Argelander-Institut für Astronomie

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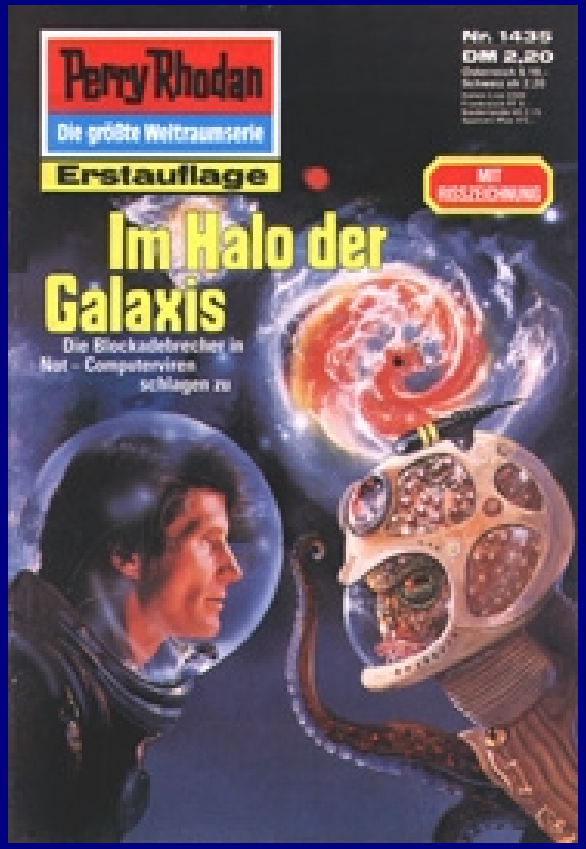
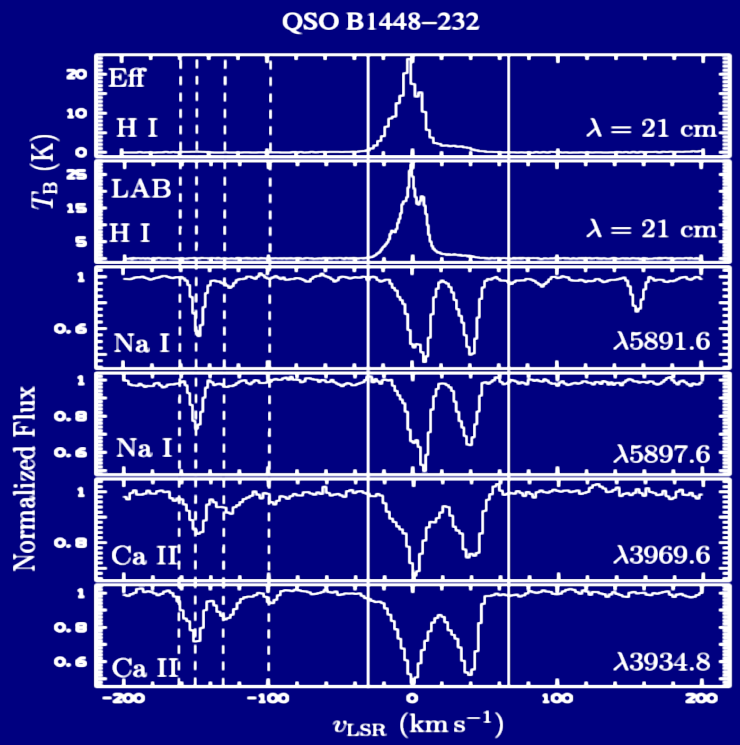
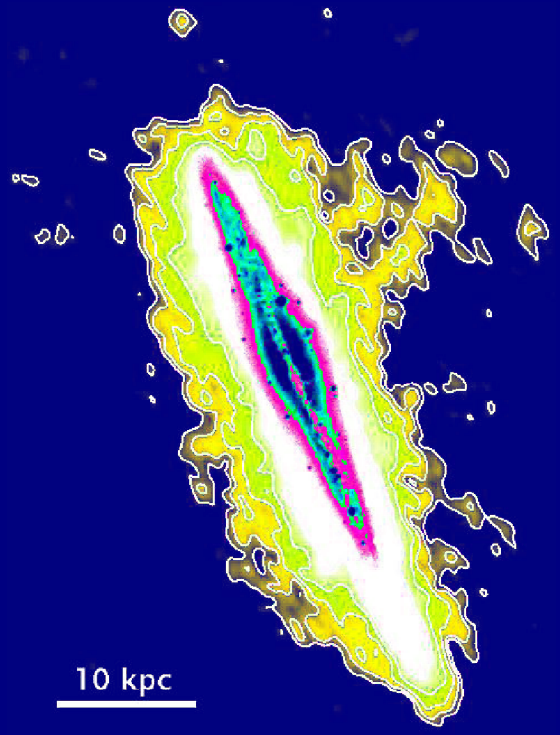
Properties of gaseous galactic halos

High- and intermediate velocity clouds

Nadya Ben Bekhti



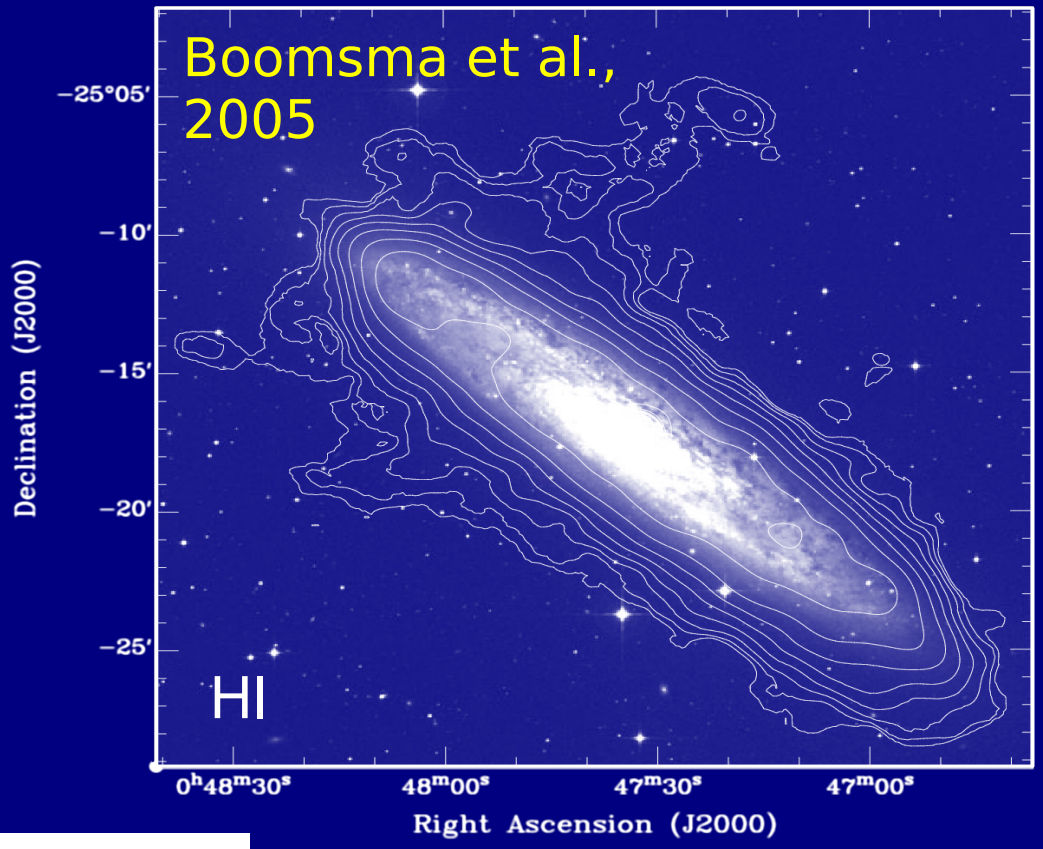


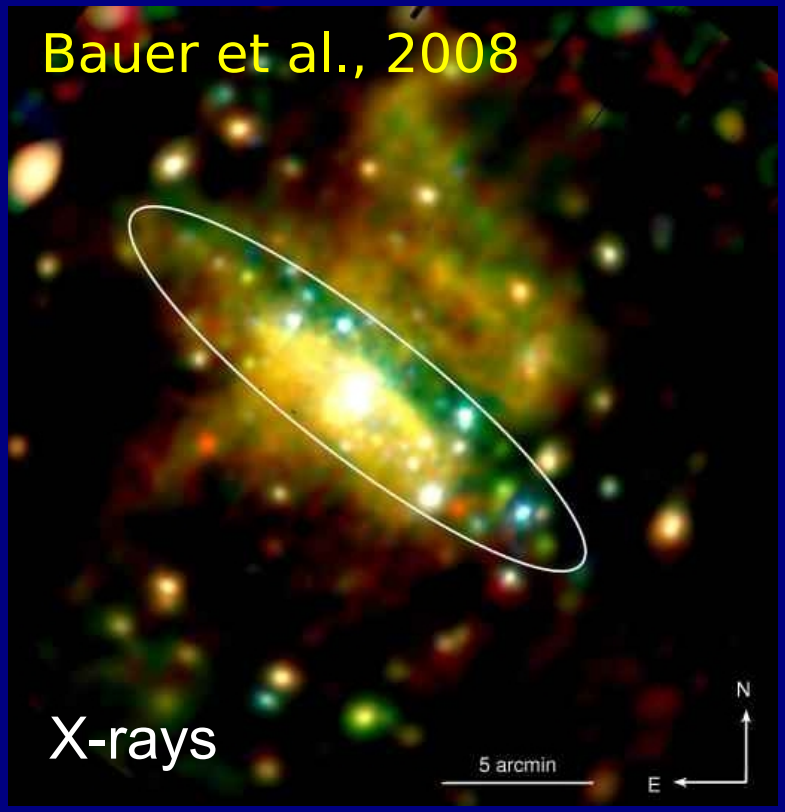


Magnetic fields, Ringberg, July 18-22, 2011

Observations

NGC 253





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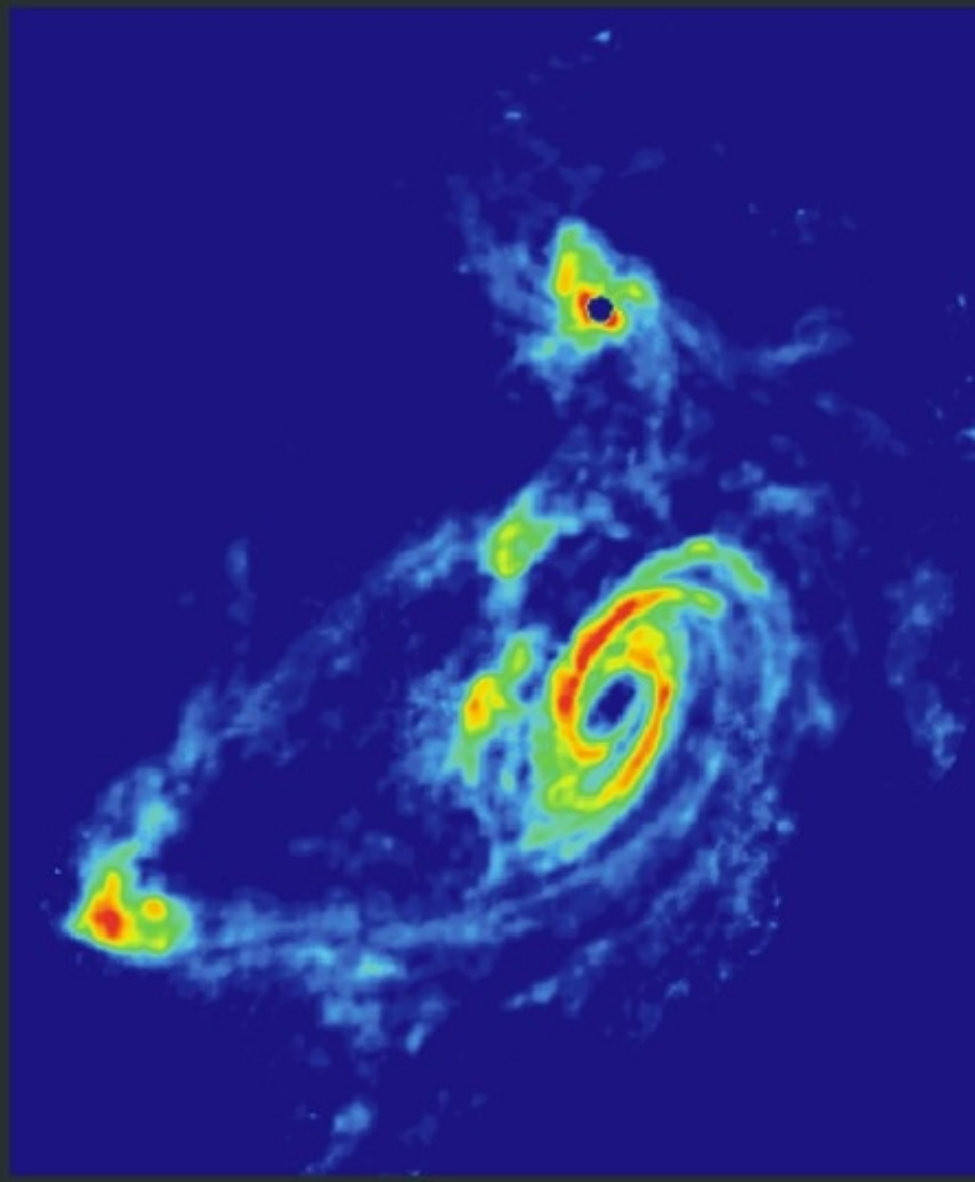
M81 Group

