The HI Environment of Galaxies

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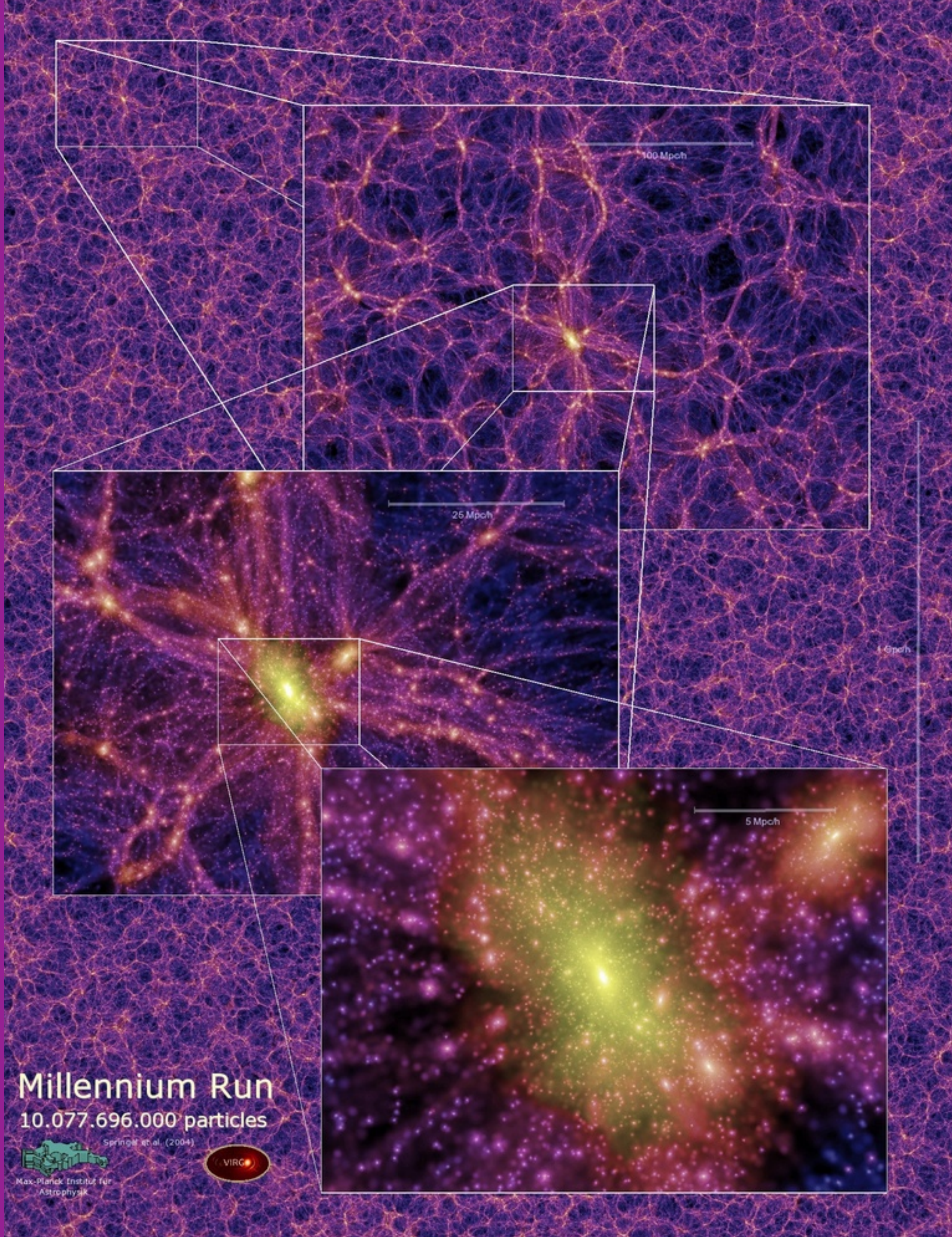
Galaxy formation

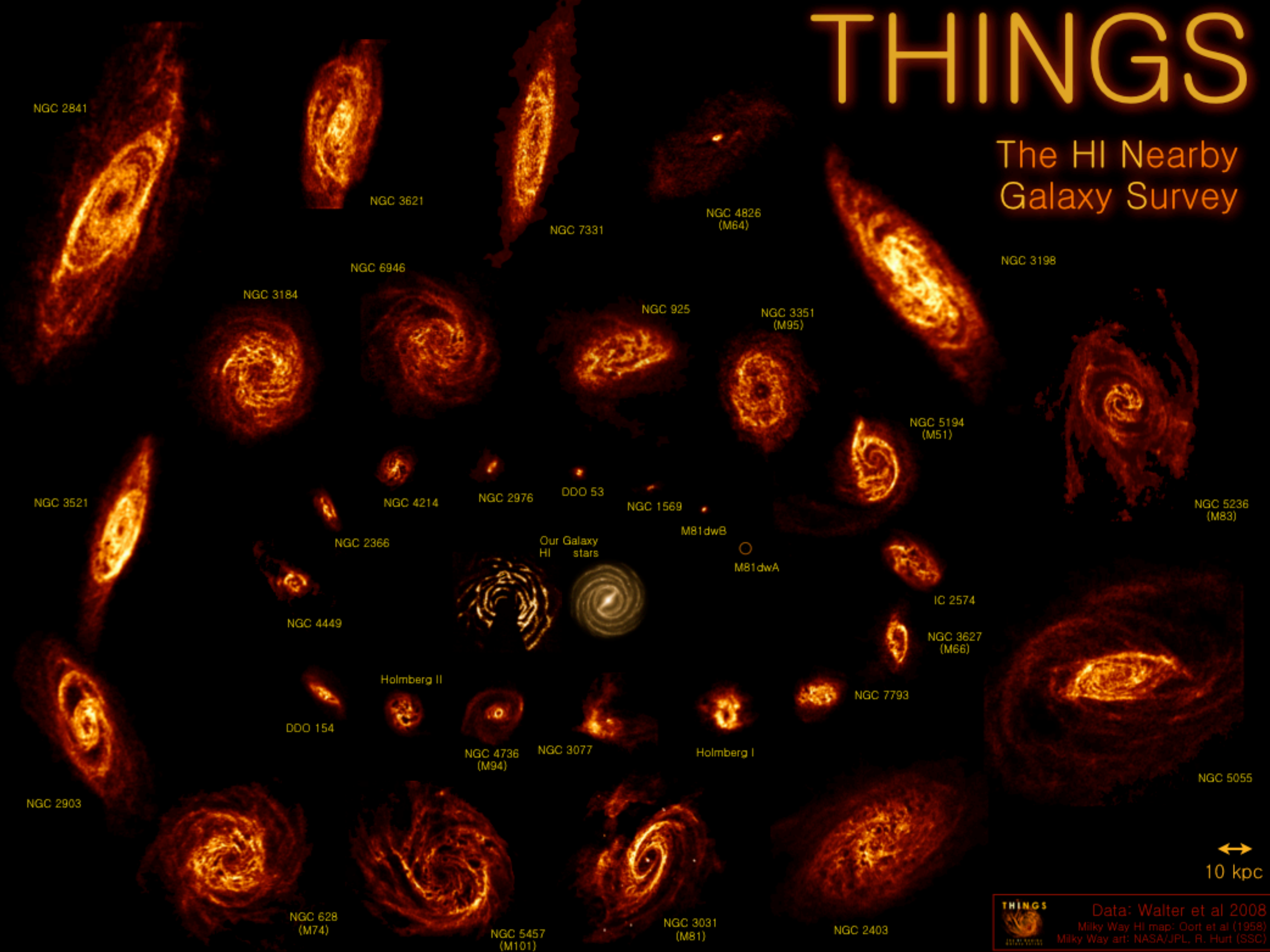
baryons flow into the DM halos and form galaxies

galaxies merge into larger galaxies

gas continues to flow in from the cosmic web

Is this observable?



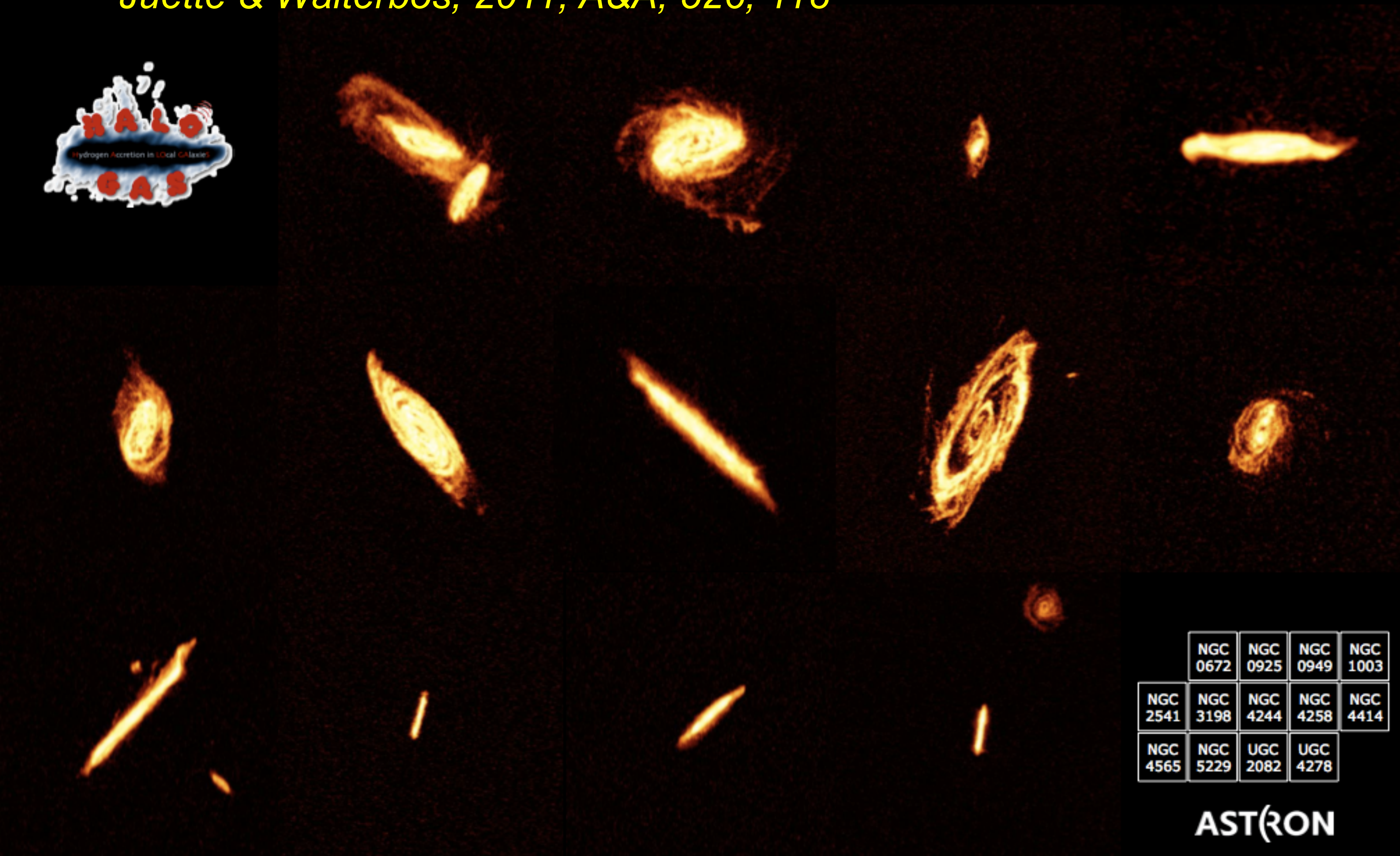


THINGS
The HI Nearby
Galaxy Survey
NGC 2841
NGC 3621
NGC 7331
NGC 4826
(M64)
NGC 3198
NGC 6946
NGC 3184
NGC 925
NGC 3351
(M95)
NGC 5194
(M51)
NGC 5236
(M83)
NGC 3521
NGC 4214
NGC 2976
DDO 53
NGC 1569
M81dwB
NGC 2366
Our Galaxy
HI
stars
M81dwA
IC 2574
NGC 4449
NGC 3627
(M66)
Holmberg II
NGC 7793
DDO 154
NGC 4736
(M94)
NGC 3077
Holmberg I
NGC 5055
NGC 2903
10 kpc
NGC 628
(M74)
NGC 5457
(M101)
NGC 3031
(M81)
NGC 2403
THINGS
Data: Walter et al 2008
Milky Way HI map: Oort et al (1958)
Milky Way art: NASA/JPL, R. Hurt (SSC)

Normal looking galaxies?

Deeper WSRT observations: Halogas project

Heald, Oosterloo, Fraternali, Sancisi, Rand, Serra, Jozsa, Gentile, Juette & Walterbos, 2011, A&A, 526, 118

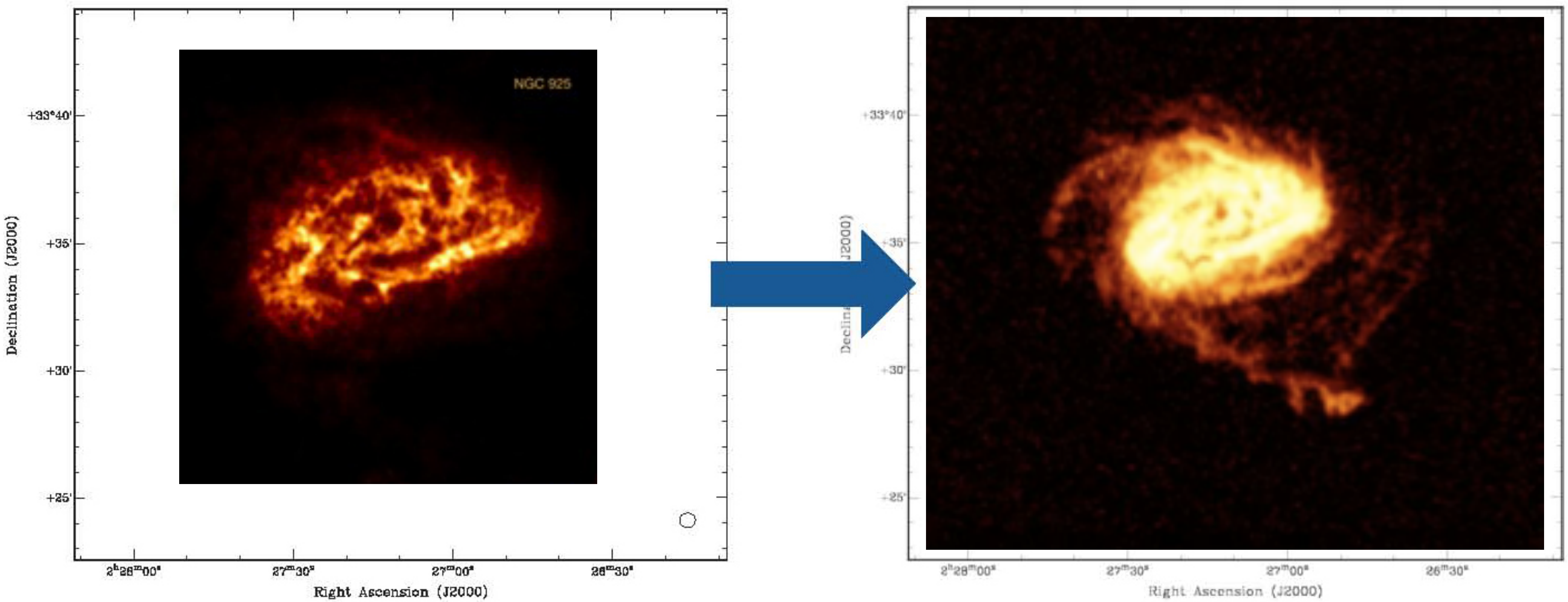


The HALOGAS project

(Heald et al. 2011, A&A, 526, 118)

