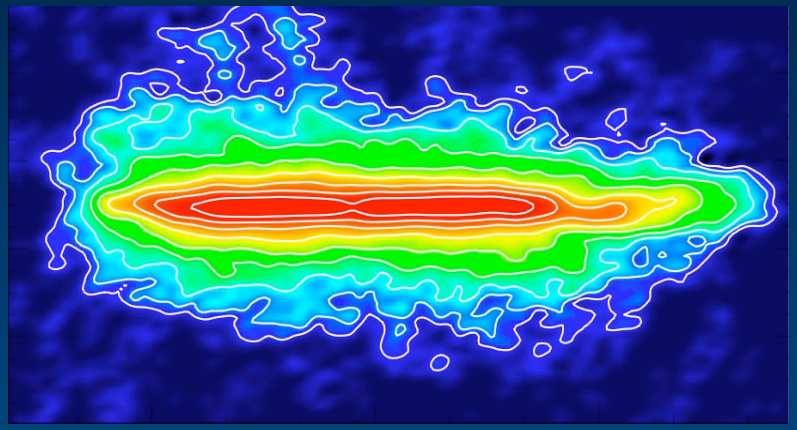
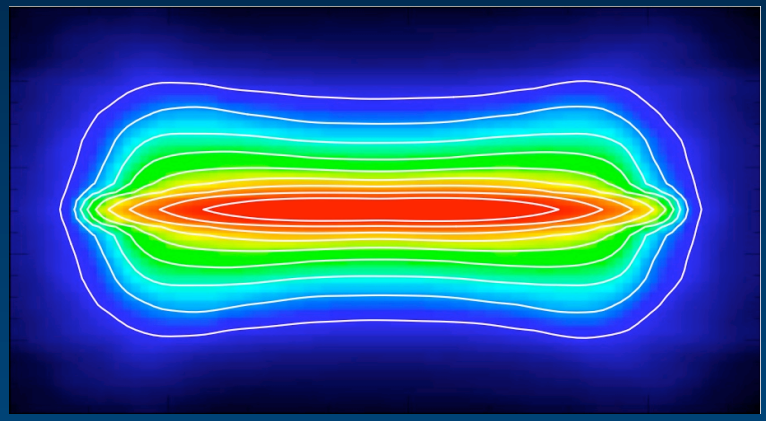
Gas accretion onto galaxies:
models vs past and future observations

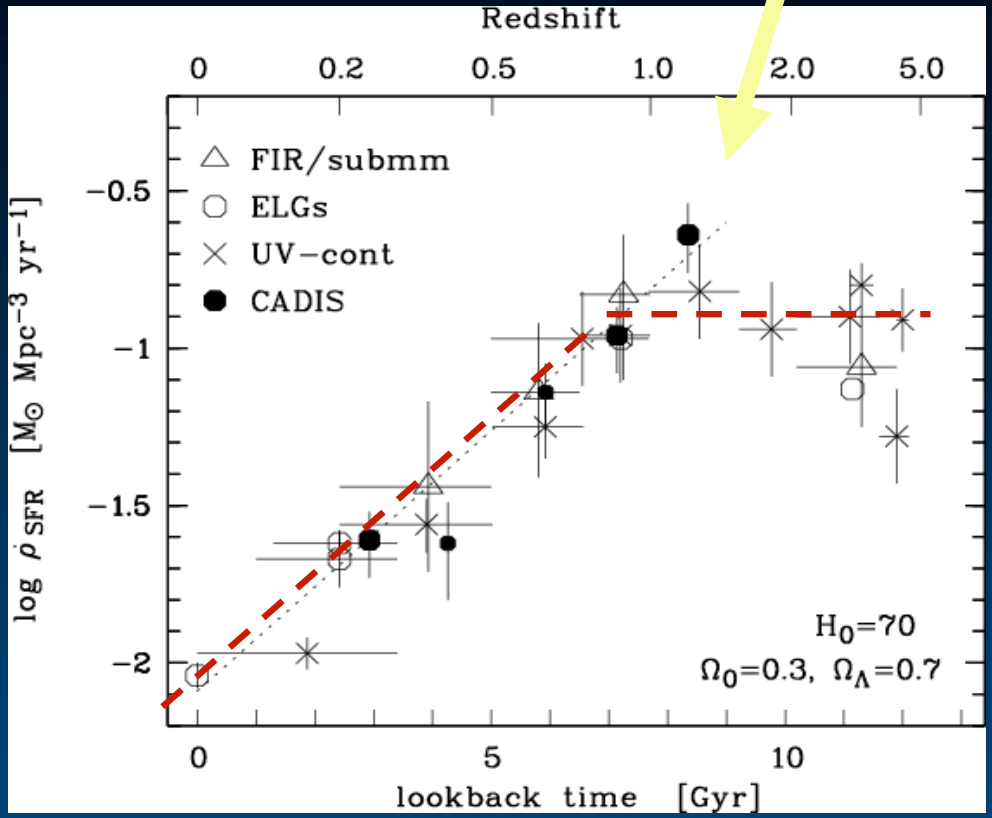




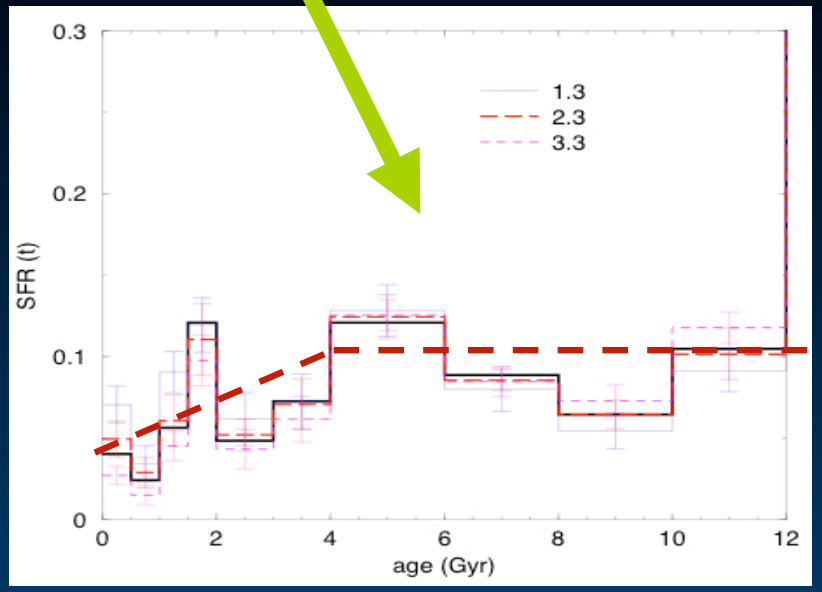
Filippo Fraternali
Department of Astronomy, University of Bologna, Italy