TIDAL INTERACTIONS IN M81 GROUP

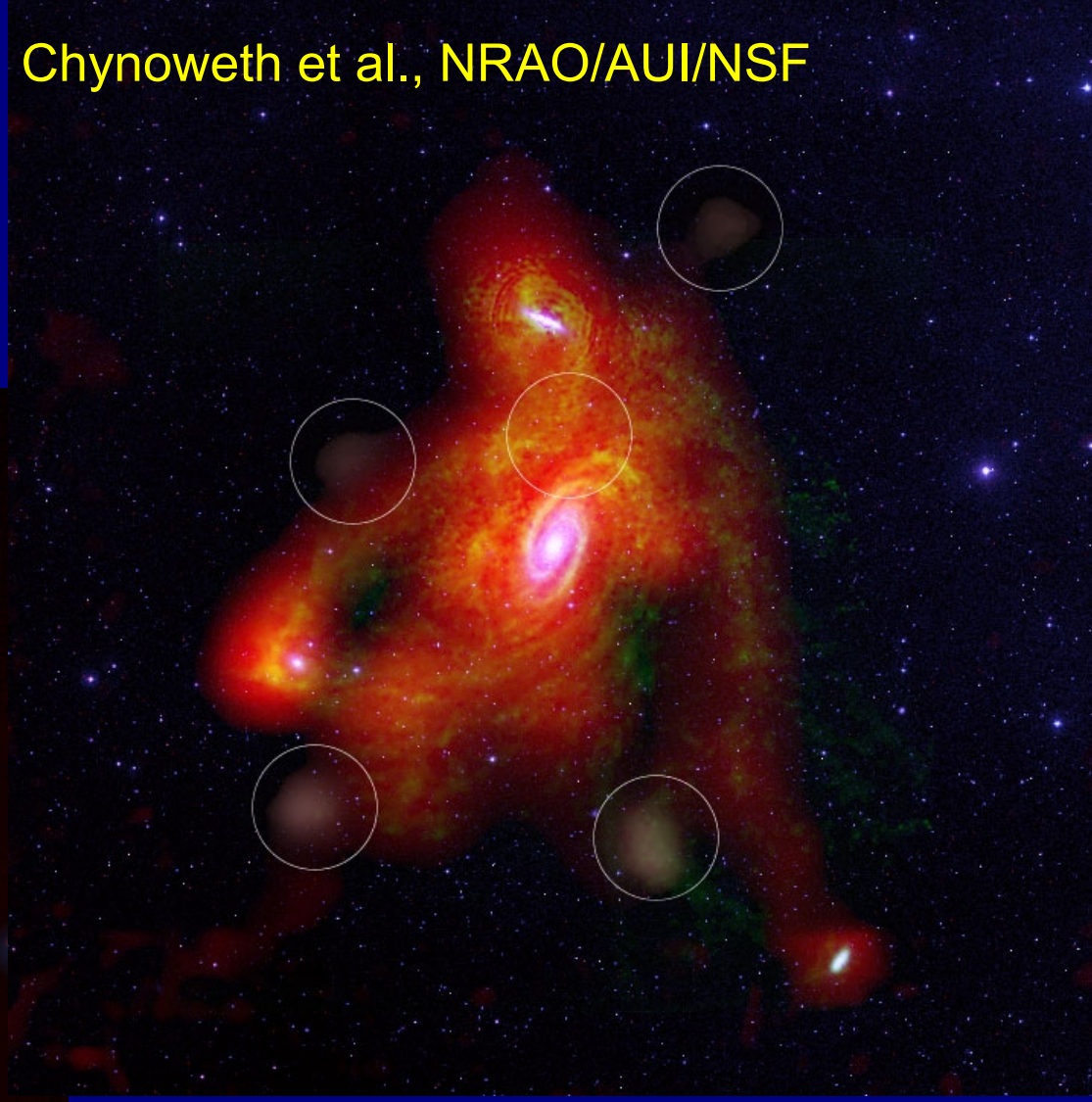
Stellar Light Distribution

21 cm HI Distribution



Starburst Galaxy M82

Hubble, Chandra, Spitzer



Chynoweth et al., NRAO/AUI/NSF

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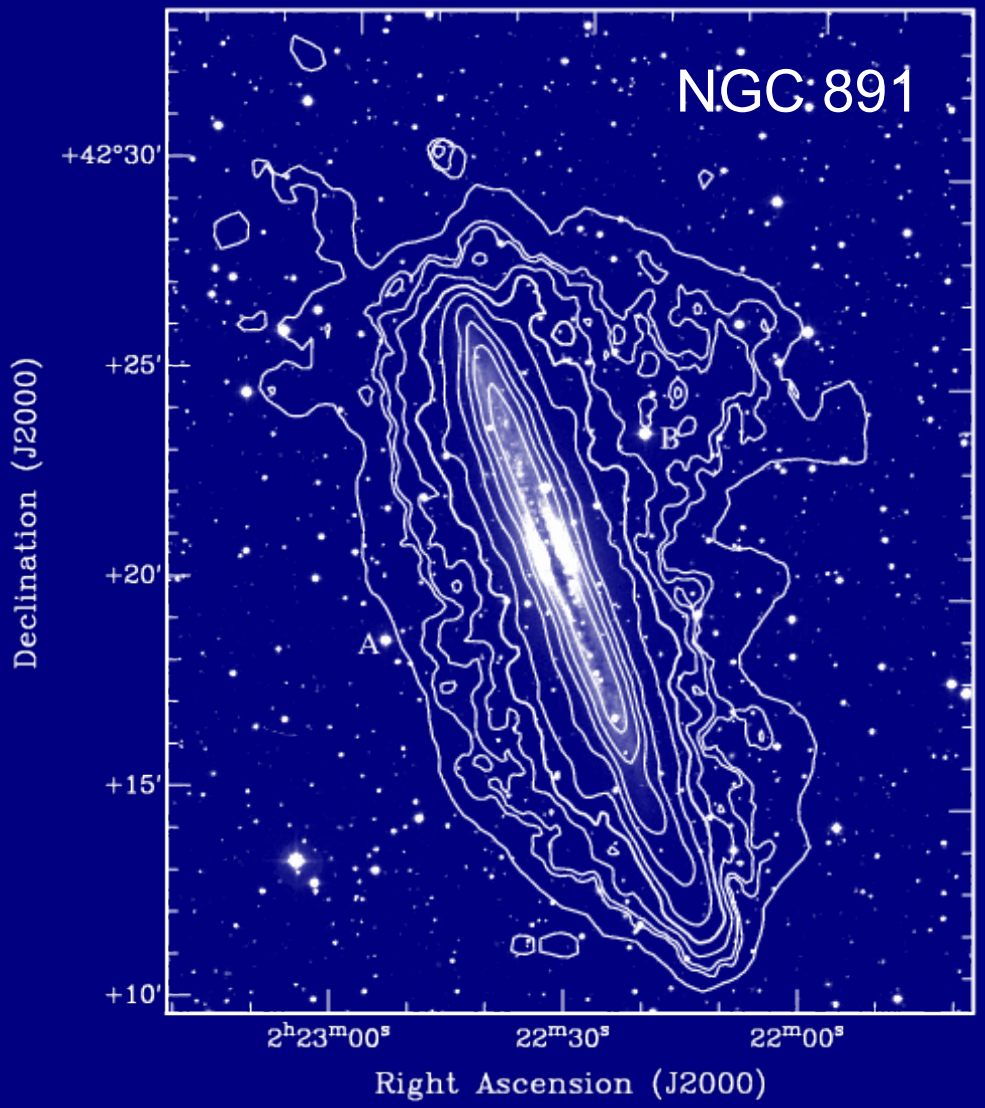
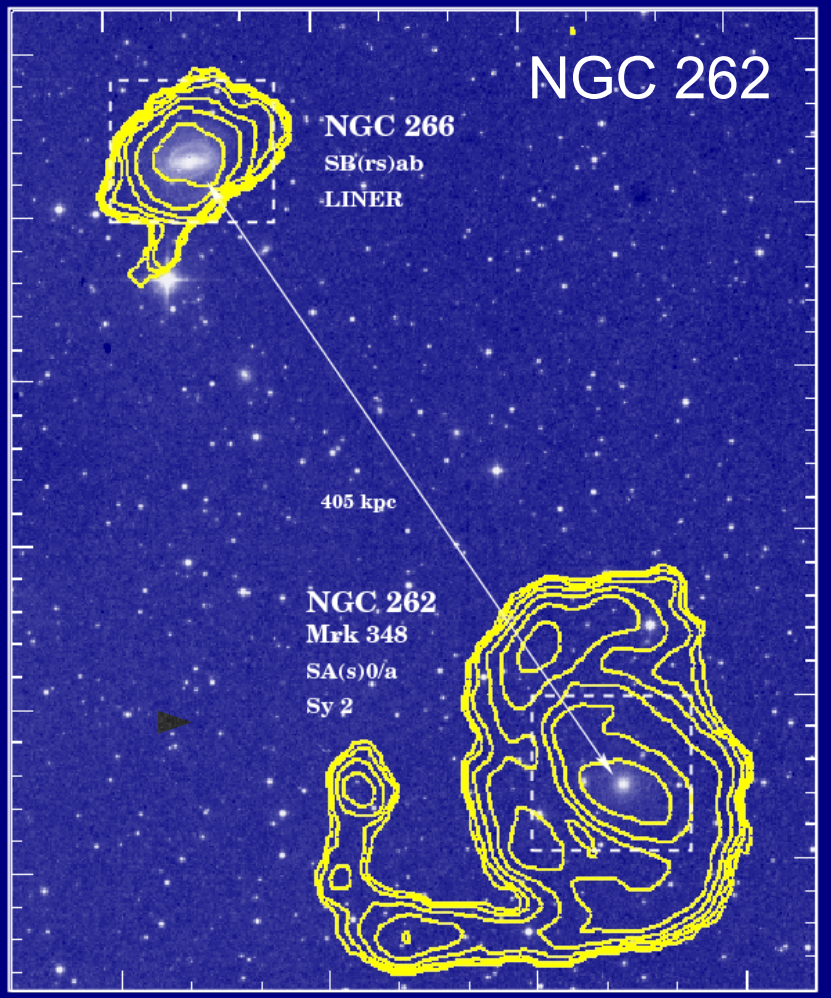
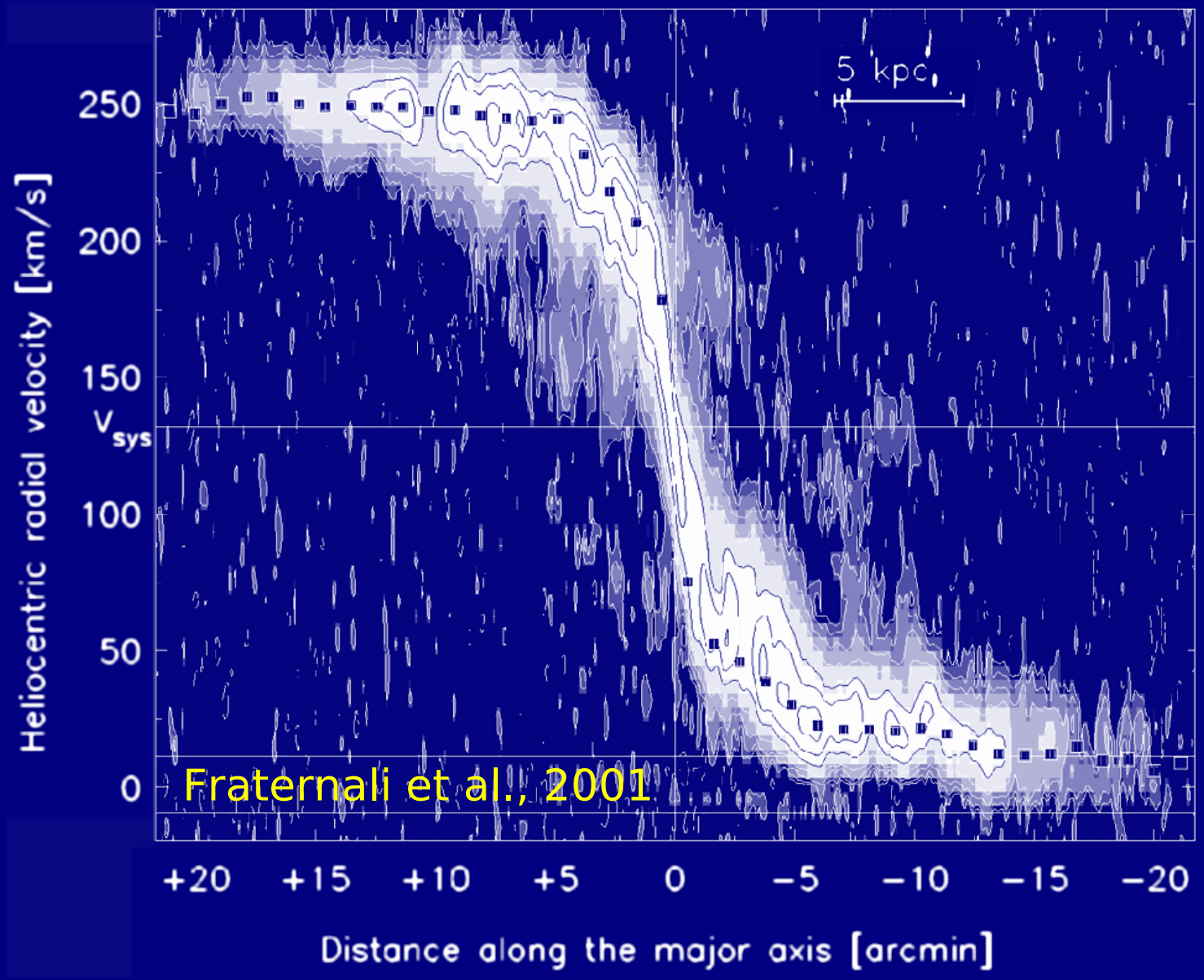




Oosterloo et al., 2007

Simkin et al., 1987

Position-velocity diagram of NGC 2403



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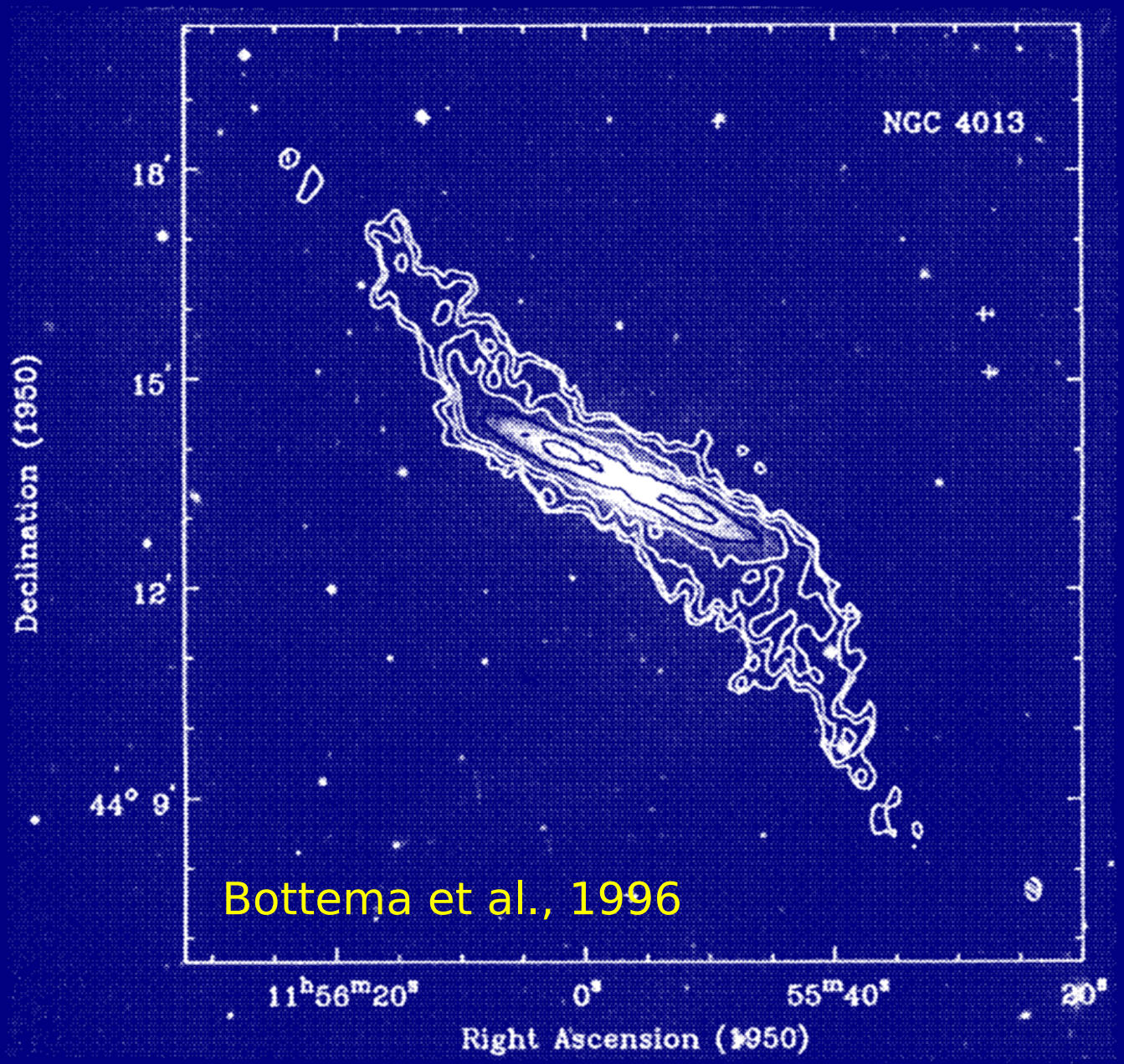
NGC 4013