Will provide a large database of the deepest available HI observations of nearby galaxies - complementary to THINGS (HALOGAS strength is detecting faint diffuse emission; THINGS strength is small-scale structure)

example: ***NGC 925***

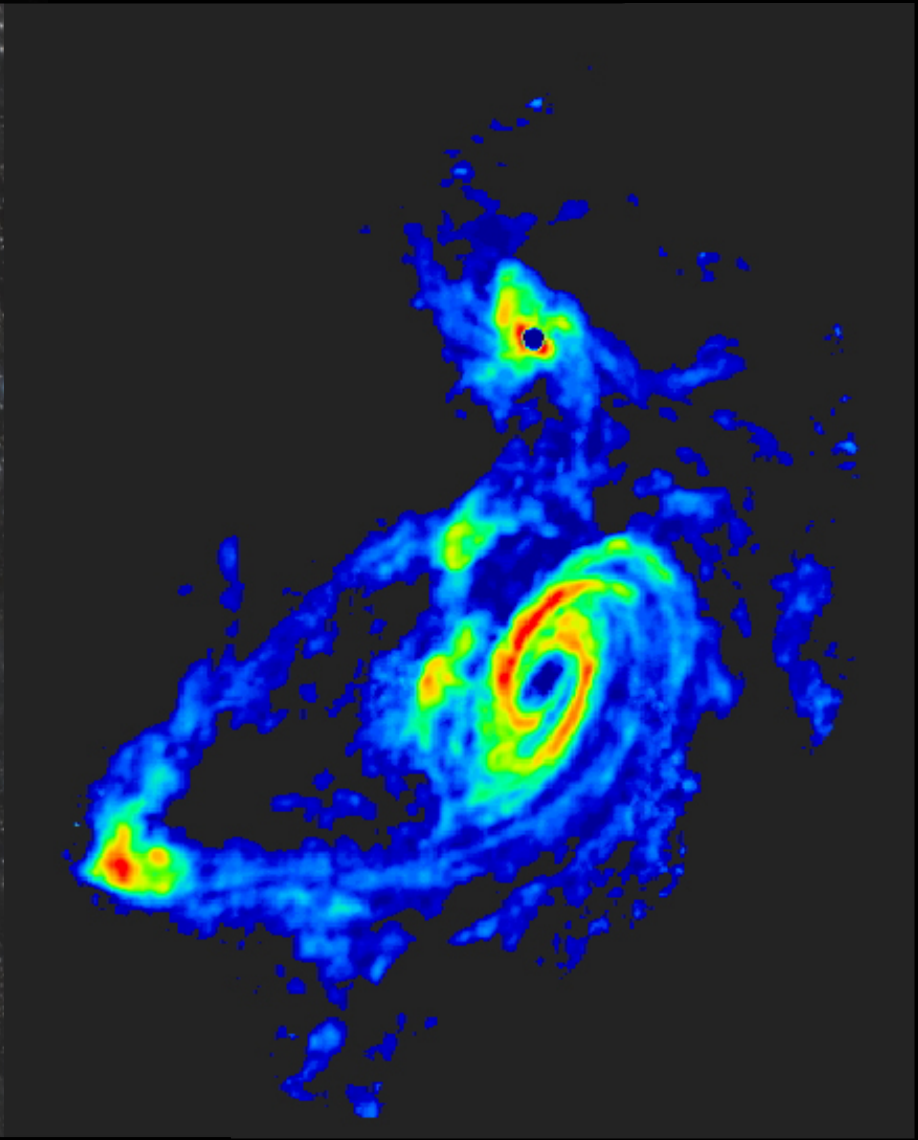


THINGS

HALOGAS

M81/M82/NGC3077

VLA HI mosaic

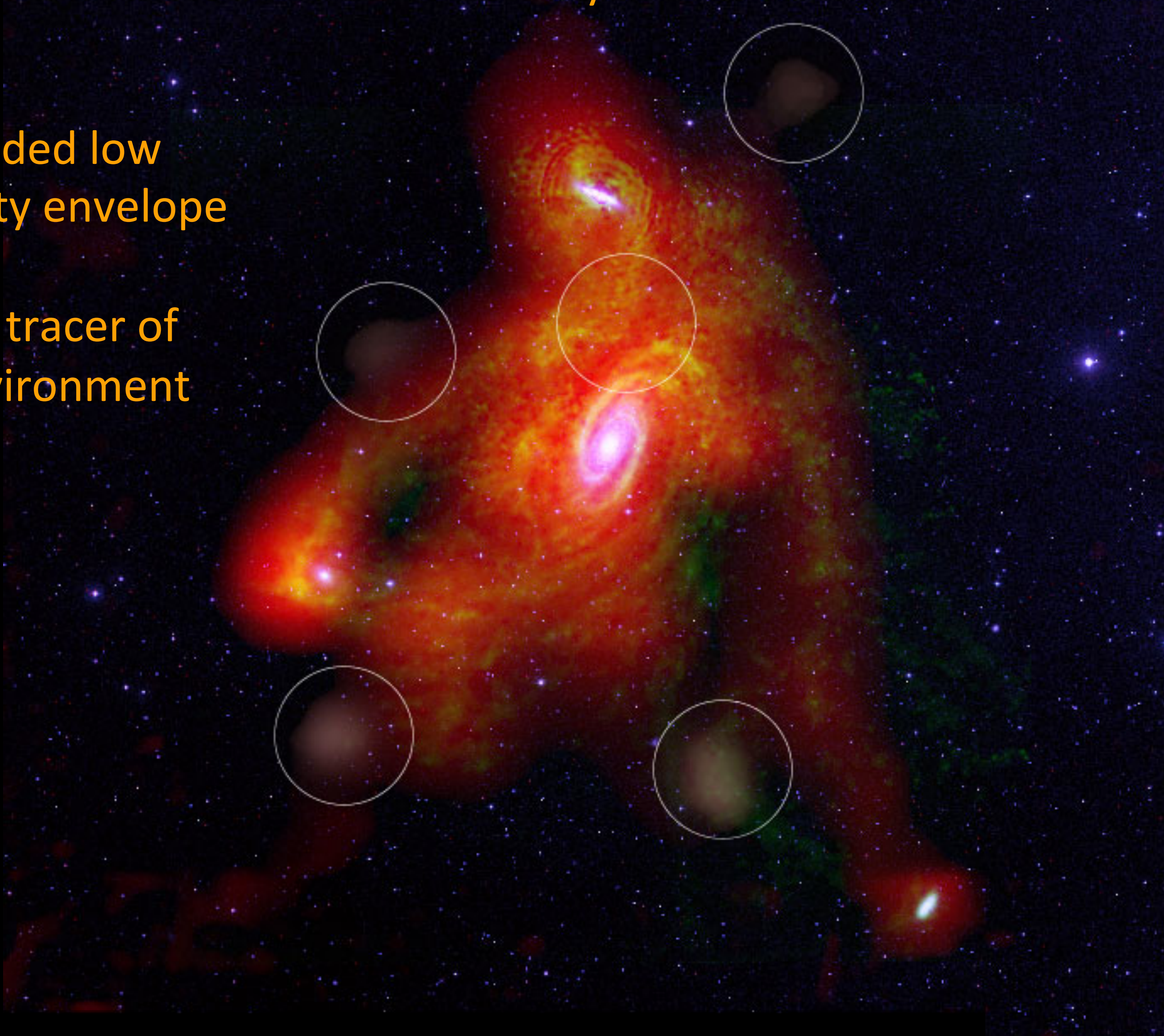


Yun et al. Nature 1994, 372, 530

M81/M82/N3077 VLA Mosaic + GBT survey

Reveals extended low column density envelope

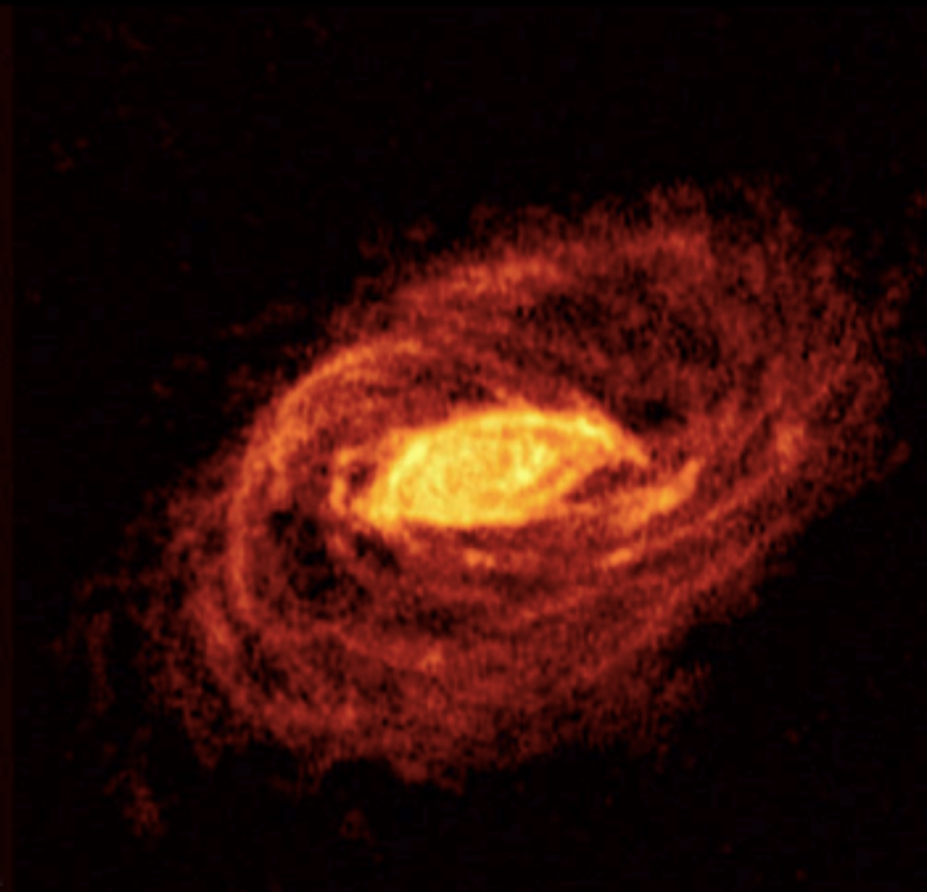
HI is a superb tracer of the direct environment



NGC 5033 warped outer disk with structure

HI much more extended ?

DSS image



WSRT HI image

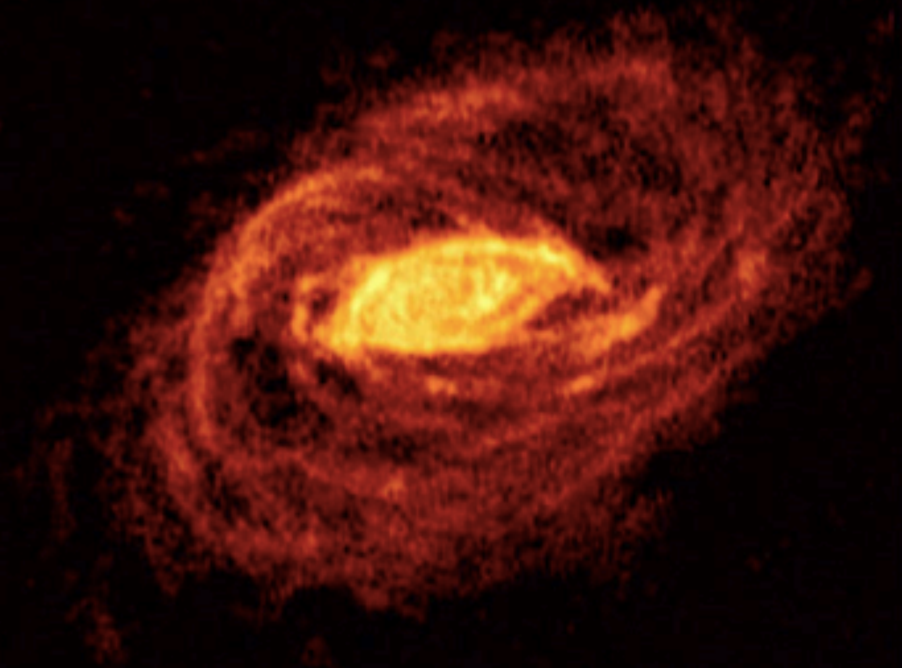
(Battaglia et al. 2005, A&A,447,49)

NGC 5033 warped outer disk with structure

Deep images also show structure in the outer disk

Deep optical image

(Martinez-Delgado et al. 2008, AJ 140, 962)

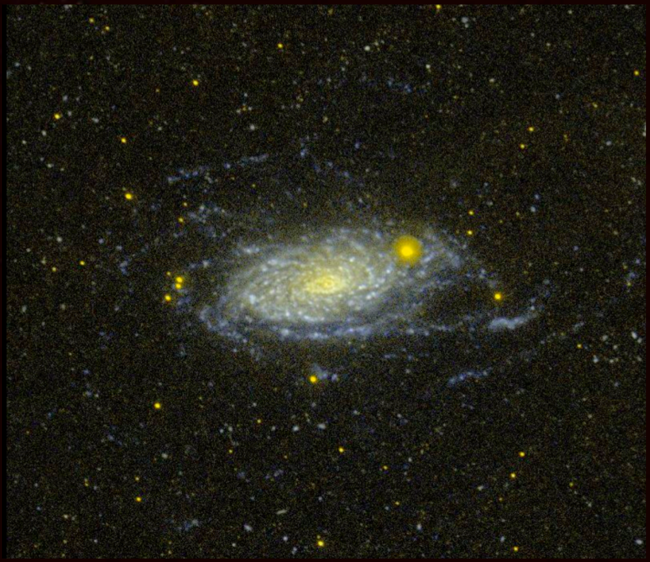


WSRT HI image

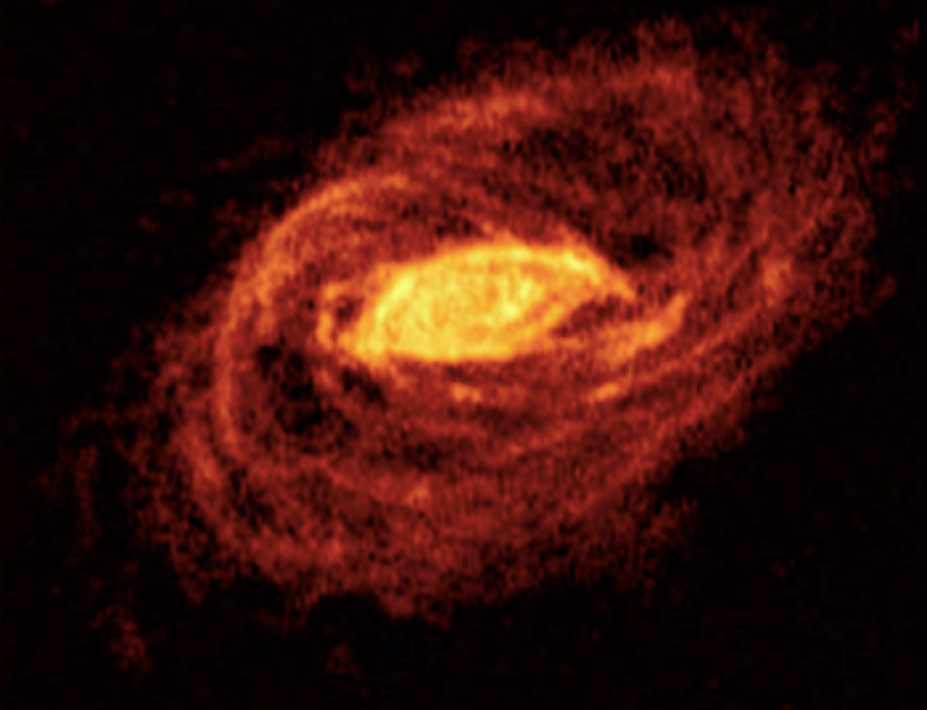
(Battaglia et al. 2005, A&A,447,49)