The need for gas accretion

SFH: Global vs Milky Way



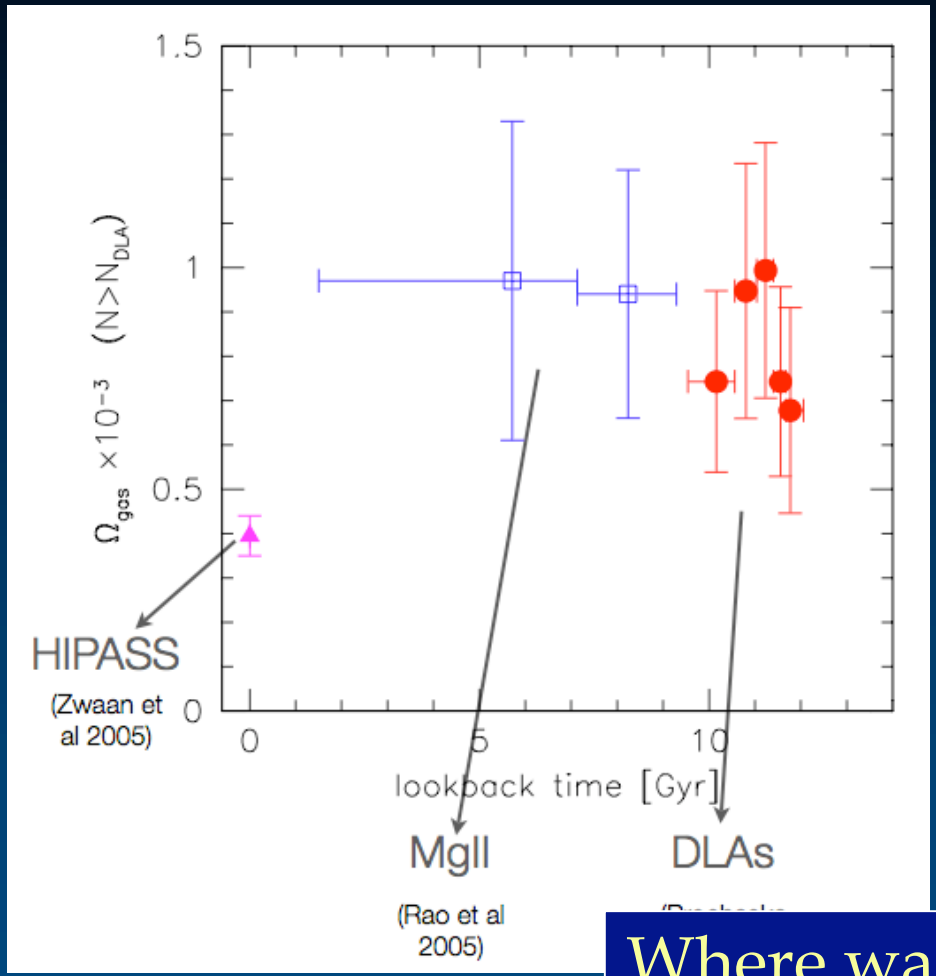
Hippelein et al. 2003

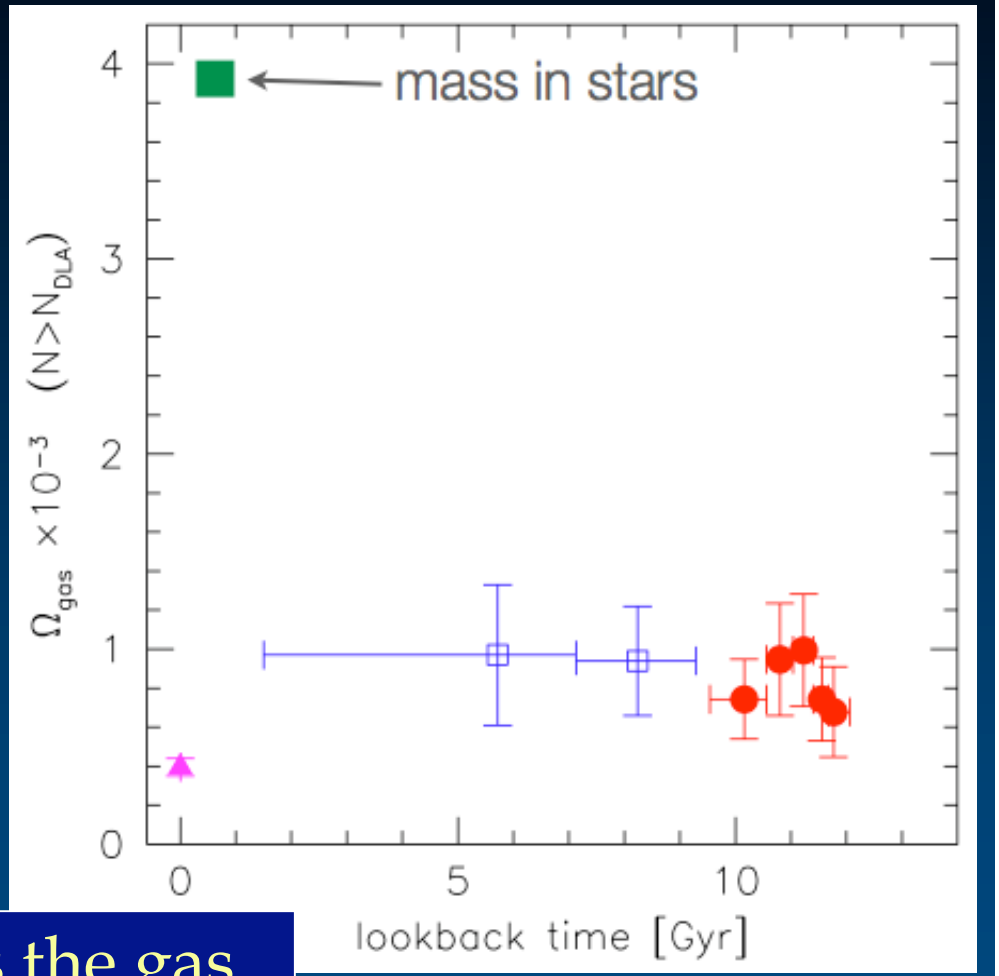


Cignoni et al. 2008

A MW galaxy does not follow a global SF history

Gas in galaxies



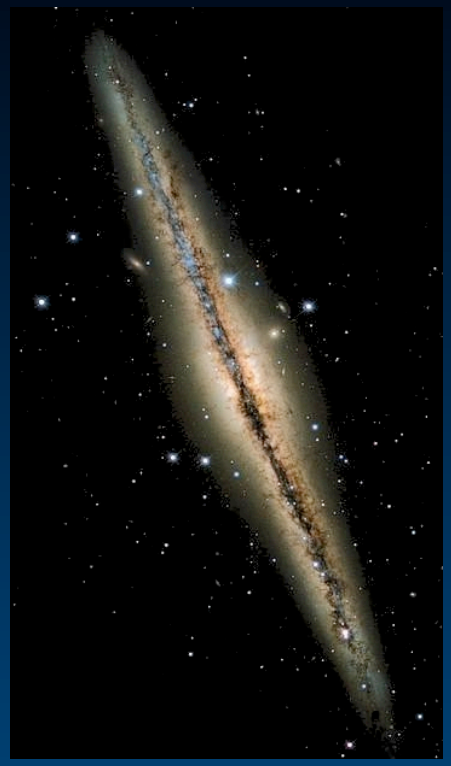


Where was the gas that turned into stars?