Bottema et al., 1996

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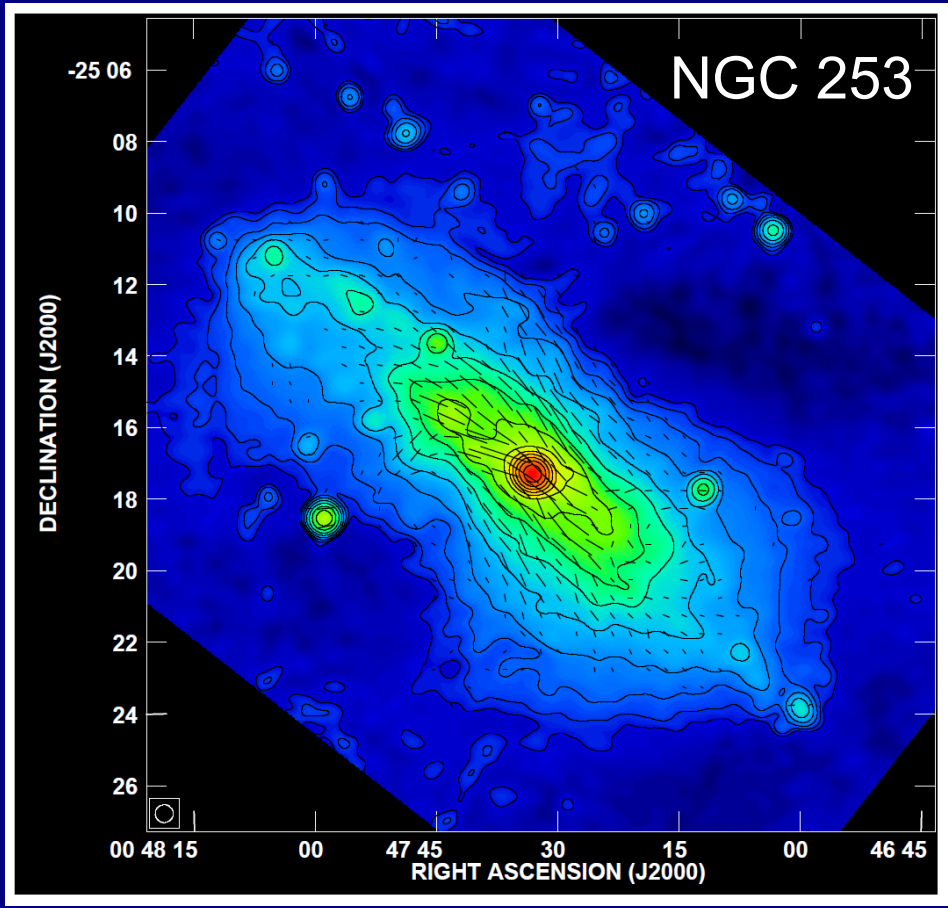
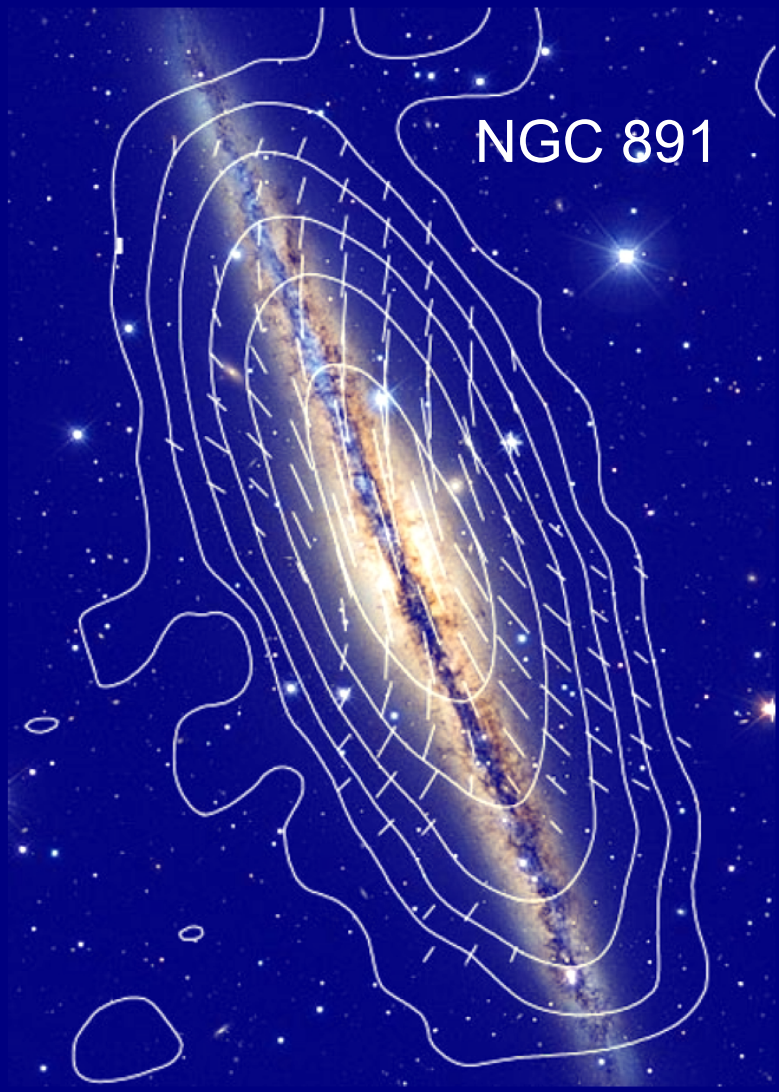
Large-scale magnetic fields



Heesen et al., 2008



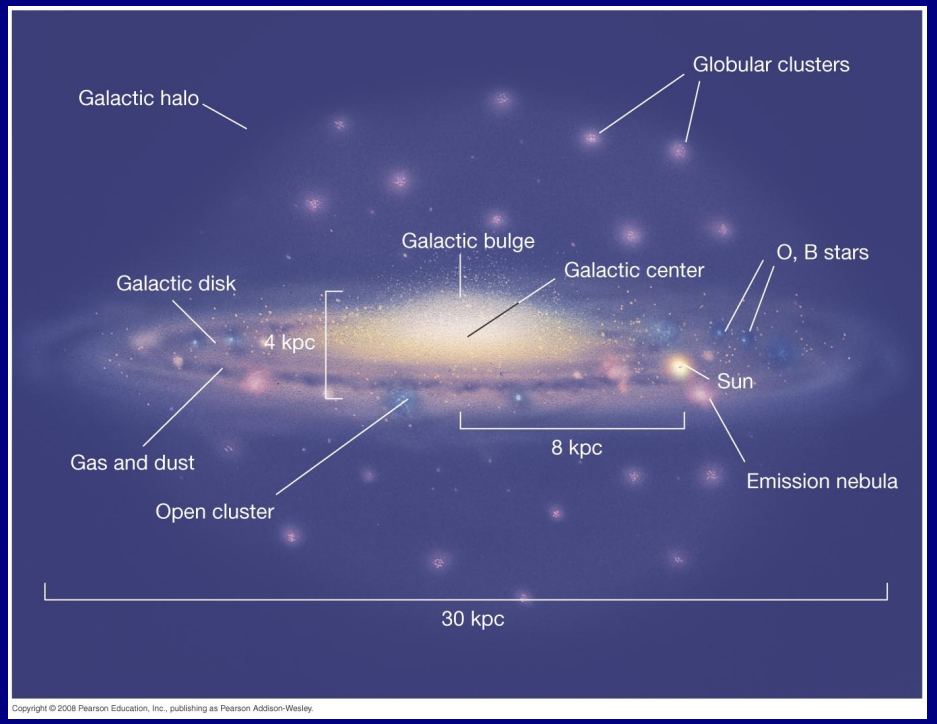
Krause, 2009

Observational results

Up to 30% of the total HI mass in the halo
Streams, filaments, clouds, clumps
Lagging halo
Overall radial inflow
Well-ordered, large-scale magnetic fields

Ingredients of halo gas

- Atoms (mostly ions)
- Free electrons
- Very little dust
- Almost no molecules



Element abundance:

$[X/H] = \log (X/H) - \log(X/H)_{\odot}$

Multiphase halo

Parameters describing the physical state of halo gas:
Temperature, density, ionisation stage, metal content

Phase	N (cm^{-3})	T (K)	f_V (%)	f_M (%)	h (pc)
Molec.	10^2...10^5	10...50	<1	~20	~70
CNM	40...80	50...200	2...4	~40	~140
WNM	0.1...0.6	5500...8500	~30	~30	~400
WIM	~0.2	~8000	~20	~10	~900
HIM	10^{-3}...10^{-2}	10^5...10^7	~50	~1	>1000

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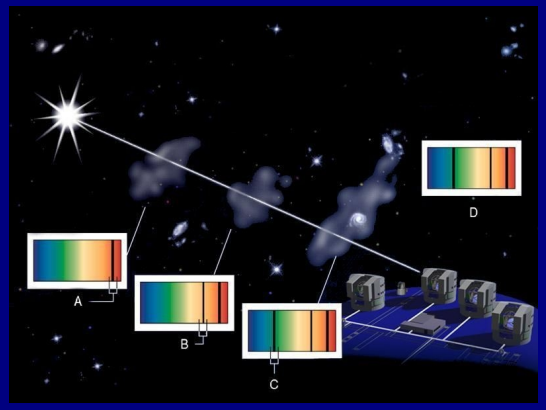
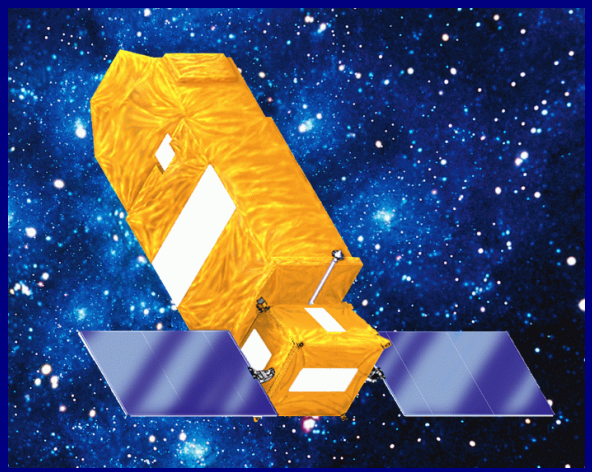
How can we observe halo gas?

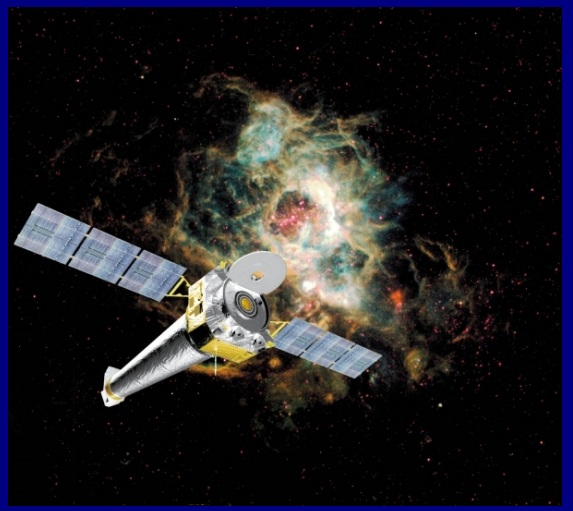
- Emission: F α $1/D^2$

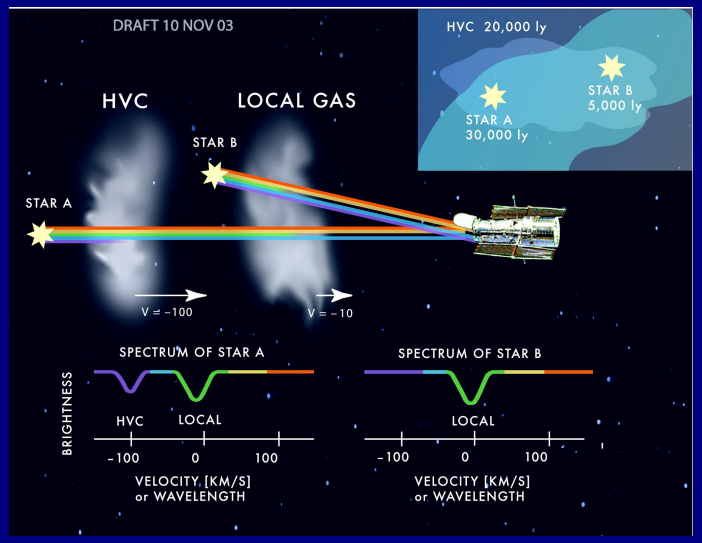
→ very low fluxes from high z objects

- Absorption: distant bright background sources are rare

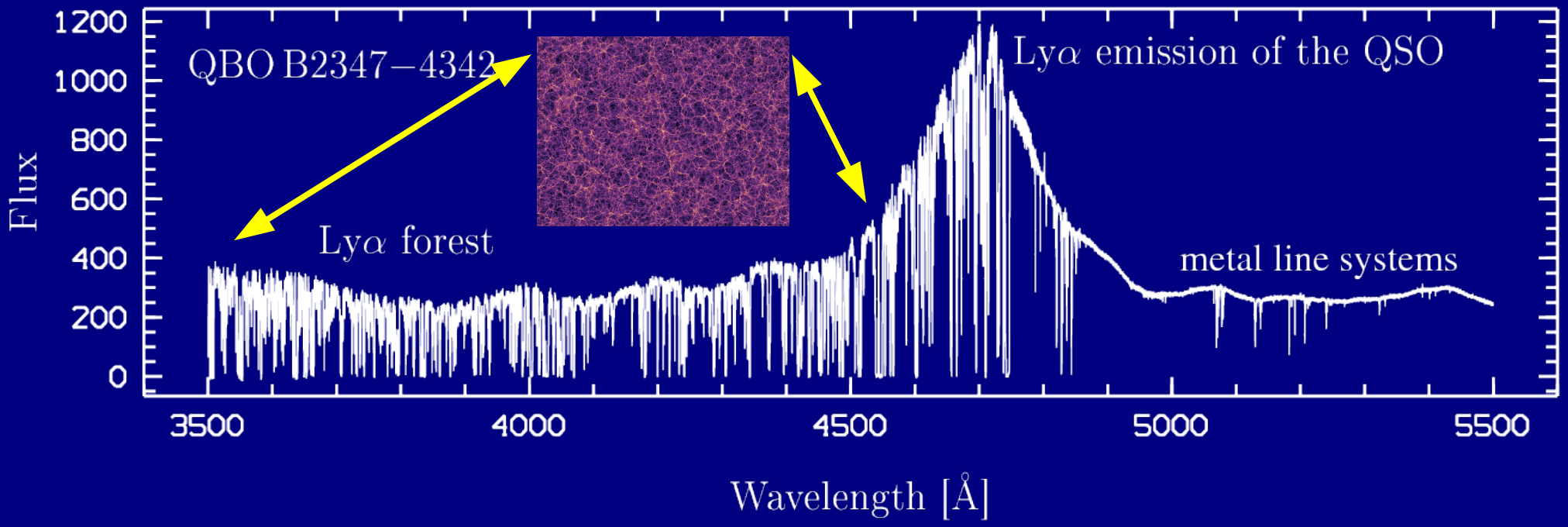








QSO absorption spectra



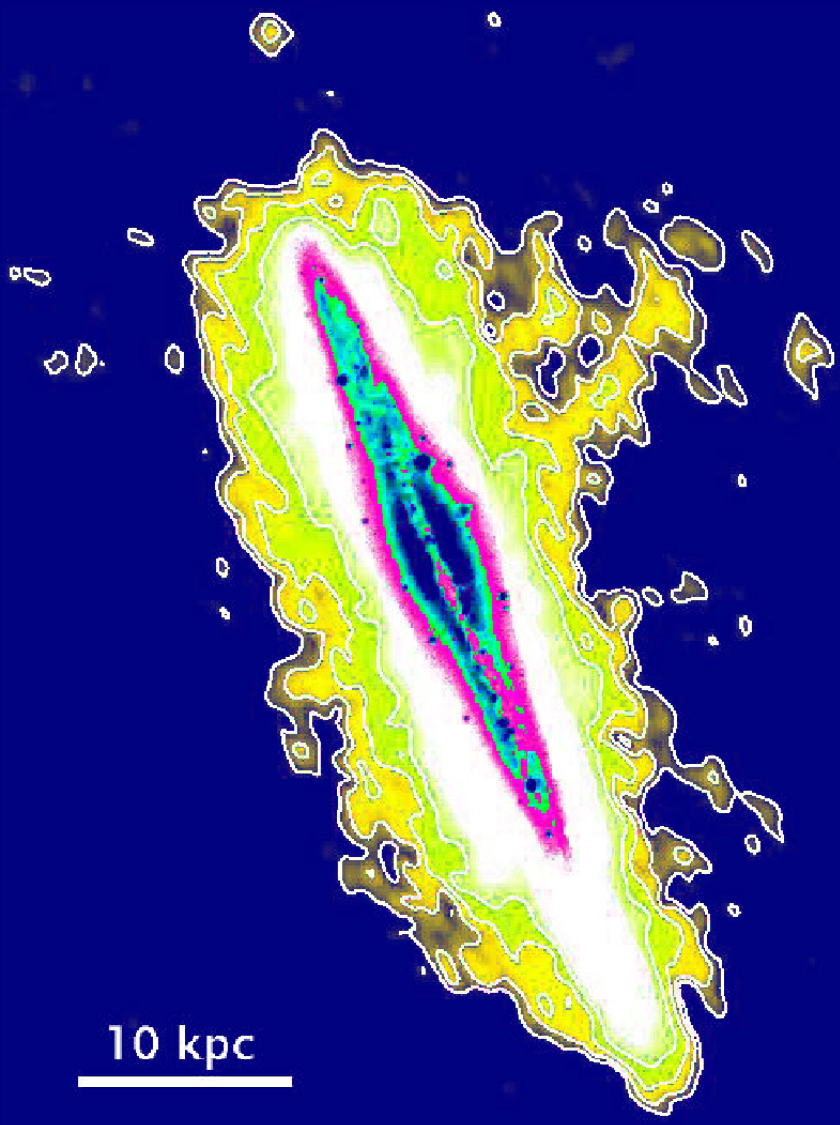
Definition of a gaseous galactic halo

Extent?
Where does a galaxy “end”?