NGC 5033 warped outer disk with structure

UV images show star formation in the outer disk

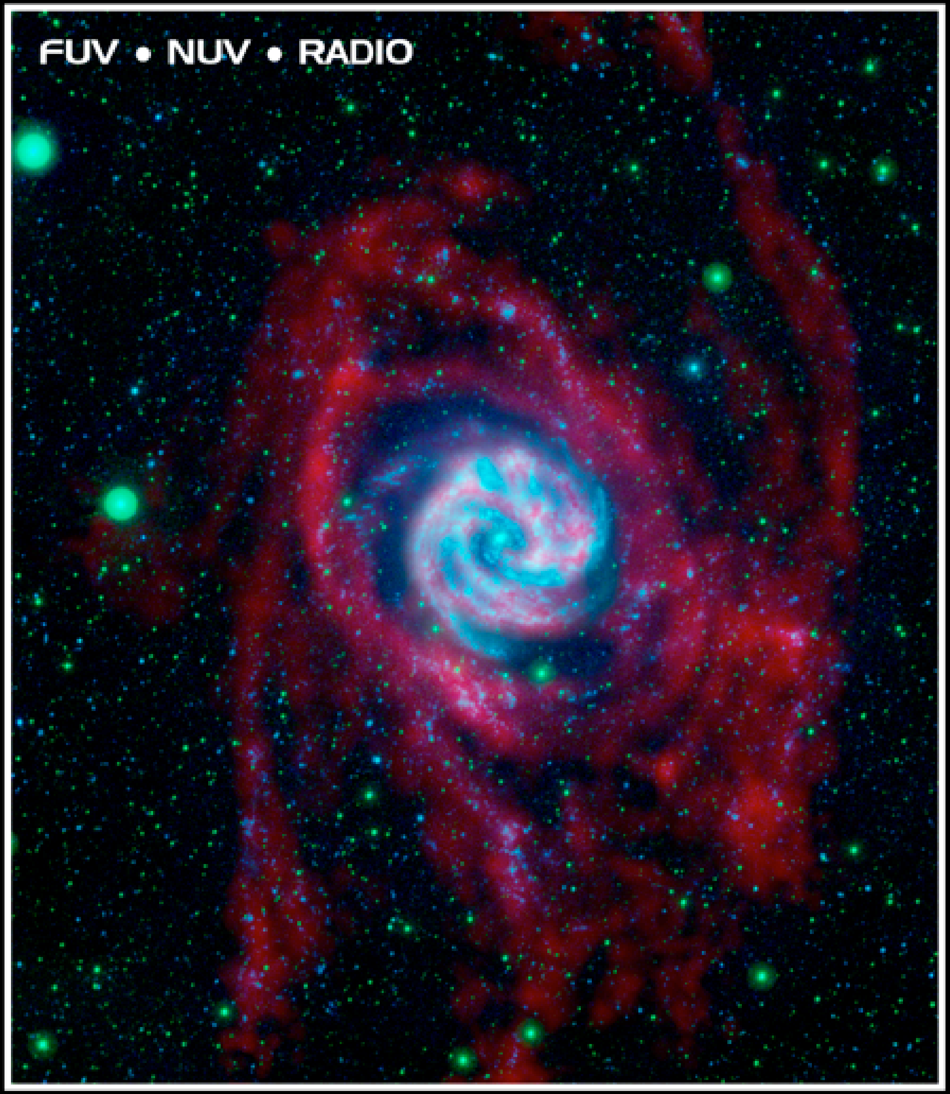


GALEX UV image
(Thilker et al. 2007, ApJS,173,538)



WSRT HI image
(Battaglia et al. 2005, A&A,447,49)

M83 its outer structure in HI and UV



Courtesy Dave Thilker and NASA/JPL-Caltech/VLA/MPIA

See also: Bigiel et al. 2010, ApJ,720,L31

HI traditionally a tracer of kinematics:

dark and luminous matter distribution

prominent tidal interactions

HI can tell us more:

we need to look carefully to recognise the evidence for processes governing the acquisition and removal of gas

Examples:

asymmetries in structure and kinematics

extraplanar gas

gas with anomalous velocities

HI *observations in the local universe*

(Sancisi, Fraternali, Oosterloo & v.d. Hulst. 2008, A&A Rev. 15, 189)

- ***Extended HI*** *disks with outer* ***spiral*** *structure*

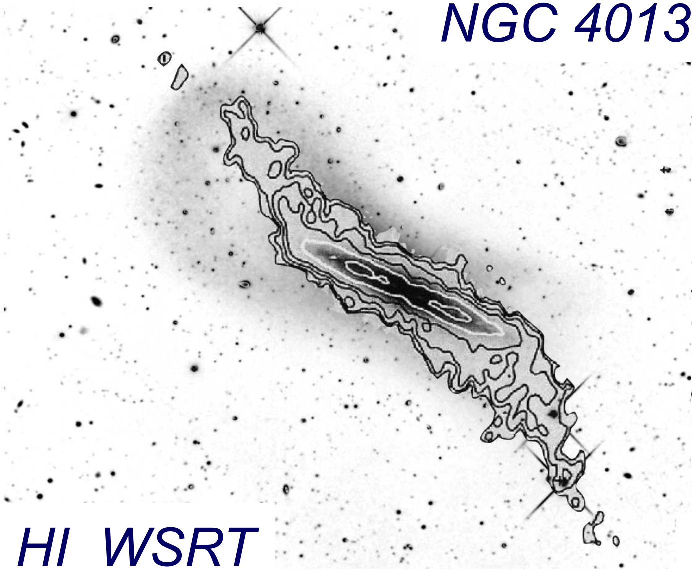
- *Large number of* ***WARPED*** *and* ***LOPSIDED*** *disks*

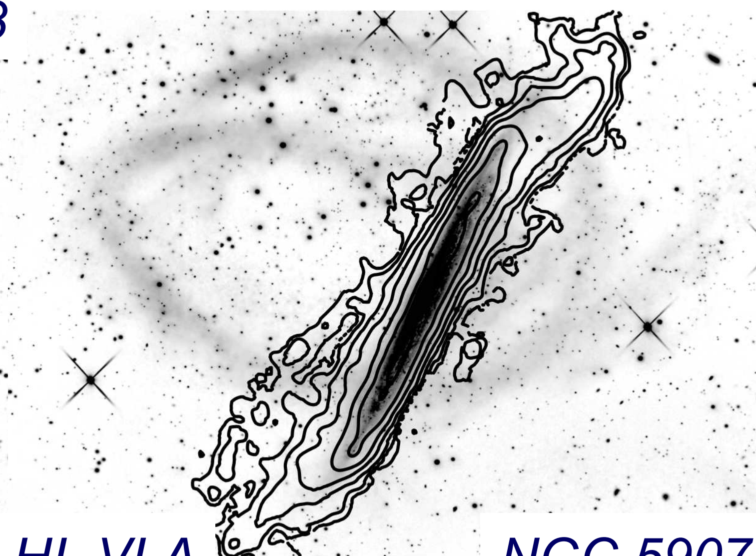
- *Large reservoirs of* ***extra-planar*** *gas*

- ***Lumpy HI*** *structures (****clouds, tails, filaments****)*
  around galaxies

Result of recent minor ***mergers****,*
accretion, outflows, stripping

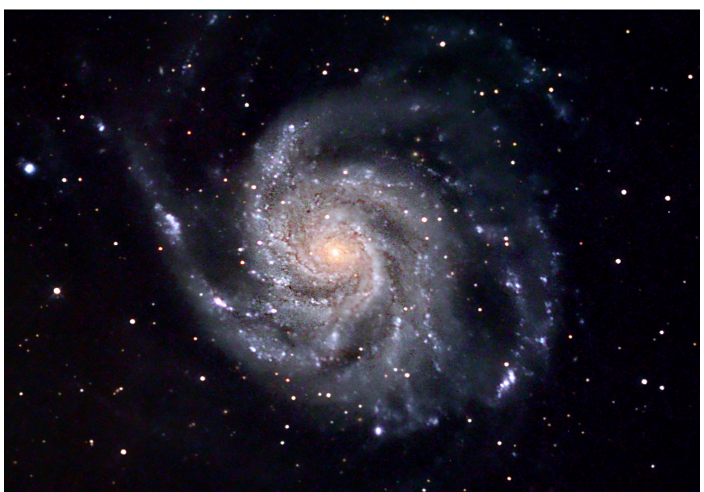
WARPS

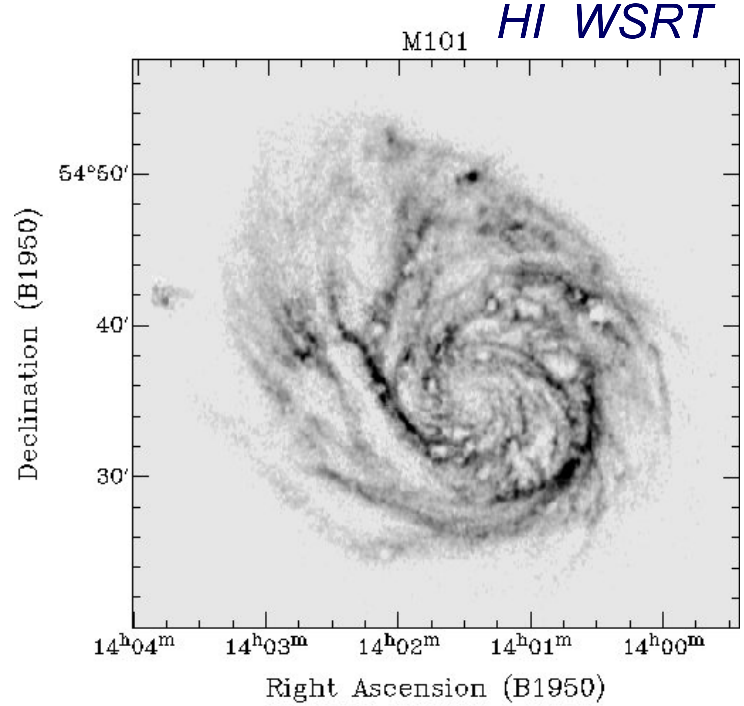




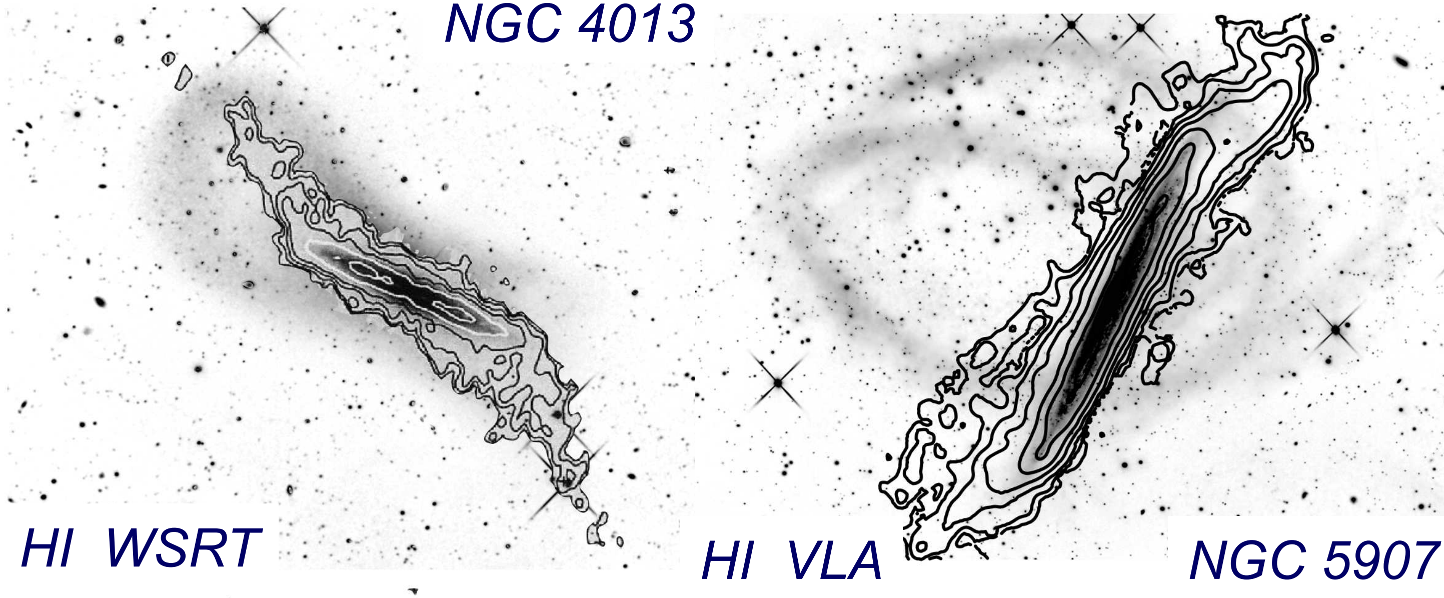
Martinez-Delgado et al. (2008/09)

LOPSIDEDNESS



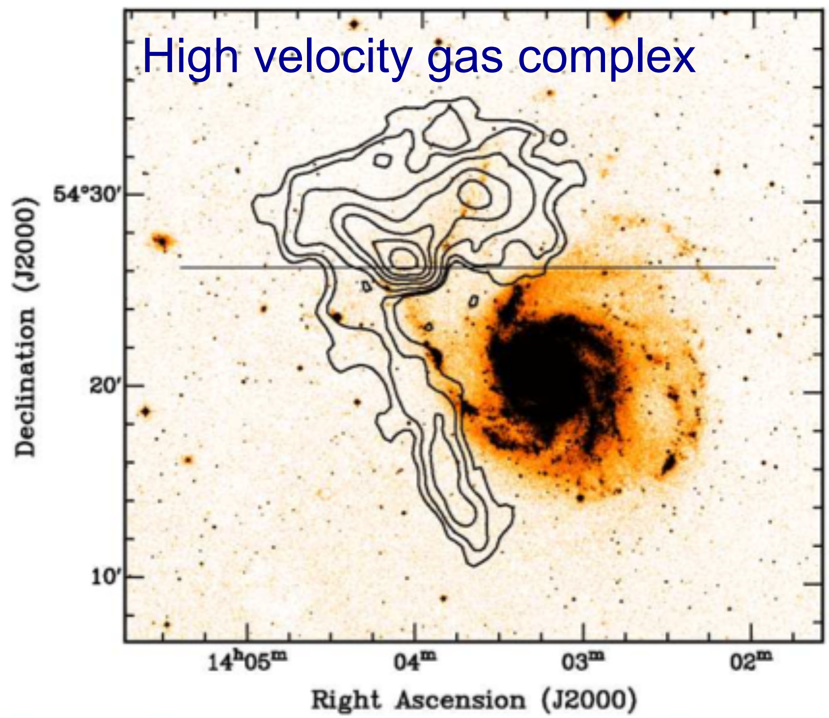


WARPS

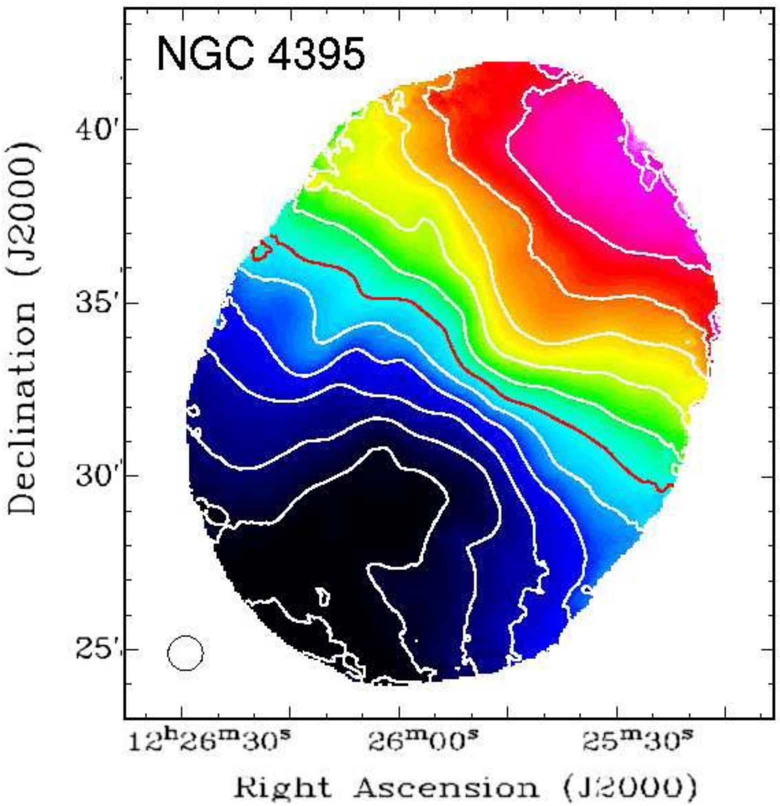


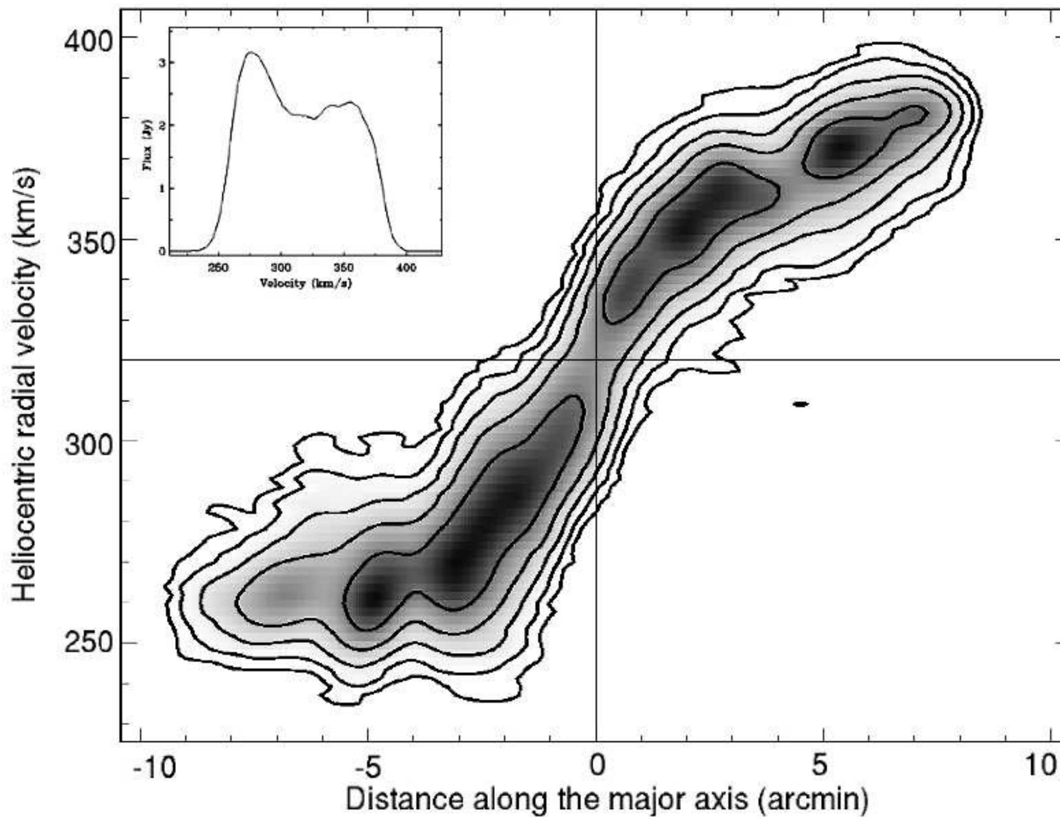
Martinez-Delgado et al. (2008/09)