Zwaan et al. 2005, MNRAS

Gas in galaxy halos

NGC 891: HI observations



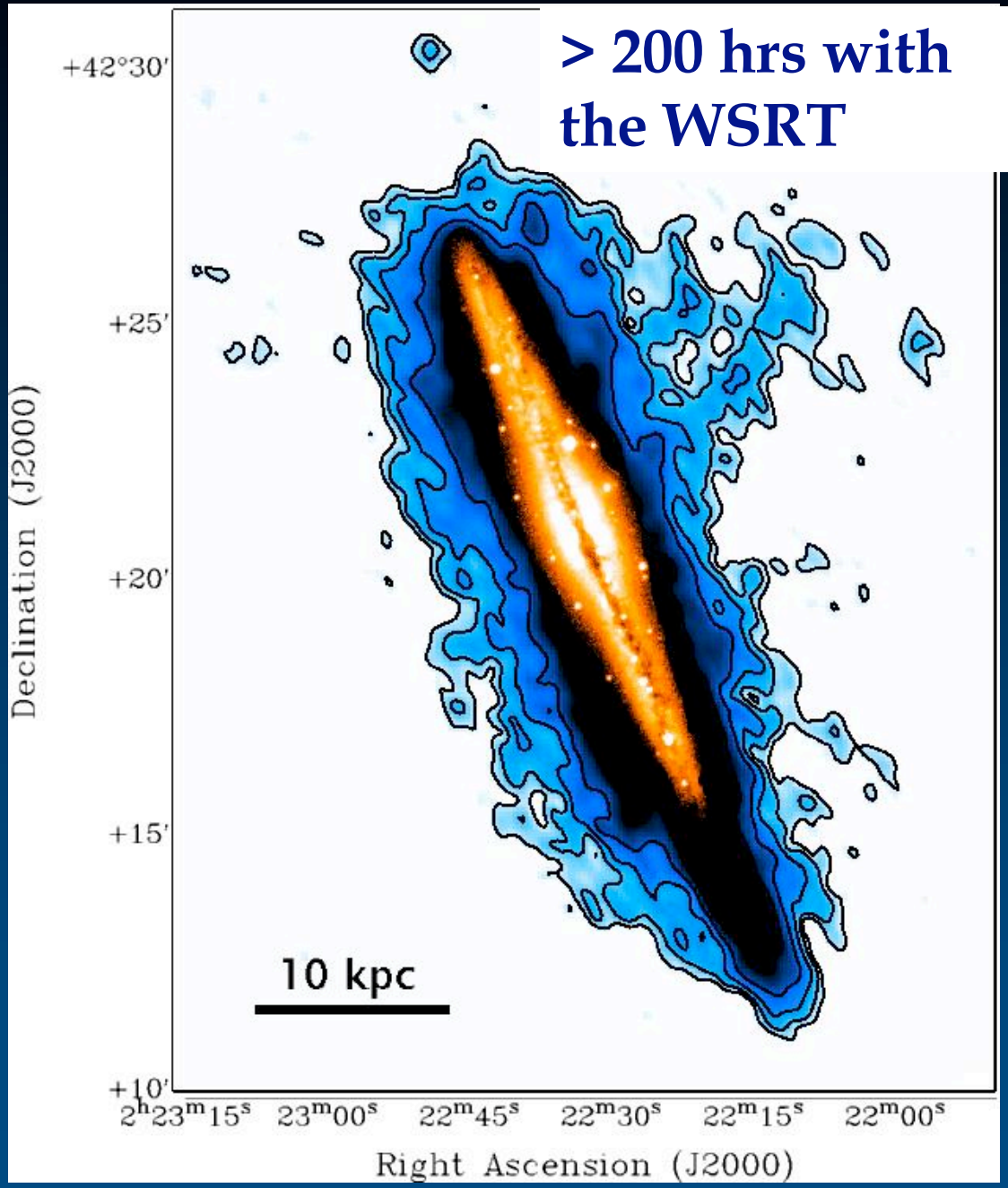
Total Mass of the HI halo

$M_{HI} \sim 1 \times 10^9 M_\odot$

$\sim 25\% M_{HItot}$

Oosterloo, Fraternali, Sancisi 2007

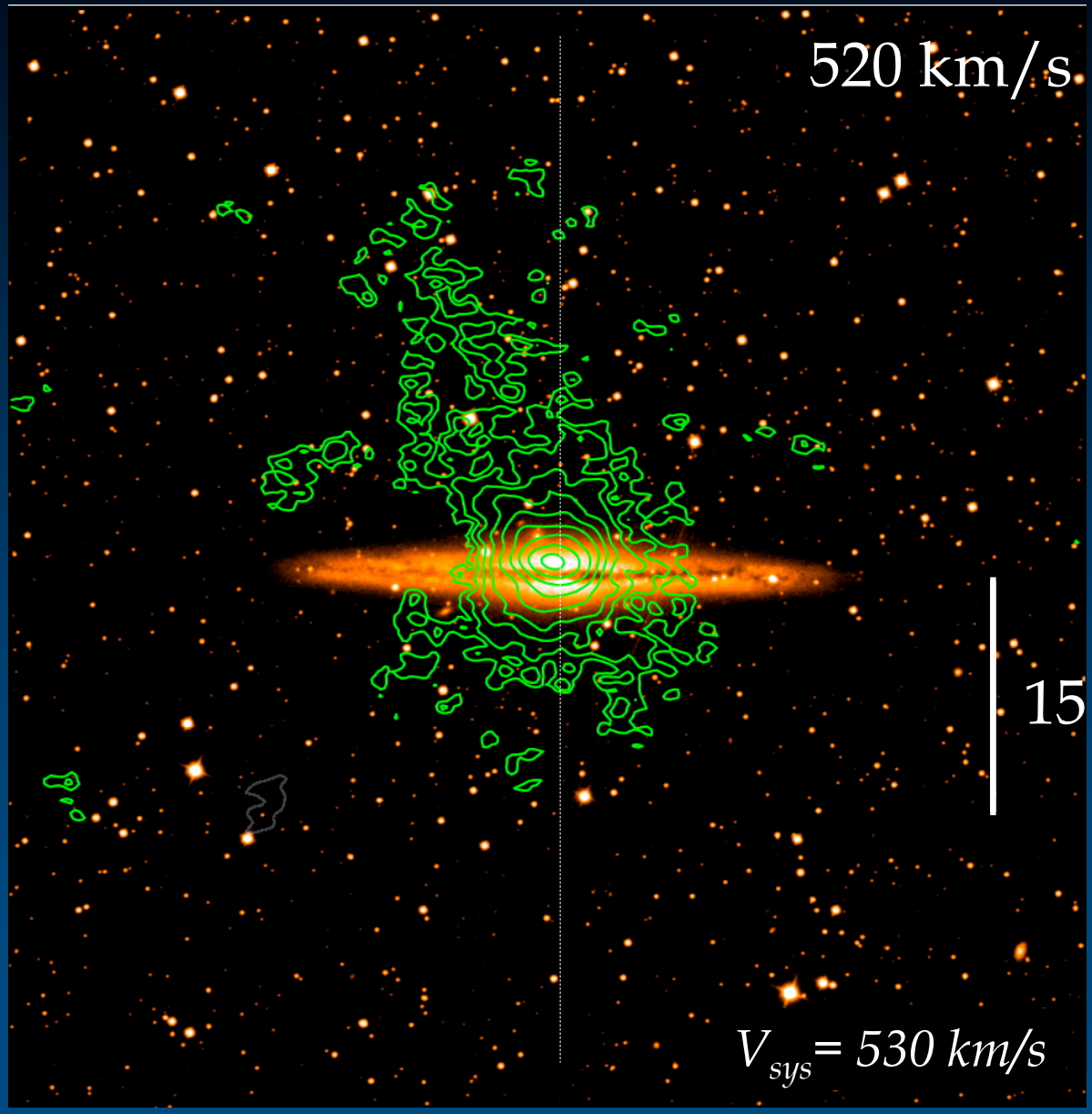
Sancisi et al. 2008, A&ARv



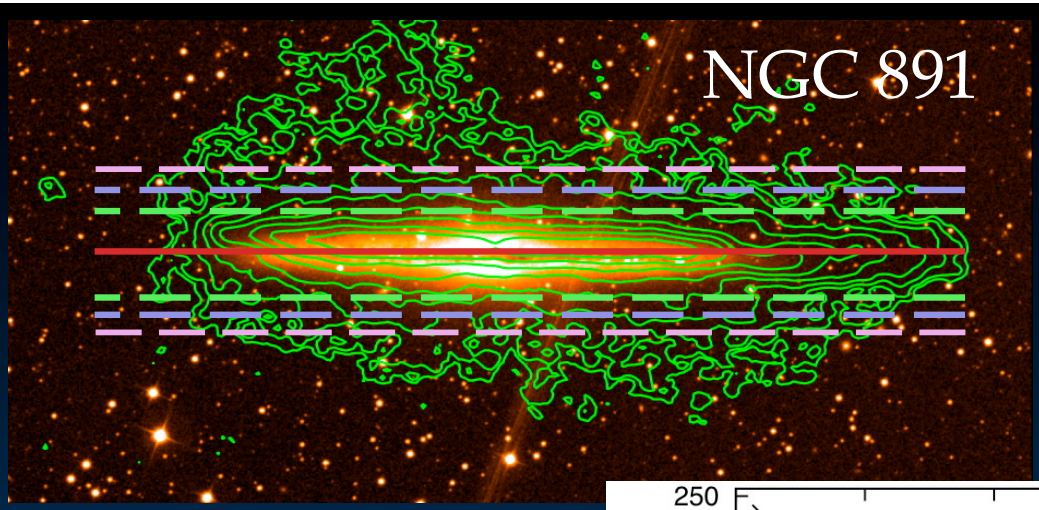
