Galactic Hydrogen at 1,420 Mc./sec. 356
H. I. EWEN & E. M. PURCELL
doi:10.1038/168356a0
References | PDF (111K)

Observation of a Line in the Galactic Radio Spectrum: The Interstellar Hydrogen Line at 1,420 Mc./sec., and an Estimate of Galactic Rotation 357
C. A. MULLER & J. H. OORT
doi:10.1038/168357a0
References | PDF (214K)

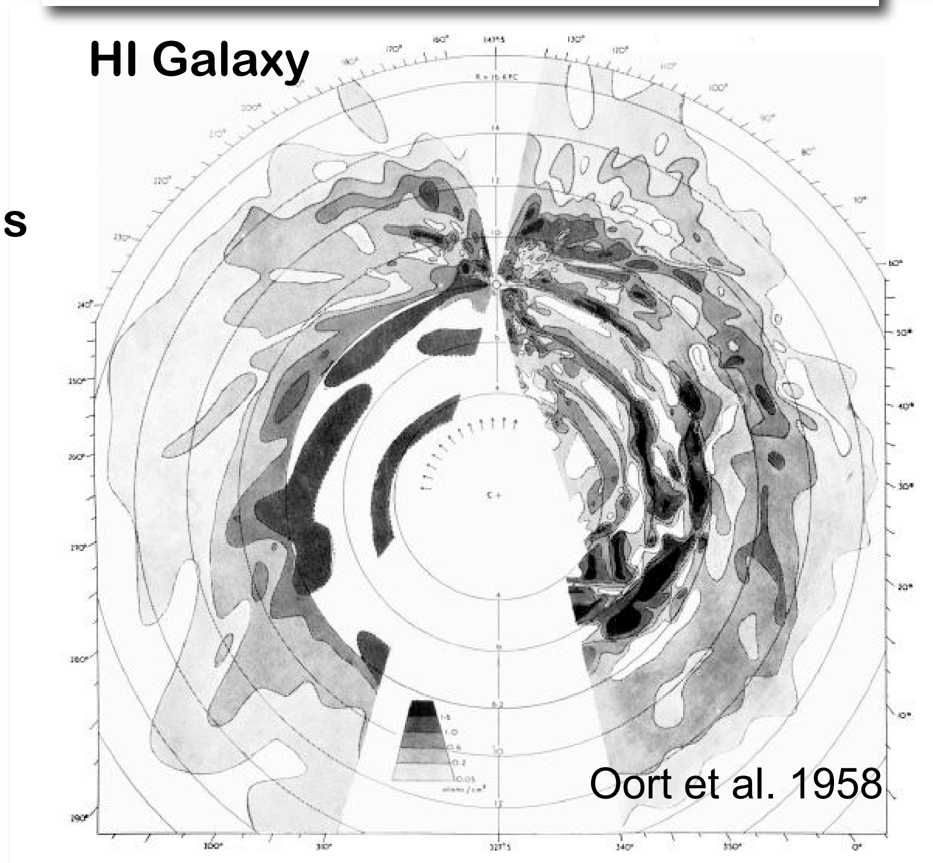
Observation of a Line in the Galactic Radio Spectrum: The Interstellar Hydrogen Line at 1,420 Mc./sec., and an Estimate of Galactic Rotation 358
J. L. PAWSEY
doi:10.1038/168358a0
PDF (119K)

van de Hulst 1944 predicted detection of the hyperfine levels of the ground state

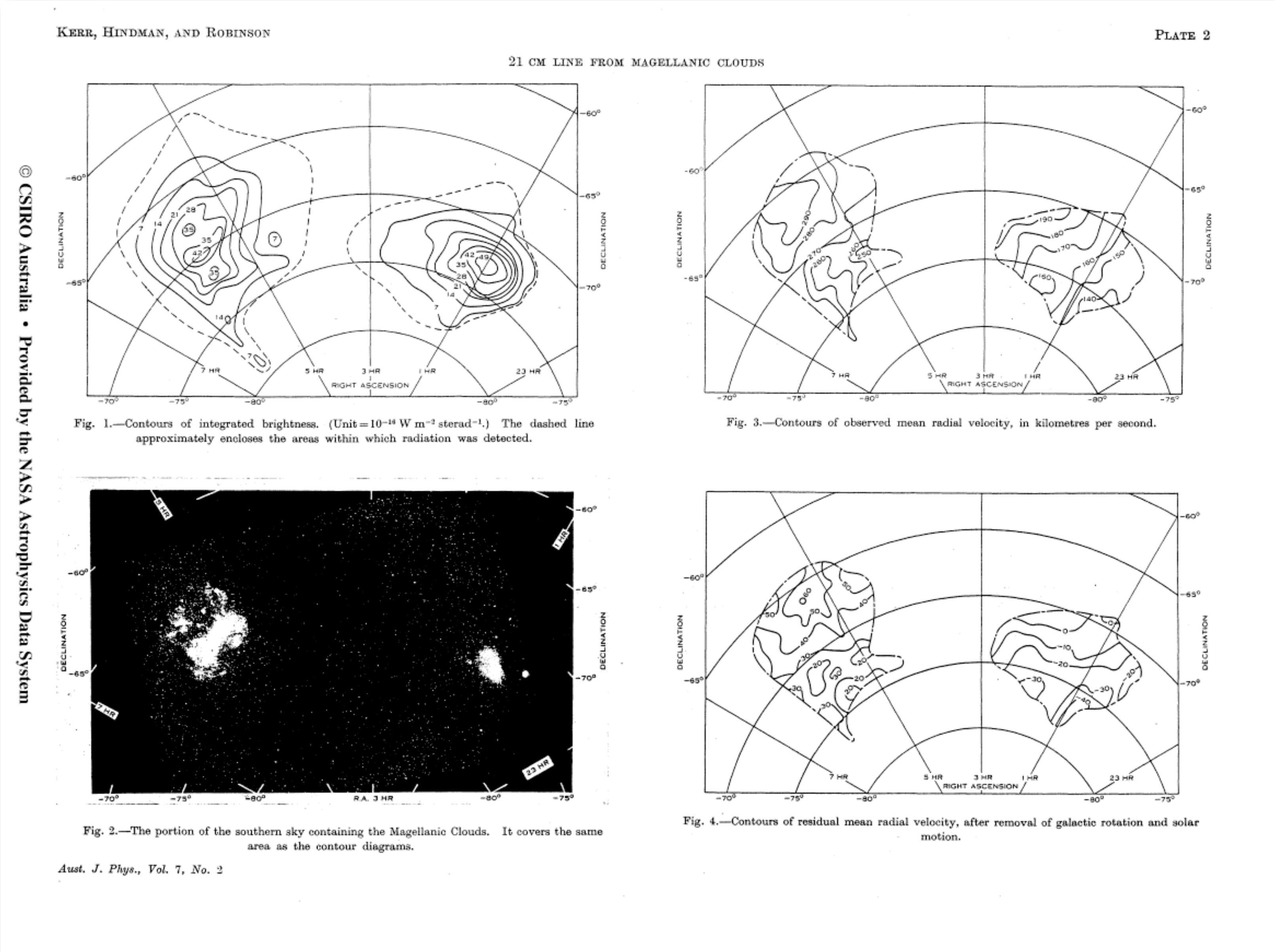


21 cm / 1420.40575177 MHz

HI Galaxy



first extragalactic HI observations (Keer et al. 1953)



KERR, HINDMAN, AND ROBINSON

PLATE 2

21 CM LINE FROM MAGELLANIC CLOUDS

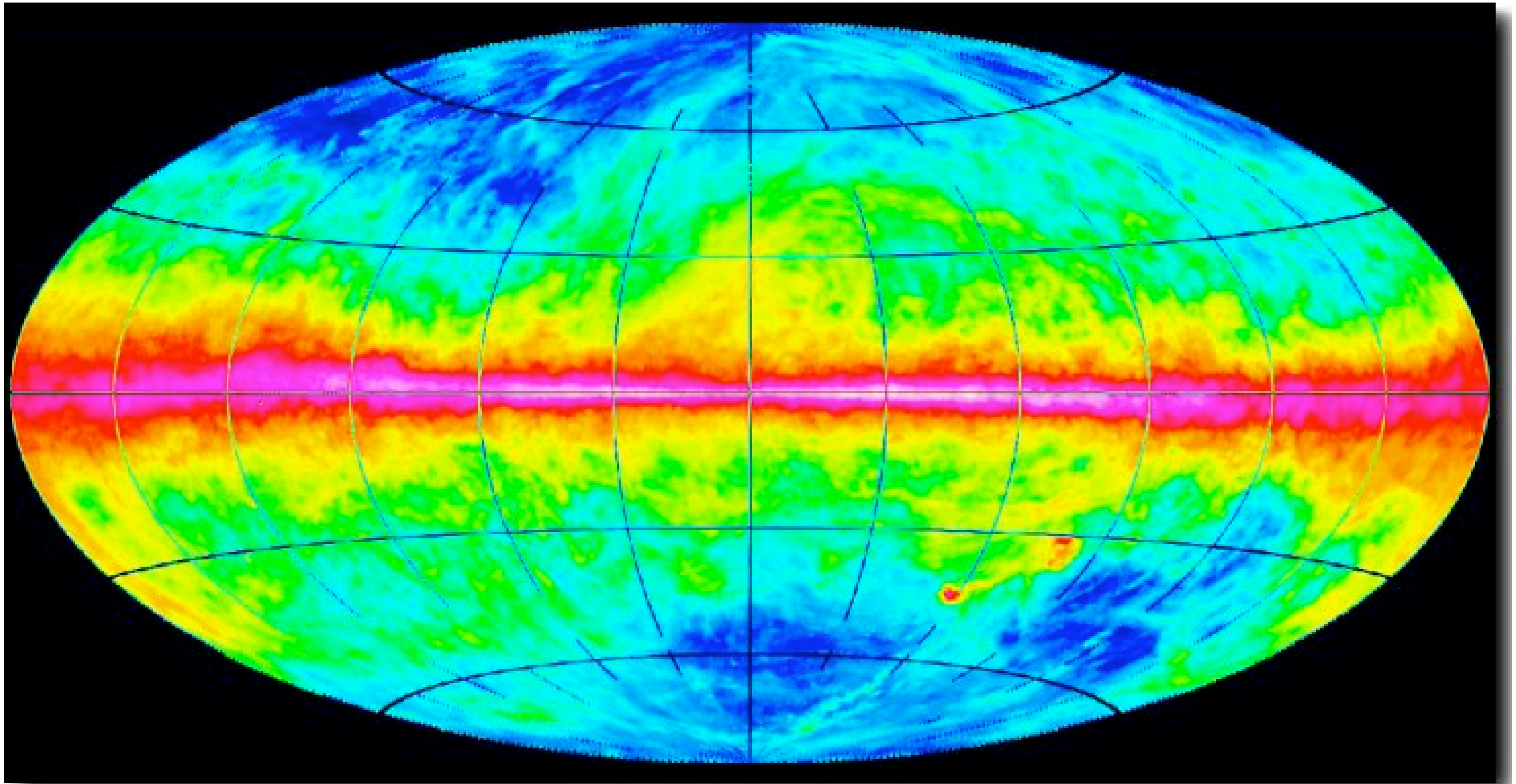
Fig. 1.—Contours of integrated brightness. (Unit = 10^{-16} W m^{-2} sterad^{-1}.) The dashed line approximately encloses the areas within which radiation was detected.

Fig. 2.—The portion of the southern sky containing the Magellanic Clouds. It covers the same area as the contour diagrams.

Fig. 3.—Contours of observed mean radial velocity, in kilometres per second.

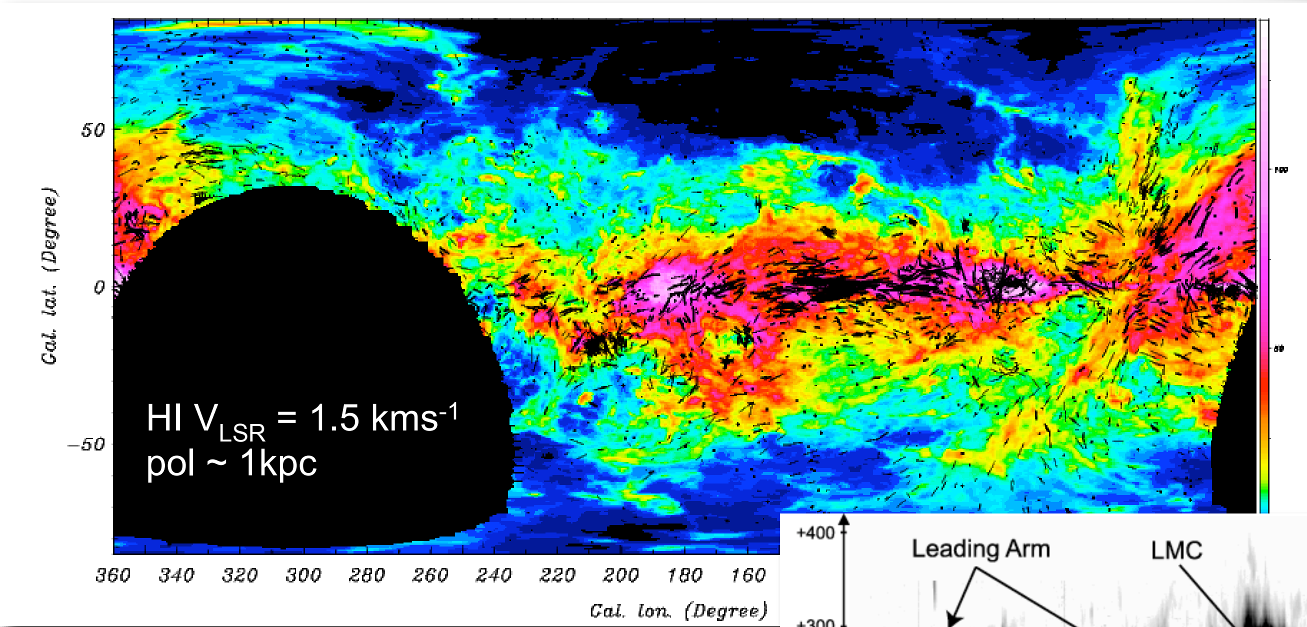
Fig. 4.—Contours of residual mean radial velocity, after removal of galactic rotation and solar motion.

Leiden - Argentina - Bonn (Kalberla et al.)



http://www.astro.uni-bonn.de/~webaiub/english/tools_labsurvey.php

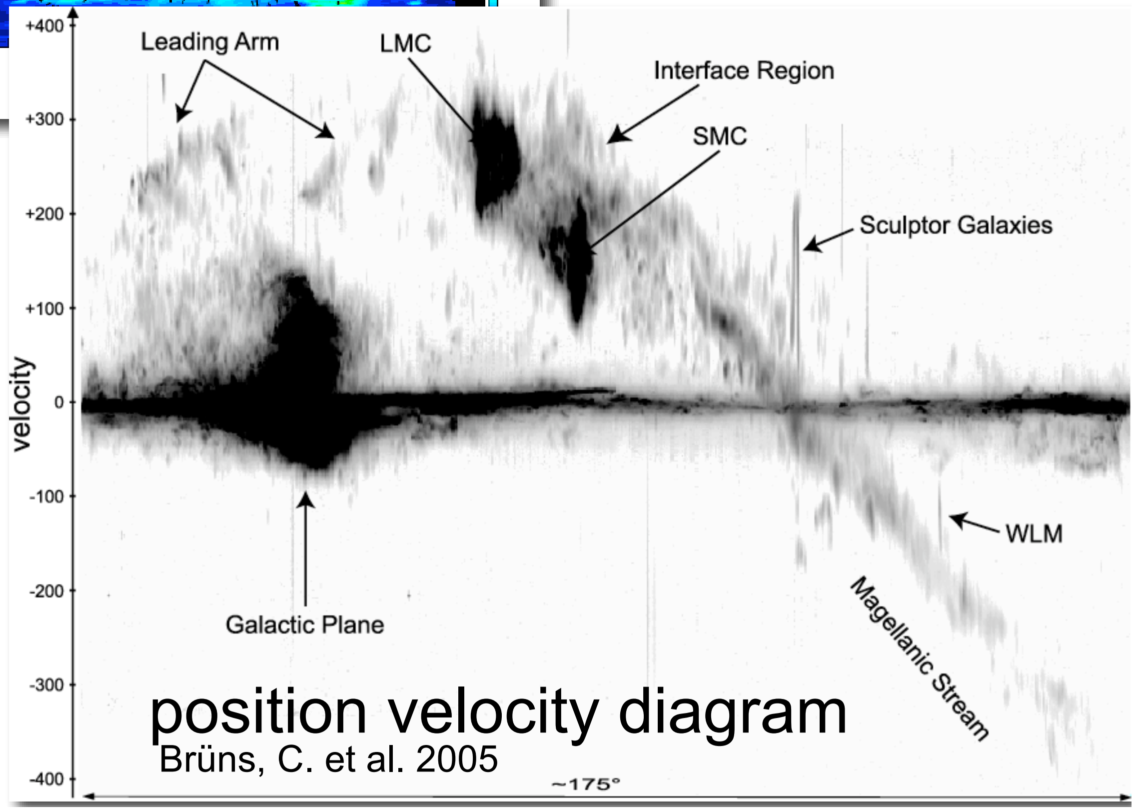
Effelsberg-Bonn-HI- Survey (EBHIS) under construction



Filaments

Loops

Klöckner et al.1998



Galactic rotation

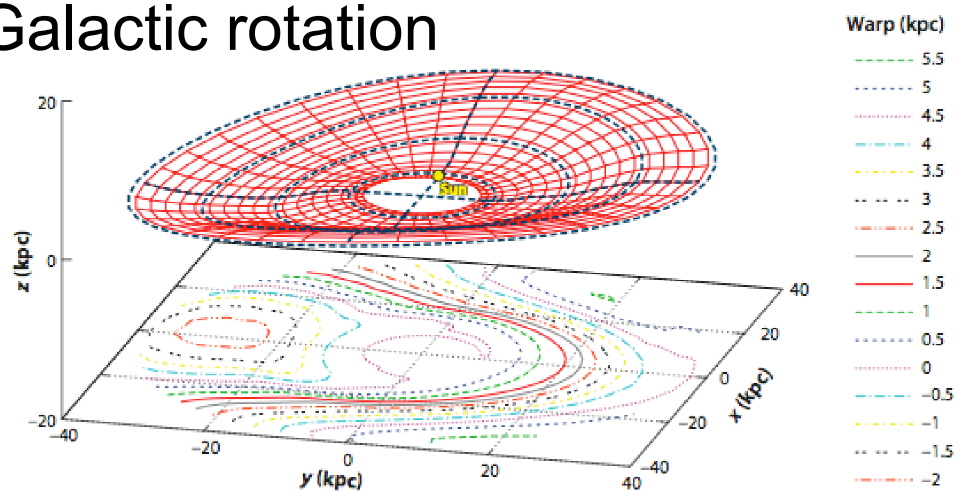


Figure 3

The warped Galactic plane; average midplane positions as derived from the Leiden-Argentine-Bonn 21-cm line survey by fitting three basic modes. Isophotes are from $z_0 = -2$ to 5.5 kpc in steps of 0.5 kpc. The $z = 0$ plane is inclined by 60° and viewed from $\phi = 15°$. The location of the Sun is indicated by the yellow dot. The blue dashed lines mark quadrants in azimuth and distances R = 10, 20, 30, and 40 kpc, respectively.