LOPSIDEDNESS



KINEMATIC LOPSIDEDNESS



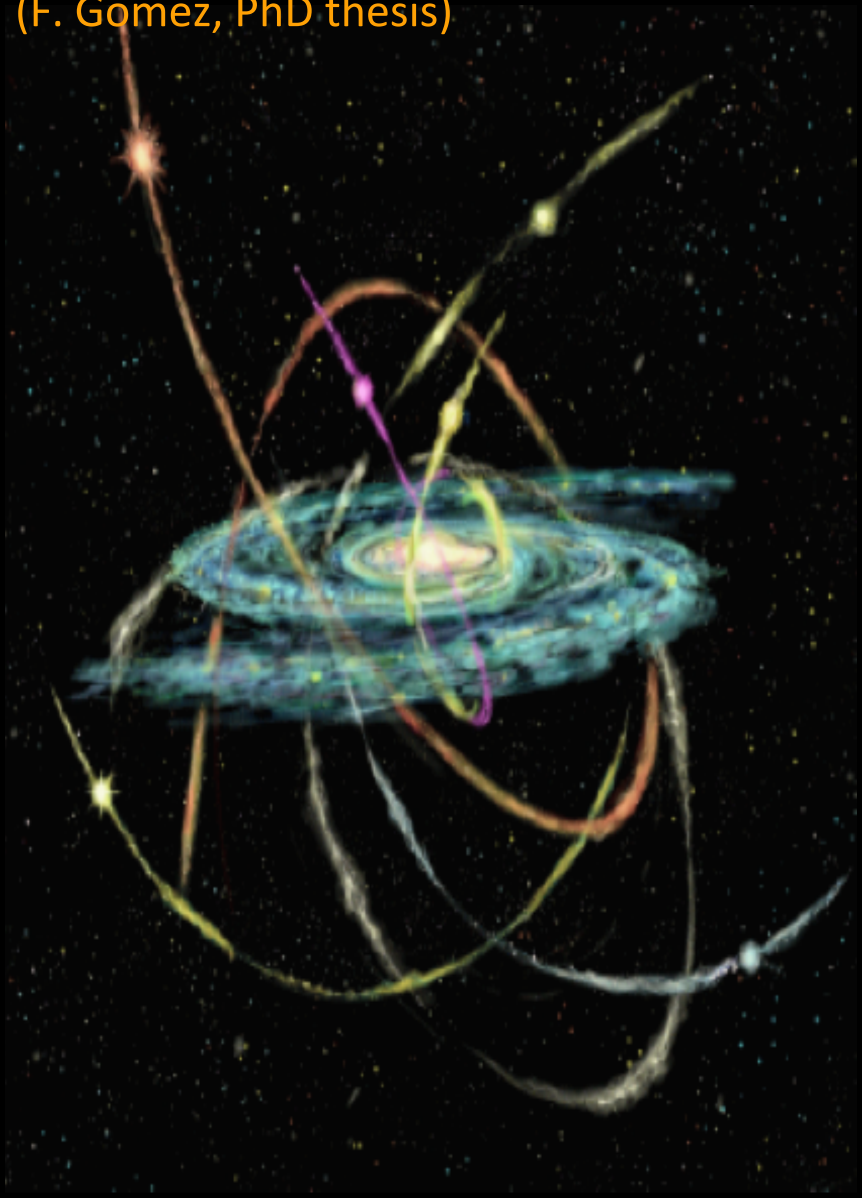


Heald and Oosterloo, 2008, ASP Conf. Series 396, 267

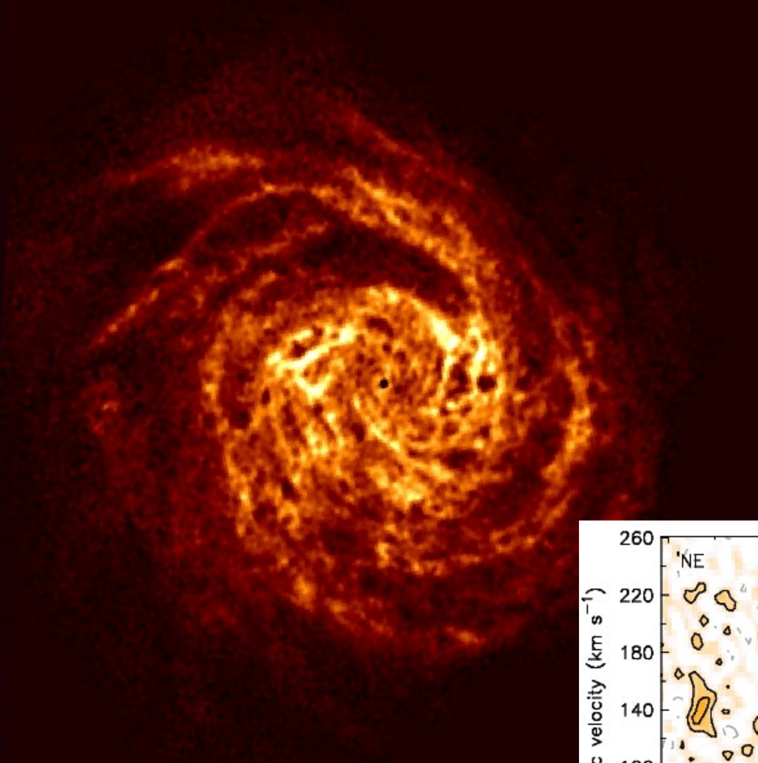
Building galaxies through accretion of satellites

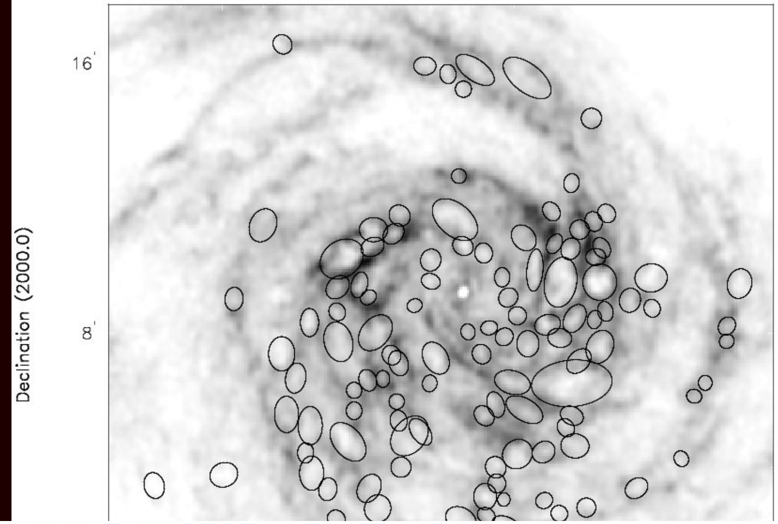
NGC 5907

Artist impression of satellite capture
(F. Gomez, PhD thesis)

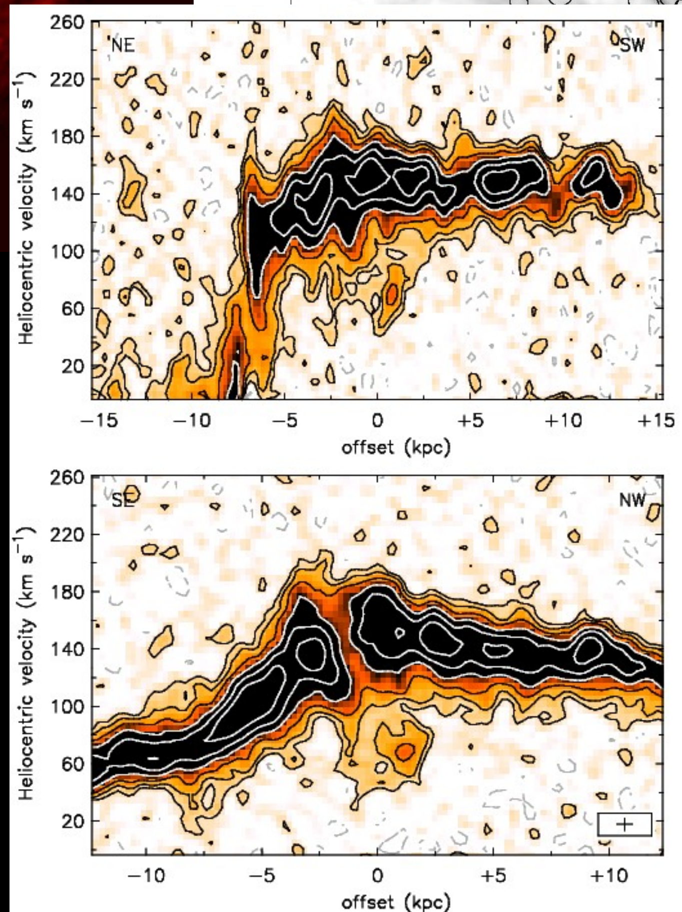


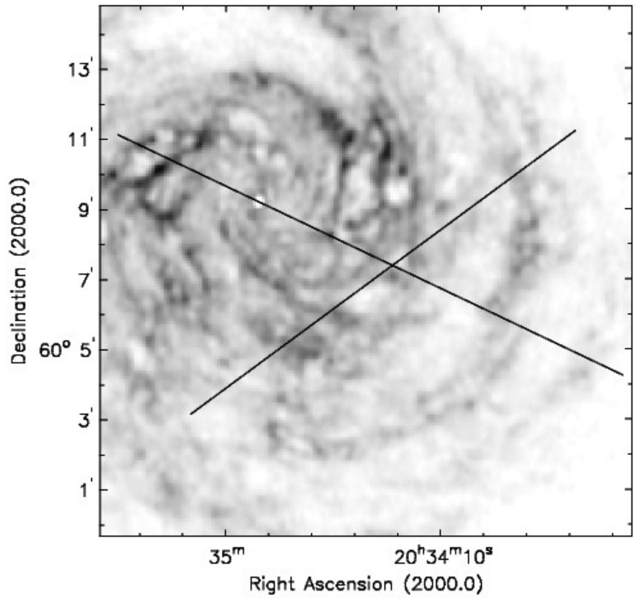
NGC 6946





"HIGH VELOCITY CLOUDS"
(total amount:
$\sim 3 \times 10^{8}\ M_{\odot}$)