Origin?

Filling factor?

Diffuse or clumpy?

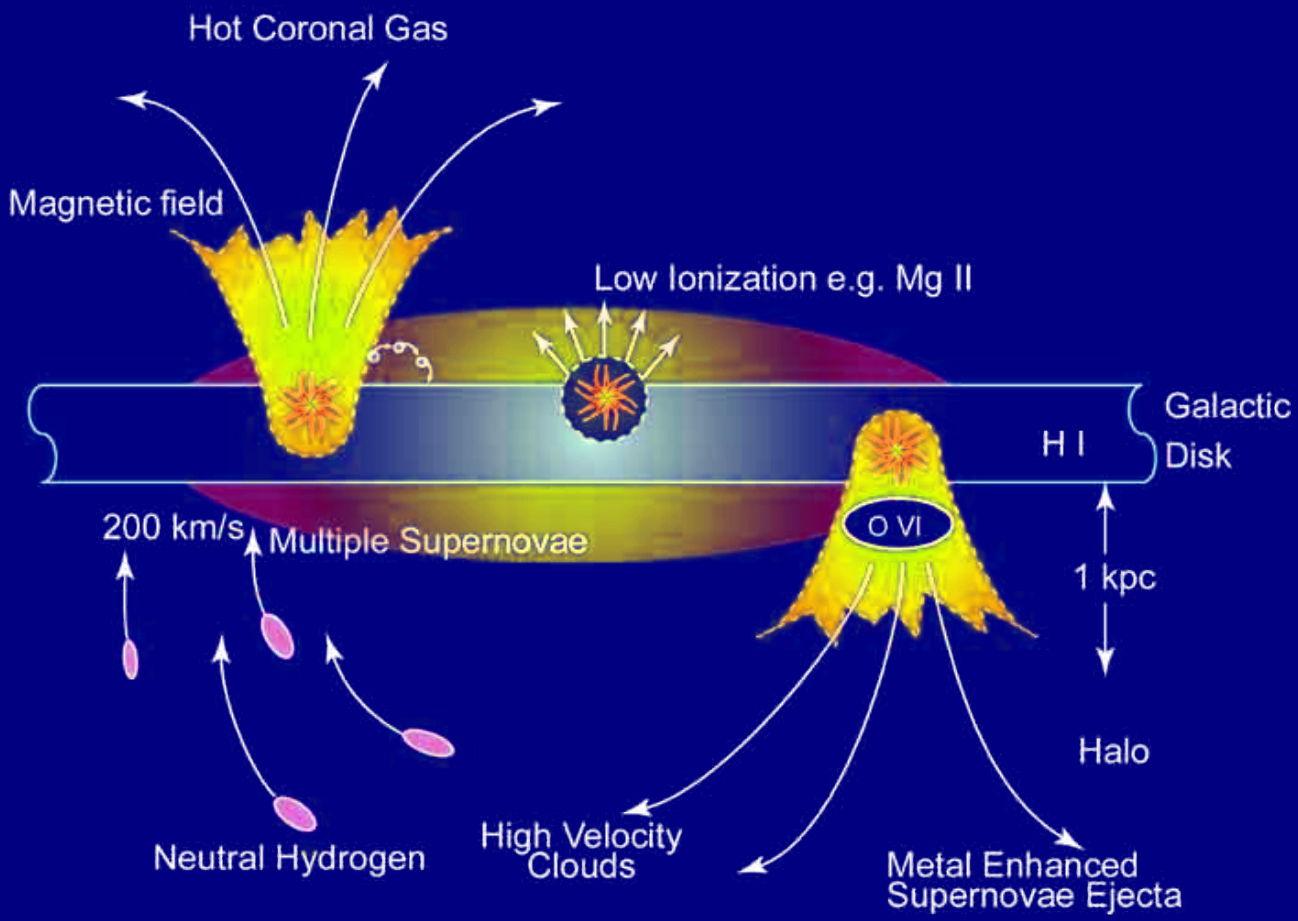


Origin of the halo gas

Galactic origin

Galactic fountains

Winds



http://satrec.kaist.ac.kr/fims/

Extragalactic origin

Primordial

Gaseous streams (merging, tidal interaction)

Accretion (remnants of earlier mergers)

Halo gas is the result of complex phenomena involving internal and external processes

1. Studying the evolution of galaxies

Halos: up to 30% of the total HI mass in a galaxy

Material exchange
→ Circulation is fundamental for galactic life circle

HI gas interacts and influences the host galaxy
→ Constant star formation rates
→ Warps

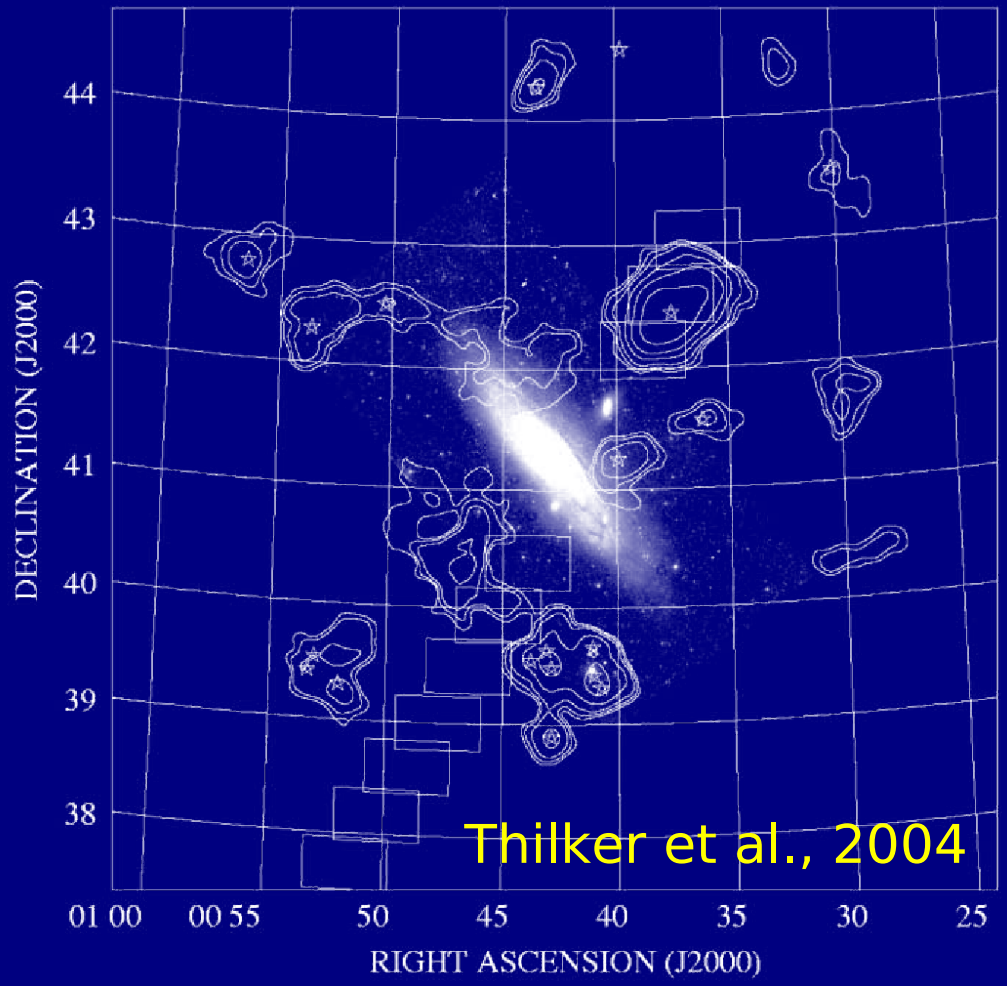
2. Studying the Intergalactic Medium

Halos: interface between galaxies and the IGM
→ linking galaxies to the IGM

λCDM cosmology predicts: most of the baryonic matter in the local universe is in the IGM (White & Frenk, 1991)
(70 % IGM, 30% galaxies)

Studying the halo: efficient way to probe the IGM near galaxies

M31



Westmeier et al. 2008:

Lack of clouds beyond 50 kpc

Detection limit: $8 \times 10^4\ M_\odot$

$M_{clouds} = 10^5$ to $10^6\ M_\odot$

→ Area filling factor of f~30%

(Richter et al., in prep.)

The Milky Way halo

Intermediate- and high-velocity clouds

Inconsistent with galactic rotation

IVCs

$d \lesssim 2$ kpc

Metal abundances 0.7 to 1.0 solar

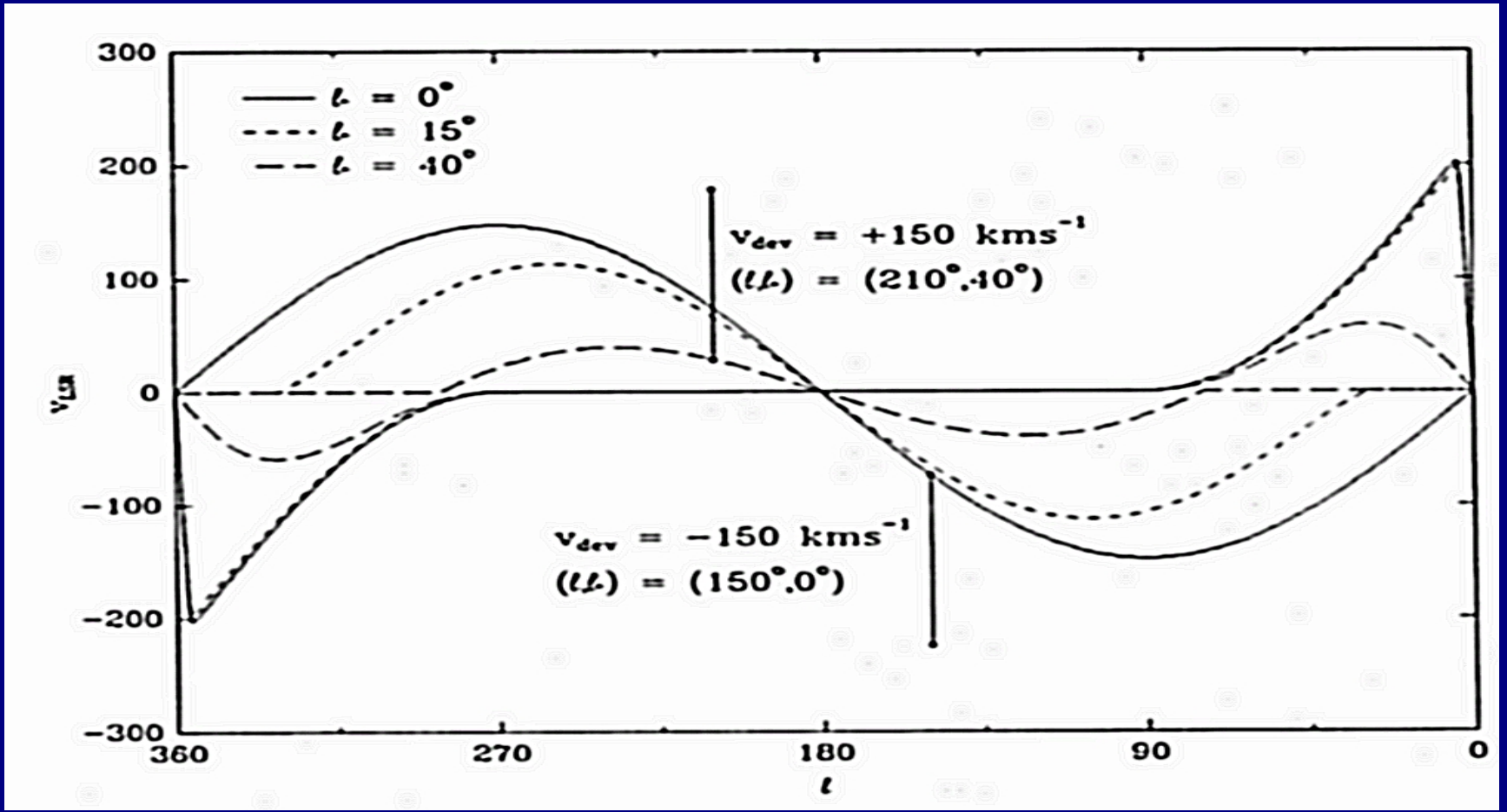
HVCs

$d \lesssim 50$ kpc

Metal abundances 0.1 to 1.0 solar

(Wakker et al., 2001, 2007, 2008, Richter et al., 2001, Thom et al. 2006)

Deviation velocity



$|v_{dev}| \leq 50$ km s^{-1} → IVCs

$|v_{dev}| > 50$ km s^{-1} → HVCs

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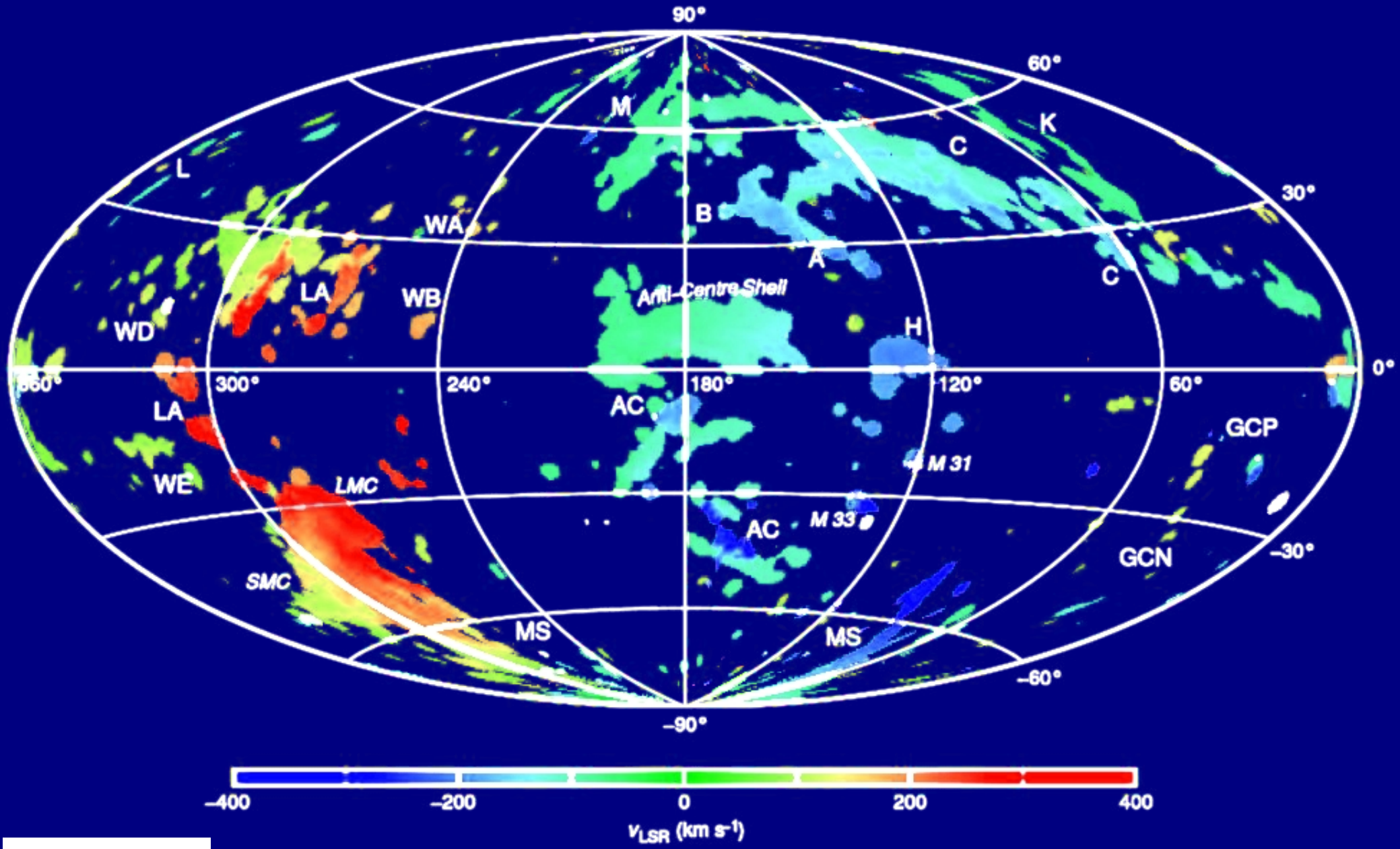
The high-velocity sky