Kalberla & Kerp 2010

simple rotation curve

e.g. solid body r< 0.5 kpc

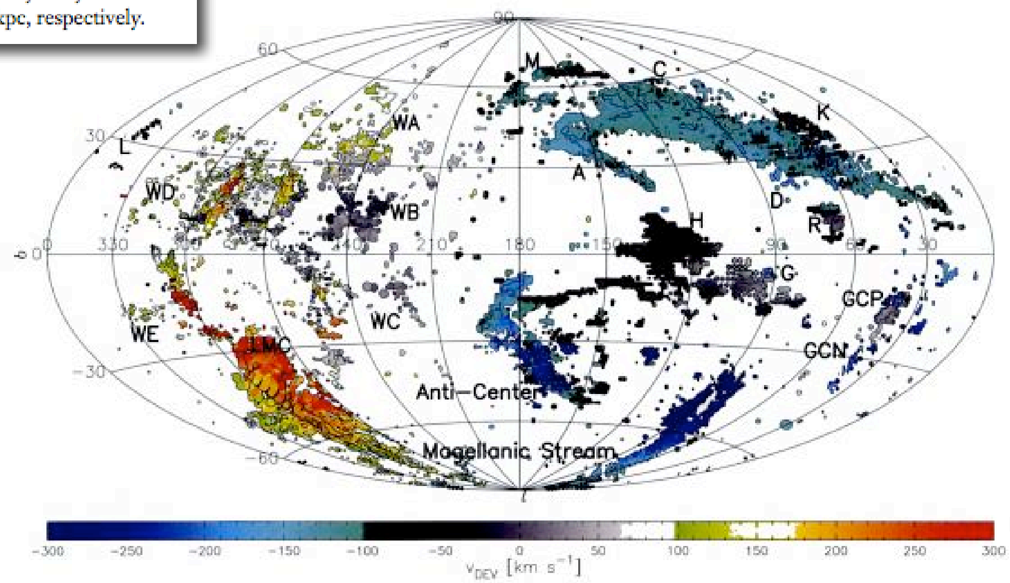
v(r) = 220 kms^{-1}; R_0 = 8.5 kpc

$$v_{\rm LSR} = \left(\frac{R_0}{R}\, v(R) - v(R_0)\right) \sin l \cos b,$$

$$R = R_0 \sqrt{\cos^2 b \left(\frac{d}{R_0}\right)^2 - 2 \cos b \cos l \left(\frac{d}{R_0}\right) + 1};$$

$$z = d \sin b. \qquad R > R_{\rm max} \text{ or } |z| > z_{\rm max}$$

HVC



Wakker et al. 2004

$$v_{\rm DEV} = v_{\rm LSR} - v_{\rm min} \text{ if } v_{\rm LSR} < 0; \quad v_{\rm DEV} = v_{\rm LSR} - v_{\rm max} \text{ if } v_{\rm LSR} > 0.$$

CNM - cold neutral medium

Narrow absorption features in front of strong galactic sources $T_{kin\_gas} < 50$ K

WNM - warm neutral medium

located close to galactic plane $T_{kin\_gas} > 200$ K

WIM - warm ionized medium

Halpha emission in Galaxy widespread $T_{kin\_gas} > 10^4$ K

HIM - hot ionized medium

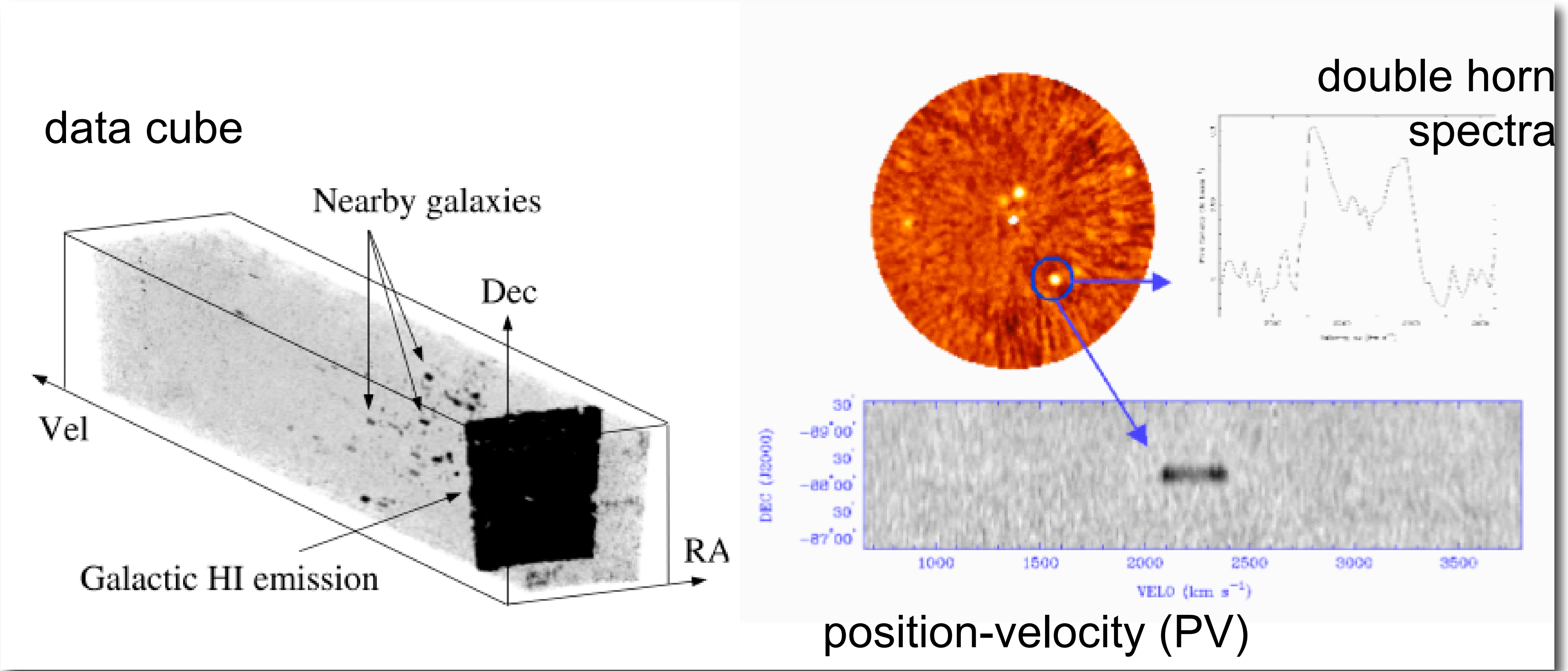
diffuse soft X-ray emission & O IV line $T \sim 10^6$ K

WHIM - warm-hot intergalactic medium

Heating: convert external energy into thermal motion of the gas

Cooling: collisional excitation (by heavy elements)

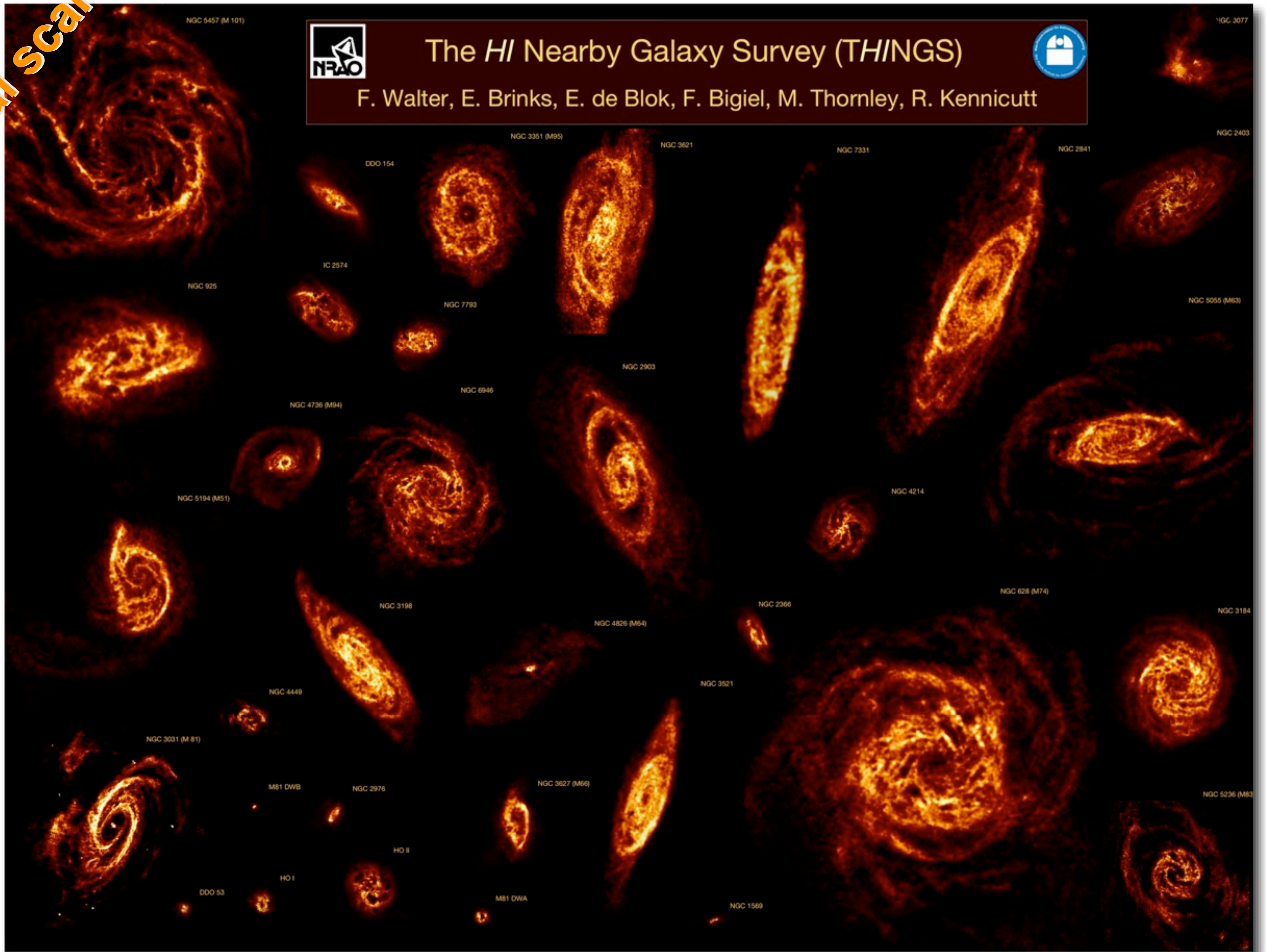
HI/spectral line talk



Zwaan 2008

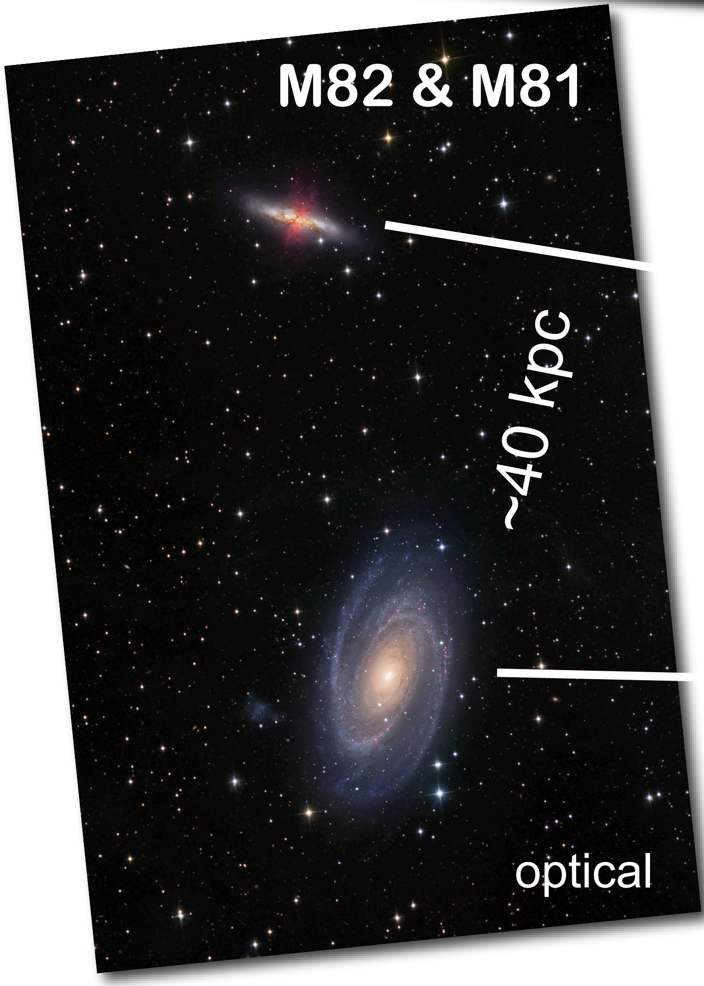
extragalactic HI

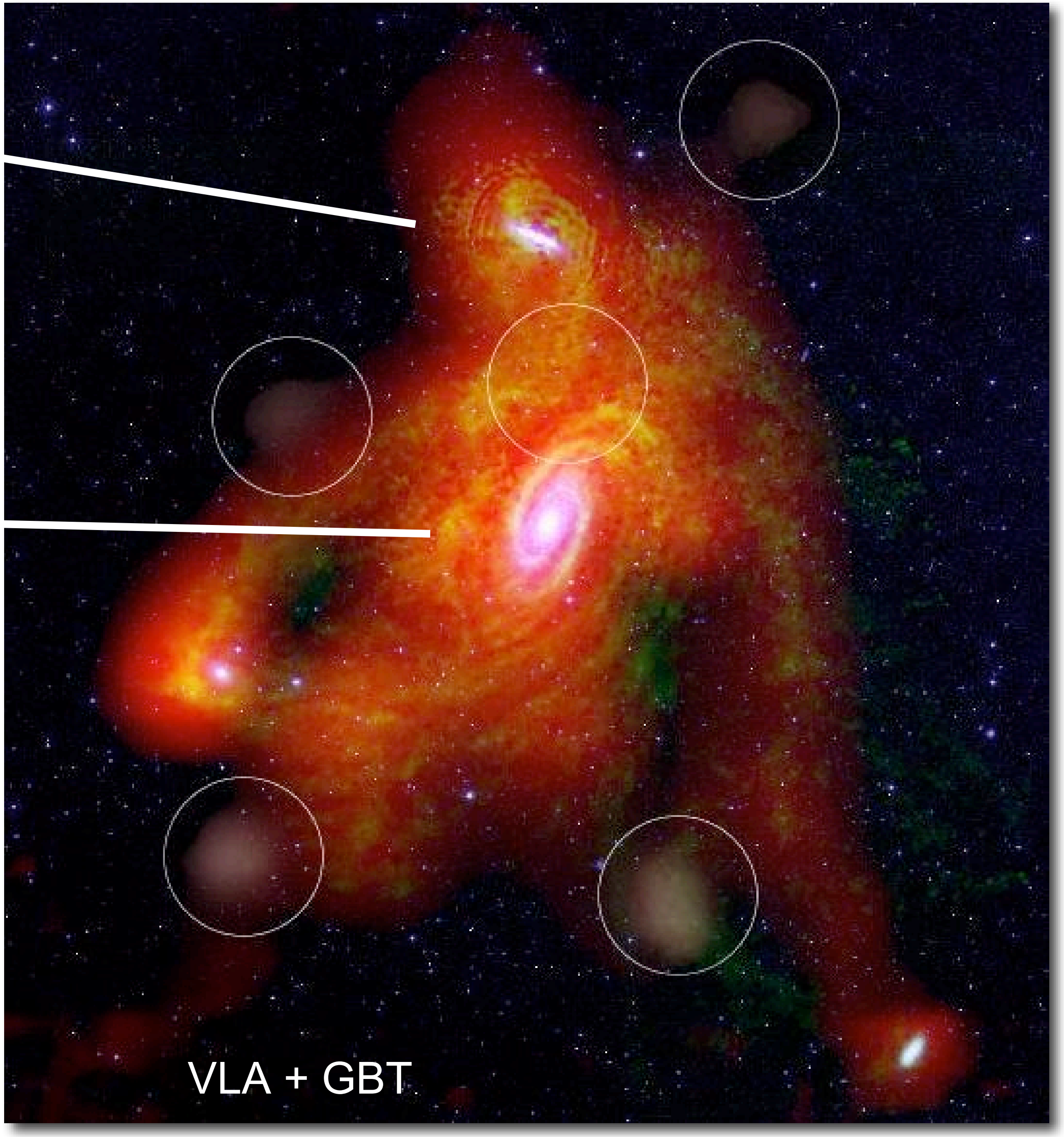
Same physical scales!