NGC891

NGC 891:
HI channel maps overlaid on DSS

High latitude clouds and gas complexes at systemic velocity



Oosterloo, Fraternali, Sancisi 2007

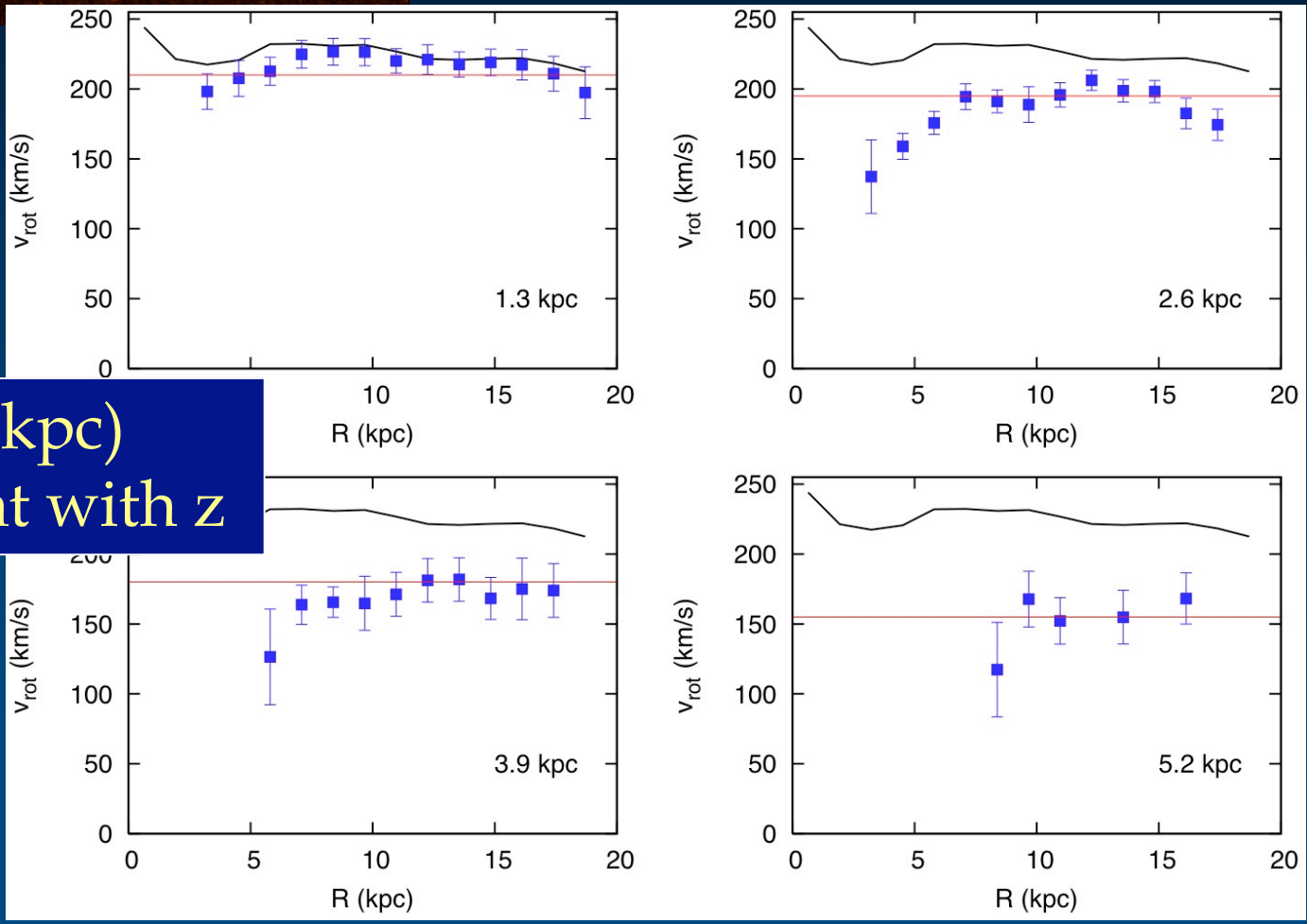


N891 Lag

Fraternali et al. 2005, ASPC

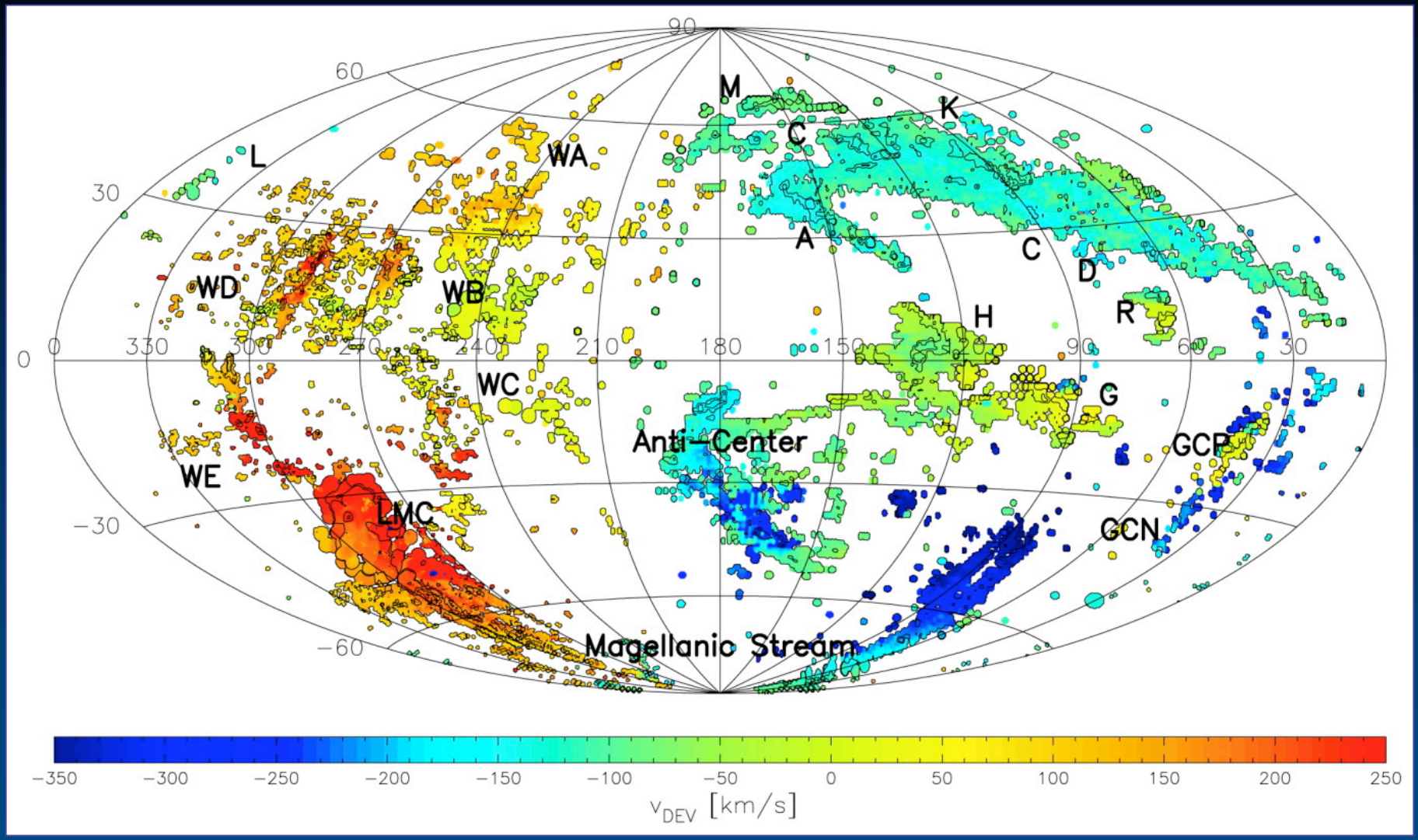
Regular kinematics that follows the disk rotation