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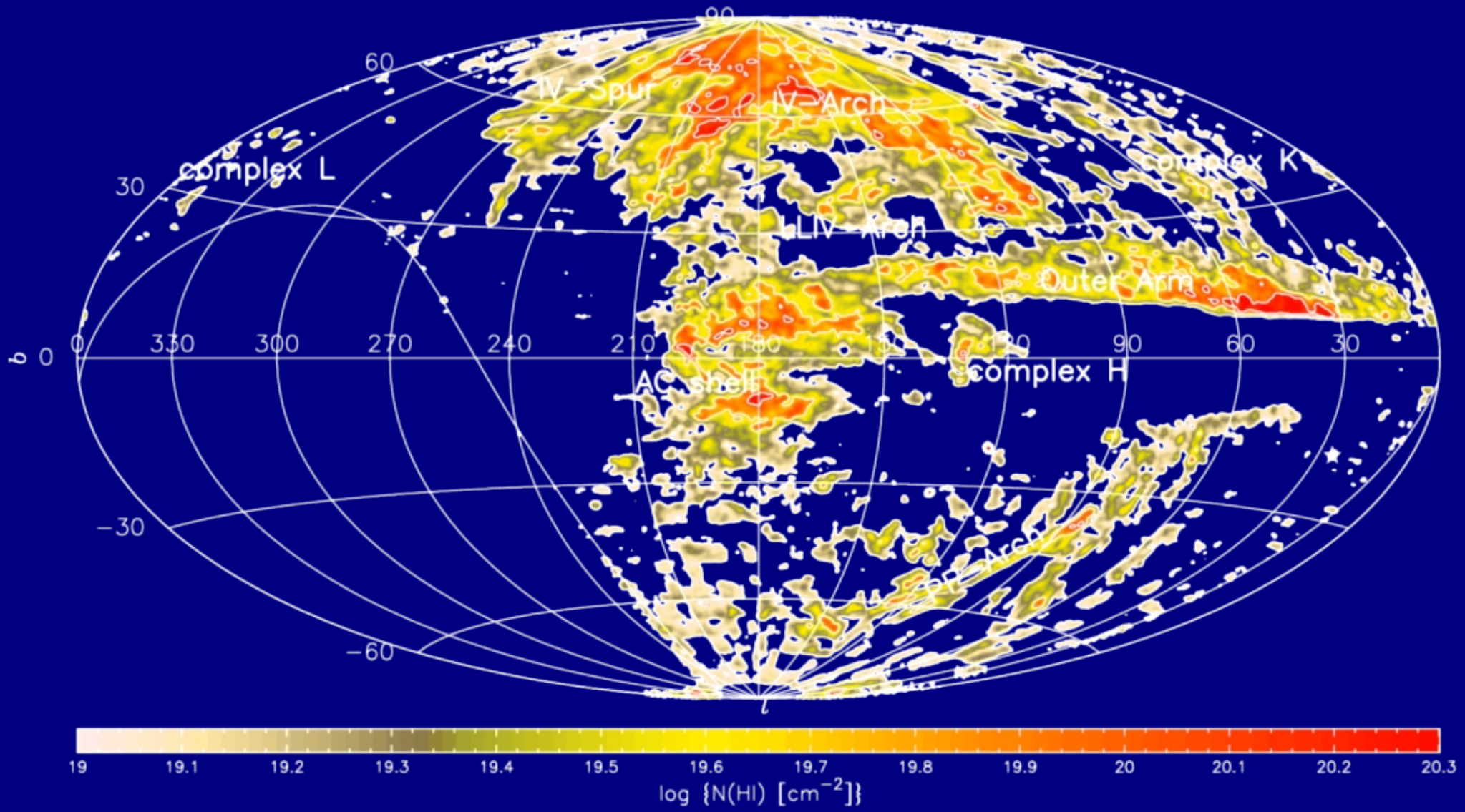
The Intermediate-velocity sky



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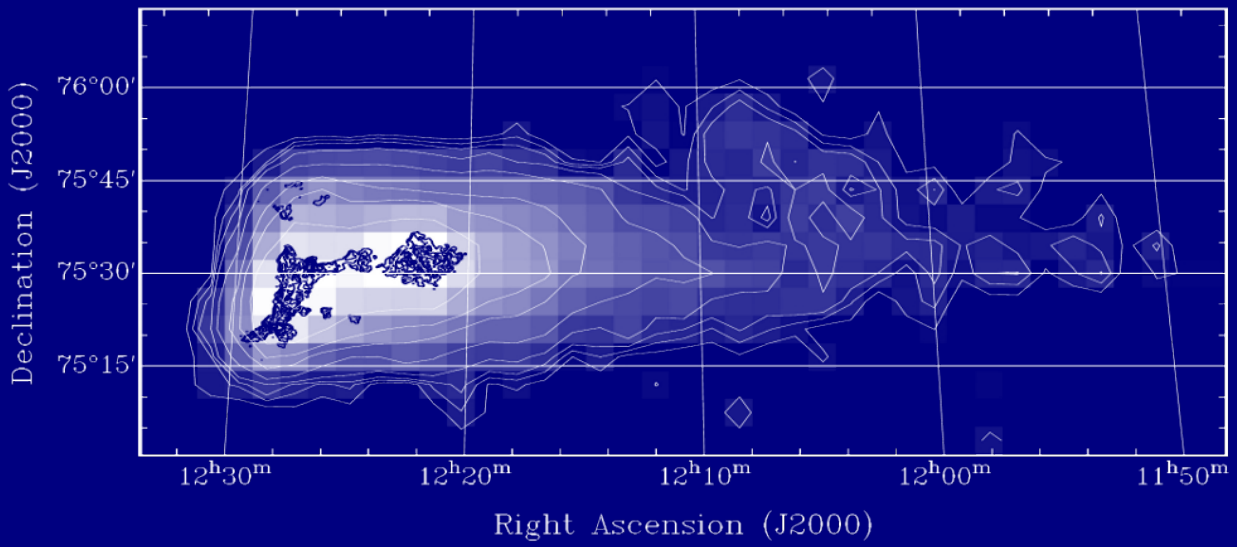
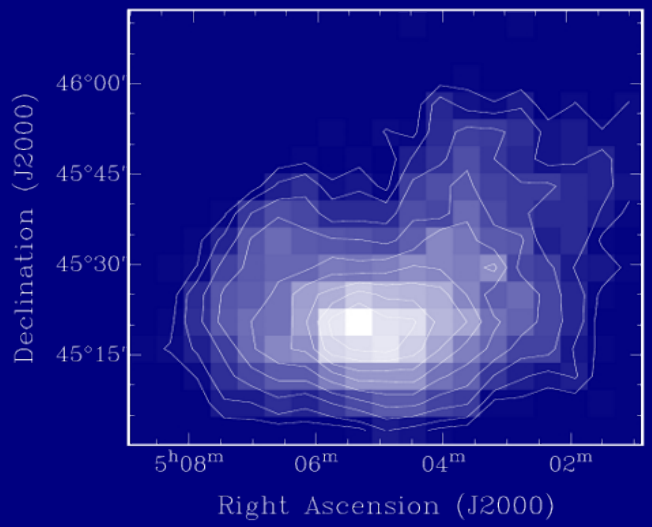
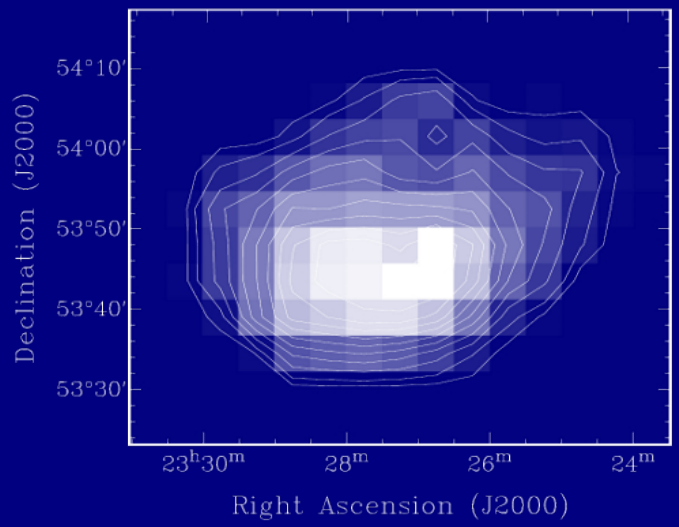
Brüns et al., 2003



Shapes of HVCs





Interaction with an ambient medium!

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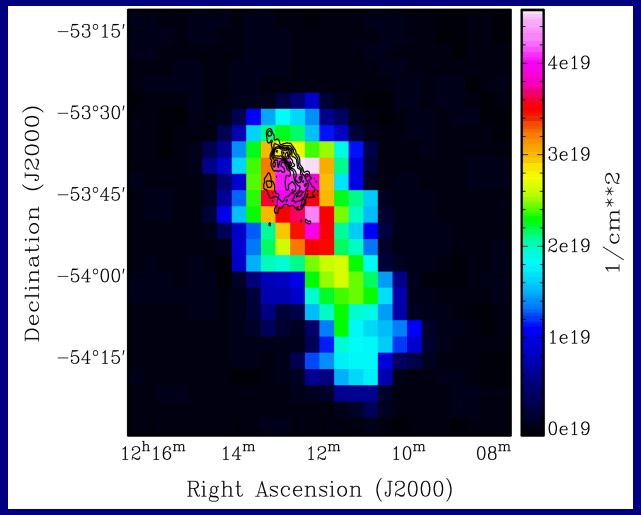
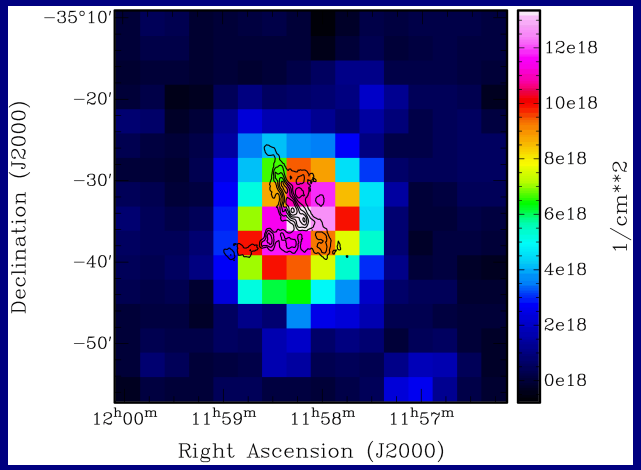
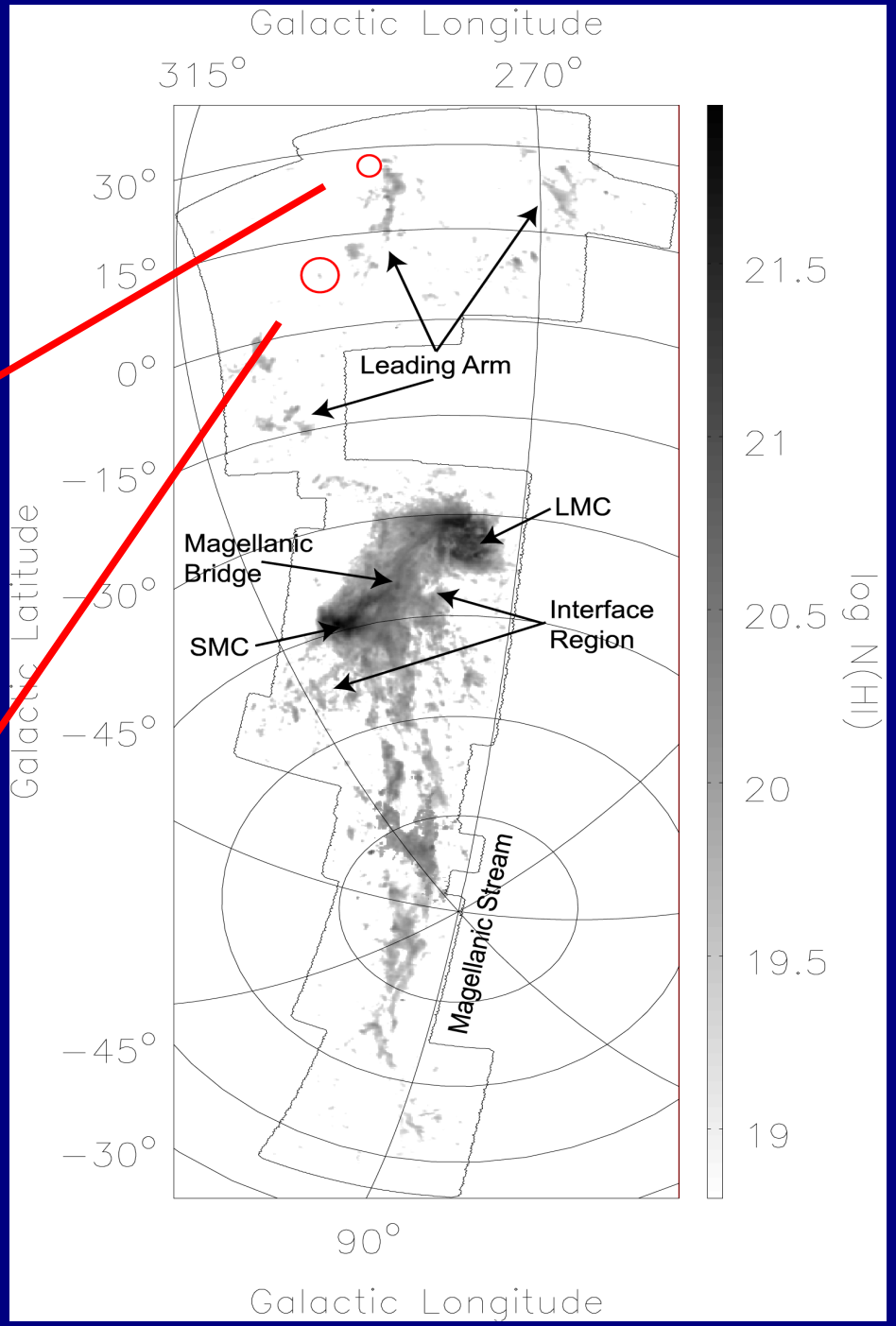
HVCs in the Magellanic System







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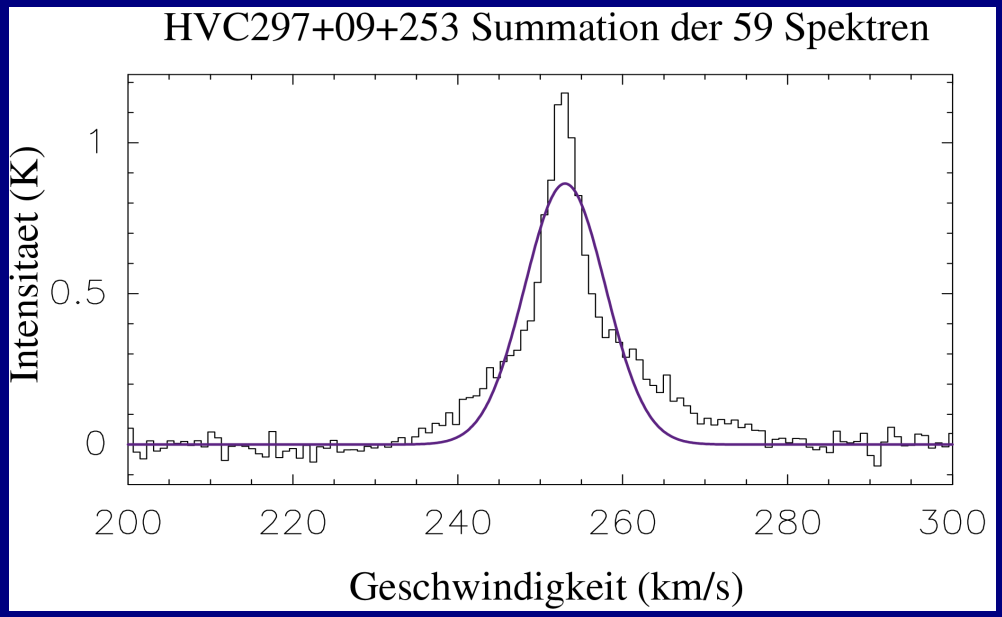
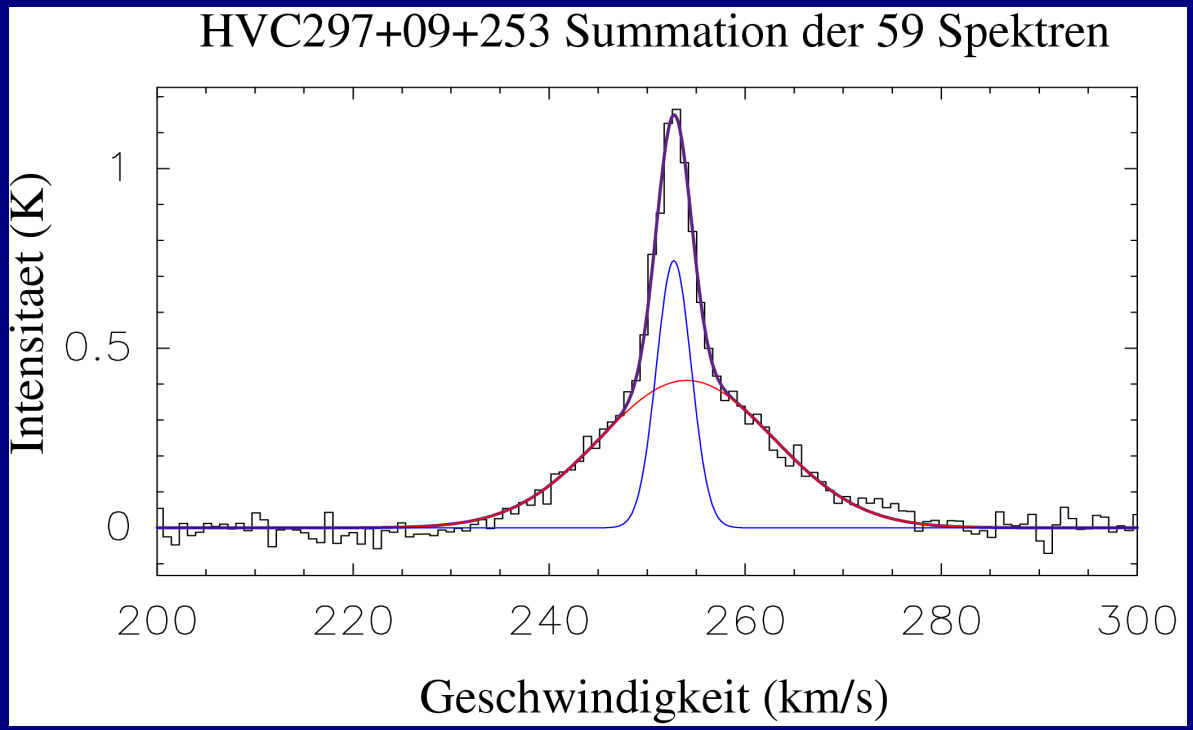
Brüns et al., 2005