VLA D, C, B array

extragalactic HI

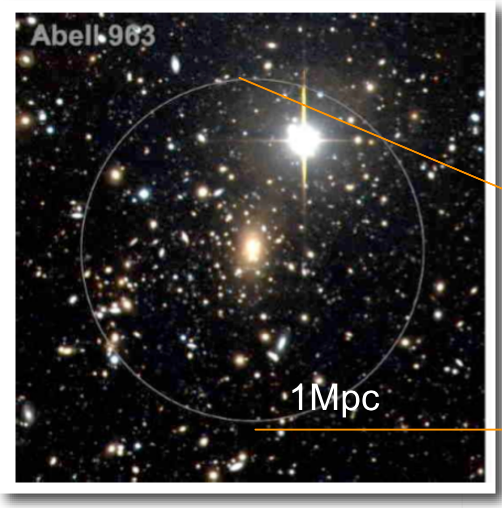


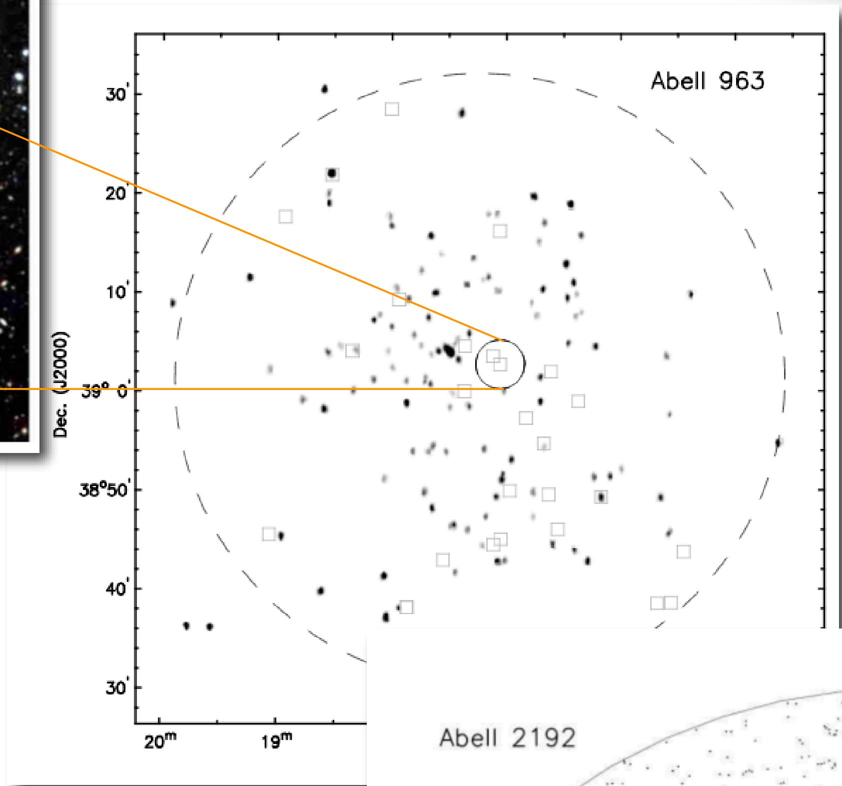


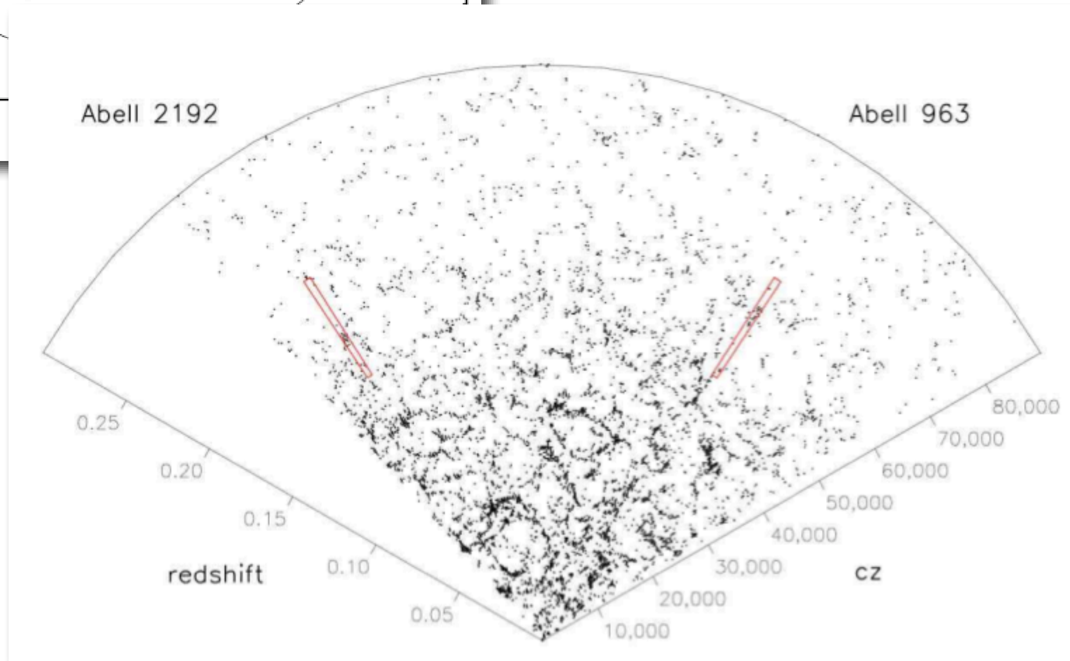
extragalactic HI

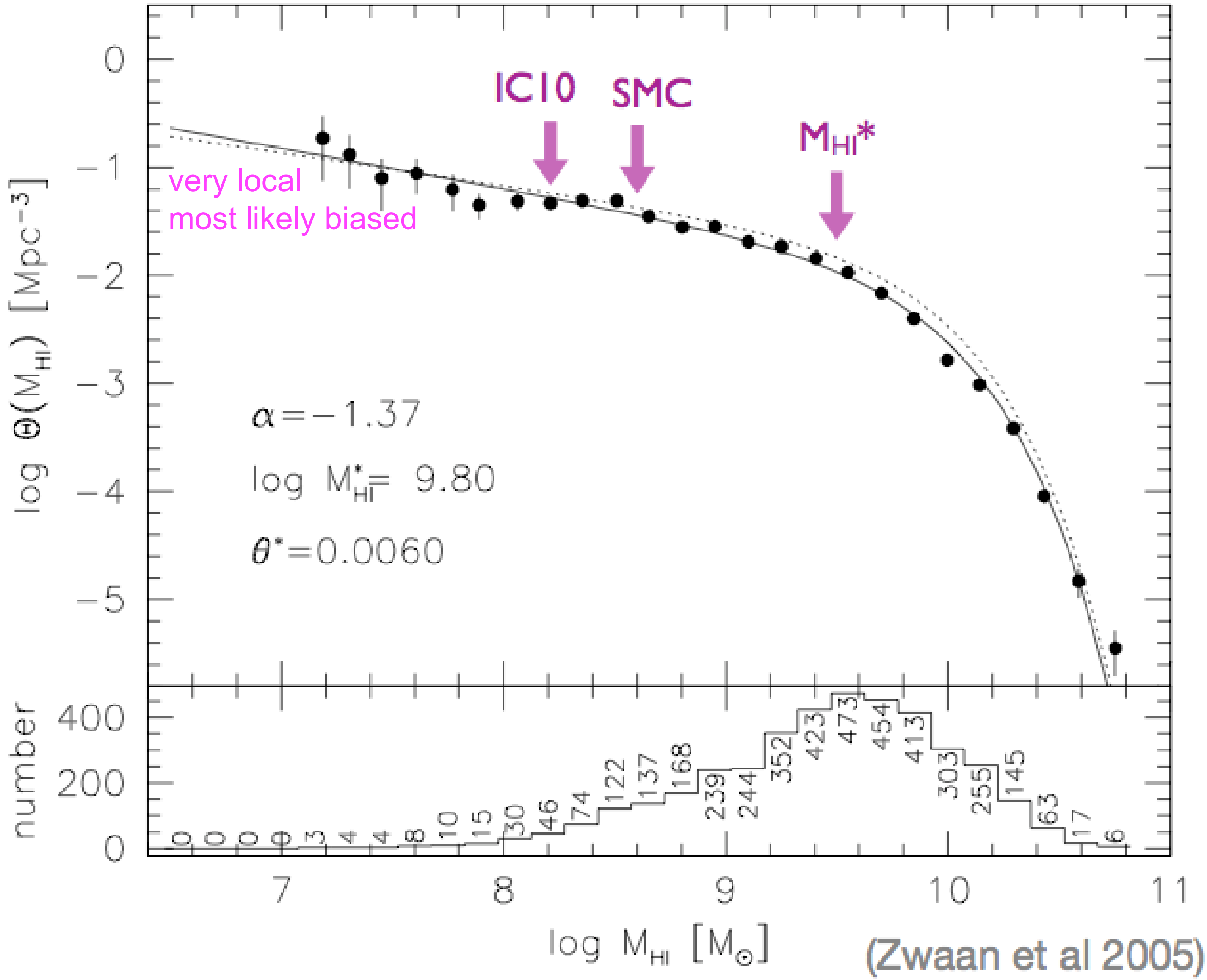
Verheijen et al. 2010

little correspondences
to SDSS redshifts



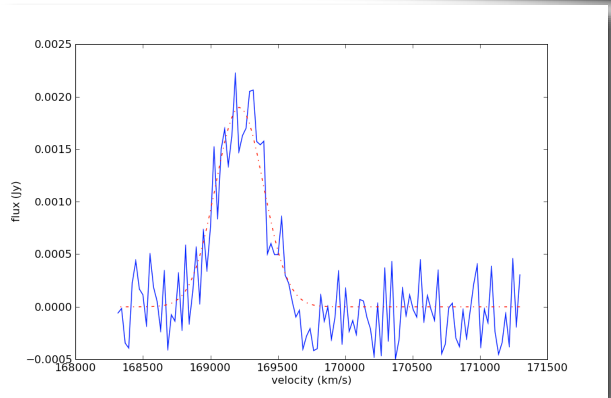


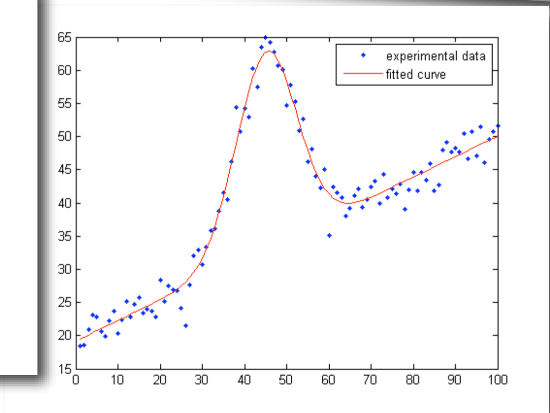




(Zwaan et al 2005)

measurements



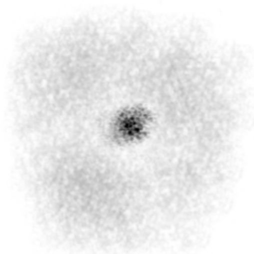


- peak flux; caution continuum!
- frequency/velocity = redshift
- width (50% or 20%)
- Gauss approx. bad

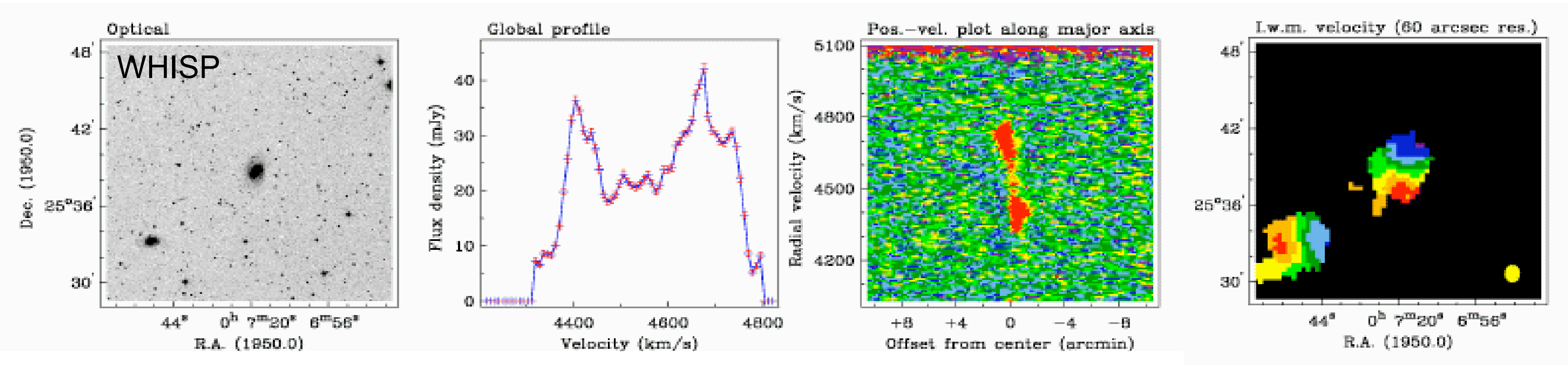
M^*_{HI} with 220 kms^{-1}
(10 channels) @ z = 1 → 5 μJy

$$M_{\mathrm{H\,I}} = \frac{236}{(1+z)} \left(\frac{S_v}{\mathrm{mJy}}\right) \left(\frac{d_{\mathrm{L}}}{\mathrm{Mpc}}\right)^2 \left(\frac{\Delta V}{\mathrm{km\ s^{-1}}}\right)$$

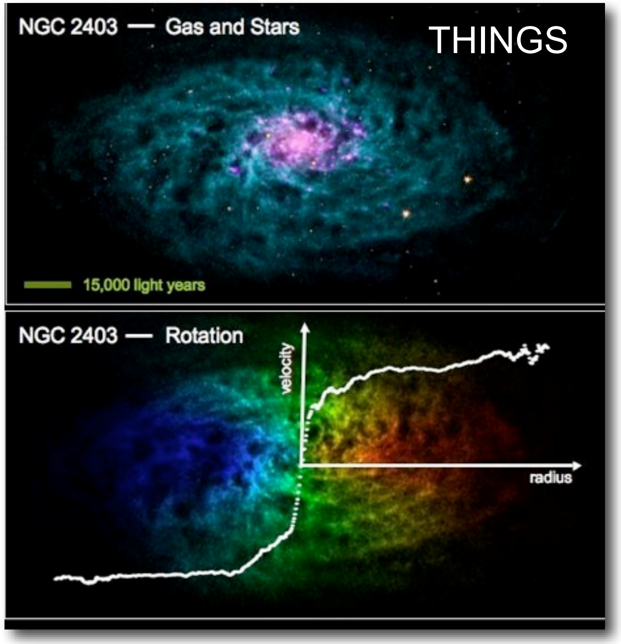
$$N_{HI} = 1.823 \cdot 10^{18} \int T_b dv \qquad T_b = \frac{\lambda^2 S}{2k\Omega}$$