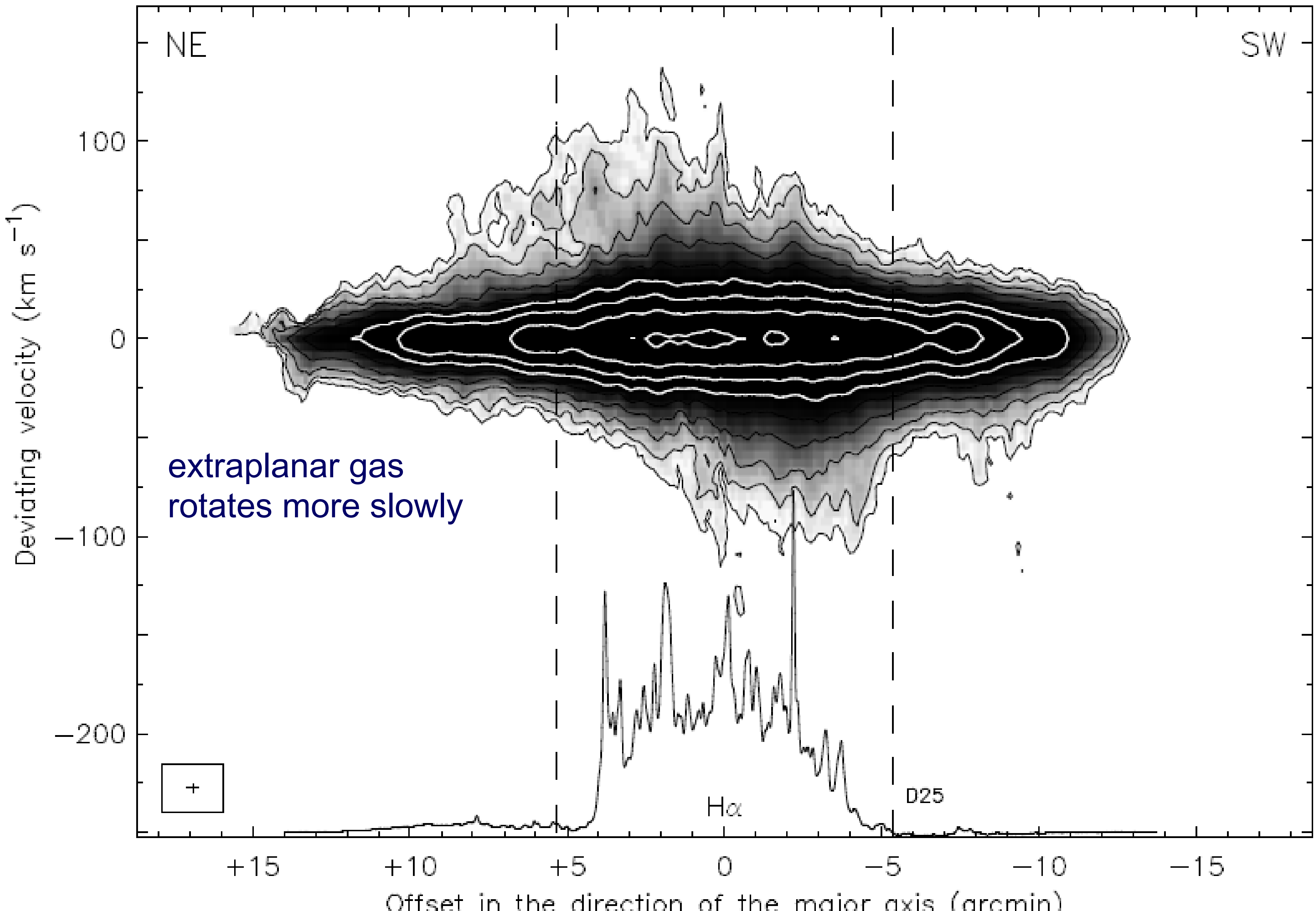




Boomsma et al. 2008
A&A 490, 555

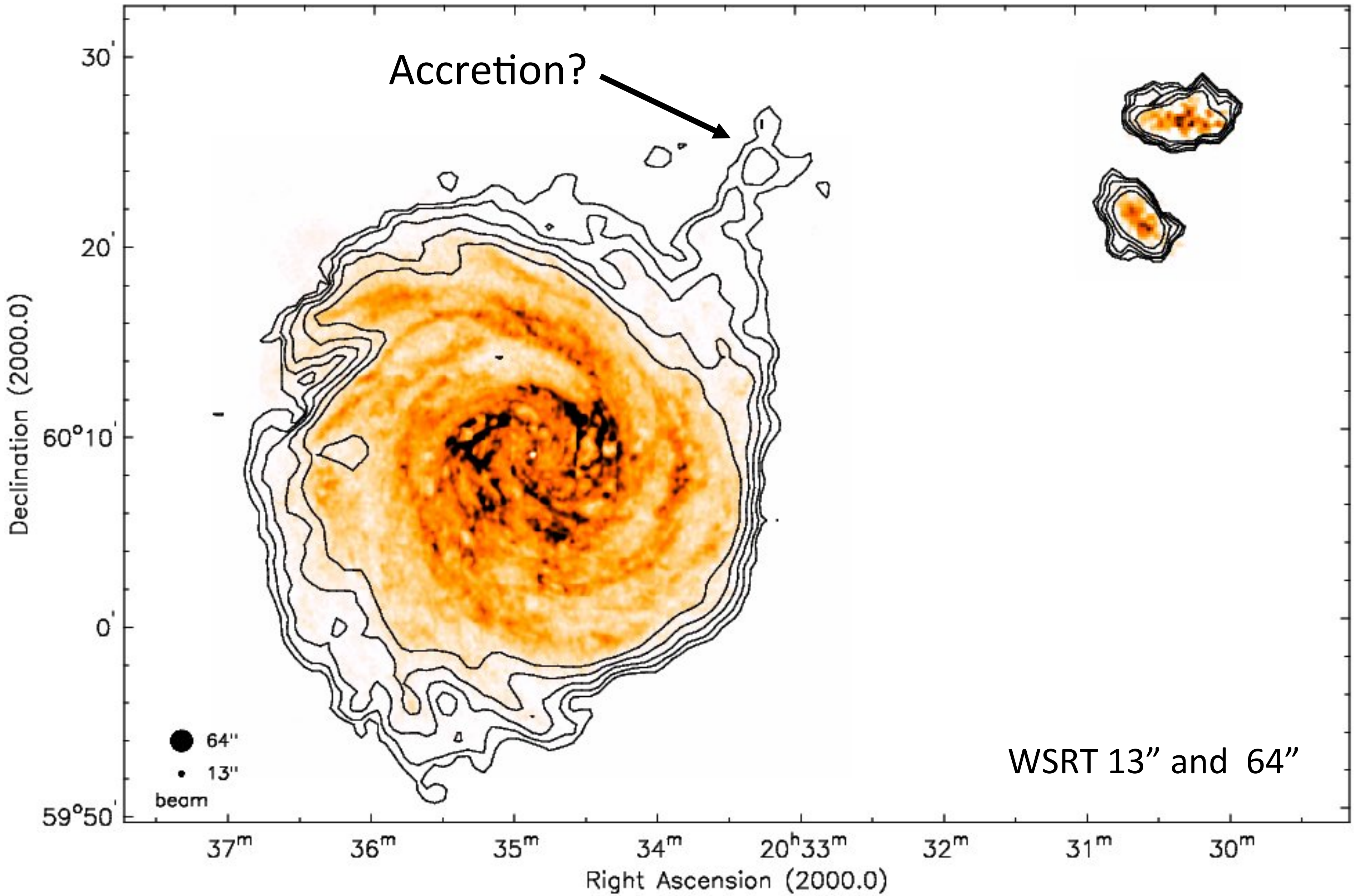
NGC 6946 extraplanar gas

Boomsma, PhD Thesis 2007



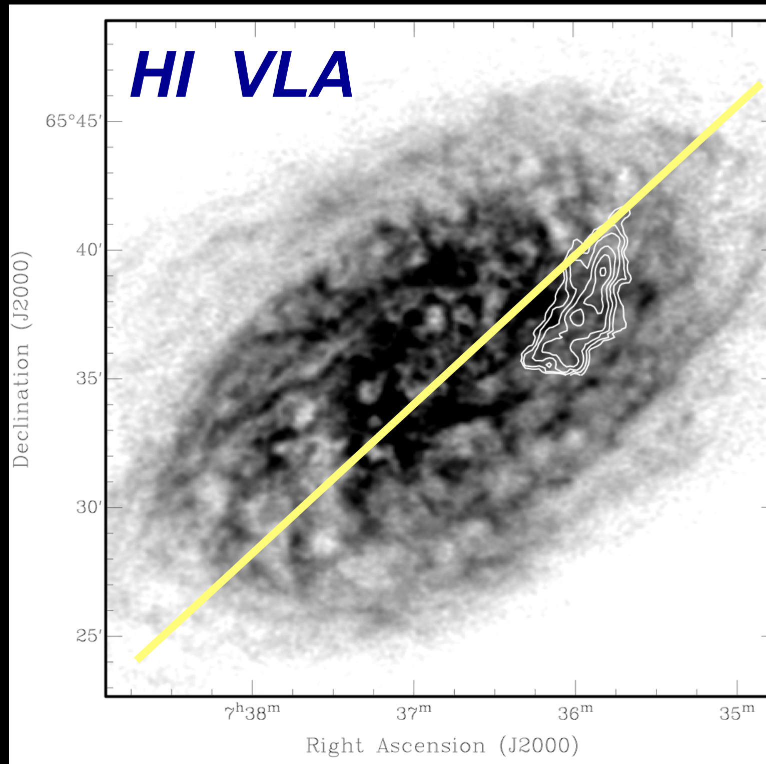
NGC 6946 HI

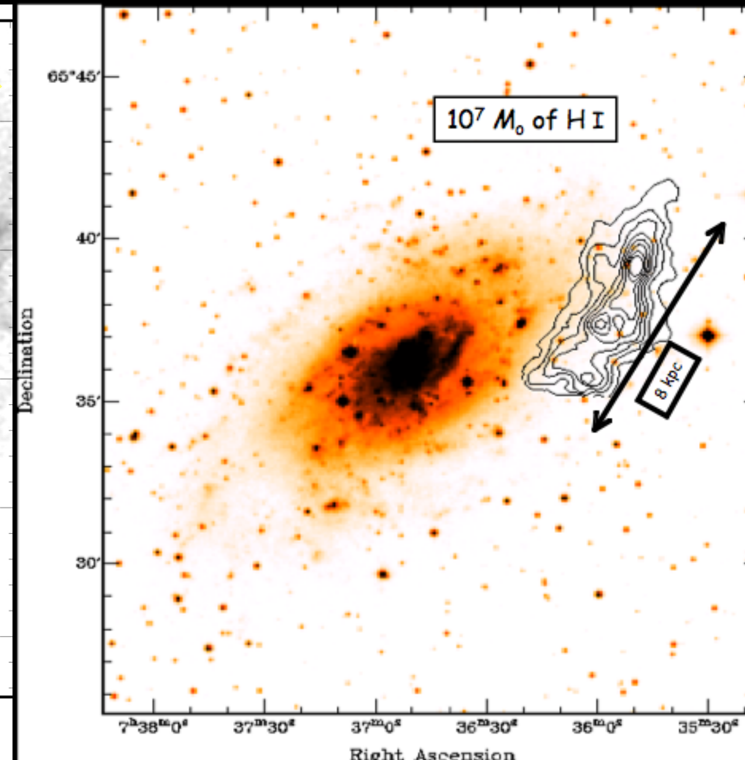
Boomsma et al. 2008, A&A 490, 555

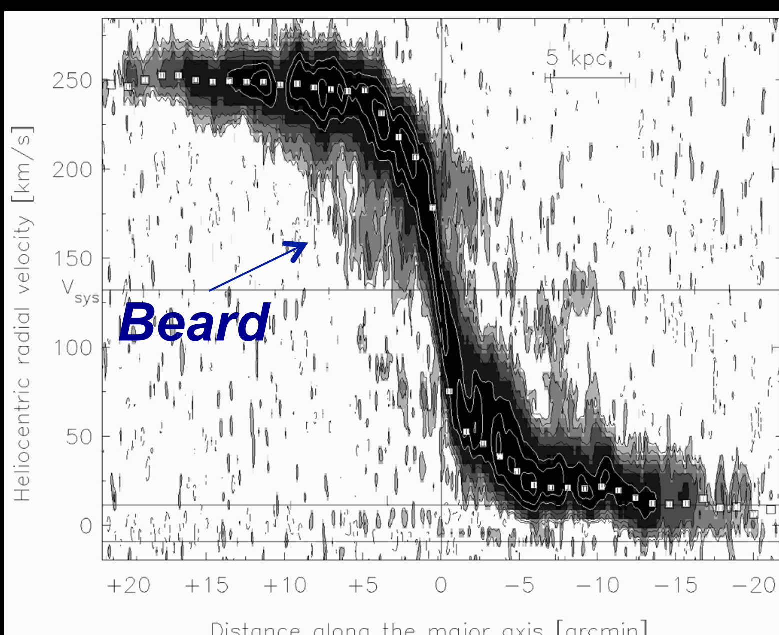


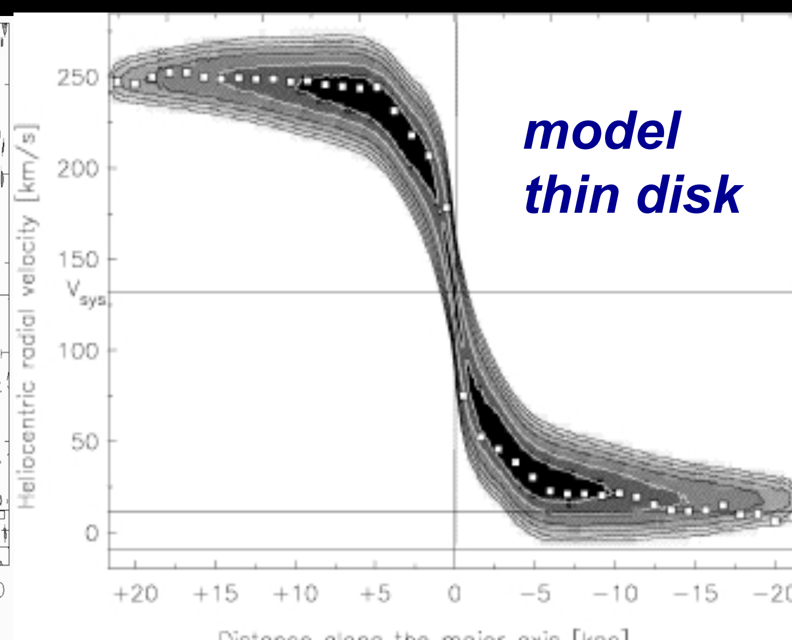
NGC 2403

Anomalous gas
gas
$3x10^8$ $M_\odot$

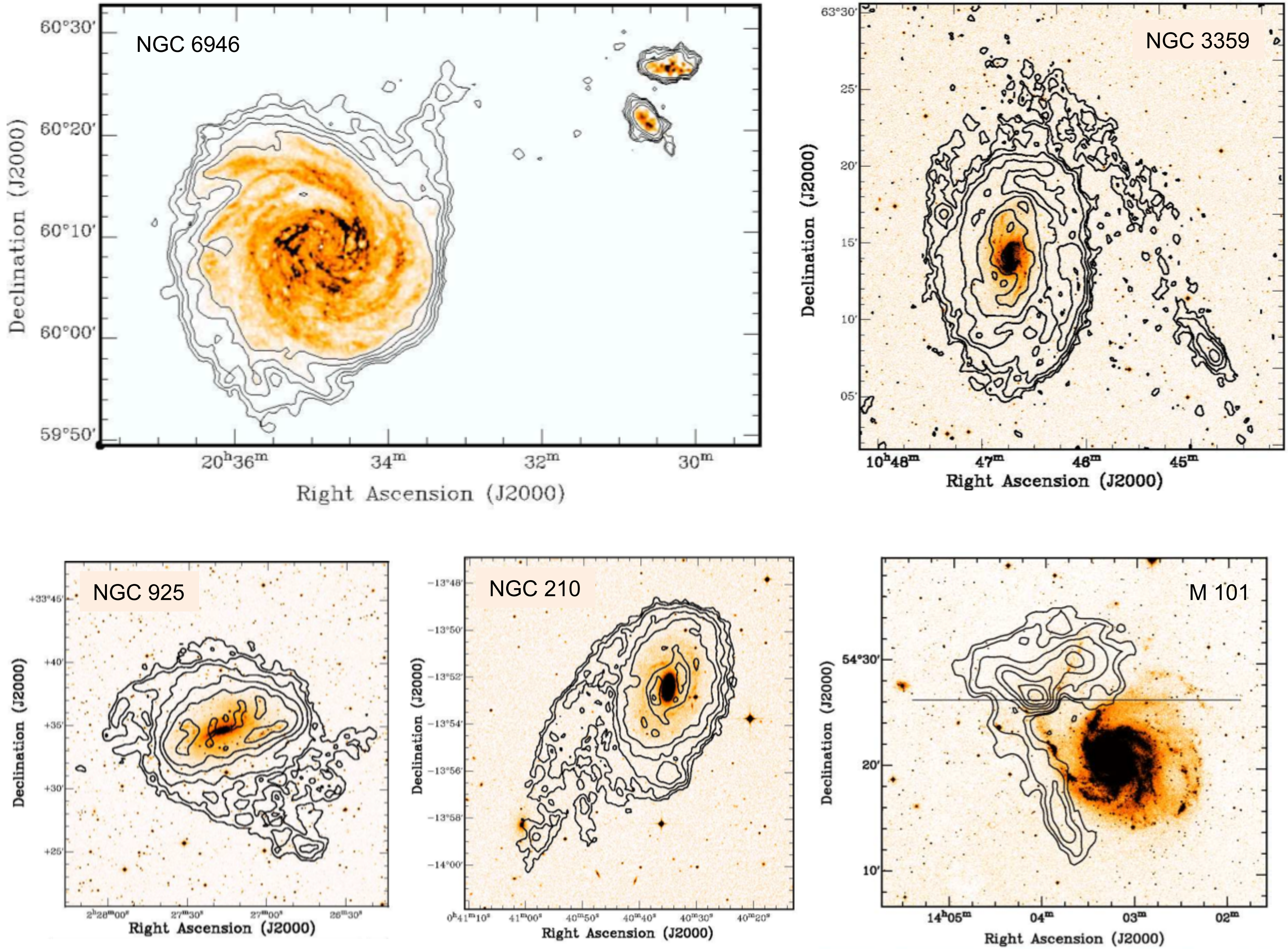






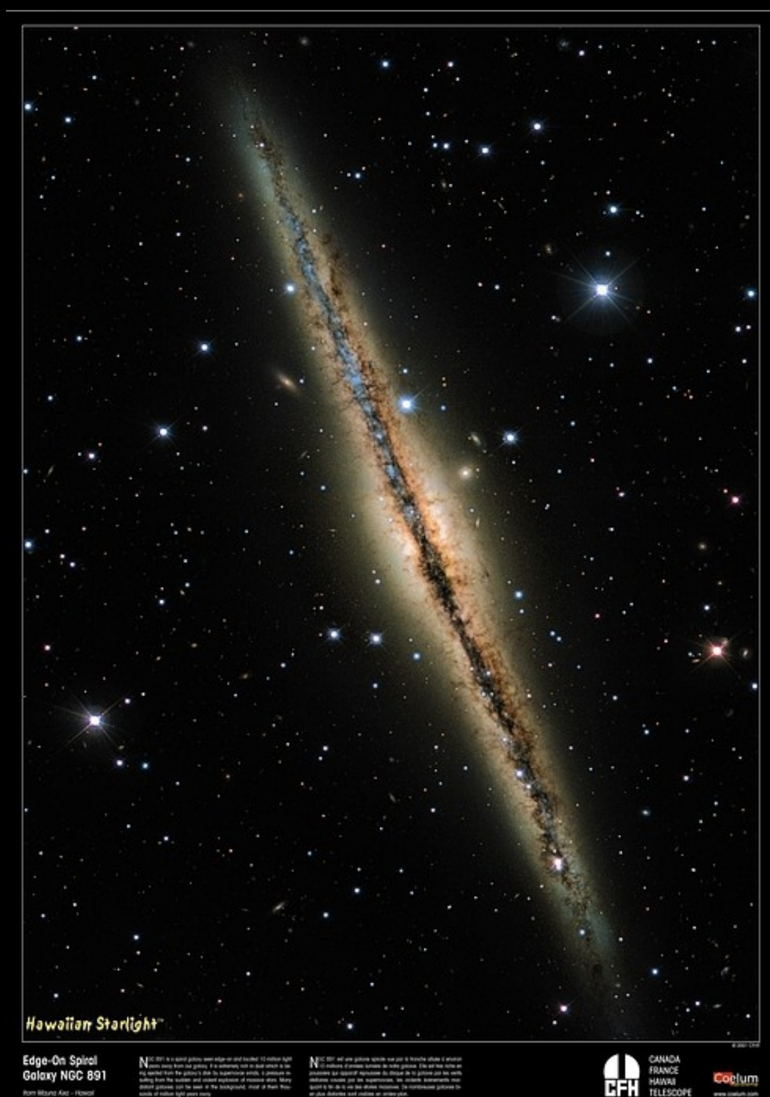


Fraternali, Oosterloo et al. 2001 ApJ 562,47


NGC 6946
60°30′
60°20′
60°10′
60°00′
59°50′
Declination (J2000)
20h36m
34m
32m
30m
Right Ascension (J2000)
NGC 3359
63°30′
25′
20′
15′
10′
05′
Declination (J2000)
10h48m
47m
46m
45m
Right Ascension (J2000)
NGC 925
+33°45′
+40′
+35′
+30′
+25′
Declination (J2000)
2h28m00s
27m30s
27m00s
26m30s
Right Ascension (J2000)
NGC 210
−13°48′
−13°50′
−13°52′
−13°54′
−13°56′
−13°58′
−14°00′
Declination (J2000)
0h41m10s
41m00s
40m50s
40m40s
40m30s
40m20s
Right Ascension (J2000)
M 101
54°30′
20′
10′
Declination (J2000)
14h05m
04m
03m
02m
Right Ascension (J2000)