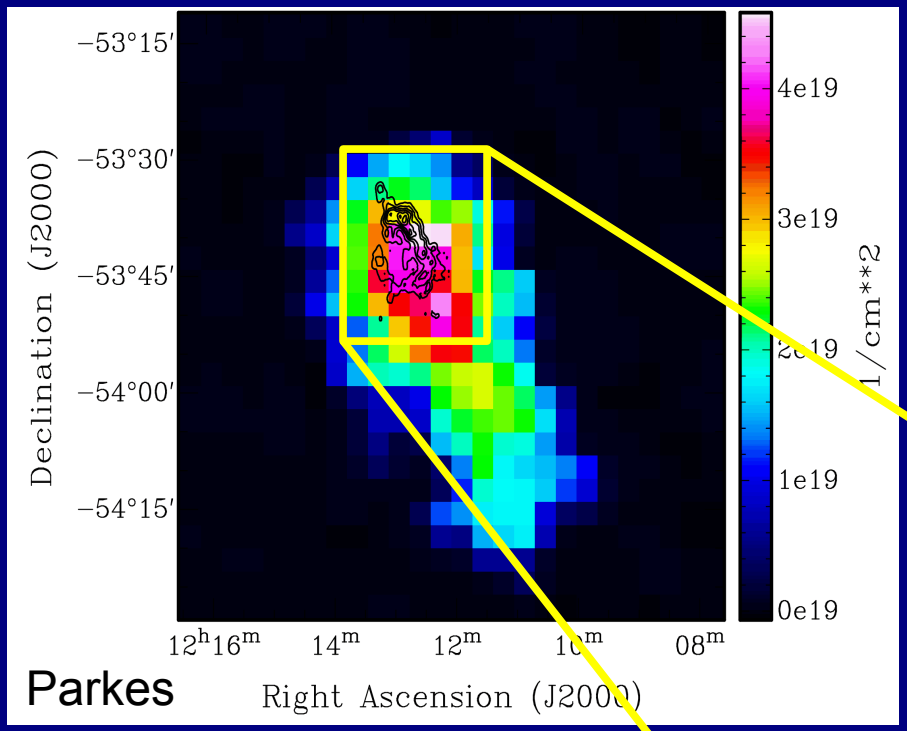


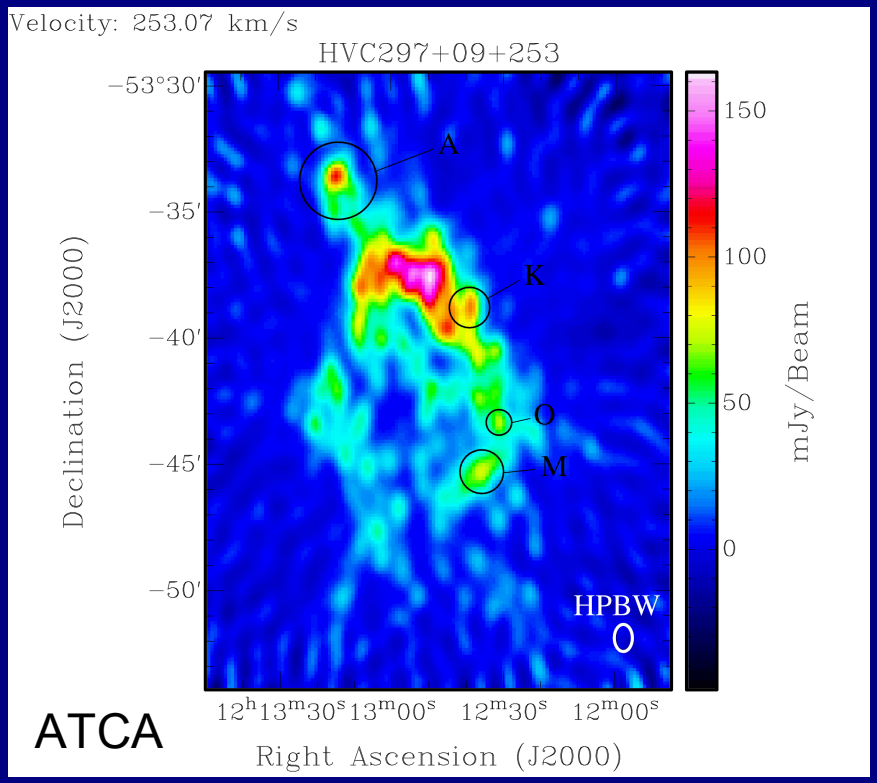
Typical spectra of HVCs

Two phase medium!

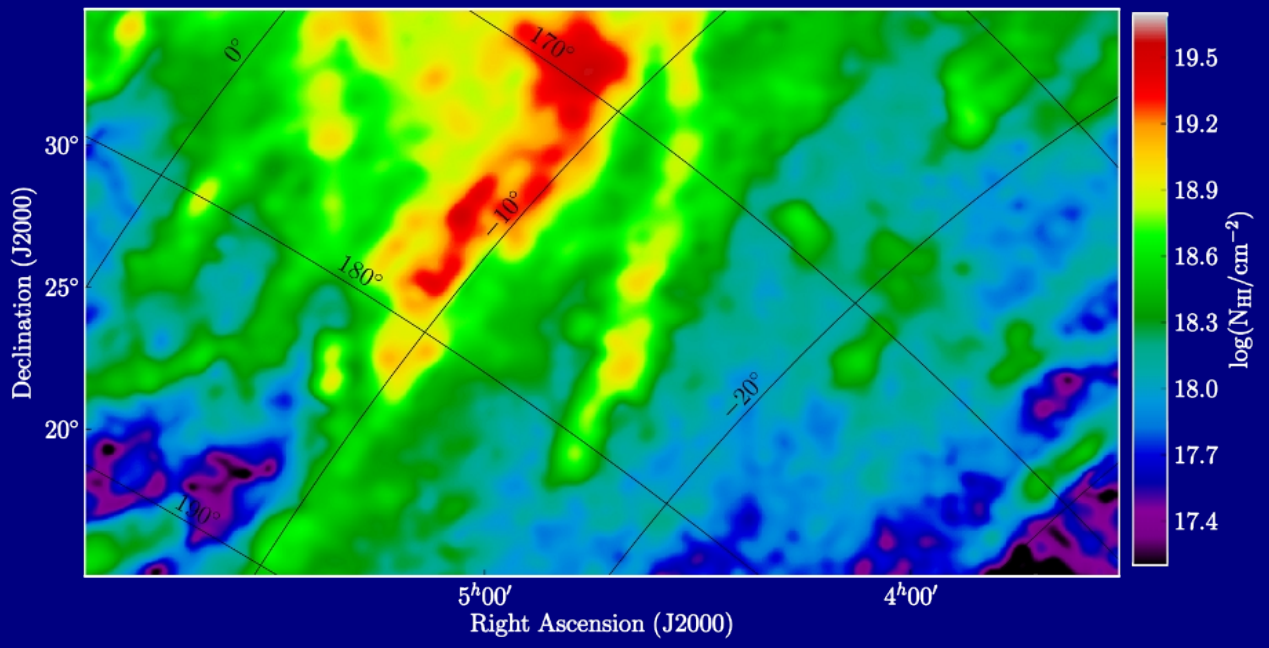


The warm diffuse and cold compact phase



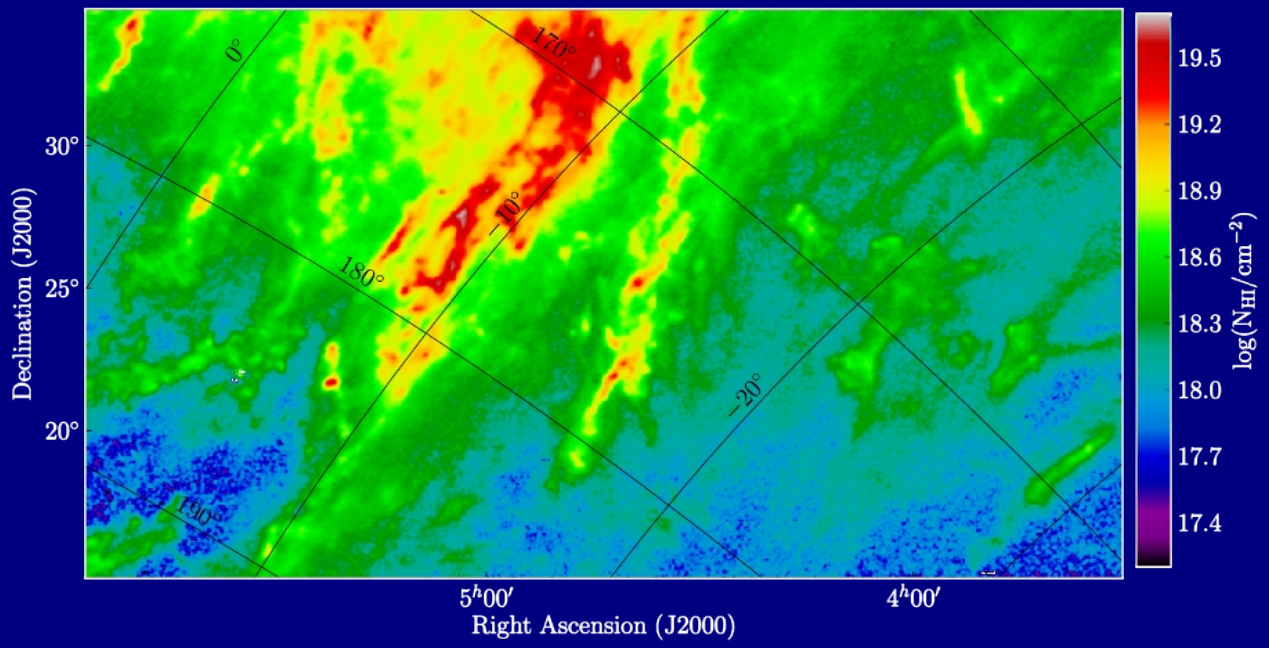


Ben Bekhti et al., 2008



LAB

vs.



EBHIS

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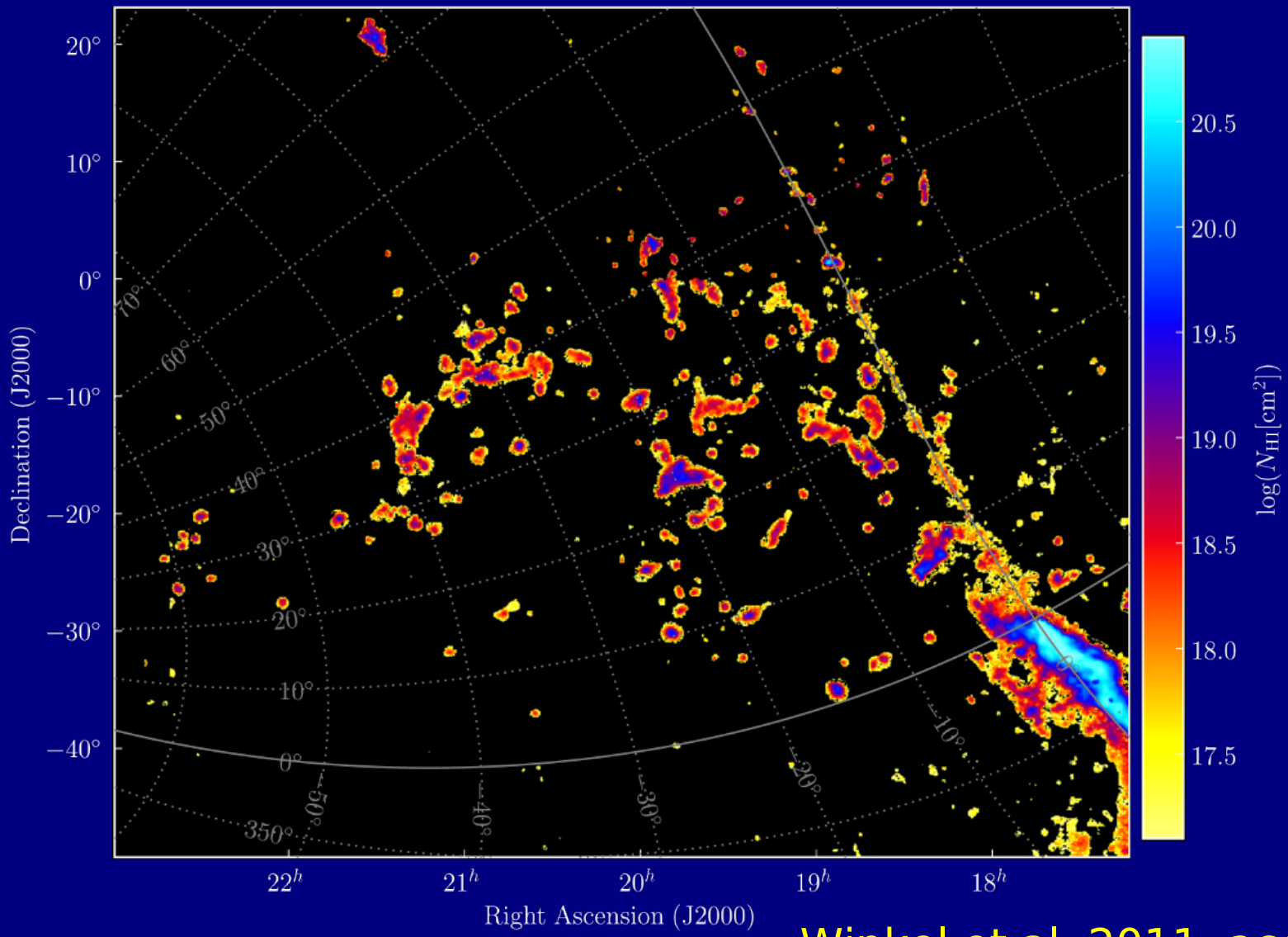
The new face of HVC complexes