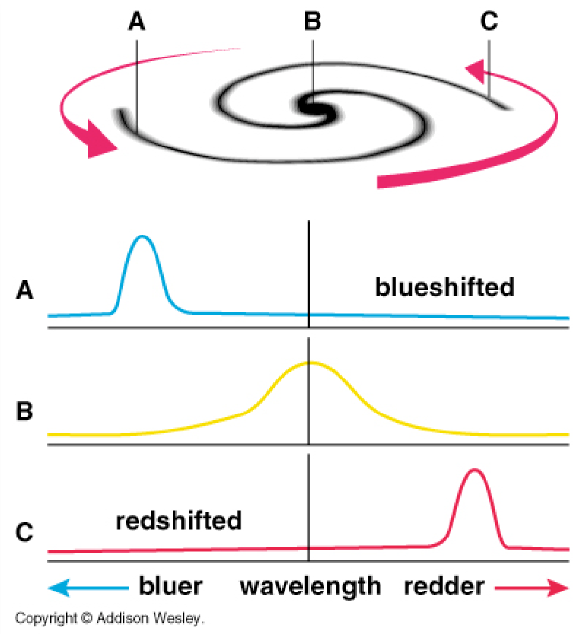


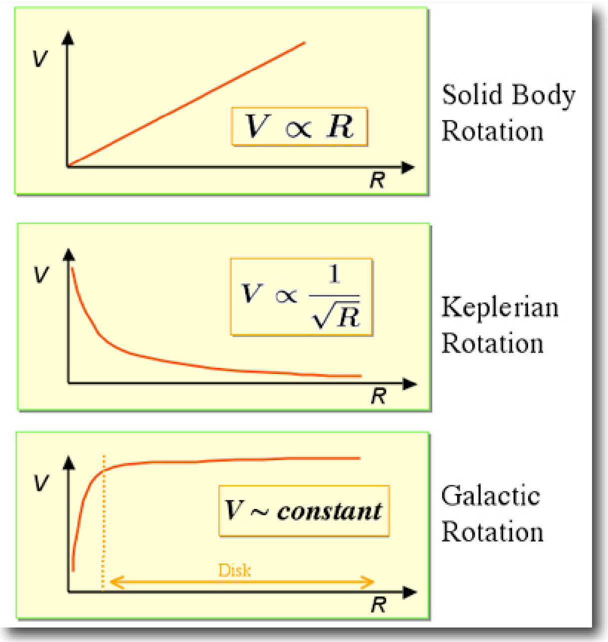
500 hrs 25kms^{-1}
Parkes(15.5') N_{HI} = 3.4 10^{16}
Effelsberg (9')
SKA(2.5') N_{HI}=1.8 10^{16}



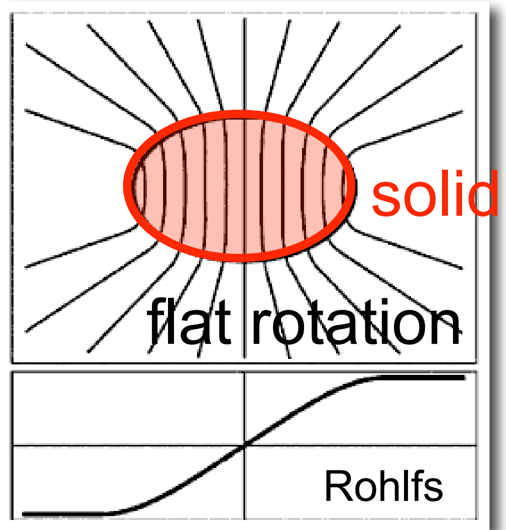
velocity field

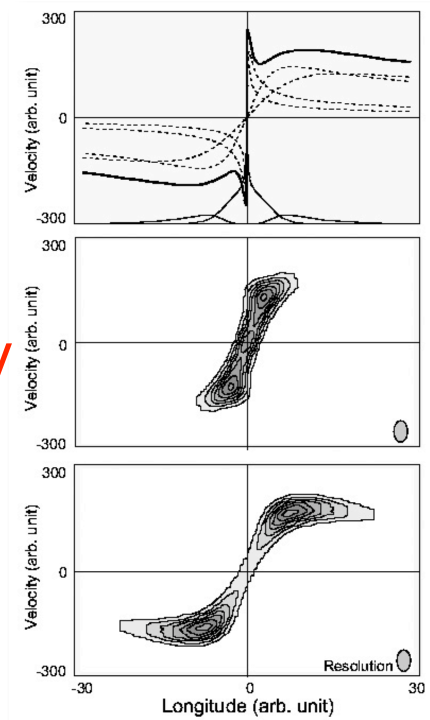






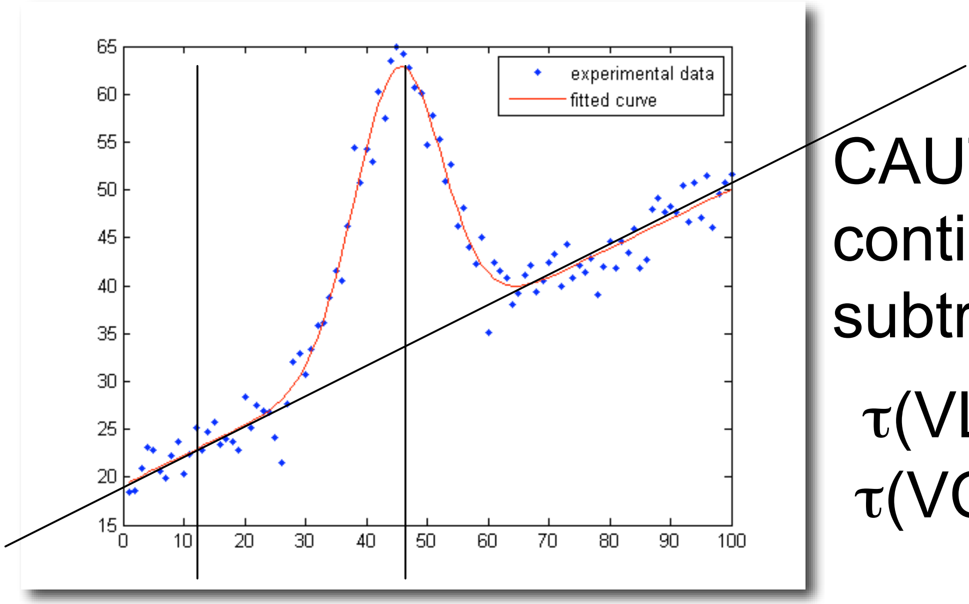
PV





radiative transfer

isothermal cloud



V_C V_L

CAUTION
continuum
subtraction

$\tau(VL) \neq 0$

$\tau(VC) = 0$

$$I_B(V_L) = T_S\,(1 - e^{-\tau(VL)}) + T_C\, e^{-\tau(VL)})$$

$$I_B(V_c) = T_S\,(1 - e^{-\tau(VC)}) + T_C\, e^{-\tau(Vc)})$$

$$I_B(V_L) - I_B(V_c) = (T_S - T_C)\,(1 - e^{-\tau(VL)}))$$

$$T_L = (T_S - T_C)\,(1 - e^{-\tau(VL)}))$$

optical depth

$$\tau = -\ln\,(1 + T_L/(T_S - T_C))$$

$T_C >> T_S$:

$$\tau = -\ln\,(1 - T_L/T_C)$$

$$N(\mathrm{H\ I})/T_s = C \int \tau_v\, dv\ \mathrm{cm^{-2}\ K^{-1}},$$

$$C = 1.823 \times 10^{18}\ \mathrm{cm^{-2}\ (km\ s^{-1})^{-1}}.$$

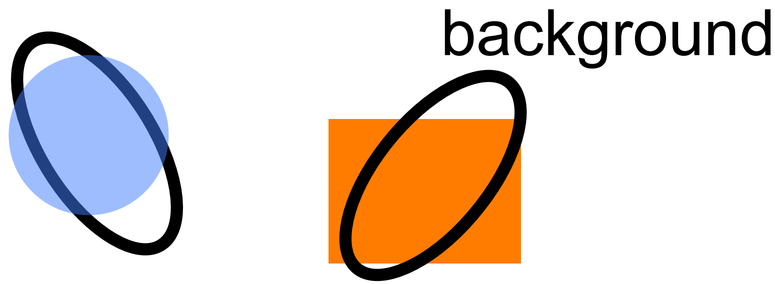
measurements

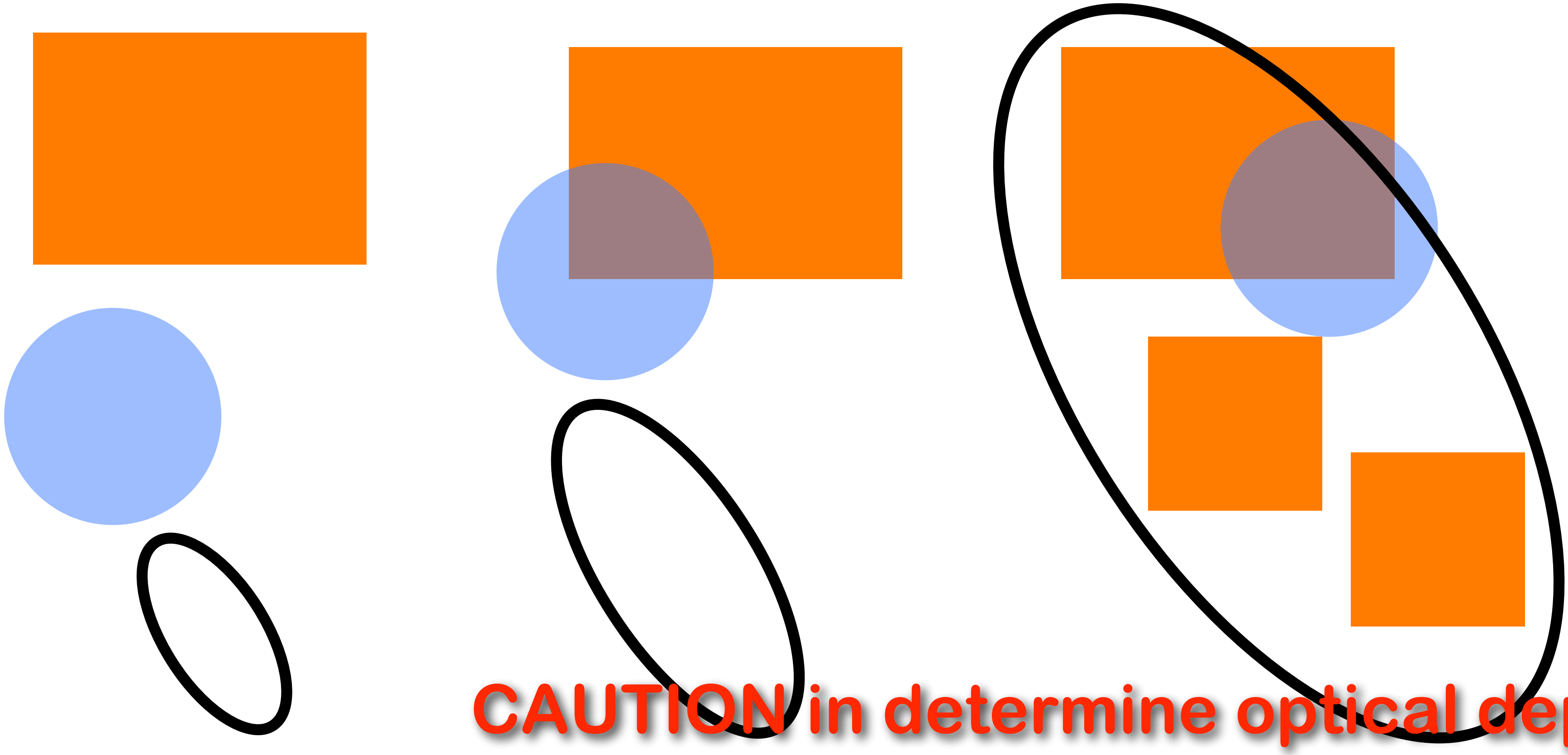
$$T_L = (f_{cl} T_S - f_0 f_c T_C)\,(1 - e^{-\tau(VL)})$$