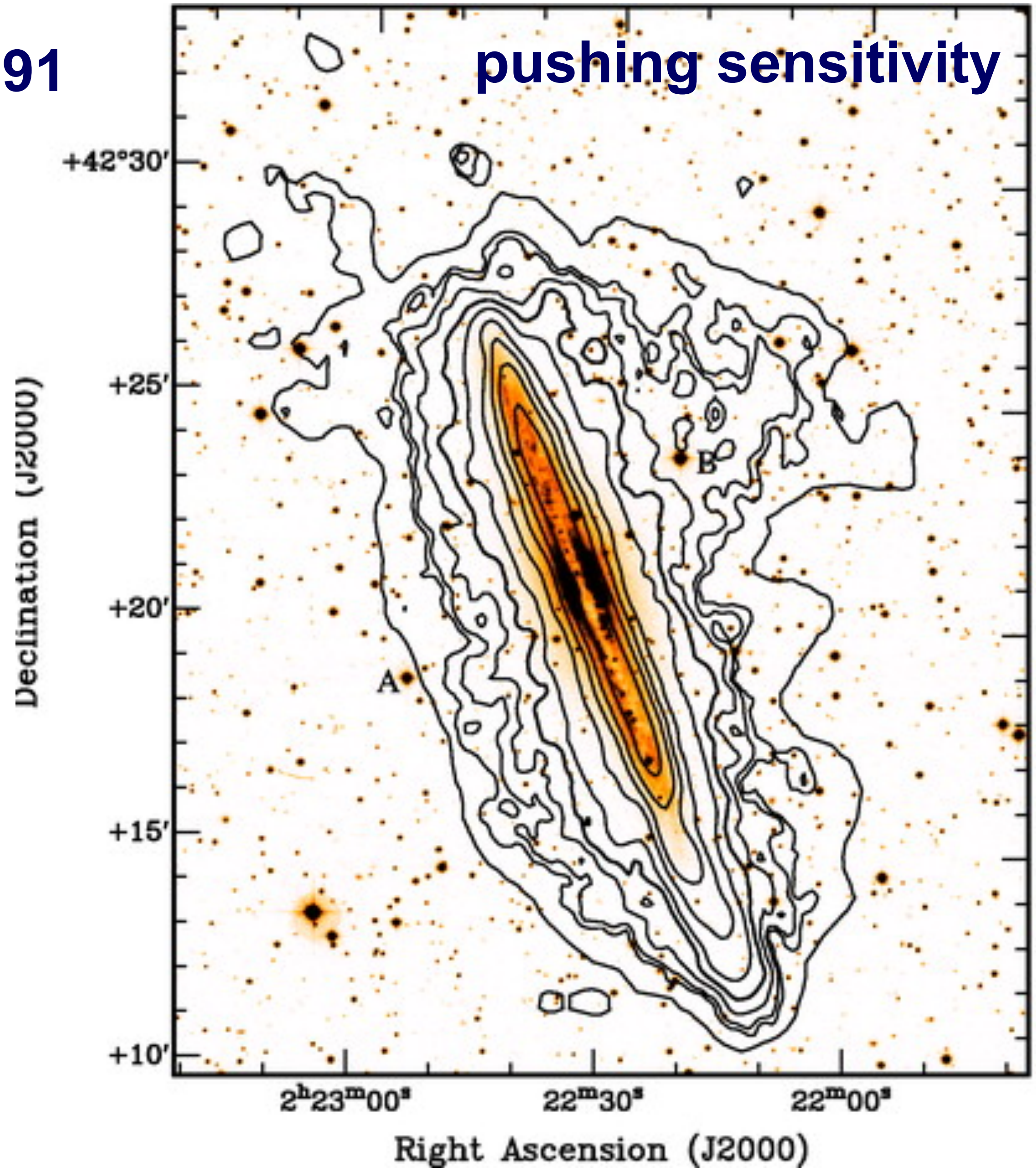
NGC 891 *edge-on galaxy: extra-planar gas?*

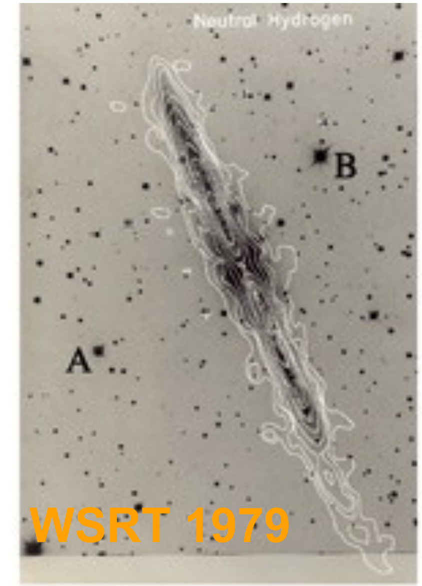
optical

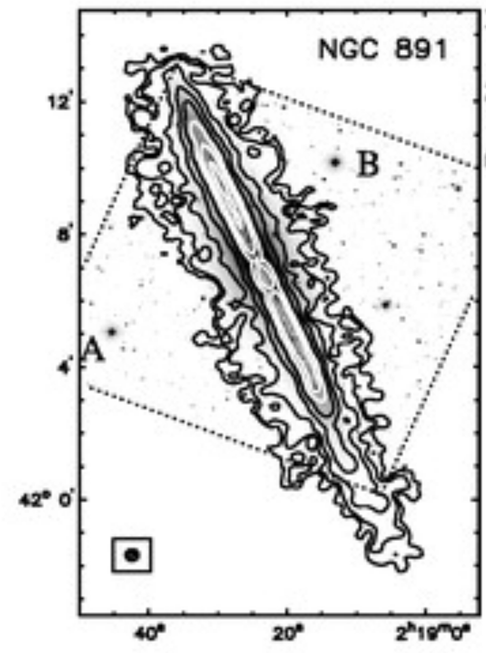


near infrared

NGC 891



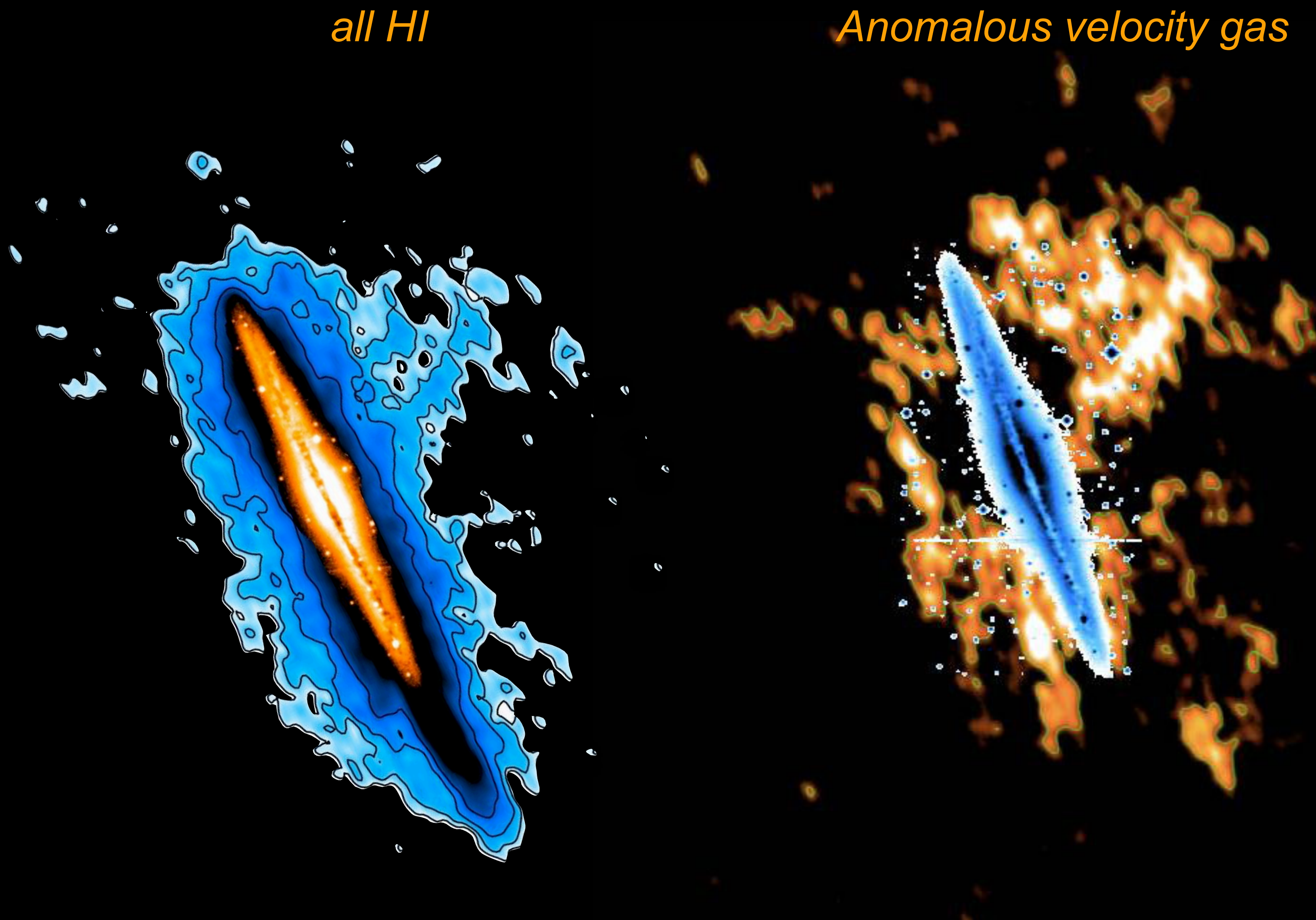




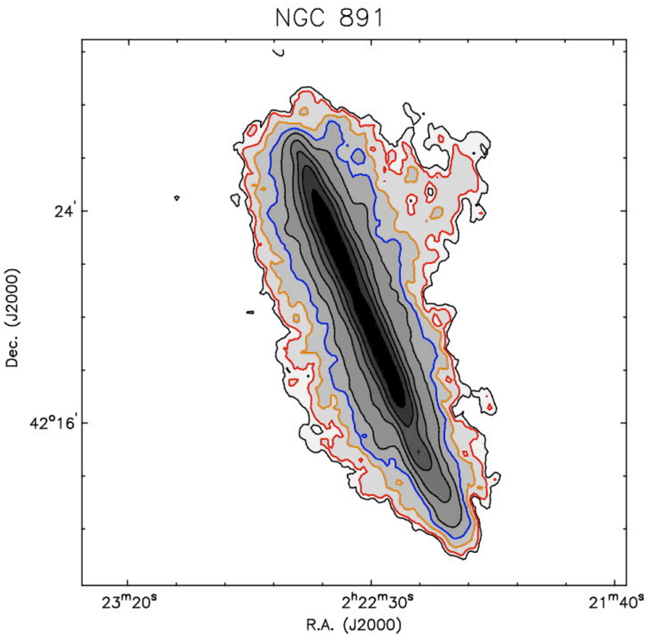
WSRT 1997

Oosterloo, Fraternali & Sancisi 2007, AJ 134, 1019

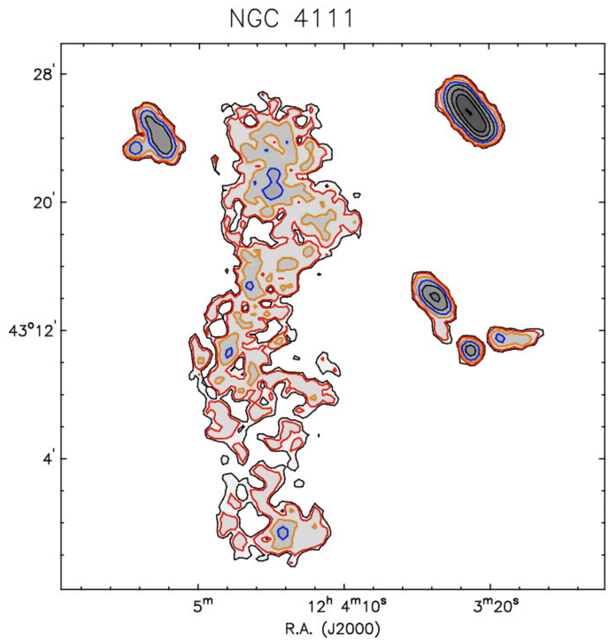
NGC 891



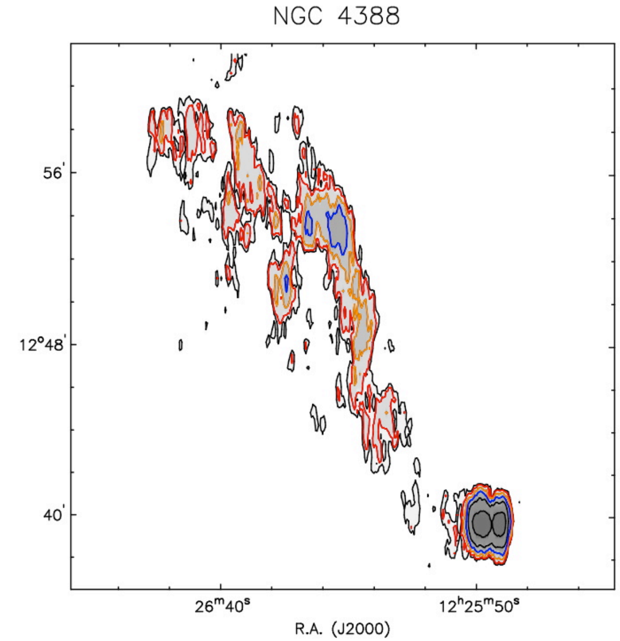
Oosterloo et al. 2007, AJ 134, 1019



Beam 30" x 30"



Beam 45" x 45"



Beam 18" x 90"