Winkel et al. 2011, accepted

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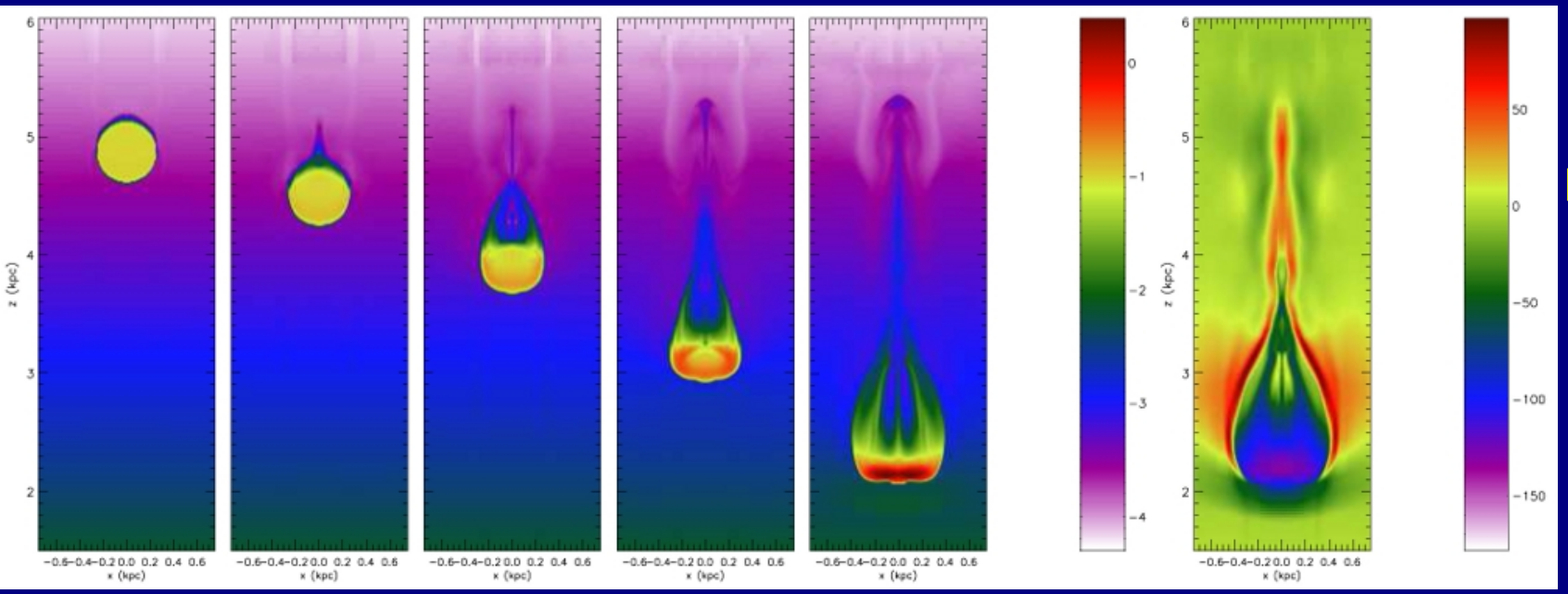
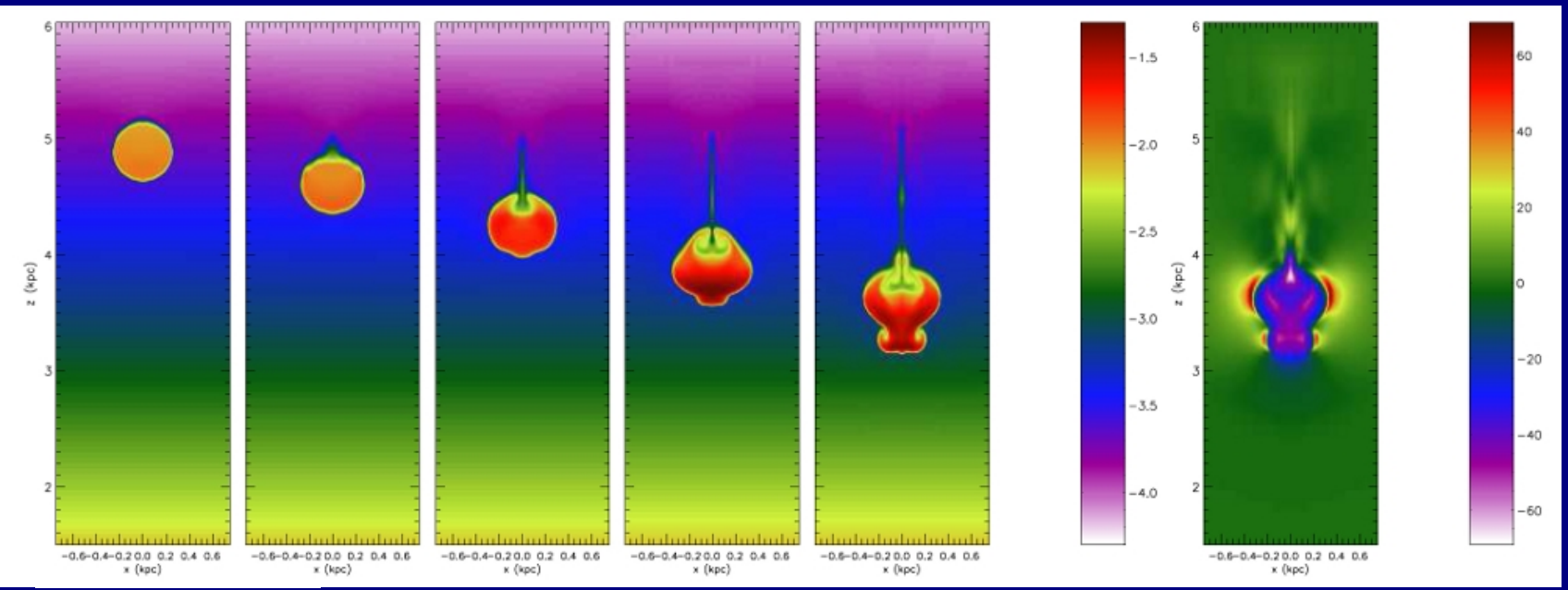
HVCs in a magnetised galactic halo



B_{II}=1.3 μG

n_c=0.1 cm^{-3}



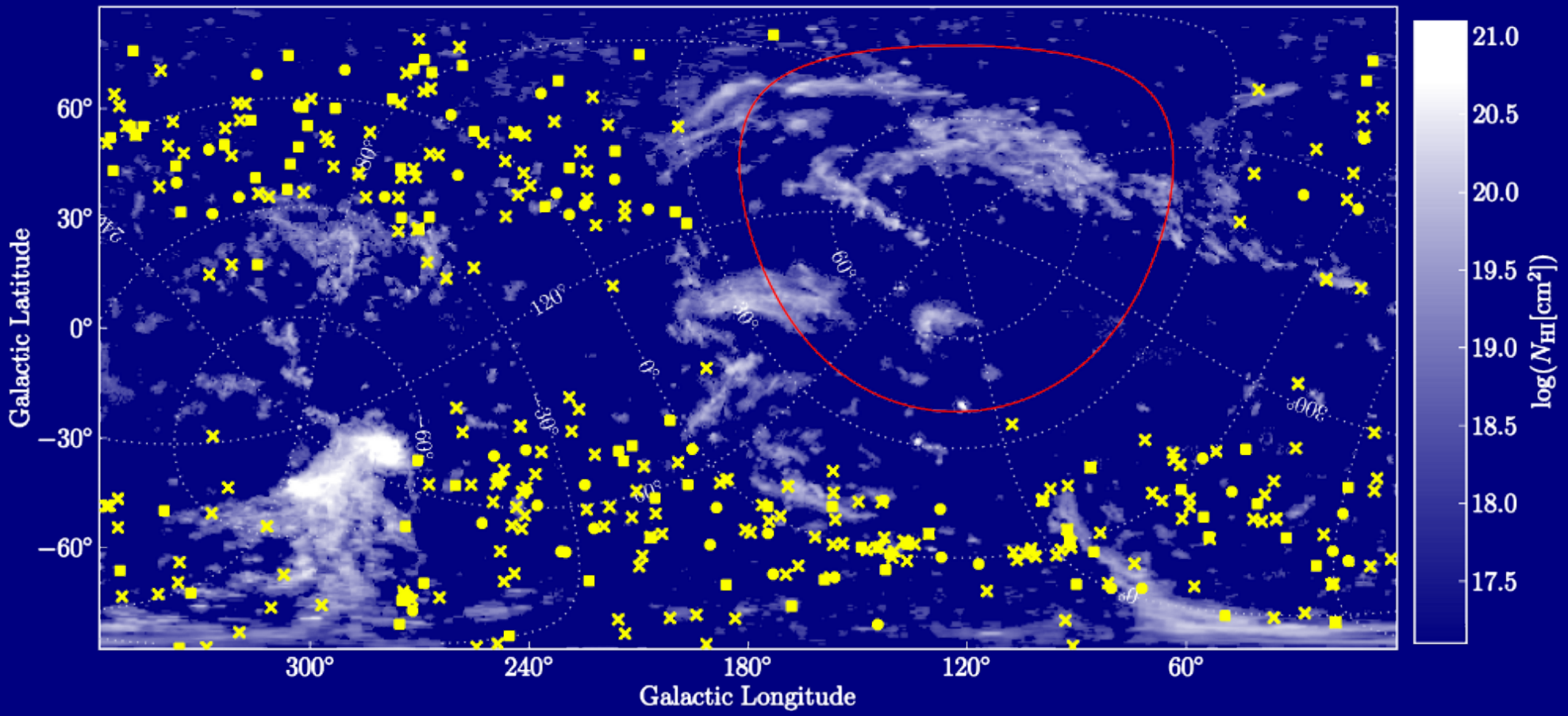
n_c=0.01 cm^{-3}

Kwak et al., 2009

Our project

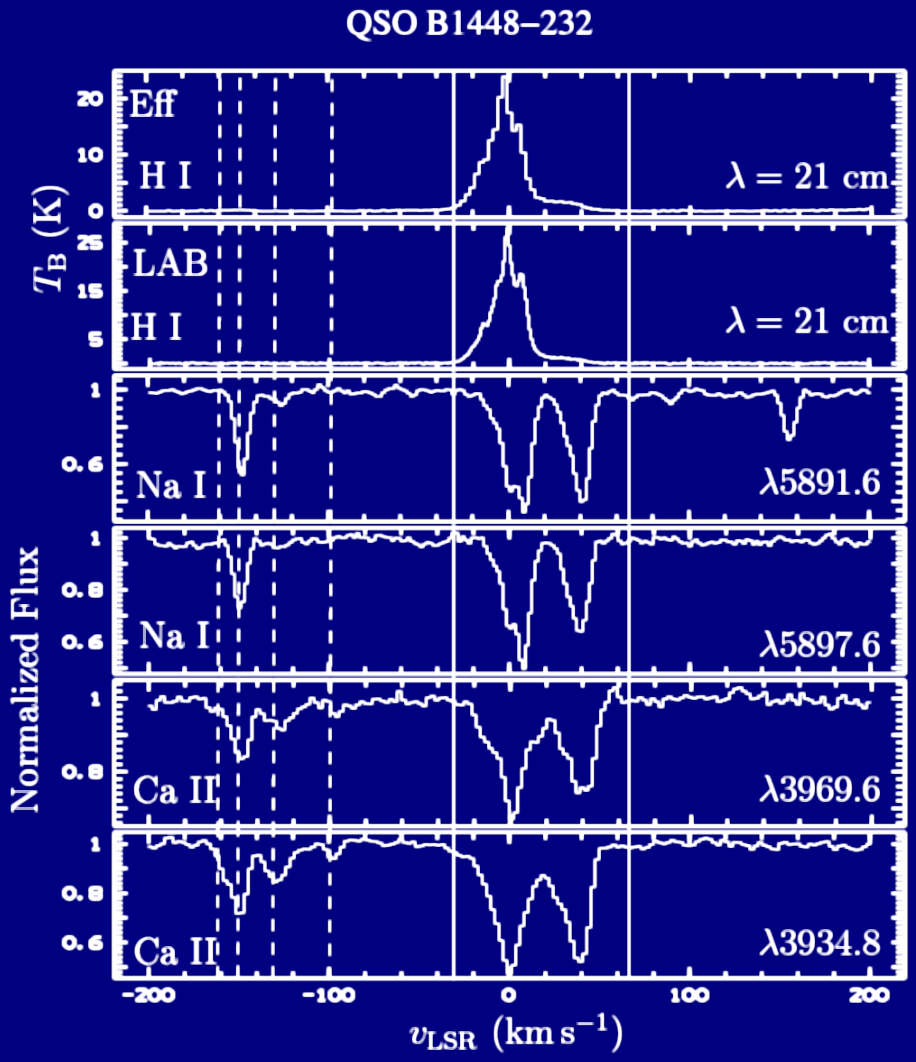
HVC all-sky map

400 in total



Ben Bekhti et al., in prep.

Emission and absorption spectra



Ben Bekhti et al., 2008

Typical parameters:

Absorption

$\log(N_{CaII}/cm^{-2}) \approx 11...12.5$

$b \leq 7$ km/s

Emission

$\log(N_{HI}/cm^{-2}) \approx 19...20$

$b \leq 20$ km/s

Area filling factor f~30%

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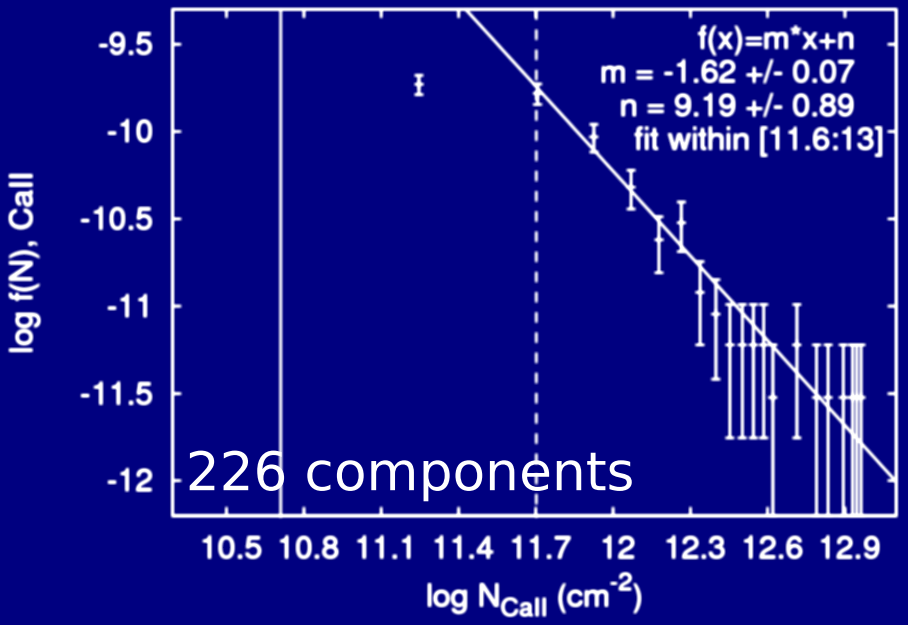

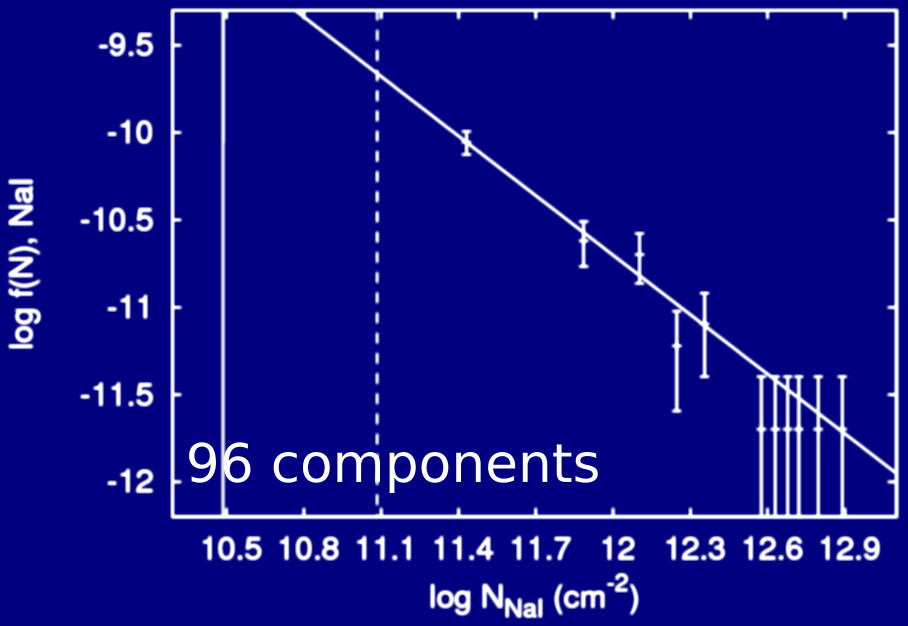

CaII/NaI column densities

Column-density distribution function

$f(N)=m/\Delta N$

Power law, N^{β},with

Ben Bekhti et al., 2008

$\beta = -1.62 +/- 0.1$ (CaII)