f_{cl} beam filling factor cloud

f_c beam filling factor continuum

f_0 fraction of continuum source covered by cloud

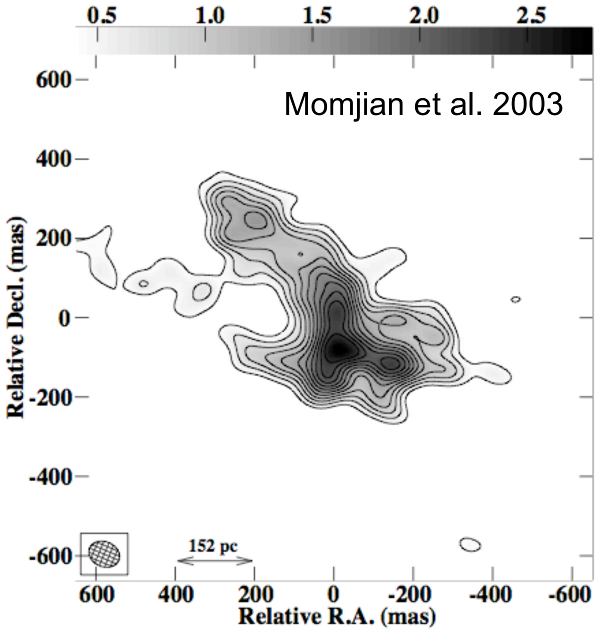




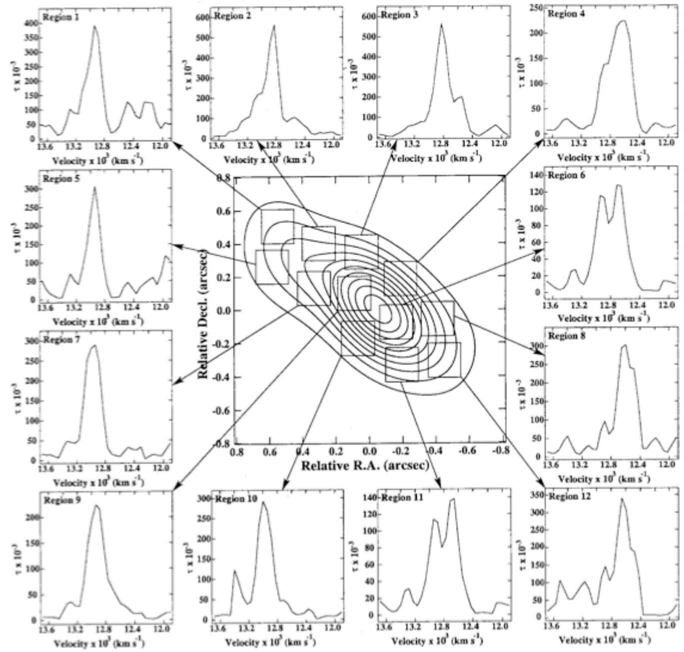
CAUTION in determine optical depth

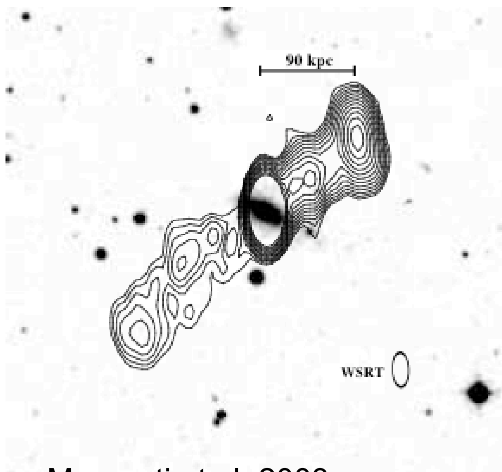
HI absorption

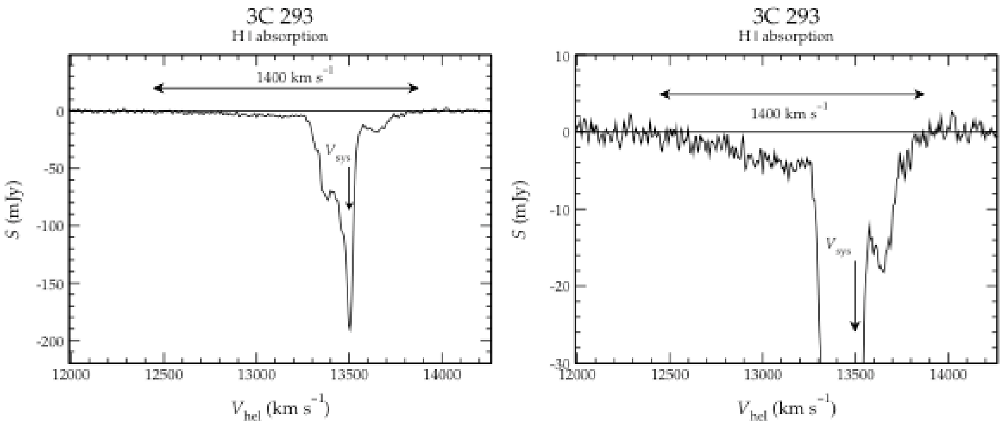
IRAS 17208-0014



optical depth



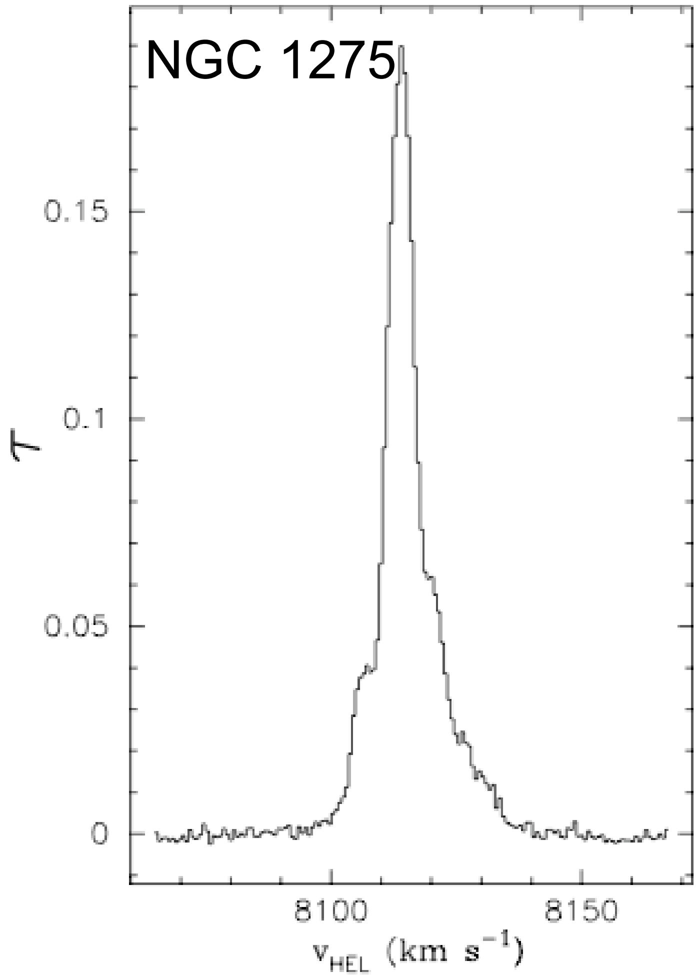


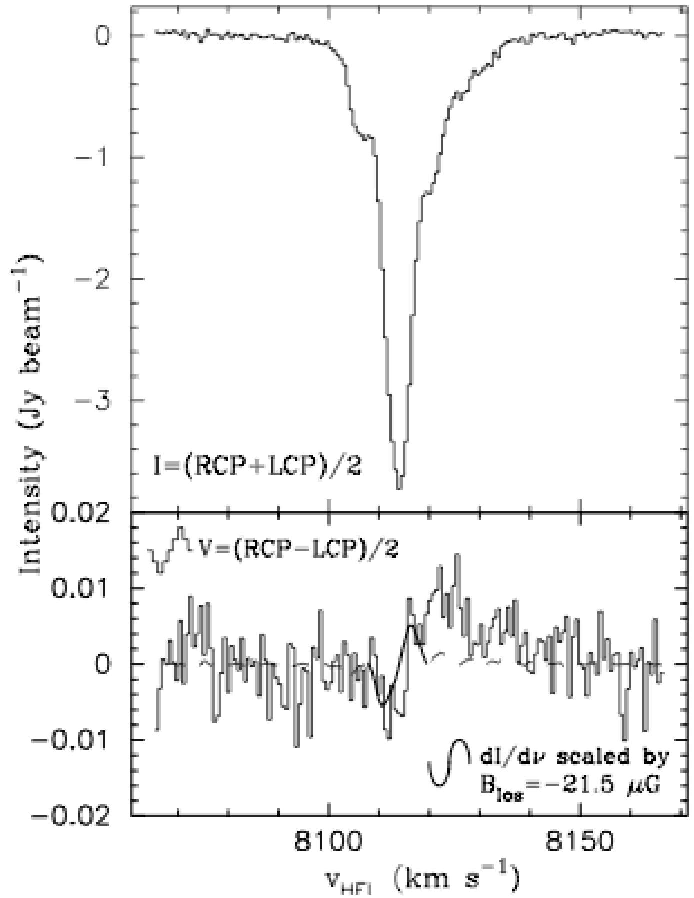


Morganti et al. 2003

magnetic field measurements

$$\Delta E = \frac{e}{2m}(\vec{L} + 2\vec{S}) \cdot \vec{B} = g_L \mu_B m_j B$$ Magnetic interaction energy



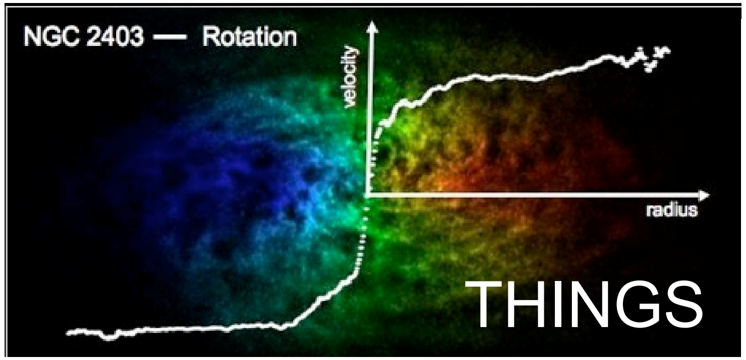


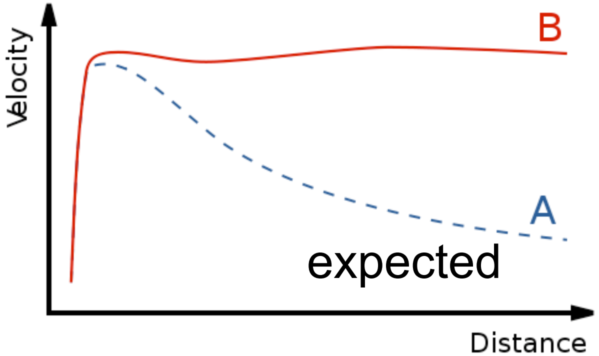
Sarma et al. 2005

$$N(\mathrm{H\ I})/T_s = 4 \times 10^{18}\ \mathrm{cm}^{-2}\,\mathrm{K}^{-1}$$

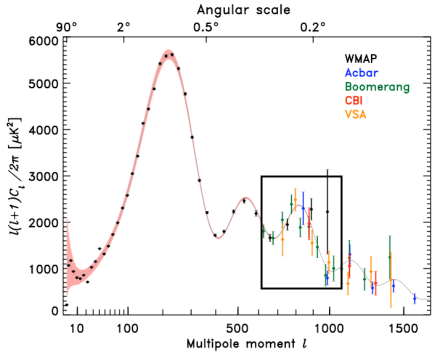
$$B_{\mathrm{los}} = -21.5 \pm 6.5\ \mu\mathrm{G}$$

Tully-Fisher relation (1977; spirals L ~ Δv^{β} β =3.0-4.2)



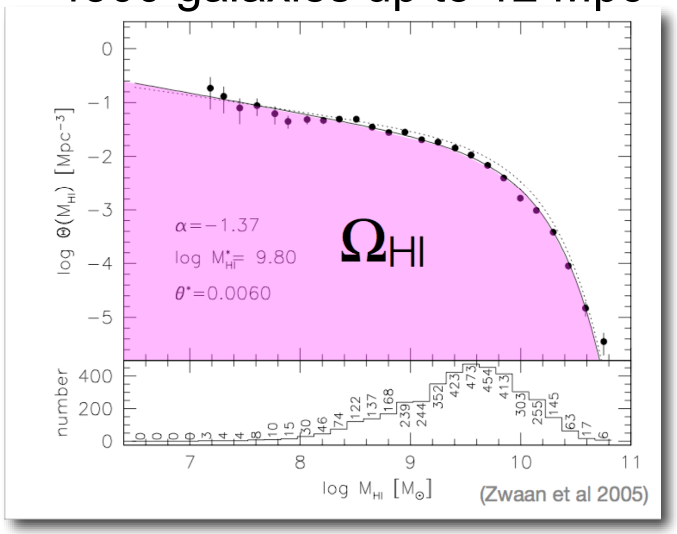


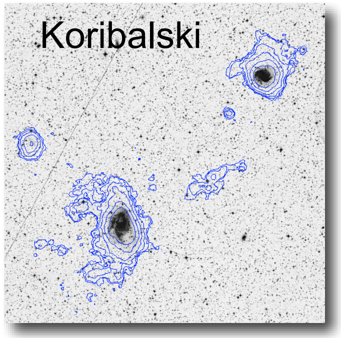
dark matter



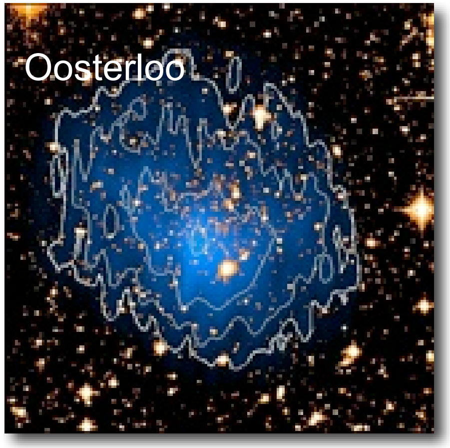
HIPASS local HI content

4300 galaxies up to 12 Mpc



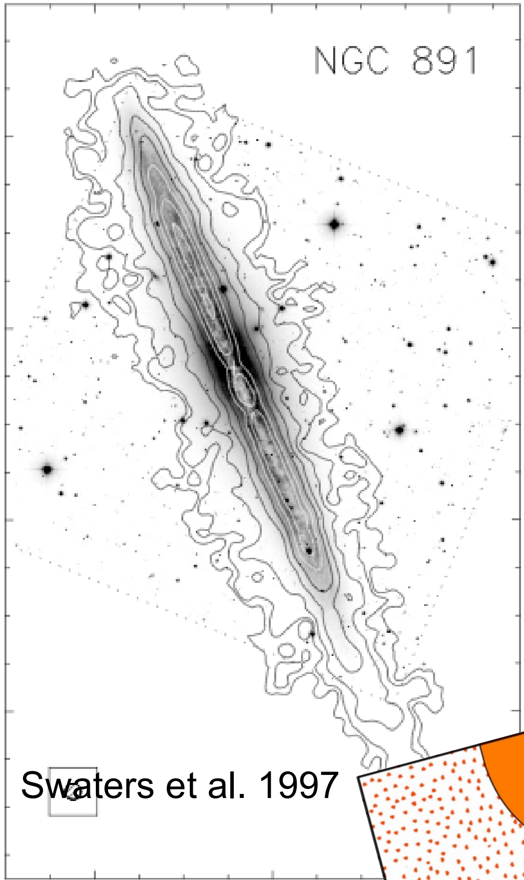


HI Group
(NGC 6221/6215) 8*10^{10} M_o



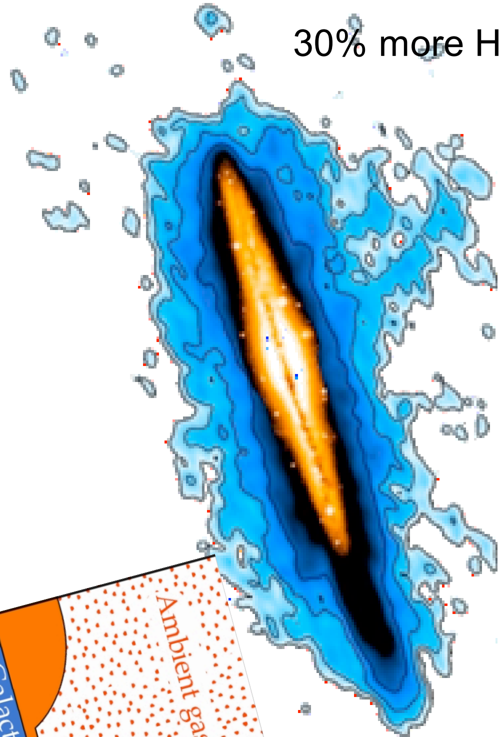
Leo T
smallest galaxy in the local group
10^5 M_o : HI 80% Stars 20 % baryons

low mass HI

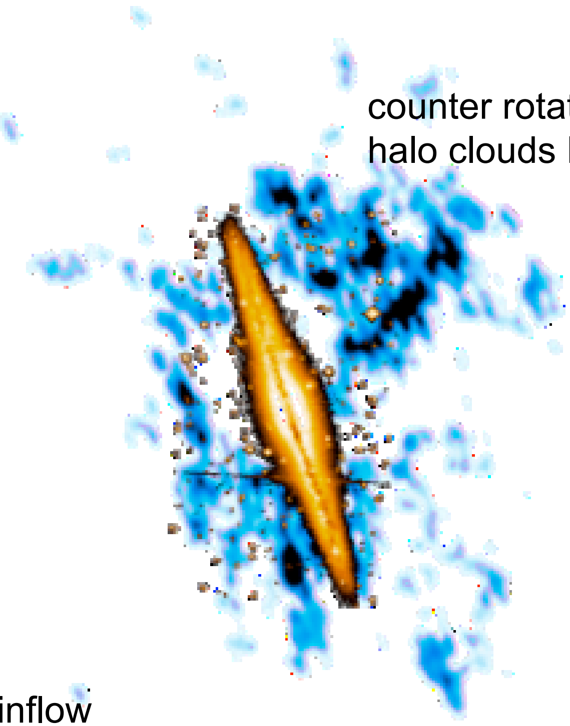


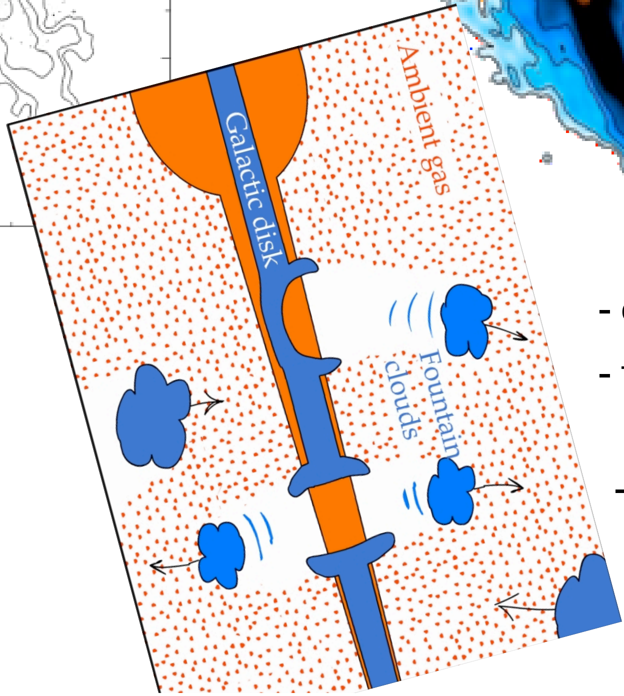
Swaters et al. 1997

30% more HI is detected Oosterloo 2007)



counter rotating
halo clouds $M_{HI} > 10^6$

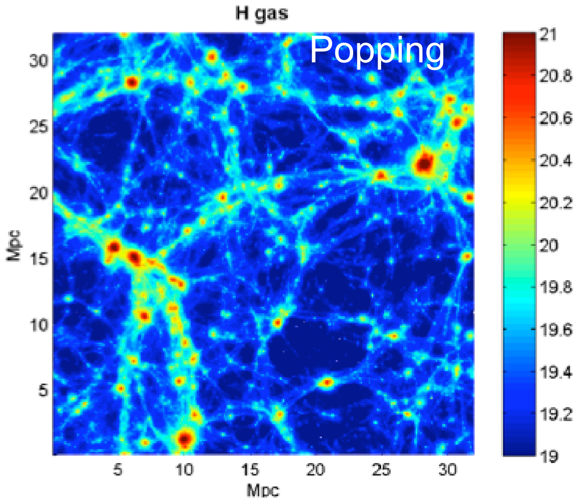




- outflow/inflow
- fountain model is not sufficient to explain kinematics
  Fraternali & Binney 2006, 2008
- LAB Kalberla et al. 1998 priv. comm.

intergalactic - low angular momentum material needed

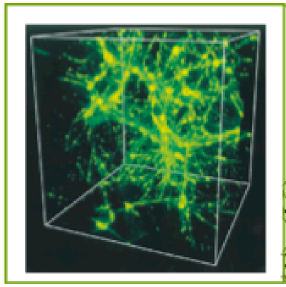
cosmic web



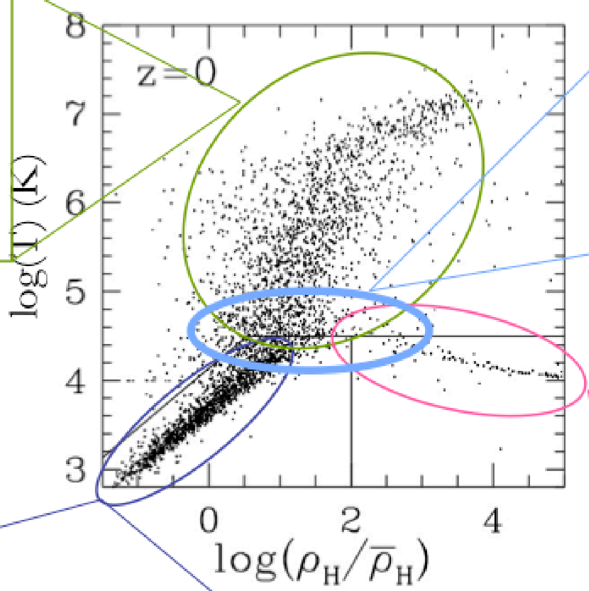
- galactic concentrations
- warm-hot intergalactic medium (WHIM)
- diffuse intergalactic medium (Lya forest)

simulation of galaxies ; Obreschkow et al. 2009

Gas particles simulation, temperature/density (Davé et al. 1999)



WHIM ???