Strong (15 km/s/kpc) rotational gradient with z



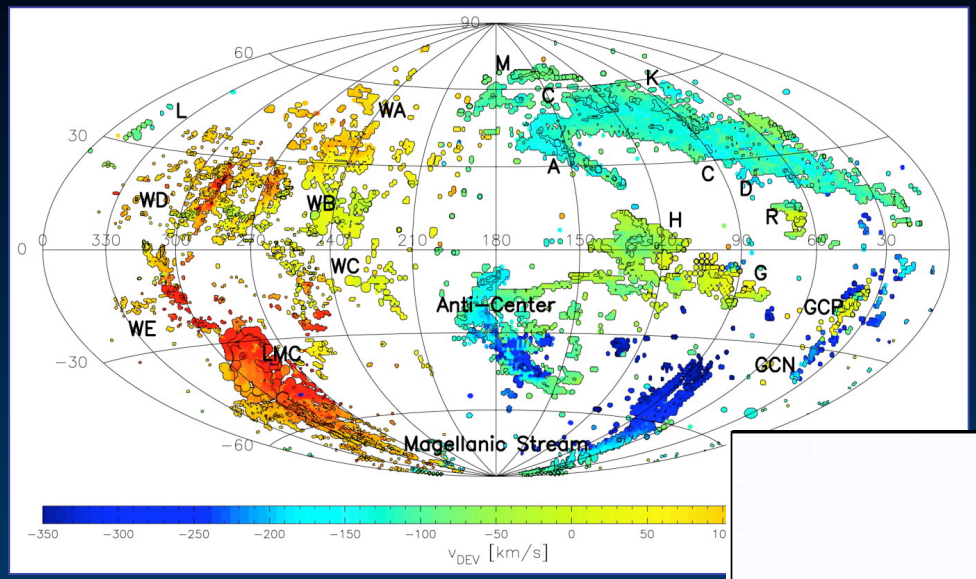
The Milky Way

High Velocity Clouds

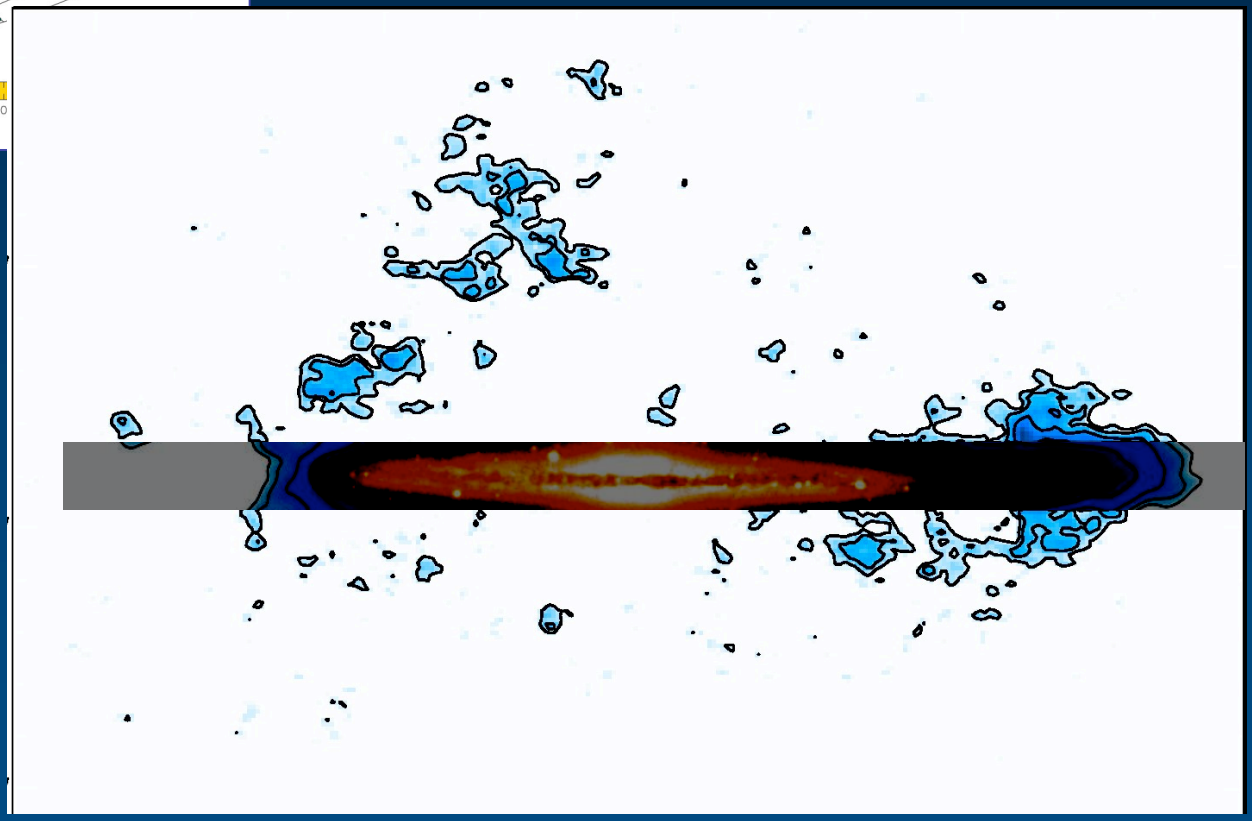


Wakker & van Woerden 1997

HVC-analogues in NGC 891



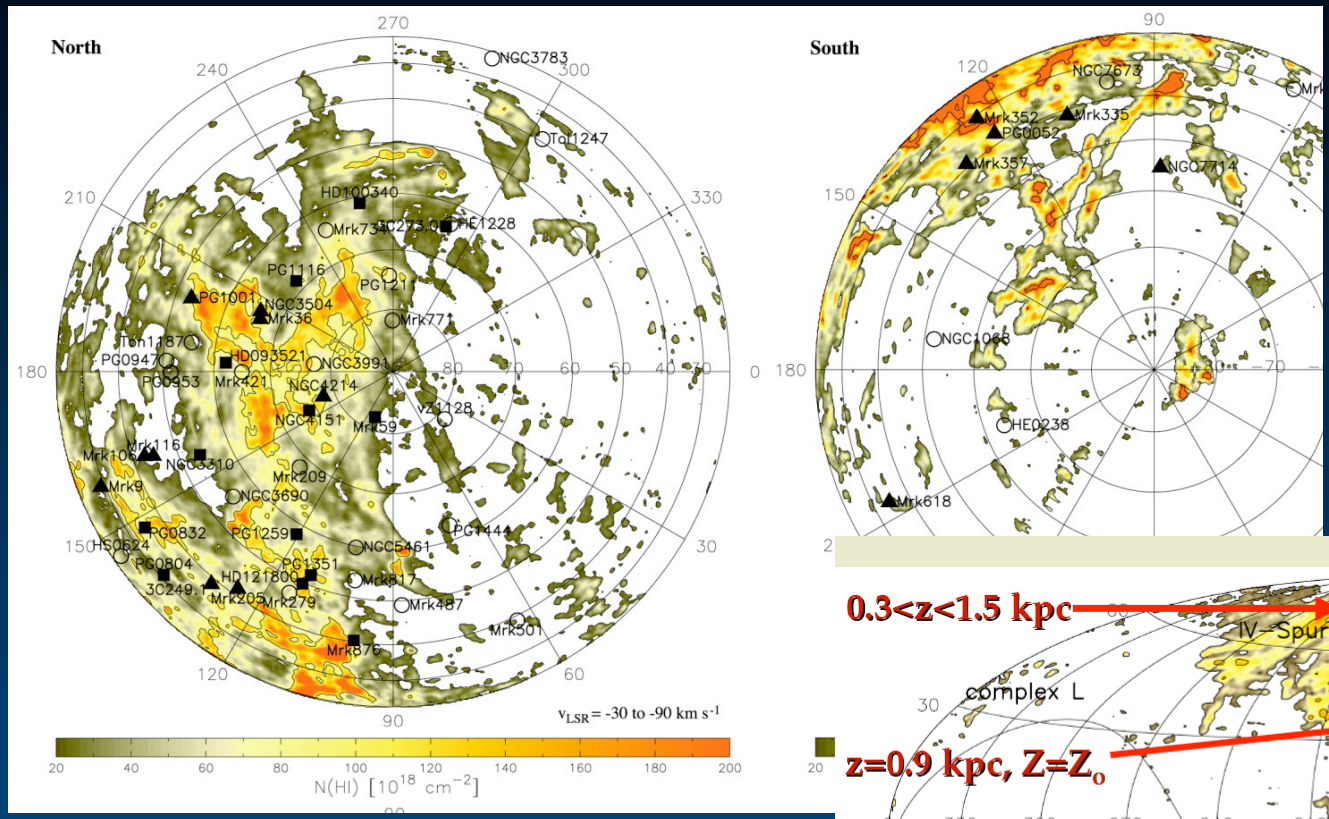
Selection: $|V_{DEV}| >\sim 90$ km/s



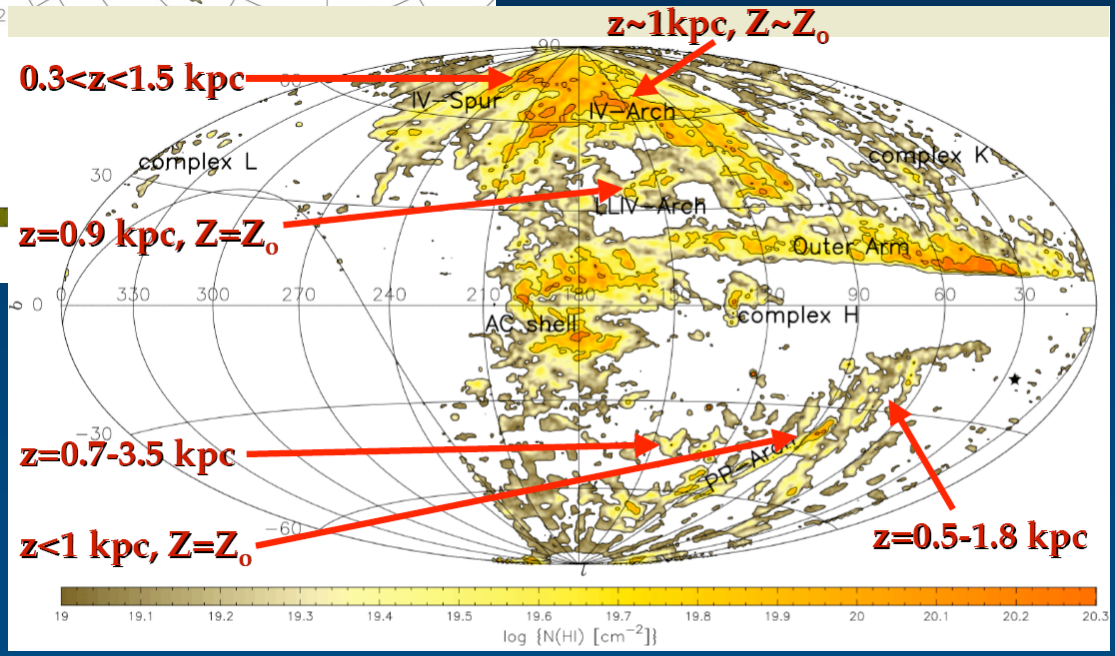
$Mass_{HI\ halo} \sim 1 \times 10^9\ M_O$