$\beta = -1.14 +/- 0.07$ (NaI)

MgII absorbers

Churchill et al., 2003

$\beta = -1.6 +/- 0.1$

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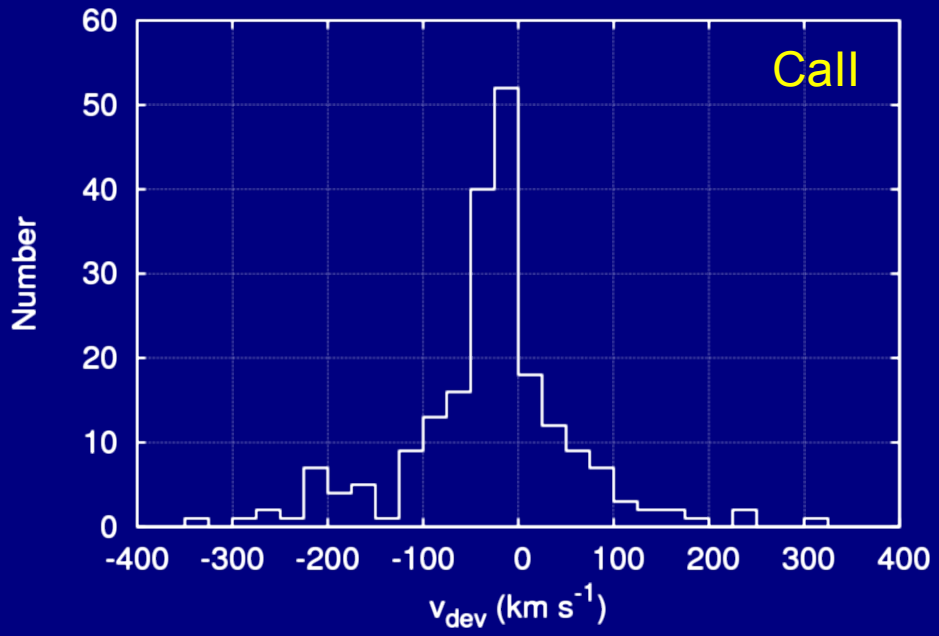
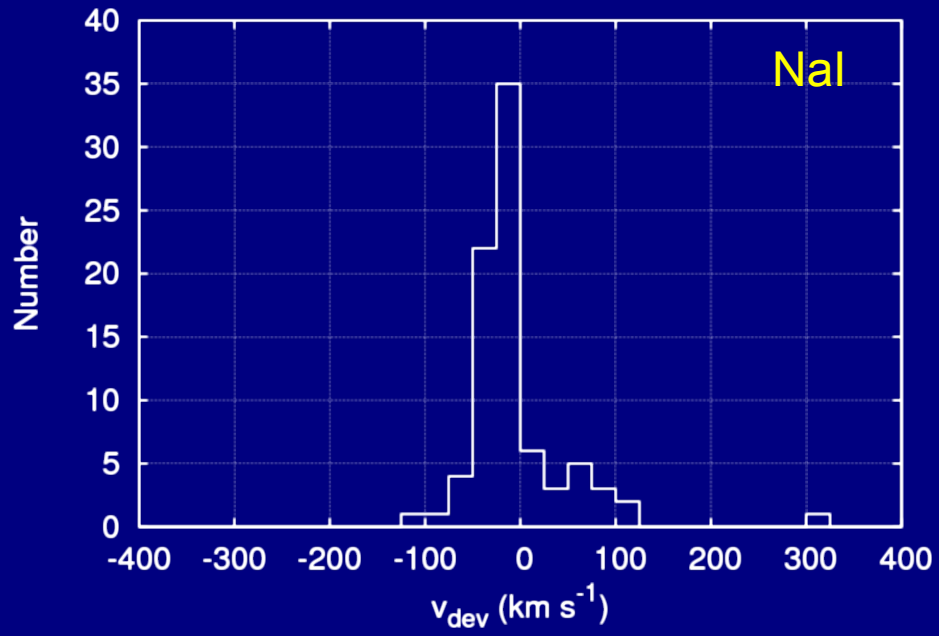
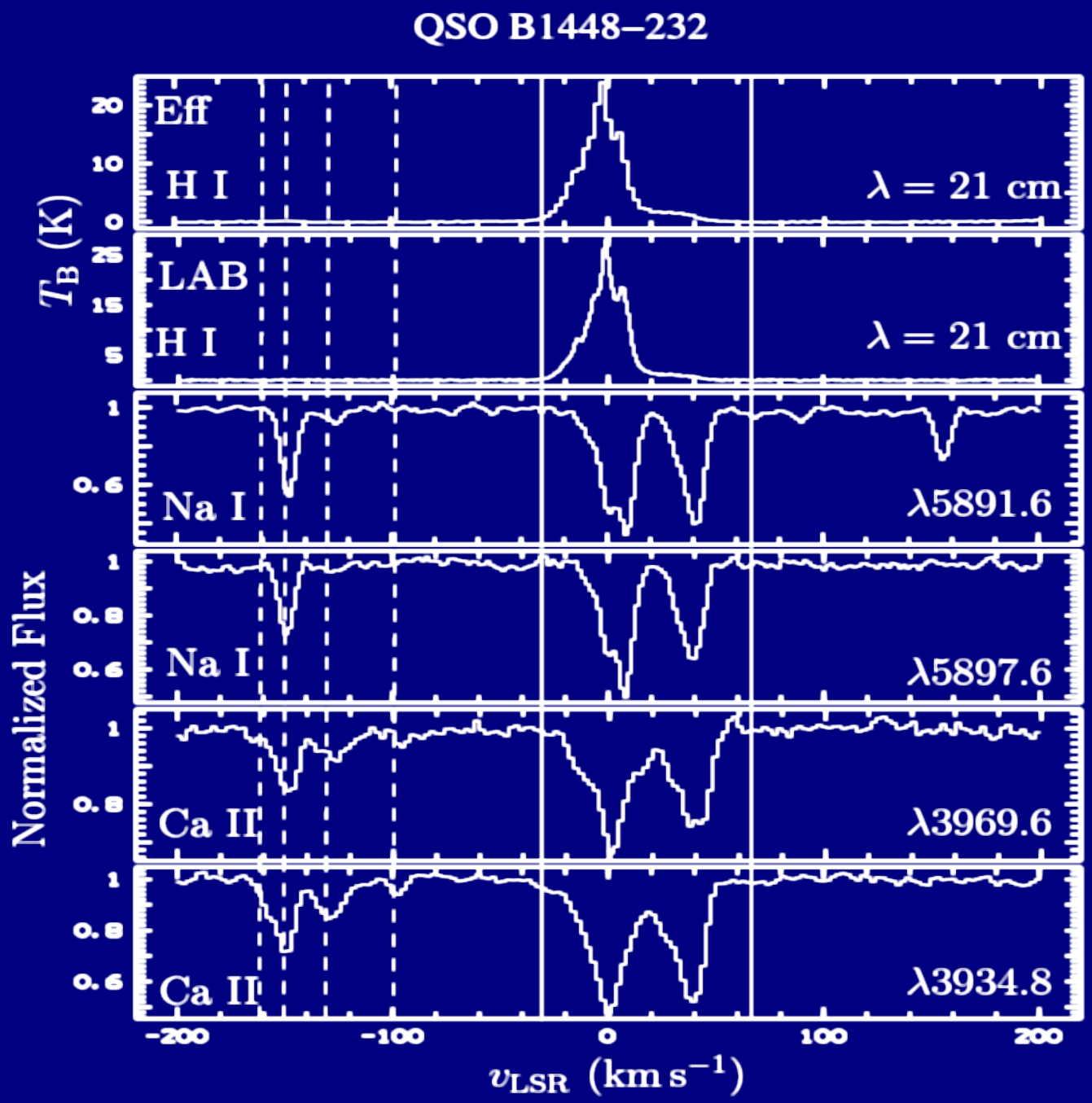
Velocity distribution





Slight excess towards negative velocities, probably due to infall

Small-scale structure



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HI results from VLA and WSRT

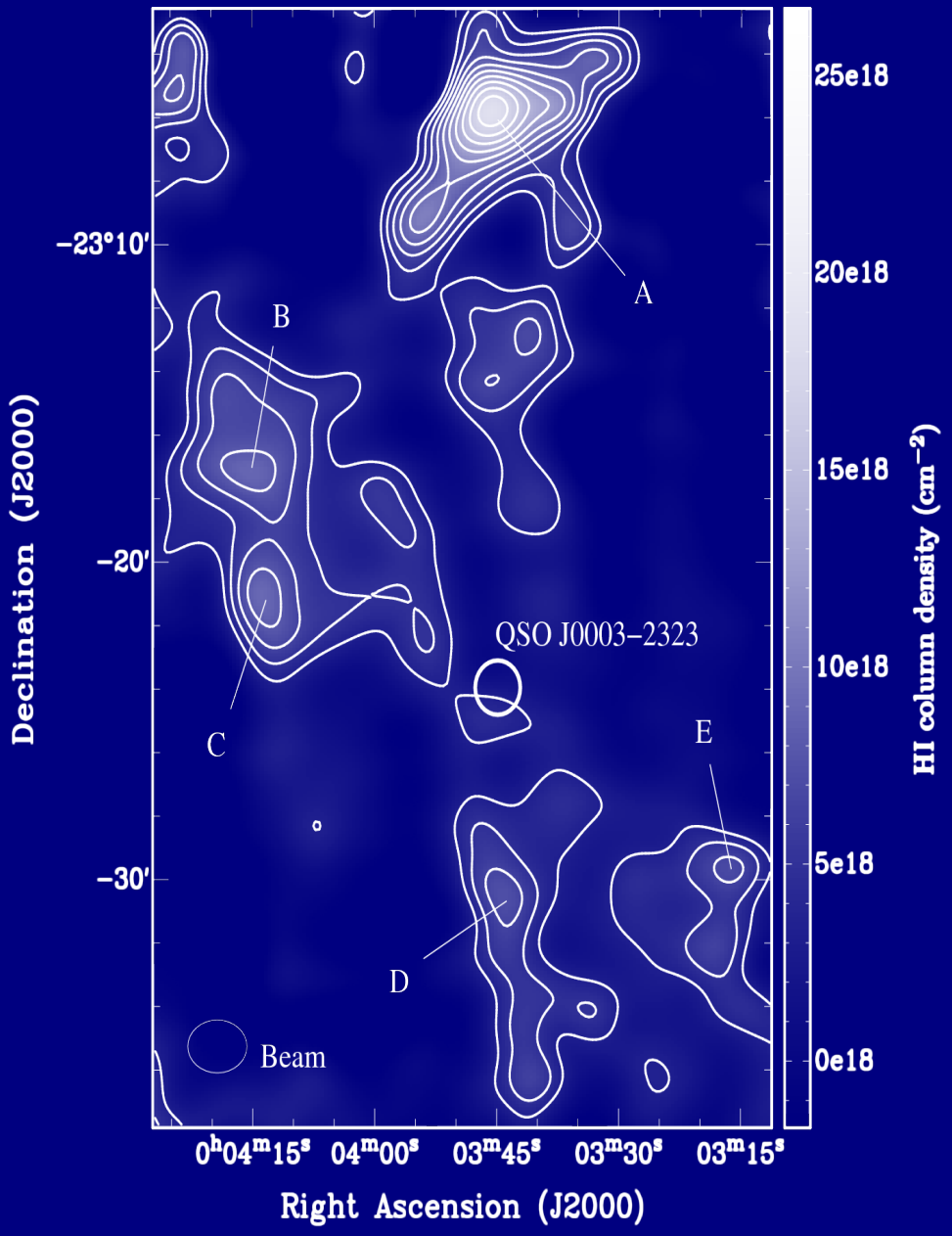
$N_{HI}=10^{18}...10^{19}cm^{-2}$

$\Delta v_{FWHM}=2...13$ km/s

$70 \leq T_{max} \leq 3700$ K

$\Phi \leq 5'$

Cold, compact, clumps in all observed directions



Ben Bekhti et al., 2009

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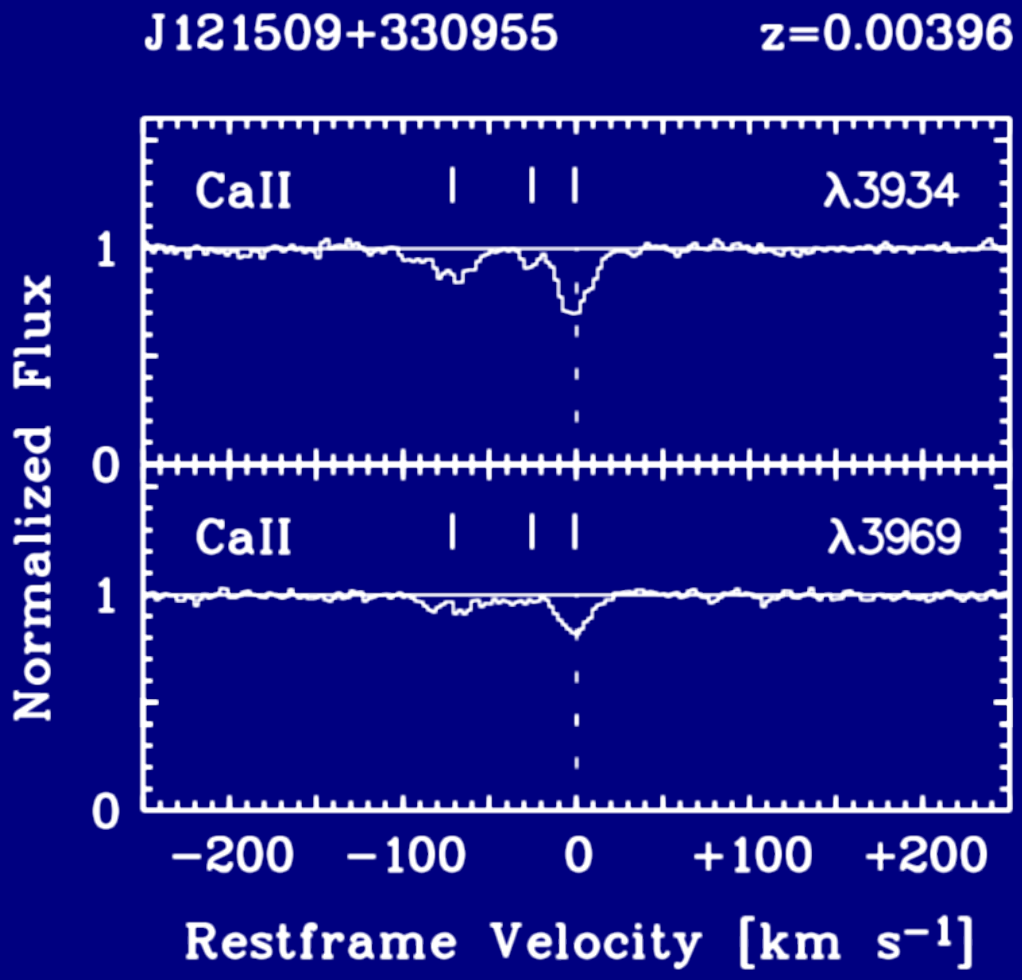
CaII absorbers around other galaxies



23 intervening systems ($z < 0.5$)
log N(CaII) = 11 – 13
Same properties as Milky Way HVCs
dN/dz (CaII) = 0.117

→ Radial extend: 55 kpc

Richter et al., 2011

Conclusions

Extended gaseous 21-cm HI halos are just the tip of the iceberg

Structures on all scales: AU to kpc

Streams, clouds, clumps, and filaments do not have a common origin

The HI gas is mostly made of discrete clouds with typically f~30%

Neutral gas halos are common for low and high redshift galaxies

The influence of magnetic fields can not be neglected

Open questions

How much HI gas is in galaxy halos?
→ Extent, radial distribution

Evolution effects:
→ Accretion rate → const. SFR
→ warps

How does the gas cycle work?

What role do magnetic fields play?

Is the accretion cold or warm?

Stable or transient objects?

Outlook

Multi-wavelength studies

Combining:

Absorption line studies in the Optical and UV
→ COS

High-resolution & sensitivity data:
EBHIS, GASS, WSRT, ATCA, ASKAP, LOFAR
→ SKA

X-ray data