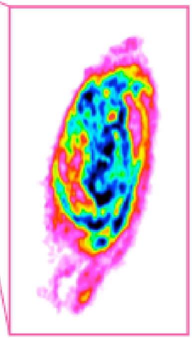


Davé et al. 1999

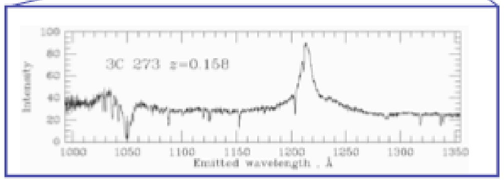
Lyman Limit System

NHI ~ 10^{14} – 10^{19} cm^{-2}

HI emission

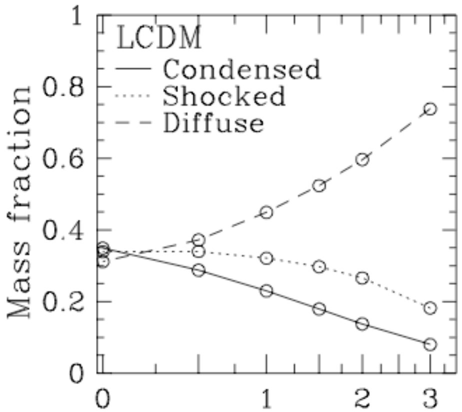


Popping



Ly-α Forest

Baryonic mass fraction (Davé et al. 1999)

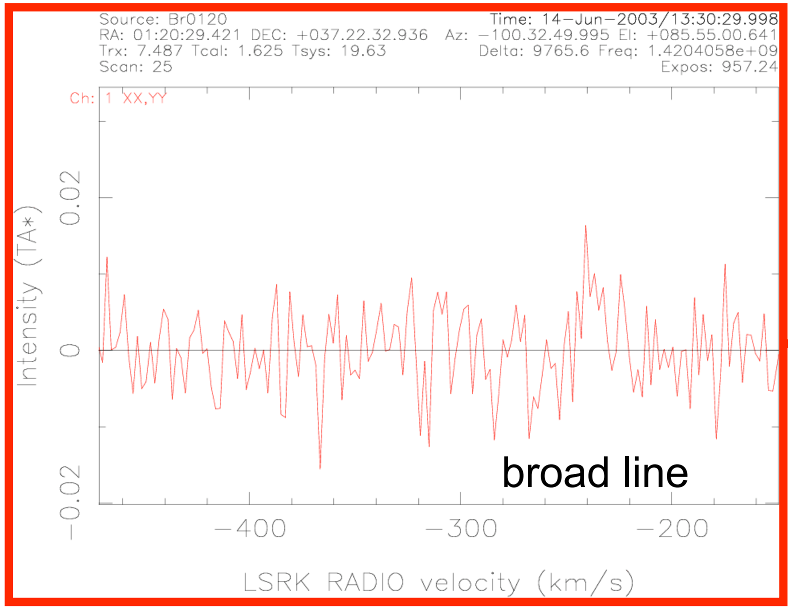


For all cosmological models
above z = 1 diffuse IGM dominates
Mass fraction is redshift depended !

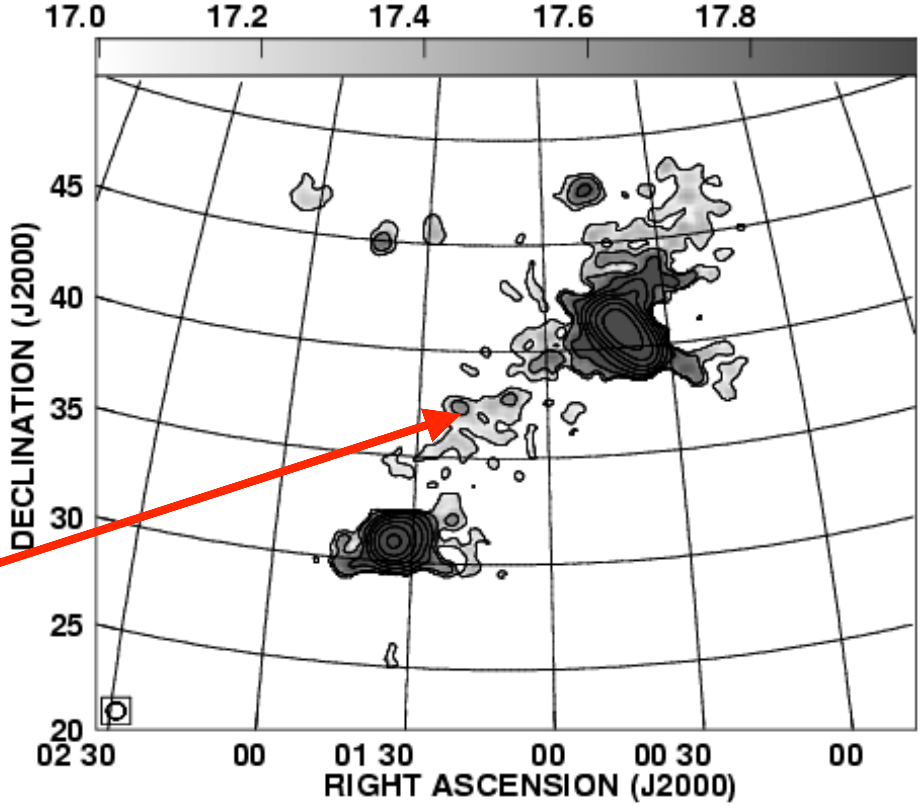
missing baryons in cosmic web

The M31 – M33 filament (Braun et al. 2004)

- extremely diffuse in bridge region (same low N_{HI} in GBT and WSRT)



GBT confirmation (30 min ON/OFF)

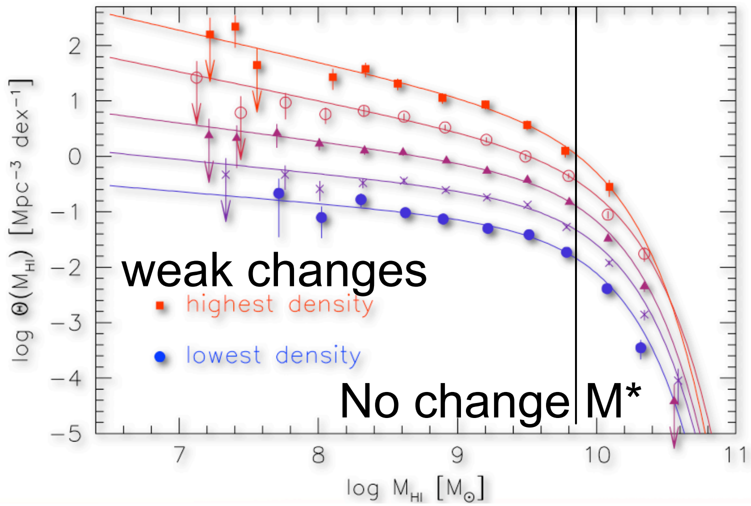


wide-field WSRT data

The bridge might be the first detection of the “cosmic web”/ WHIM in HI emission

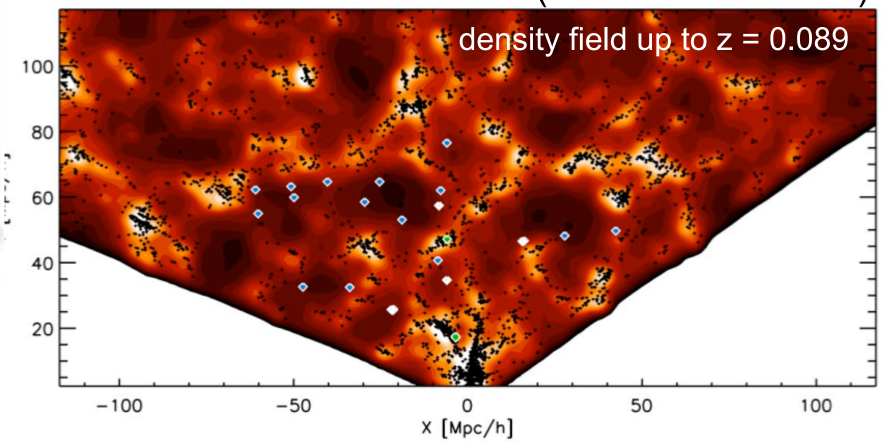
Environmental effect ?

Zwaan et al.



15 HI void galaxies

(Kreckel et al. 2010)

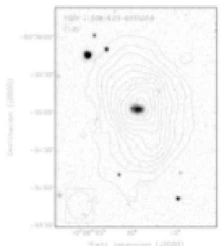


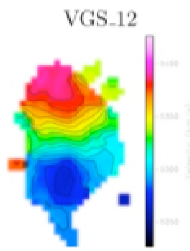
WSRT 12 hrs per source 36, 54, 72, 90 m spacing

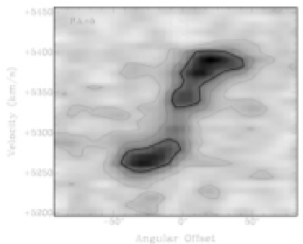
14/15 perturbed, interacting galaxies
with small disks M_{HI} = 3.5 10^8 3.9 10^9 M_o

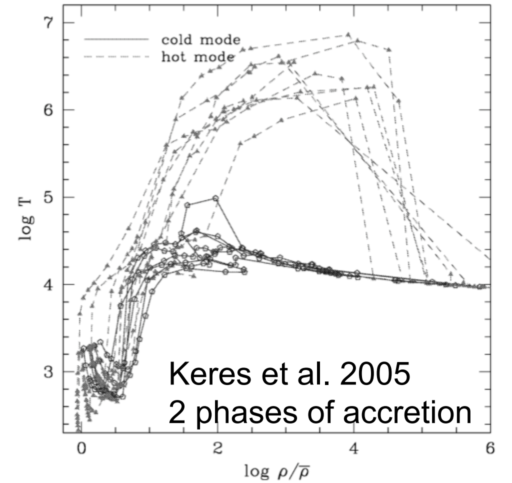
trend of increase SFR and H_{alpha} ew_{width}

one galaxy found with polar HI disk







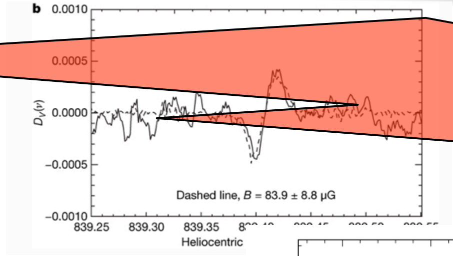


Possible sign of hot mode accretion!

(no velocity disturbance of HI by
shock heated ionized matter condense in galaxies)

HI records

z = 0.69

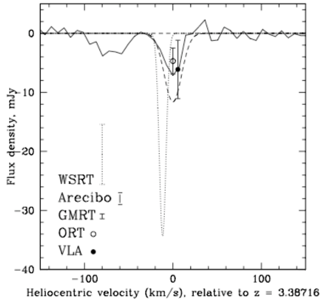


Zeeman splitting

Wolfe et al. 2008

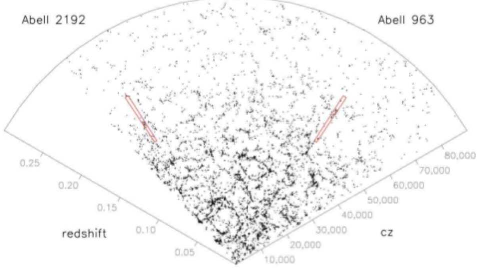
false publication
even its in Nature !

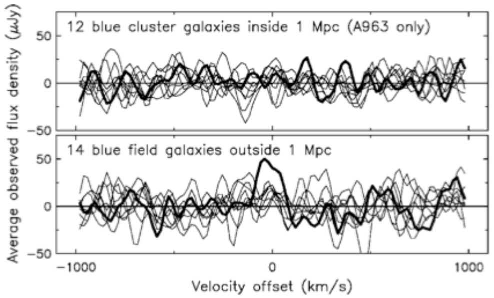
z = 3.39

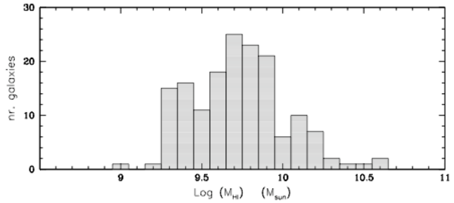


N_{HI} = ~1.8 10^{21} cm^{-2} Kanekar et al. 2007

z = 0.1644 - 0.224





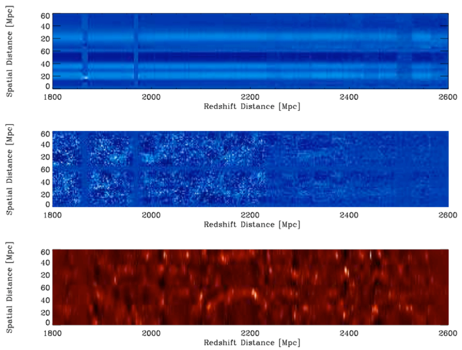


Verheijen et al. 2007, 2010

> 200 hrs WSRT time

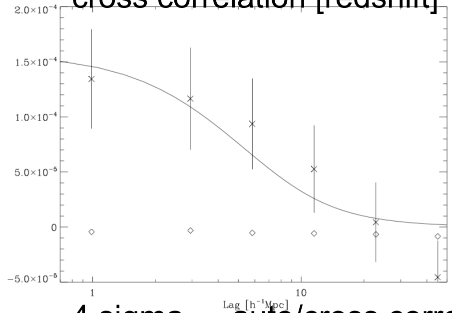
z = 0.24 Catinella 2008

z = 0.53 - 1.12



10000 SDSS redshifts

cross correlation [redshift]

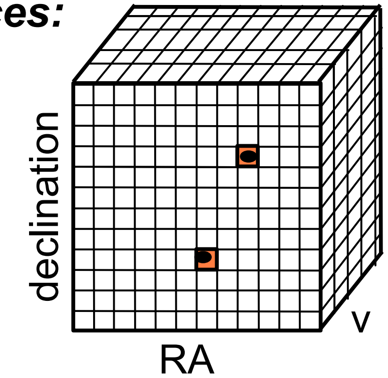


Chang et al. 2010

4 sigma ~ auto/cross correlation
average M_{HI} =10^{11} M_o per volume element

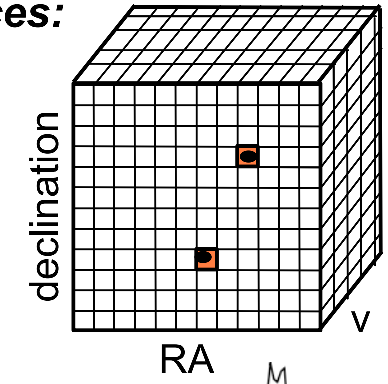
in total 10^{14} M_o

Since measured signals are weak, we need independent redshift measurements of the sources:



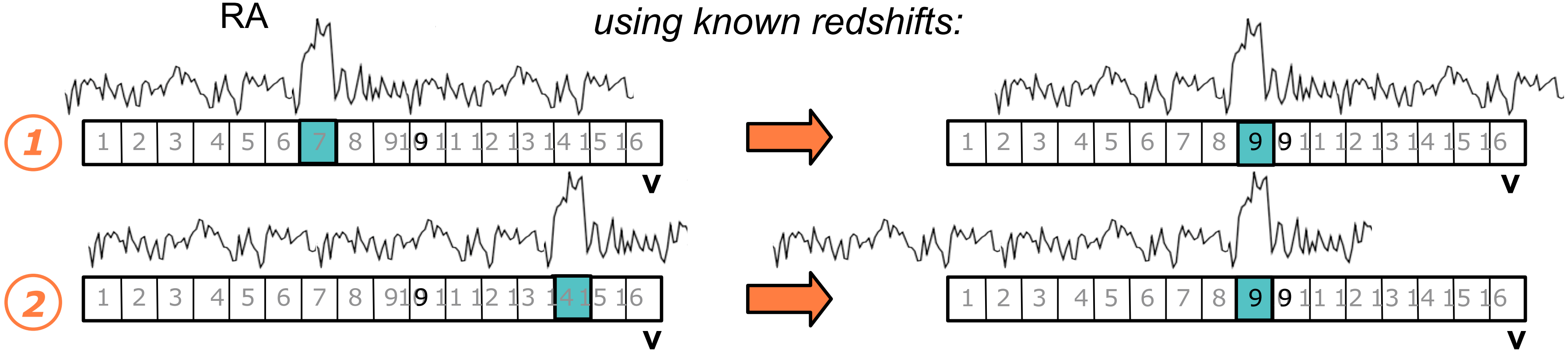
Step 1: *Identify locations of galaxies with known redshifts in data-cube*

Since measured signals are weak, we need independent redshift measurements of the sources:



Step 1: Identify locations of galaxies with known redshifts in data-cube

Step 2: Extract spectra and shift to a common frequency/velocity using known redshifts:



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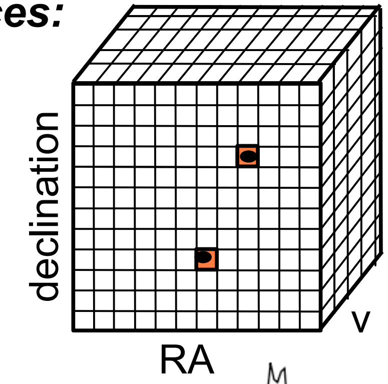
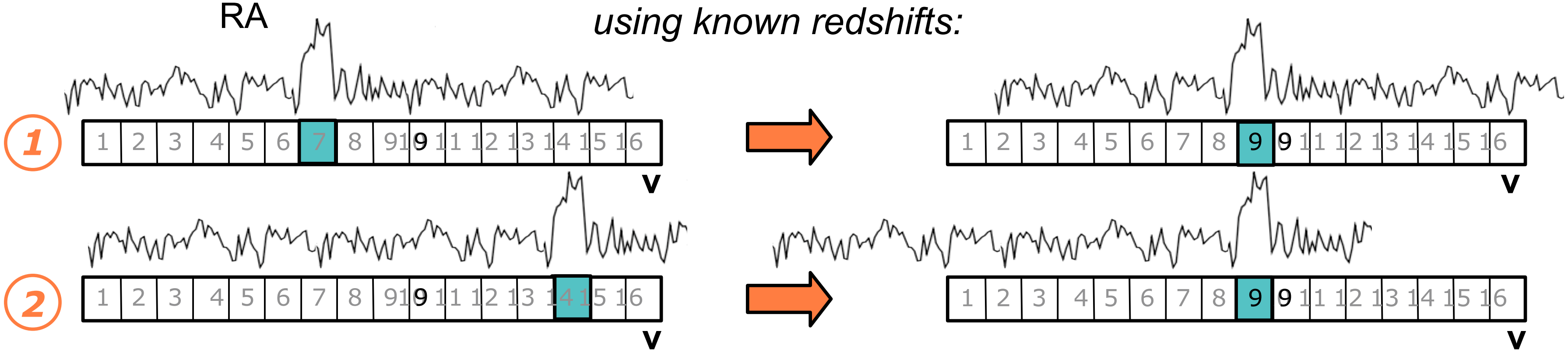
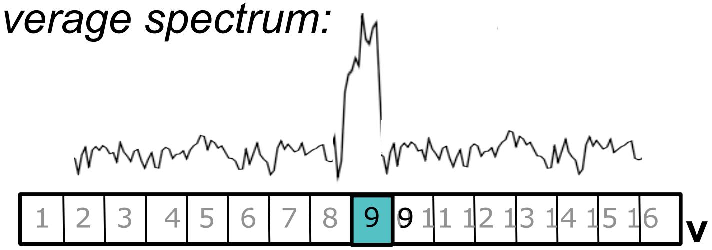


Step 1: *Identify locations of galaxies with known redshifts in data-cube*

Step 2: *Extract spectra and shift to a common frequency/velocity using known redshifts:*



Step 3: *Co-add spectra and calculate weighted-average spectrum:*



... and estimate the average HI mass:

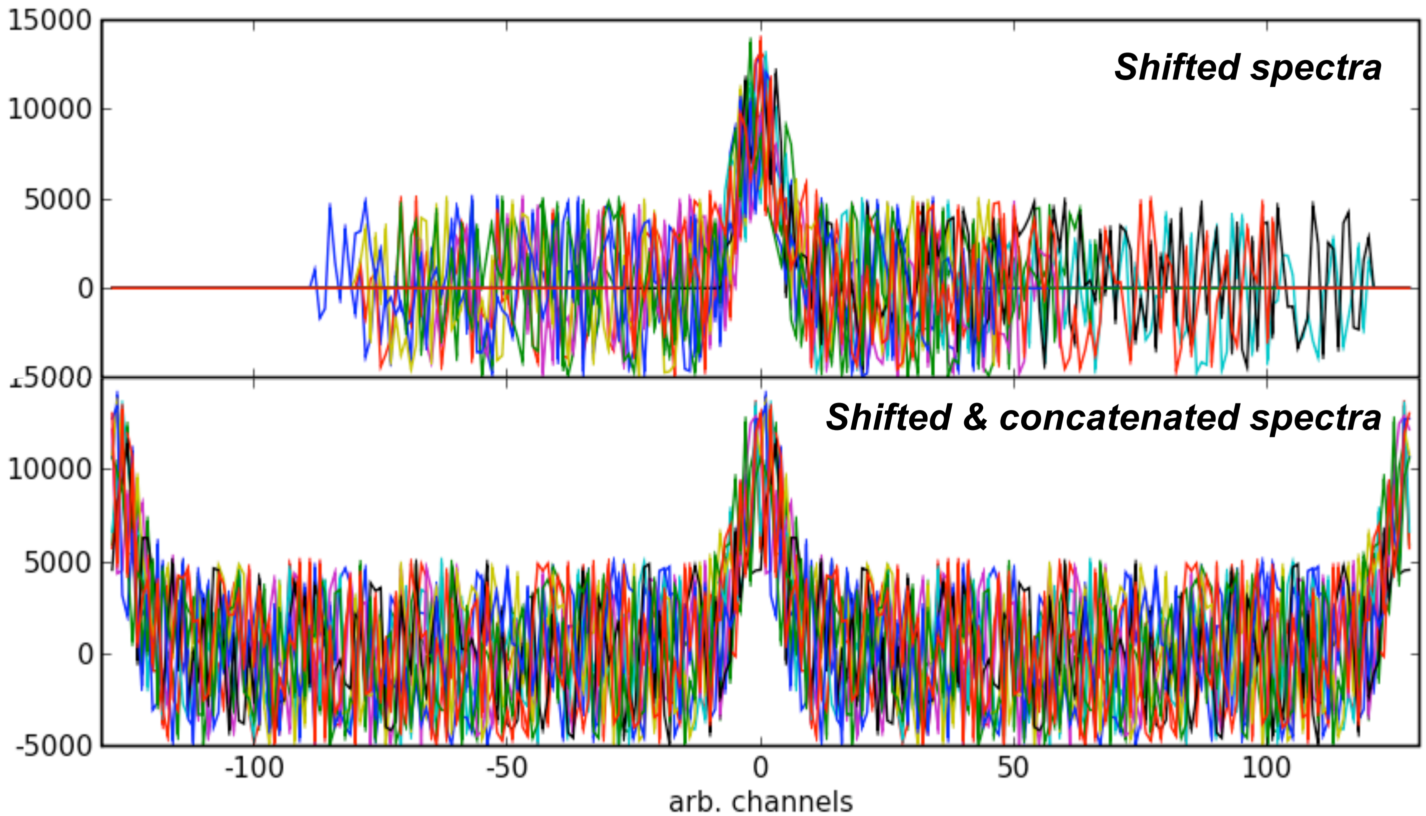
$$\frac{M_{HI}}{M_{sun}} = \frac{236}{(1+z)}\left(\frac{S}{mJy}\right)\left(\frac{d_L}{Mpc}\right)^2\left(\frac{V}{km/s}\right)$$

Using the known optical redshifts, shift spectra to a common frequency/velocity:

Statistical multiplexing

- ***Method 1:***
- *Shift spectra to common v*

- ***Method 2:***
- *Shift spectra to common v*
- *Concatenate* ***with itself*** *to cover full v-range*

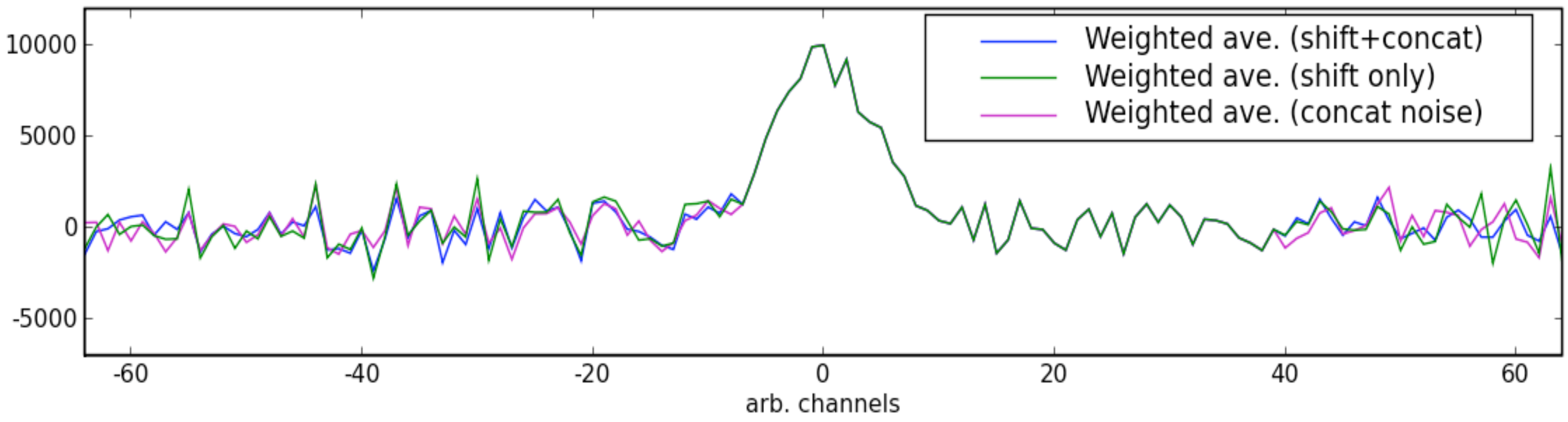


- ***Method 3:***
- *Shift spectra to common v and concatenate* ***with noise***

Statistical multiplexing

The different shifting methods result in slightly different weighted average spectra:

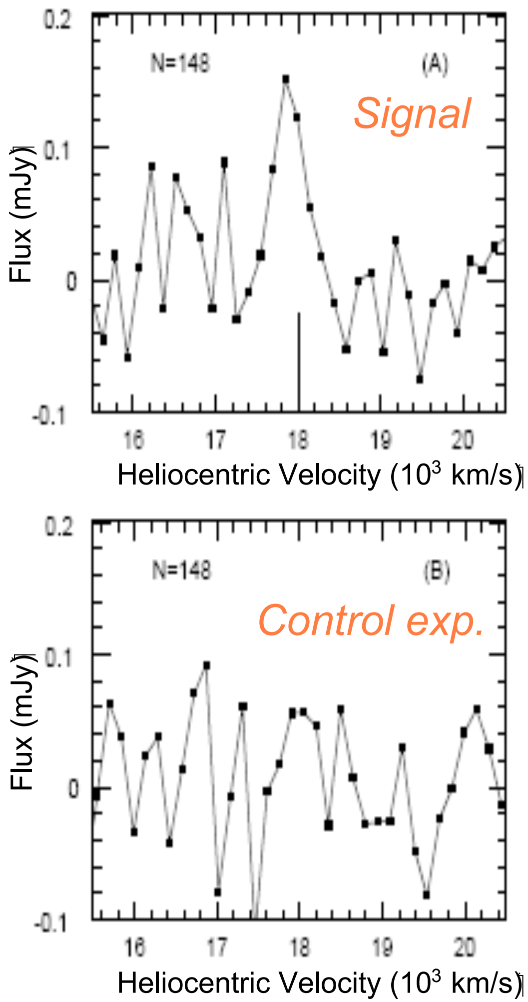
- *Weight by 1/RMS or 1/RMS^2 of each spectrum:*



- ***However...***
- *In region of interest 3 methods very similar*
- *Gives handle on systematics*

Previous results

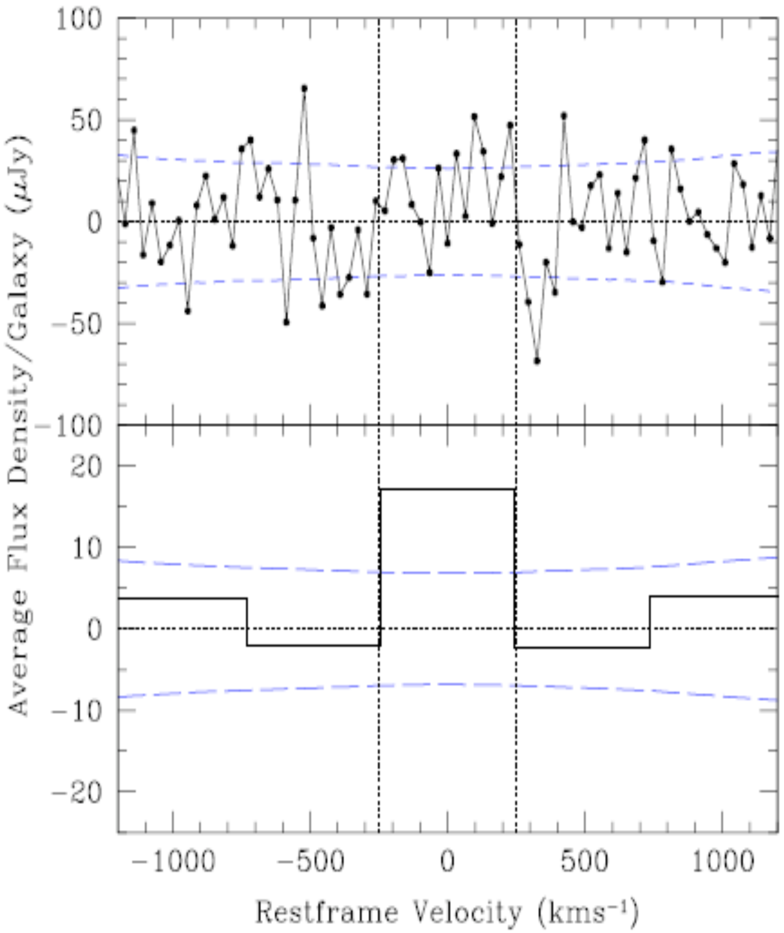
Stacking experiments at a range of redshifts have not yet produced a statistically robust HI signal...



- ***(2001) Chengalur et al.***
- ***Telescope:*** *ATCA*
- ***Target:*** *Abell 3128*
- ***z*** *= 0.06*
- ***Control experiment:***
  - *Use spectra, but shift with randomised redshifts*
- ***Signal strength:*** *4σ*

Previous results

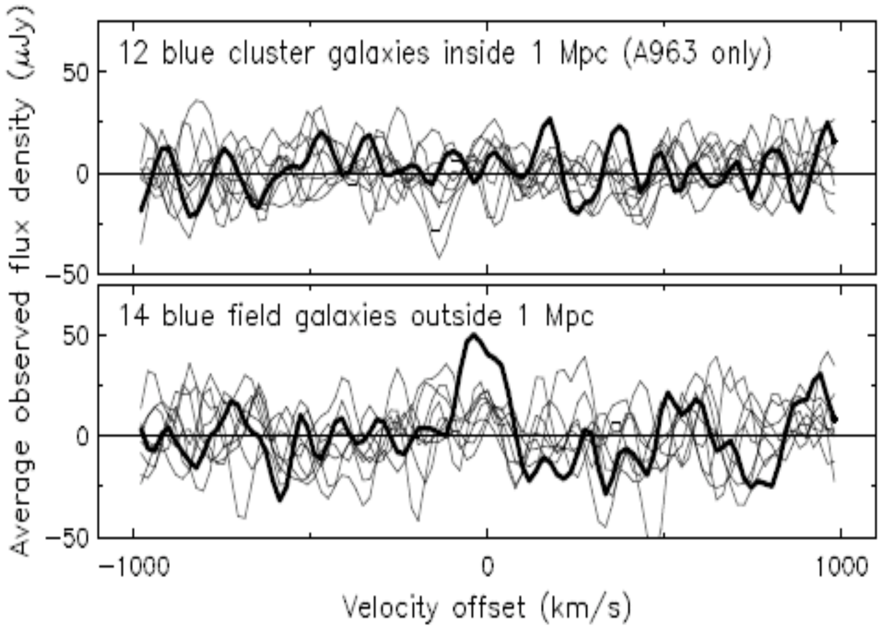
Stacking experiments at a range of redshifts have not yet produced a statistically robust HI signal...



- *(2007) Lah et al.*
- ***Telescope:*** *GMRT*
- ***Target:*** *Field galaxies (Fujita Hα-emitters)*
- ***z*** *= 0.24*
- ***Control experiment:***
  - *Simulated artificial galaxies with random positions and redshifts, shifted and co-added*
- ***Signal strength:*** *2.6σ*

Previous results

Stacking experiments at a range of redshifts have not yet produced a statistically robust HI signal...