HVCs mass ~ $3 - 4 \times 10^7\ M_O$

Intermediate velocity clouds

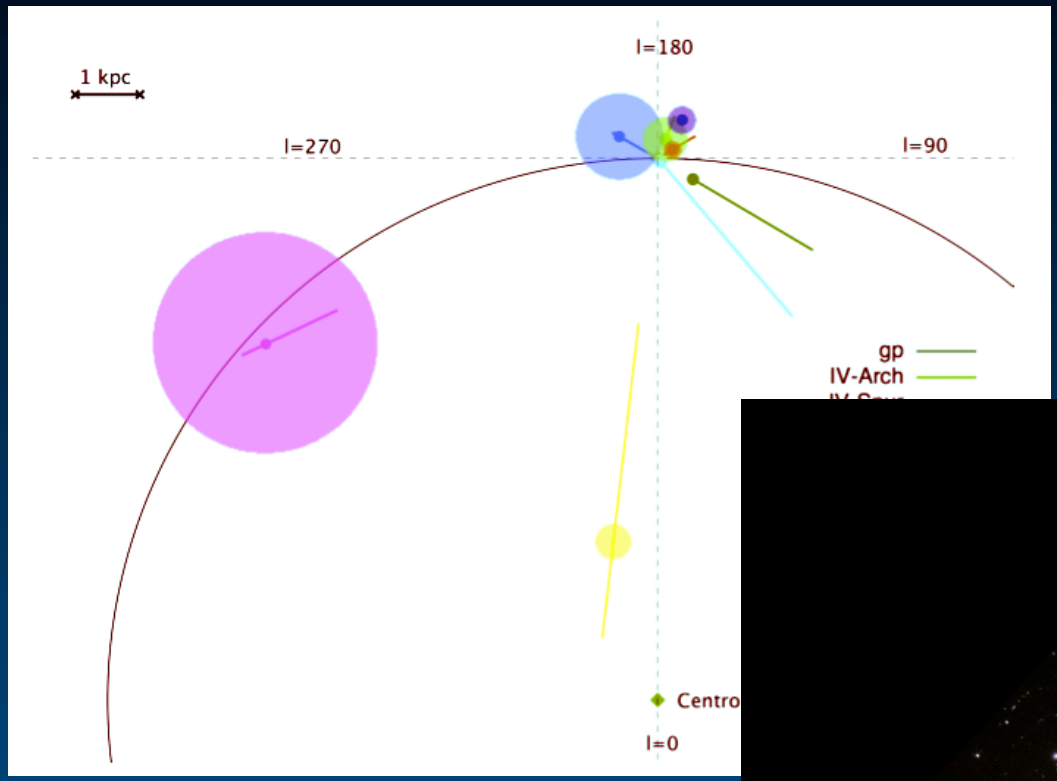


Ritcher et al. 2003



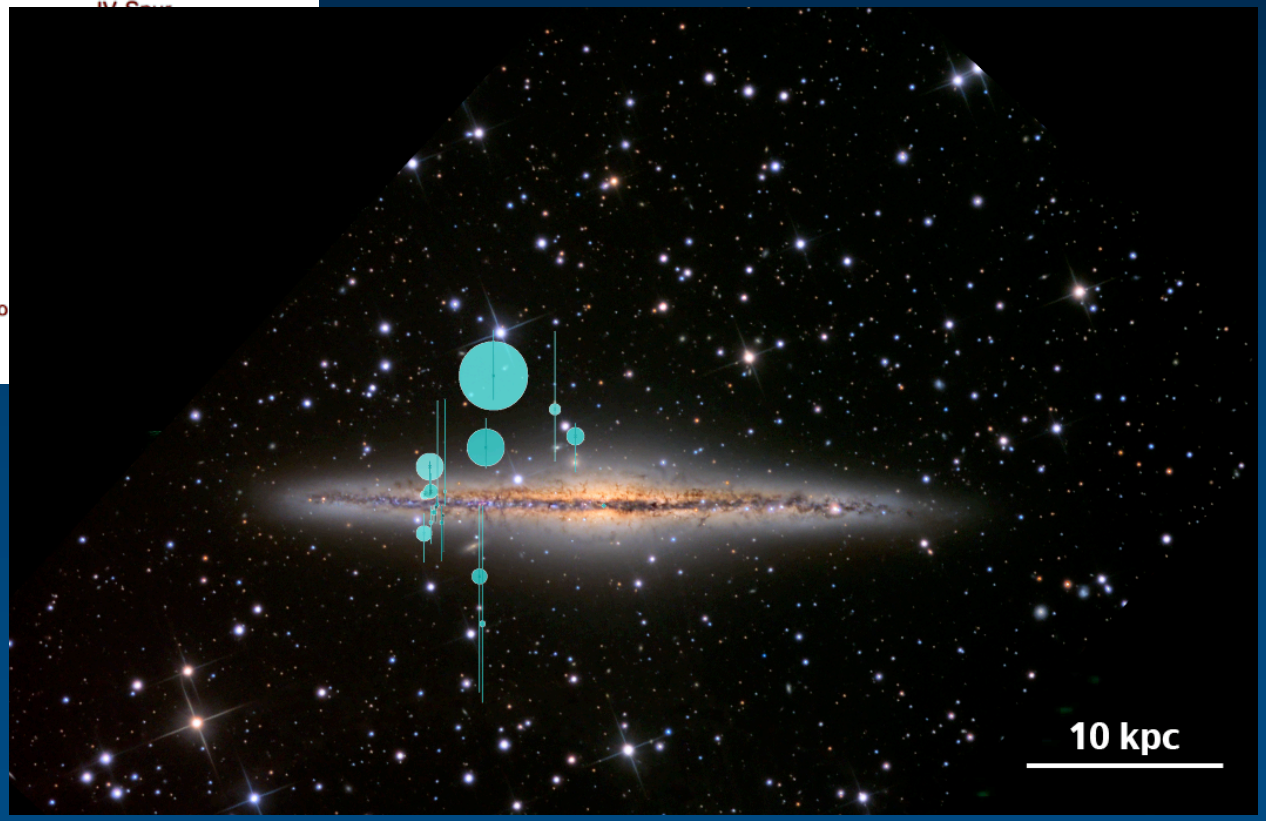
Wakker 2006

The *classical* IVCs are local



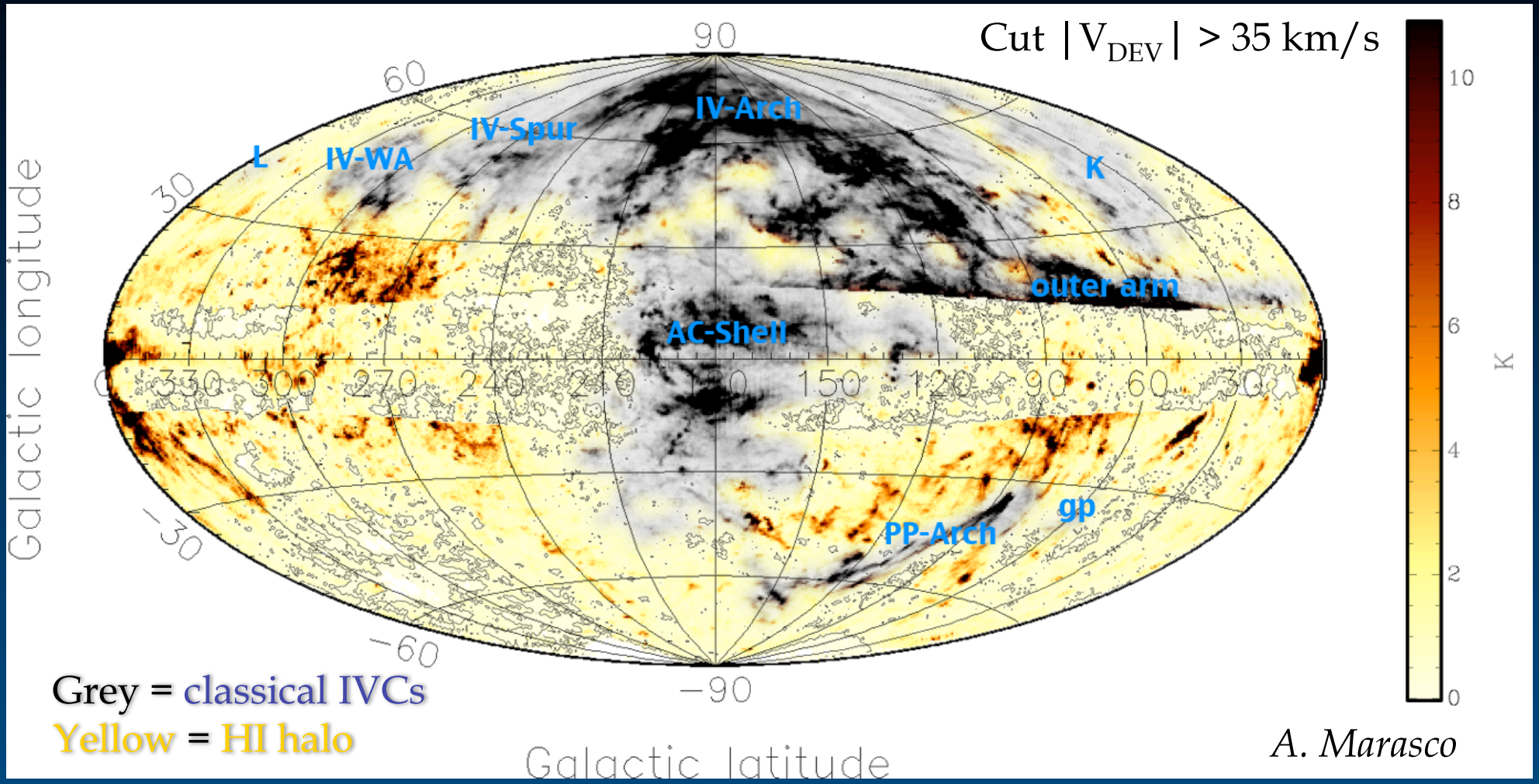
Kinematical distances of IVCs (assuming that they are a galactic fountain population)

Marasco & Fraternali, in prep.