2×10^{19}

5×10^{19}

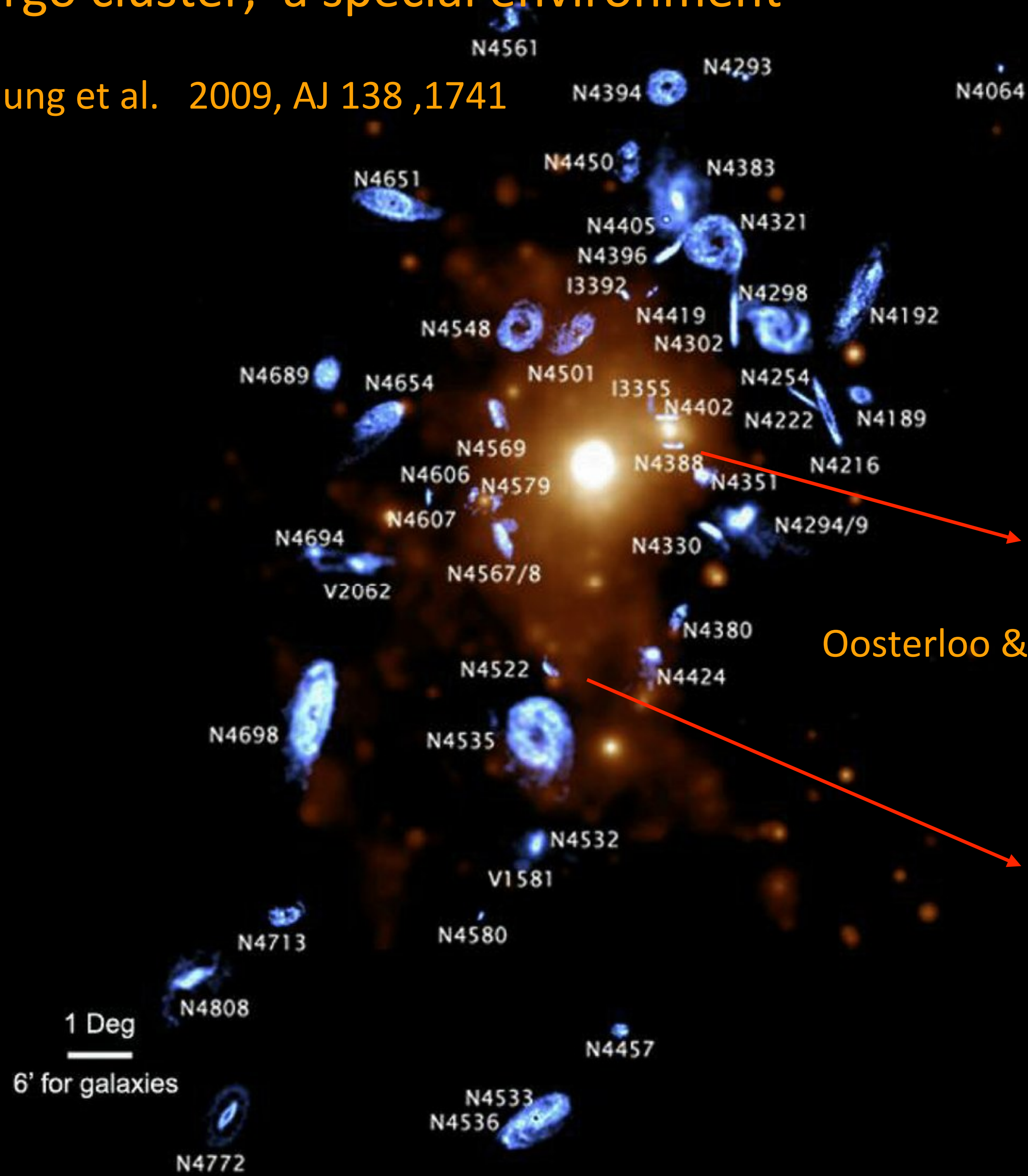
10×10^{19}

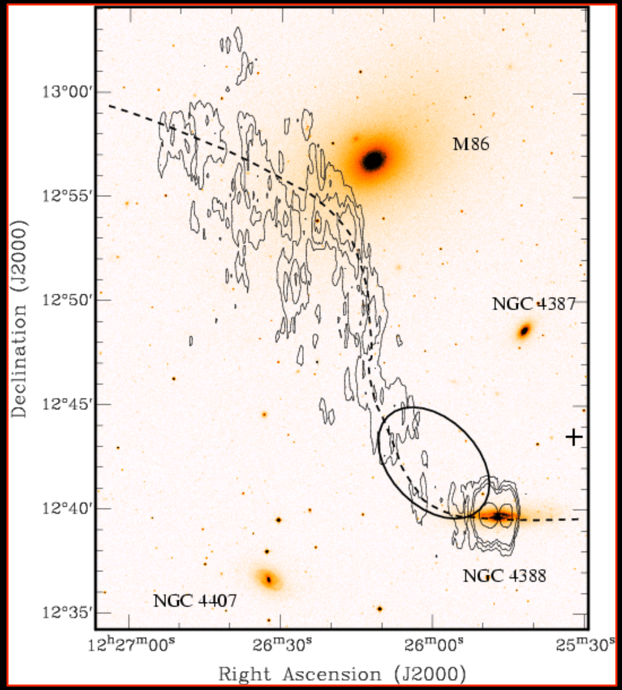
Deep integrations and low resolution reveal large low column density structures

To find the subtle HI signatures one needs to push to column densities of $< 10^{19}$

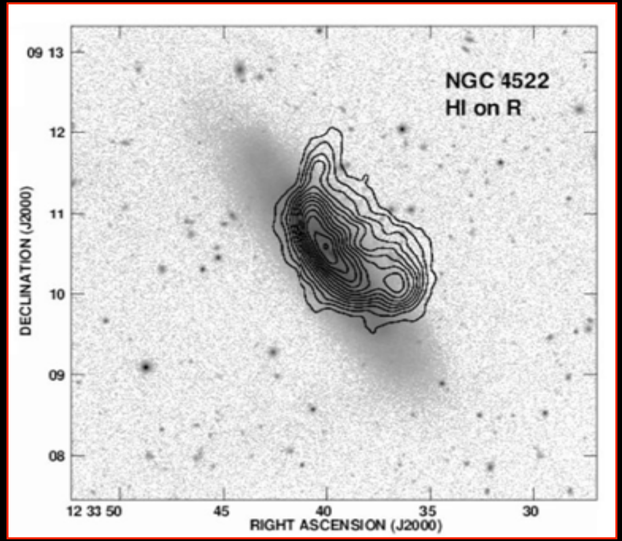
Virgo cluster, a special environment

Chung et al.   2009, AJ 138 ,1741





Oosterloo & van Gorkom 2005 A&A, 437, L19

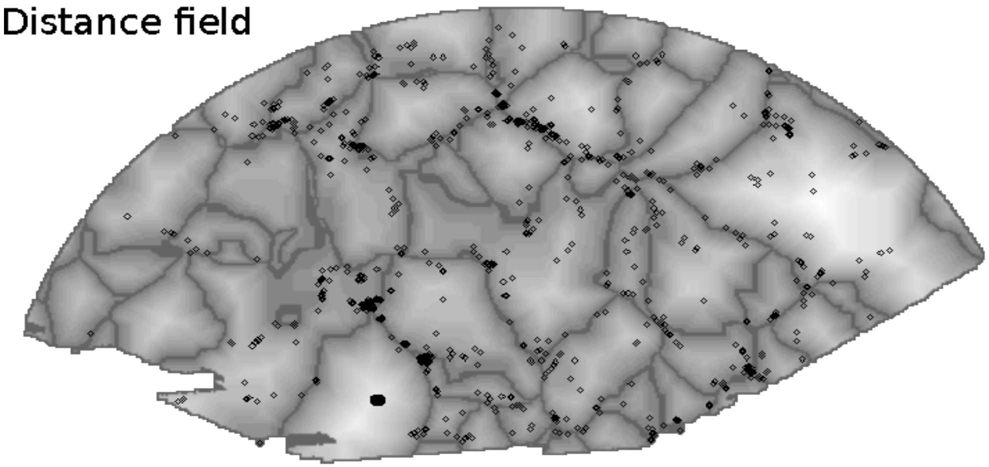


Kenney et al. 2004, AJ 127, 3361

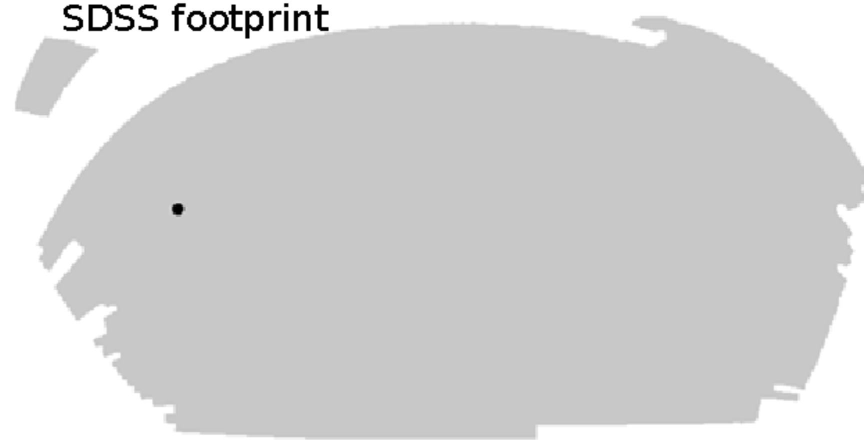
Voids: another special environment

geometrically selected (Kreckel et al. 2011 AJ 141:4 and 2012 AJ)

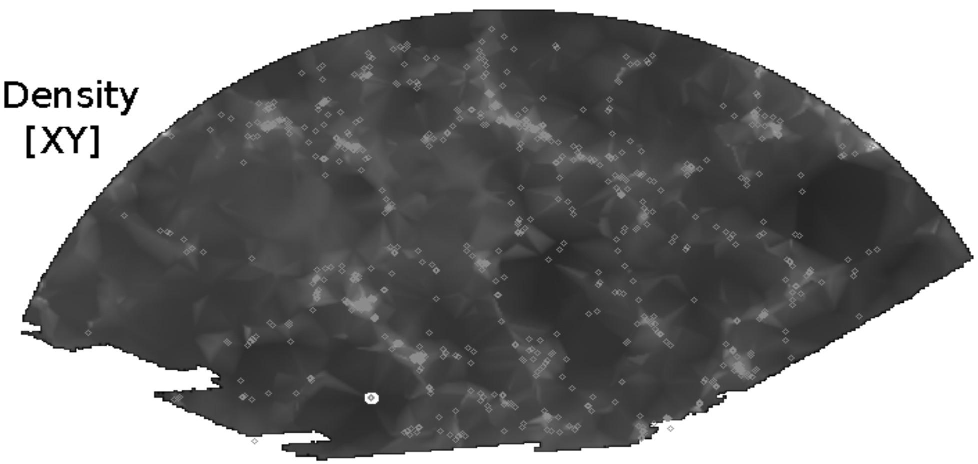
Distance field



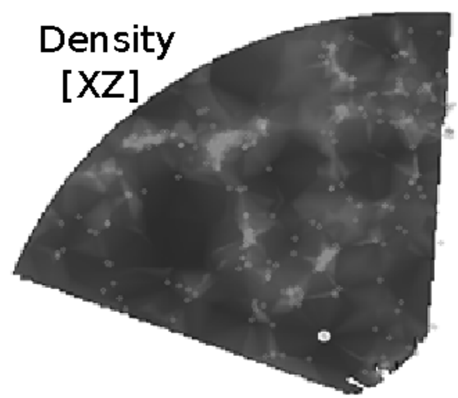
SDSS footprint



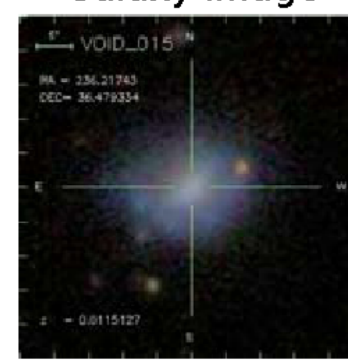
Density
[XY]



Density
[XZ]

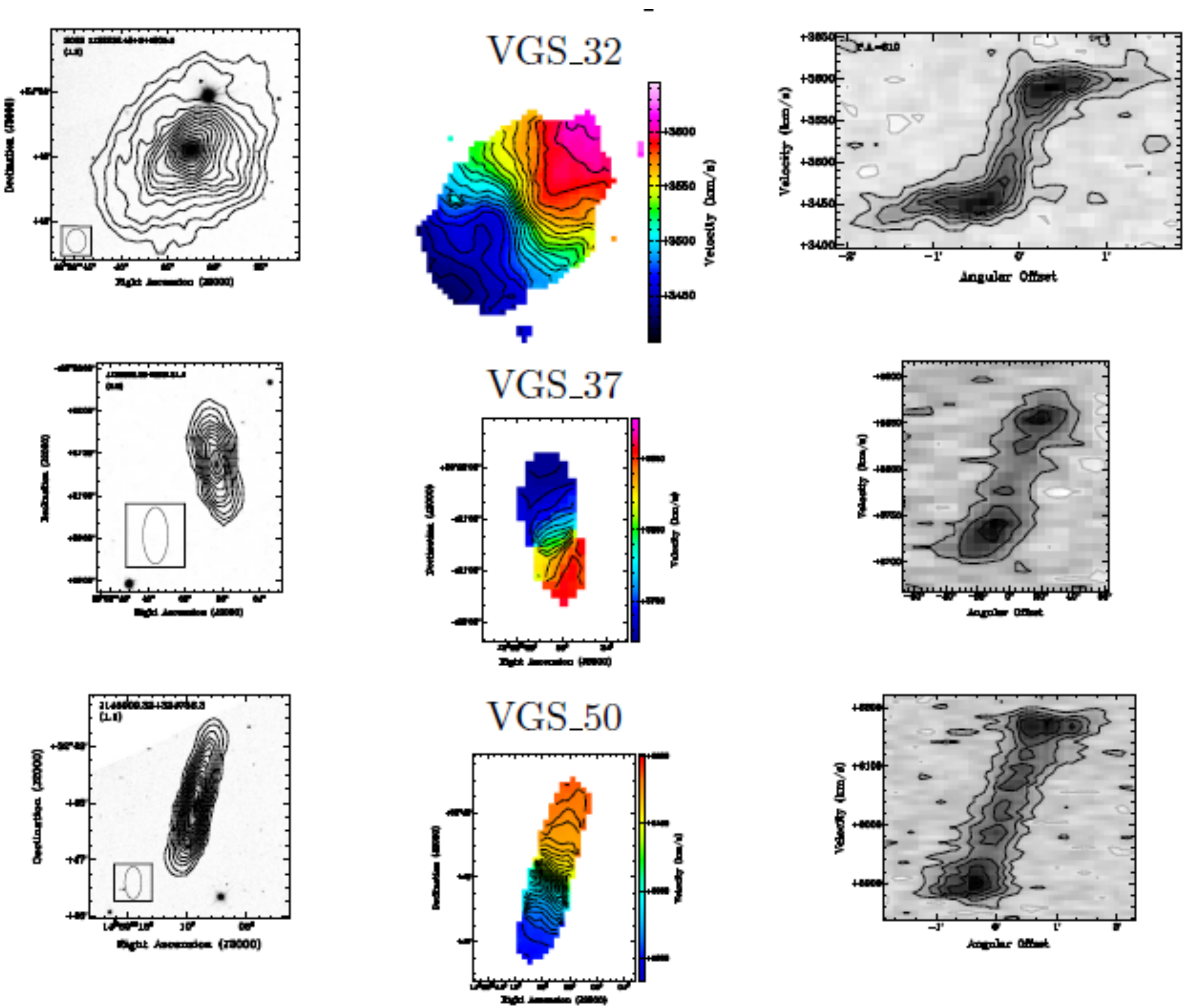


Galaxy image



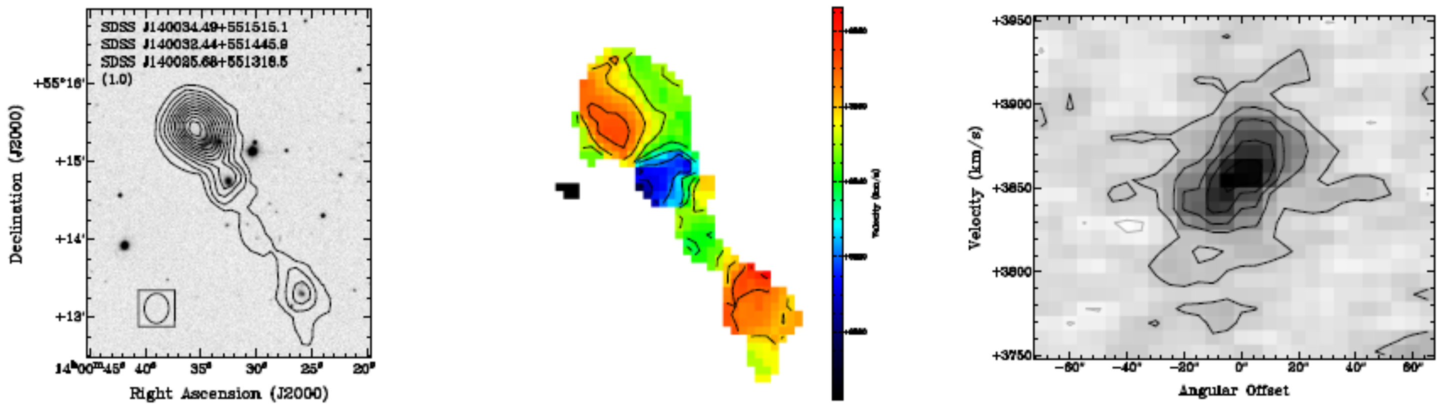
256 voids found,   60 selected observed with the WSRT