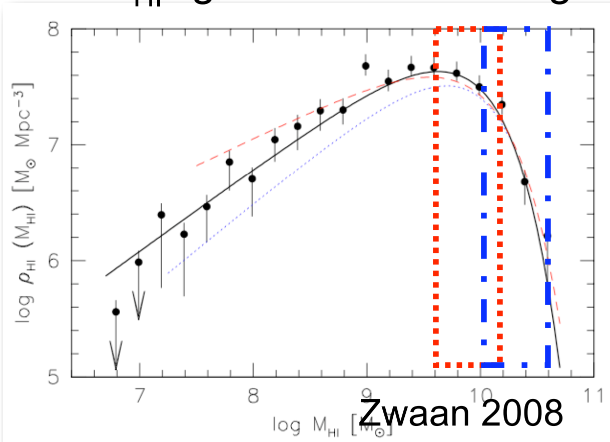


- ***(2007) Verheijen et al.***
- ***Telescope:*** *WSRT*
- ***Target:*** *Abell 963 & Abell 2192*
- ***z*** *= 0.206*
- ***Control experiment:***
  - *Stack spectra from 8 spatially offset positions (shifted to the same velocity)*
- ***Signal strength:*** *not quoted*

HI at z = 1

stacking experiments

local M_{HI}* galaxies dominate gas mass density

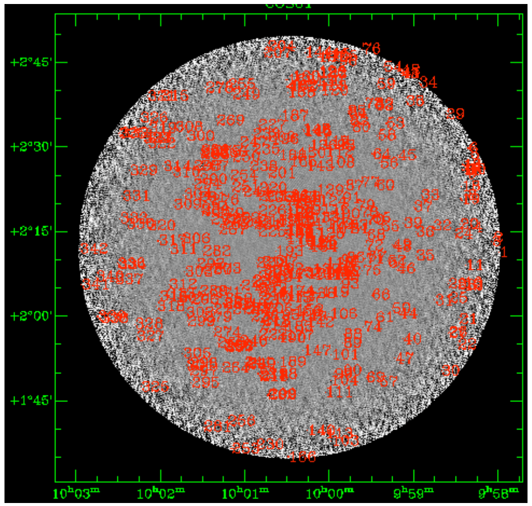


Zwaan 2008

119 redshifts:
220 kms^{-1} 3.5 10^{10} M_{sun}
3 channel limit 78 kms^{-1}:
1.2 10^{10} M_{sun}

1000 redshifts:
220 kms^{-1} 1.5 10^{10} M_{sun}
3 channel limit 78 kms^{-1}:
5.2 10^{9} M_{sun}

Cosmos field

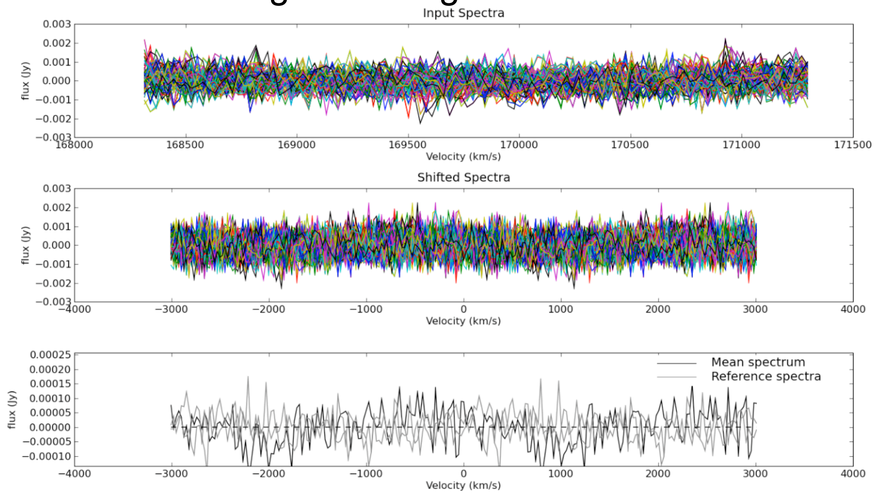


2hrs GMRT

112/342 sources

rms = 74 μJy

OLD: stacking test using 45 redshifts



M_{HI} = (0.7 ± 1.4) 10^{11} M_{sun}

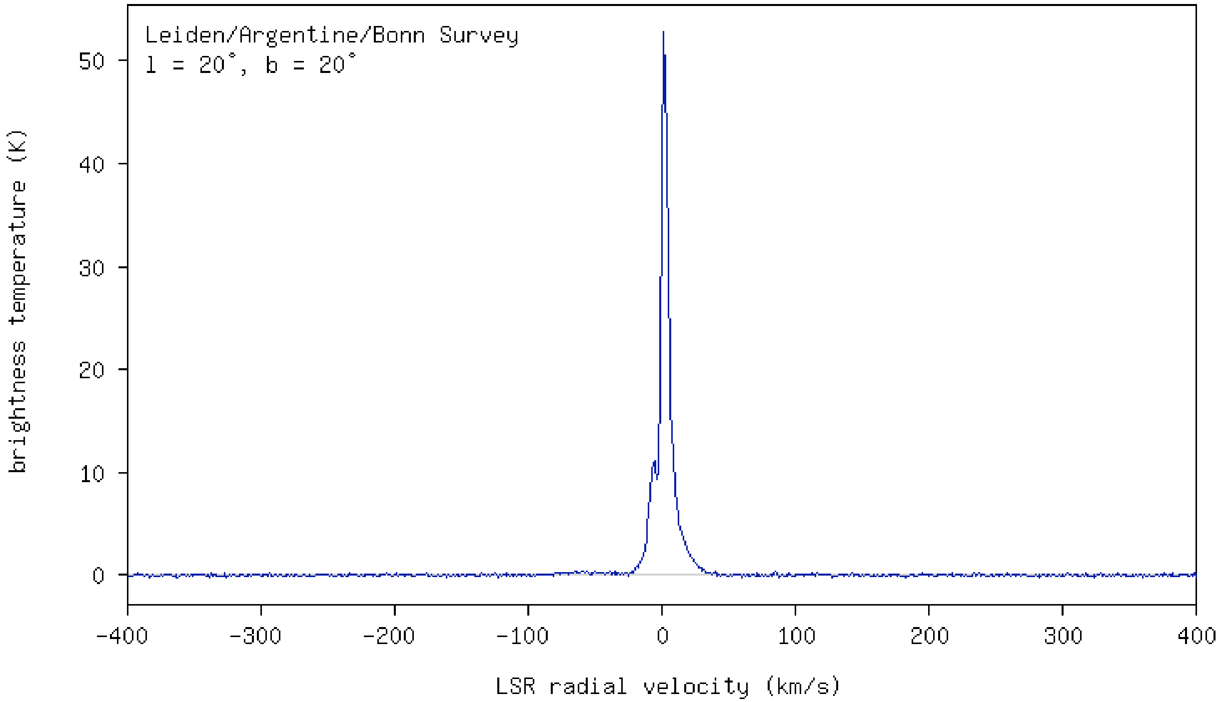
improved GMRT calibration scheme rms will drop by a factor of ~2-3 and using 119 redshift by factor of in total ~ 6-7

get your hands dirty

LAB Survey search results

http://www.astro.uni-bonn.de/~webaiub/english/tools_labsurvey.php

	RA	Dec	*l*	*b*	$N_{\mathrm{H\,I}}$
Selected position:	$17^h\ 17^m\ 0^s$	–1° 47' 0''	20.00°	20.00°	$0.973 \cdot 10^{21}$ cm^{-2}
Nearest position:	$17^h\ 17^m\ 0^s$	–1° 47' 0''	20.00°	20.00°	$0.973 \cdot 10^{21}$ cm^{-2}



You can » download the spectrum as an ASCII file with two columns separated by tabs (for Windows use WORDPAD). The first column gives the radial velocity in the LSR frame in km/s. The second column contains the corresponding brightness temperature in K.

get your hands dirty

http://www.atnf.csiro.au/research/multibeam/release/

from a genius idea to a proposal

is it a new approach?

check literature:

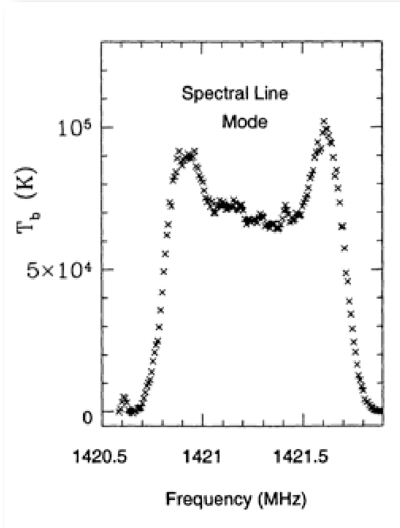
- astro-ph http://xxx.lanl.gov/archive/astro-ph
- ADS http://adsabs.harvard.edu/abstract_service.html
- www-search engine

data archives:

- VLA, VLBA, GBT http://archive.cv.nrao.edu/
- GMRT http://ncra.tifr.res.in/~gmrtarchive/
- EVN http://archive.jive.nl
- ATNF http://atoa.atnf.csiro.au/
- MERLIN http://www.merlin.ac.uk/archive/

observable?

- How strong is your source ? (Jy, mJy, μJy, nJy)

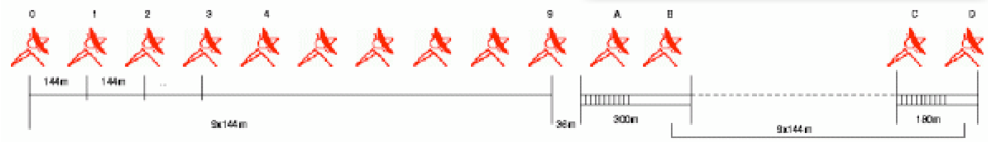


- Frequency range (< 300 MHz Ionosphere
  >15 - 20 GHz Troposphere)

- HI at redshift 1 : ν_{obs} = 1420.4/2 = 710.2 MHz

- source position (ra,dec,l,b)

http://nedwww.ipac.caltech.edu/forms/calculator.html



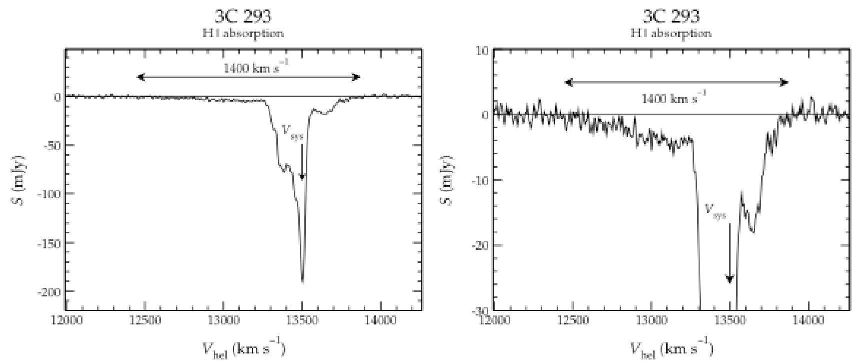
- observable at the observatory

altitude(median) = 90^o - |L - Dec|

L = latitude observatory
Dec = source declination

band / velocity

- line width versus bandwidth
- redshift: $z = \nu_{obs} / \nu_{restframe} - 1$
- velocity definition



$$\nu = \nu_0 \frac{\sqrt{1-\frac{v}{c}}}{\sqrt{1+\frac{v}{c}}}.$$

$$\frac{v}{c} = \frac{\nu_0^2 - \nu^2}{\nu_0^2 + \nu^2}.$$

$$\frac{v_{\mathrm{radio}}}{c} = \frac{\nu_0 - \nu}{\nu_0}.$$

$$\frac{v_{\mathrm{optical}}}{c} = \frac{\nu_0 - \nu}{\nu}.$$

CAUTION need to get that right!

Table 11–1. Velocity Rest Frames Derived from the Topocentric System

Rest Frame	Corrected for	Amplitude of Correction, km s^{-1}
Geocentric	Earth rotation	0.5
Earth-Moon Barycentric	Effect of the Moon on the Earth	0.013
Heliocentric	Earth's orbital motion	30
Solar System Barycentric	Effect of planets on the Sun	0.012
Local Standard of Rest	Solar motion	20
Galactocentric	Milky Way rotation	230
Local Group Barycentric	Milky Way motion	~100
Virgocentric	Local Group motion	~300
Microwave Background	Local Superclucster motion	~600

[Westpfahl; Chapter 11, Synthesis Imaging in RADIO ASTRONOMY II]

sensitivity image / baseline

[Wrobel & Walker; Chapter 9, Synthesis Imaging in RADIO ASTRONOMY II]

System Equivalent Flux Density

$$SEFD = \frac{T_{\rm sys}}{K} \qquad K = (\eta_{\rm a}\, A)\,/\,(2\,k_{\rm B})$$

equ. (9-5)

A = Area
K_b = Boltzmann
η_a = efficiency
η_s = losses in electronics
τ_{acc} = integration time [s]
$\Delta\nu$ = bandwidth [Hz]

Baseline sensitivity for one polarization

$$\Delta S_{\rm ij} = \frac{1}{\eta_{\rm s}} \sqrt{\frac{T_{\rm sysi}\, T_{\rm sysj}}{2\,\Delta\nu\,\tau_{\rm acc}\, K_{\rm i}\, K_{\rm j}}} \qquad (9\text{–}13)$$

or in terms of the $SEFD$s defined in Equation 9–5:

$$\Delta S_{\rm ij} = \frac{1}{\eta_{\rm s}} \sqrt{\frac{SEFD_{\rm i}\, SEFD_{\rm j}}{2\,\Delta\nu\,\tau_{\rm acc}}} \qquad (9\text{–}14)$$

Image sensitivity for one polarization

$$\Delta I_{\rm m} = \frac{1}{\eta_{\rm s}} \frac{SEFD}{\sqrt{N\,(N-1)\,\Delta\nu\, t_{\rm int}}}. \qquad (9\text{–}23)$$

Divide by square root 2 for 2 polarization !

Feasibility

angular resolution
interferometer = 1.02 λ / D [halve power beam width]

e.g. 1.4 GHz ~ 21 cm; 10 km baselines: 1.02 0.21/10000 * 360/(2 pi) * 3600 = 4.4 arcsec

field of view [FoV] = 1.22 λ / D

[Napier, Chapter 3, page 41]

minimum brightness temperature

$$T_{\mathrm{b,min}} = \frac{2\ln 2}{\pi}\,\frac{c^2}{k_{\mathrm{B}}}\,\frac{\Delta I}{\nu^2\,\theta^2_{\mathrm{HPBW}}}, \qquad (9\text{–}27)$$

VLBI needs strong sources emission on mas scales

Feasibility - calibrators

calibrators:

4 absolute amplitude calibrator know

3C147, 3C48, 3C286 (~few percent polarized), 1934-638

phase-calibrator should be a point source !

HI Galactic calibrators S6, S7, S8

data base:

VLA - http://www.aoc.nrao.edu/~gtaylor/csource.html

NVSS - http://www.cv.nrao.edu/nvss/

VLBA - http://www.vlba.nrao.edu/astro/calib/index.shtml

proposal

- What do you want to do
- Why is that of interest
- Do you have a backup if the signal is not detected

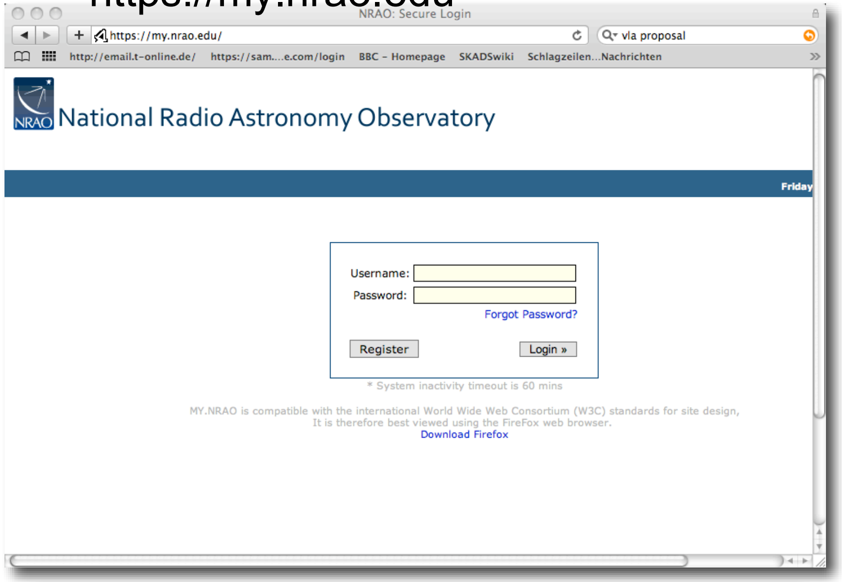
Proposal deadlines [no liability]

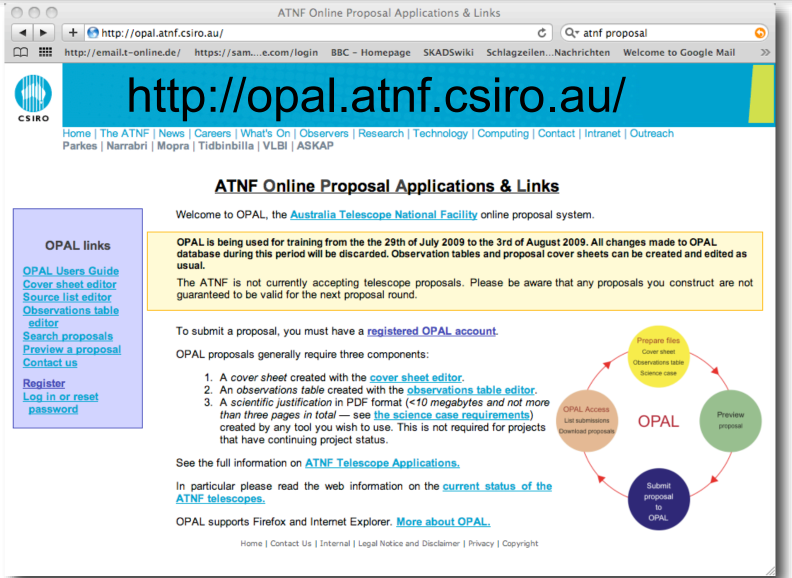
Effelsberg, EVN, VLBA & VLBI	1st Februray, June and October
WSRT	15th September next March 2010 http://www.astron.nl/radio-observatory/pc-pages/wsrt-call-proposals/wsrt-call-proposals
VLA	1st and 1st October
GMRT	2 times a year http://www.ncra.tifr.res.in/~yogesh/quickstartguide.html
MERLIN	15 th March & 15th September
ATNF	15 th June 15th December

proposal tools - online

http://proposal.mpifr-bonn.mpg.de/

https://my.nrao.edu



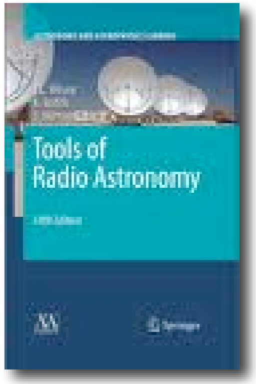


next proposal deadline is

1st October

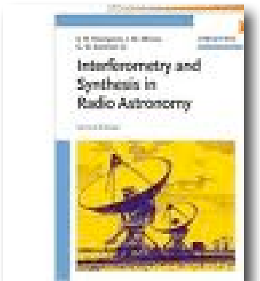
are you ready ?

literature



Tools of Radio Astronomy

Synthesis Imaging in radio astronomy



Interferometry and Synthesis in Radio Astronomy