$Mass_{IVCs} \sim 2\text{-}9 \times 10^6 M_O$

HI halo of the MW



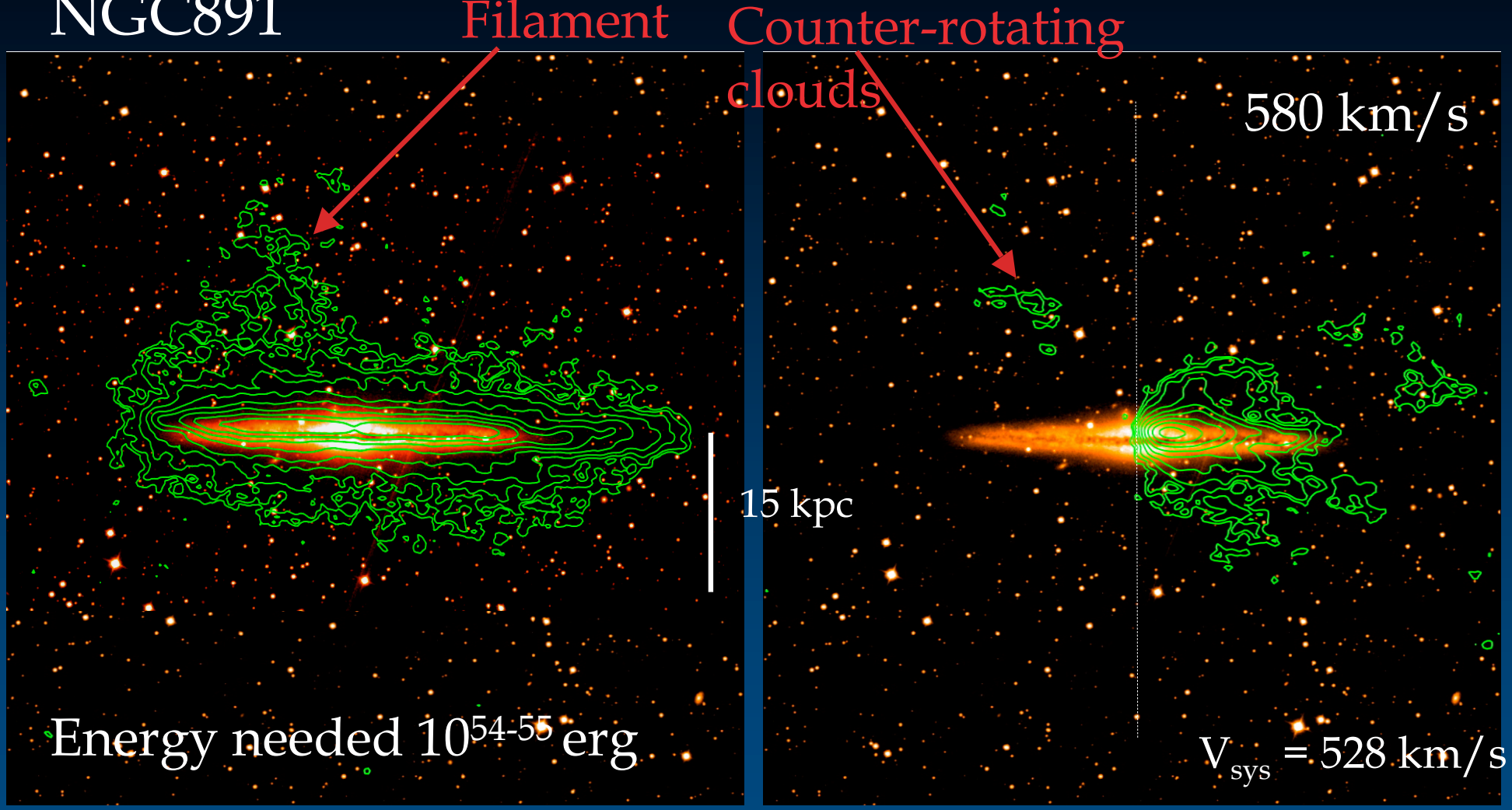
LMC, SMC and MS removed

"About 10% of the HI in the Milky Way is extra-planar and highly turbulent"