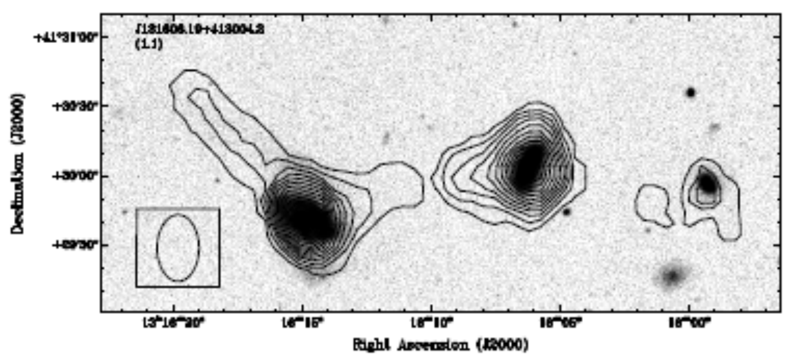
Normal disk galaxies



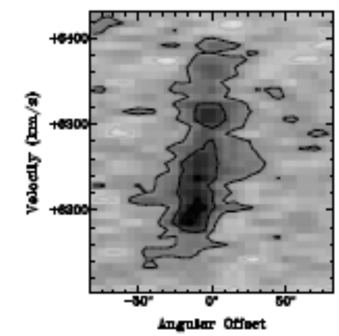
Interacting galaxies

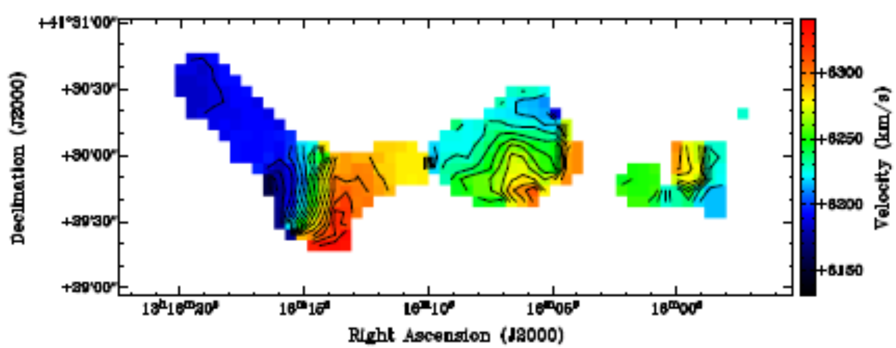
VGS_38





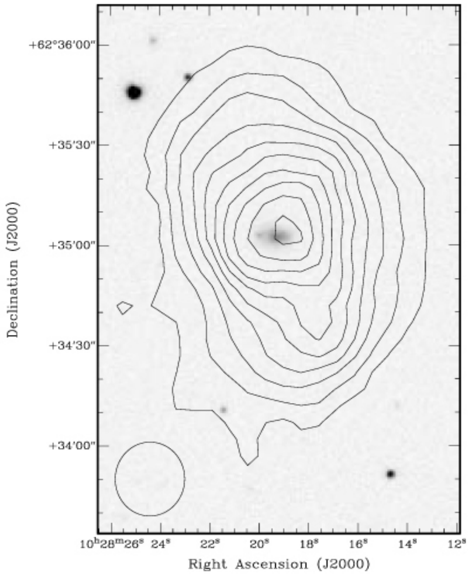
VGS_31

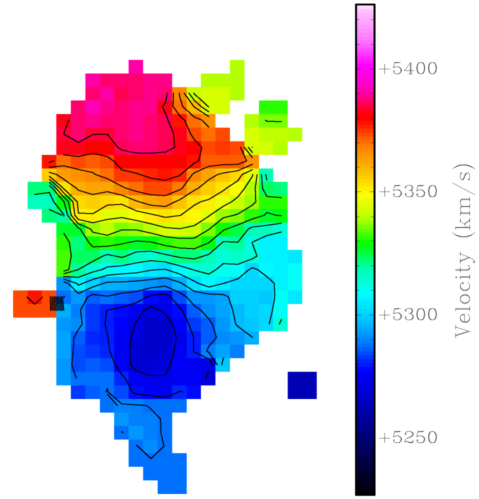


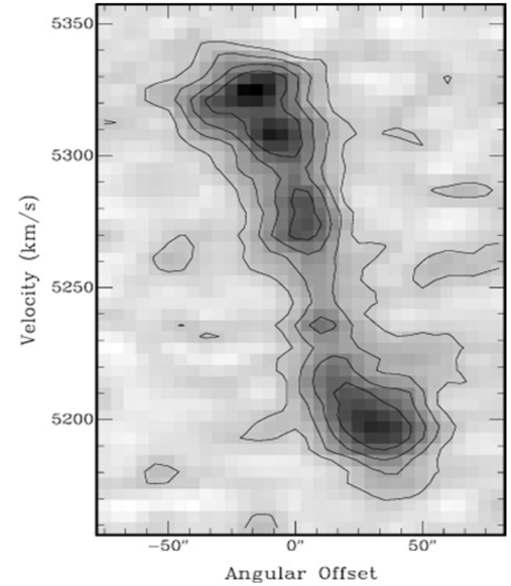


VGS_12:

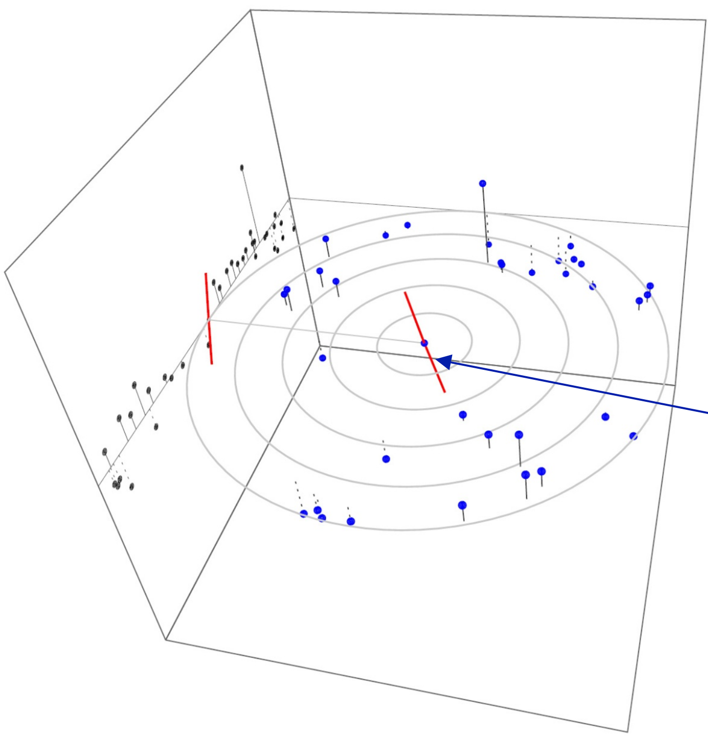
HI data review a huge polar disk





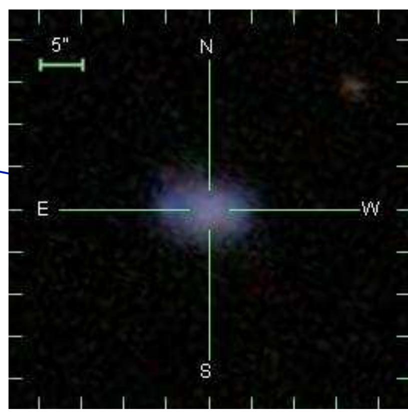


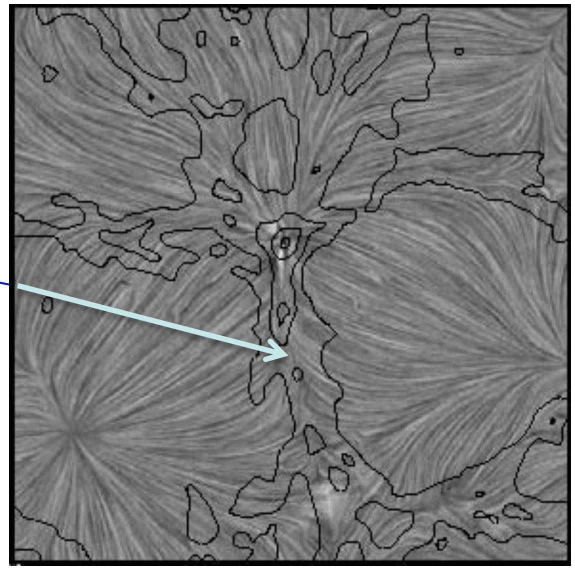
major axis XV plot



its SDSS environment: empty space > 5 Mpc in size

Void velocity field





SDSS image

(Stanonik et al. 2009, ApJ 696, L6)

Emerging picture:

We can use the HI to diagnose

- *accretion*
- *outflows*
- *stripping*
- *tidal effects*

but requires ***resolved*** imaging with adequate ***sensitivity***

How many?

How often?

How much?

HI evidence and statistics from WHISP survey of spiral galaxies:

~ 25 % of sample of 300 galaxies

HI masses involved 10^{8}-10^{9} $M_{\odot}$

See also: Van Eymeren et al. 2011 A&A 530, A29 & A30

Local Universe:

HI detection limits:

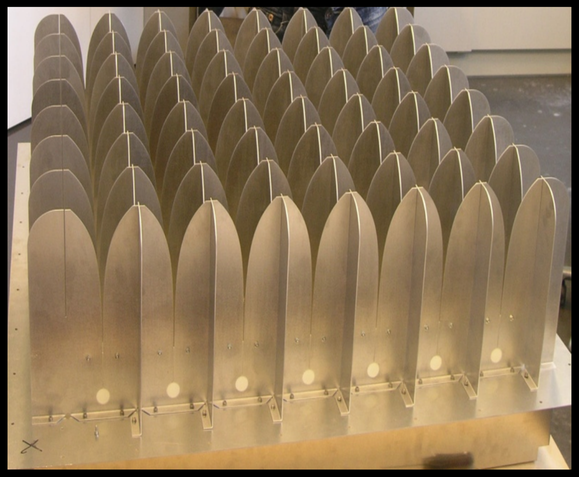
Column densities	$1 \times 10^{19}\ cm^{-2}$
Masses	$1 \times 10^{6}\ M_{\odot}$
Accreted HI	$10^{7} - 10^{9}\ M_{\odot}$
Time scales	$10^{8} - 10^{9}\ yr$
Galaxy fraction	25 - 50 %
Accretion rate	$0.1 - 0.5\ M_{\odot}\ /\ yr$

Need many more galaxies to obtain proper statistics: fairly deep, large survey

Apertif

Array of densely packed Vivaldi receptors in each WSRT dish to **fully sample focal plane**

Apertif	WSRT
121 elements (2 pol)	1 (2 pol)
37 beams on the sky	1
FoV 8 deg²	**0.3 deg²**
Range ν: 1000 – 1750 MHz	117 – 8650 MHz
T_{sys} < 55 K	30 K
Aperture efficiency 75%	55%
Bandwidth 300 MHz	160 MHz
16384 channels	1024 channels
12 dishes	14 (13) dishes



Recycle of lot of LOFAR software (pipeline & archive)

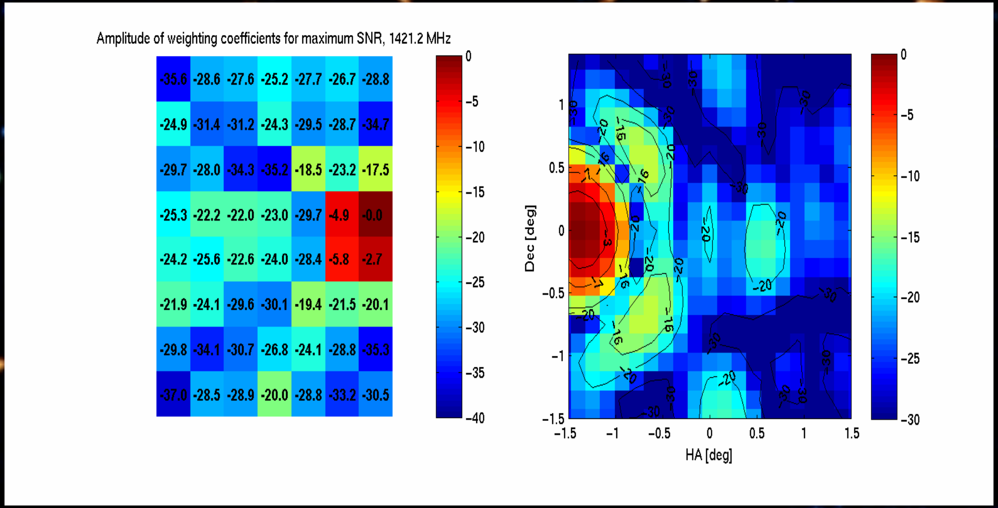
Survey speed increases by factor 20-40 .
Can do in a day what now takes a month

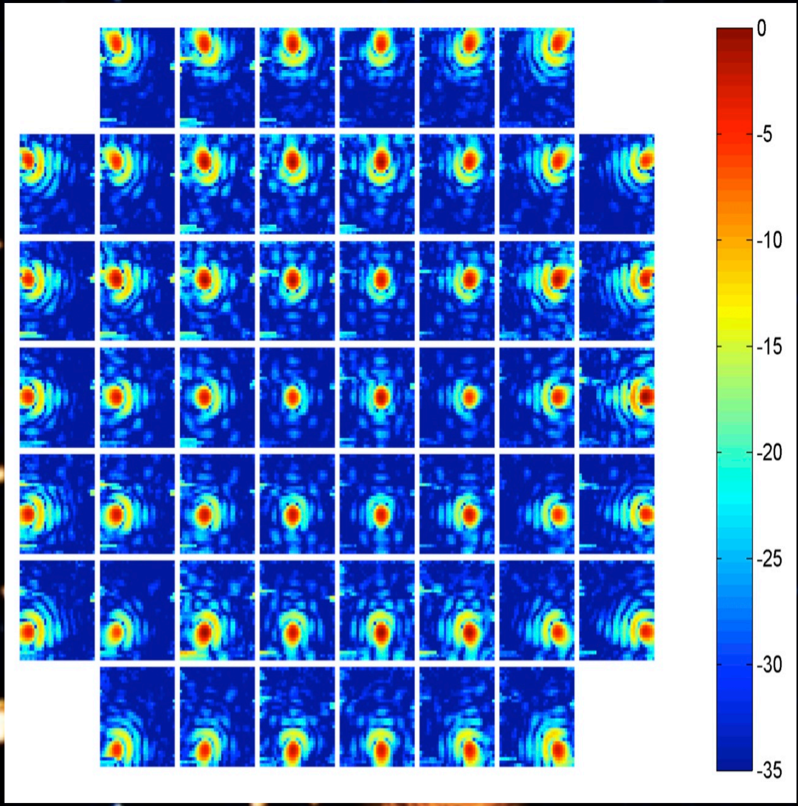
121 elements make 37 optimised beams

Each element sees a different part of the sky (it's a camera...).
But: not use elements beams directly, but make many *optimised* beams, using weighted sum of all element beams.

Optimise for:

- Optimum S/N
- Low instrumental polarisation
- Low sidelobe level





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APERTIF


Thank you