Karlerla & Dedes 2008

Estimating halo gas accretion

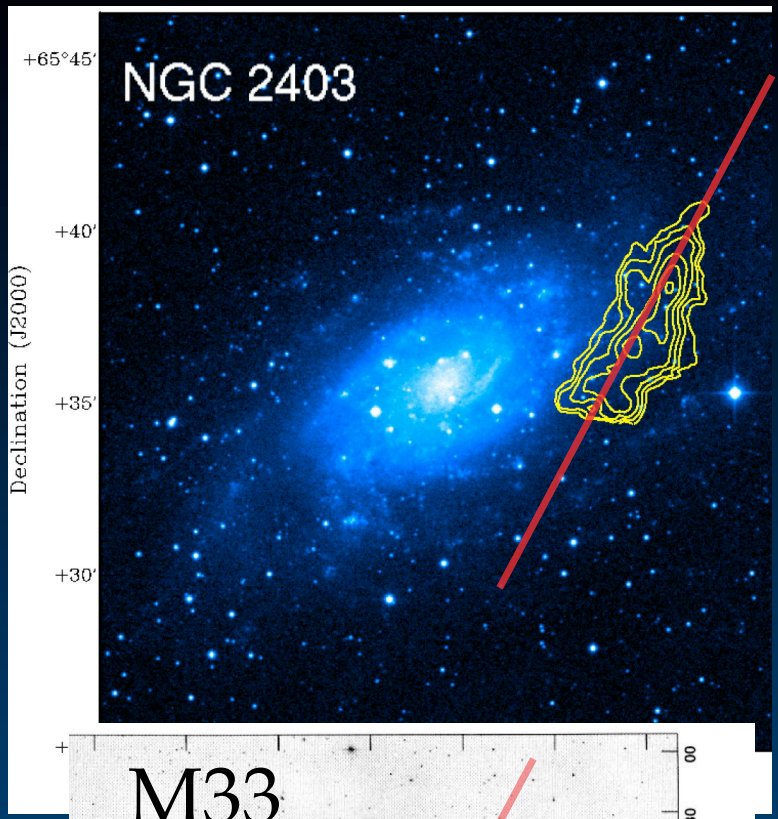
Accretion: high velocity gas

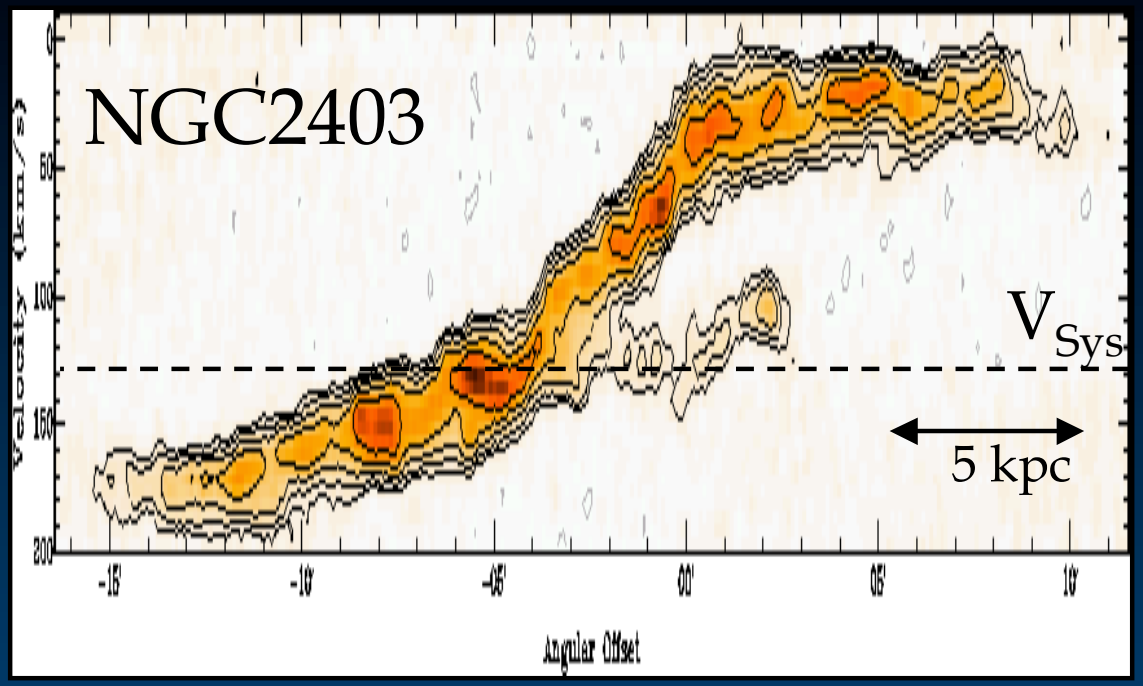


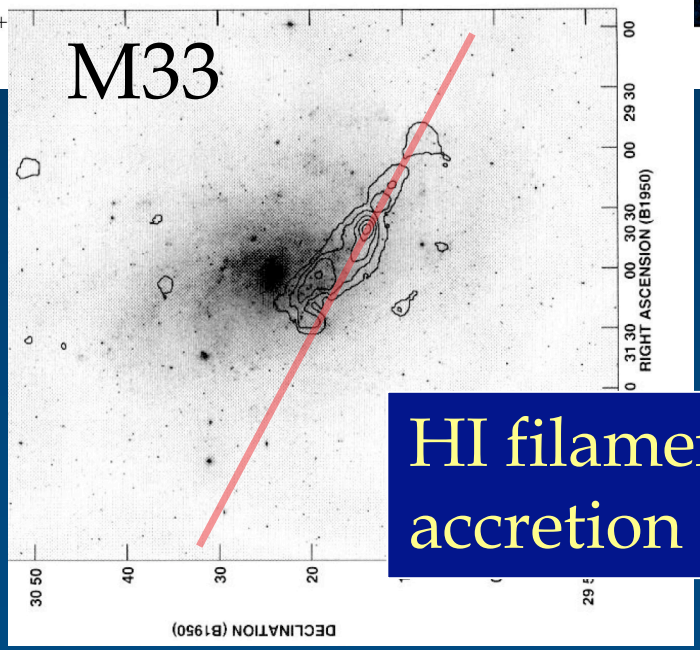
Forbidden in a fountain

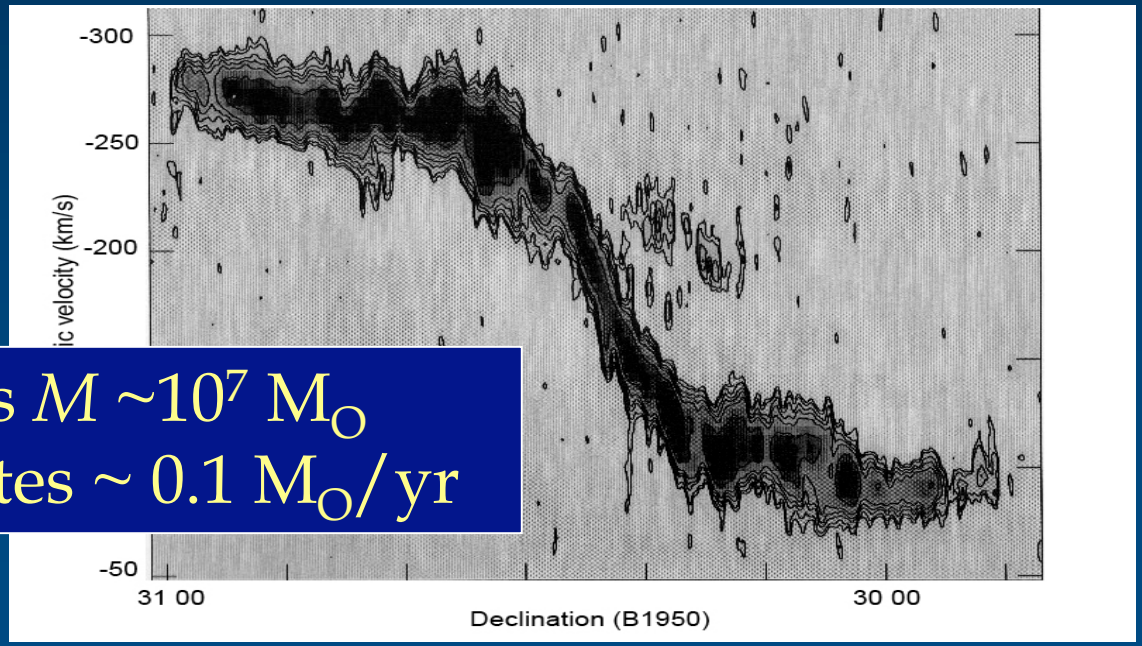
Accretion ~ few x 10^7 M_O/10^8yr
~ 0.few M_O yr^{-1}

Filaments





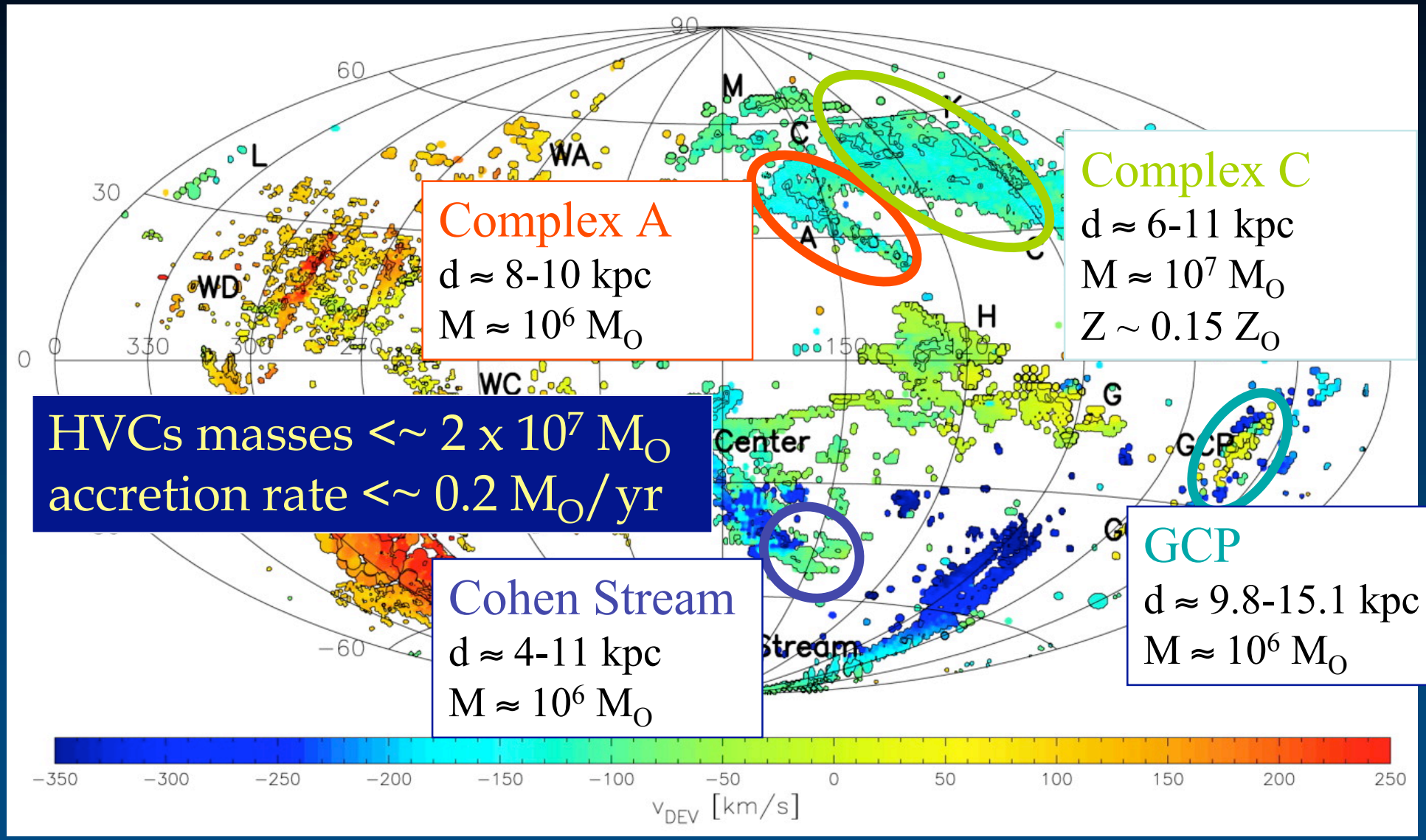




HI filaments $M \sim 10^7$ M_O
accretion rates ~ 0.1 M_O/yr

Sancisi et al. 2008, A&ARv

Accretion: High Velocity Clouds



Wakker et al. 2007, 2008; Tripp et al. 2003

Directly observed accretion rate

Table 1. Physical properties of extra-planar gas in spiral galaxies

Galaxy	Type	incl (°)	v_{flat} (km/s)	$M_{HI_{halo}}$ ($10^8\ M_\odot$)	$M_{HI_{tot}}$ ($10^9\ M_\odot$)	SFR ($M_\odot$/yr)	Accr. rate ($M_\odot$/yr)	Gradient[a] (km/s/kpc)	Ref.
Milky Way	Sb	-	220	~ 4	4	$1-3$	≈ 0.2[b]	-22	(1,2,3)
M 31	Sb	77	226	> 0.3	3	0.35	-	-	(4,5)
NGC 253	Sc	~75	~185	0.8	2.5	> 10	-	-	(6)
M 33	Scd	55	110	> 0.1	1	0.5	0.05[c]	-	(7,8)
NGC 2403	Scd	63	130	3	3.2	1.3	0.1	~ -12	(9)
NGC 2613	Sb	~80	~300	4.4[d]	8.7	5.1	-	-	(10)
NGC 3044	Sc	84	150	4	3	2.6[e]	-	-	(11)
NGC 4559	Scd	67	120	5.9	6.7	0.6[e]	-	~ -10	(12)
NGC 5746	Sb	86	310	~ 1	9.4	1.2	0.2[f]	-	(13,14)
NGC 5775	Sb	86	200	-	9.1	7.7[e]	-	-8[g]	(15)
NGC 6946	Scd	38	175	$\gtrsim 2.9$	6.7	2.2	-	-	(17)
NGC 891	Sb	90	230	12	4.1	3.8	0.2	-15	(18)
UGC 7321	Sd	88	110	$\gtrsim 0.1$	1.1	~ 0.01[h]	-	$\gtrsim -25$	(19)

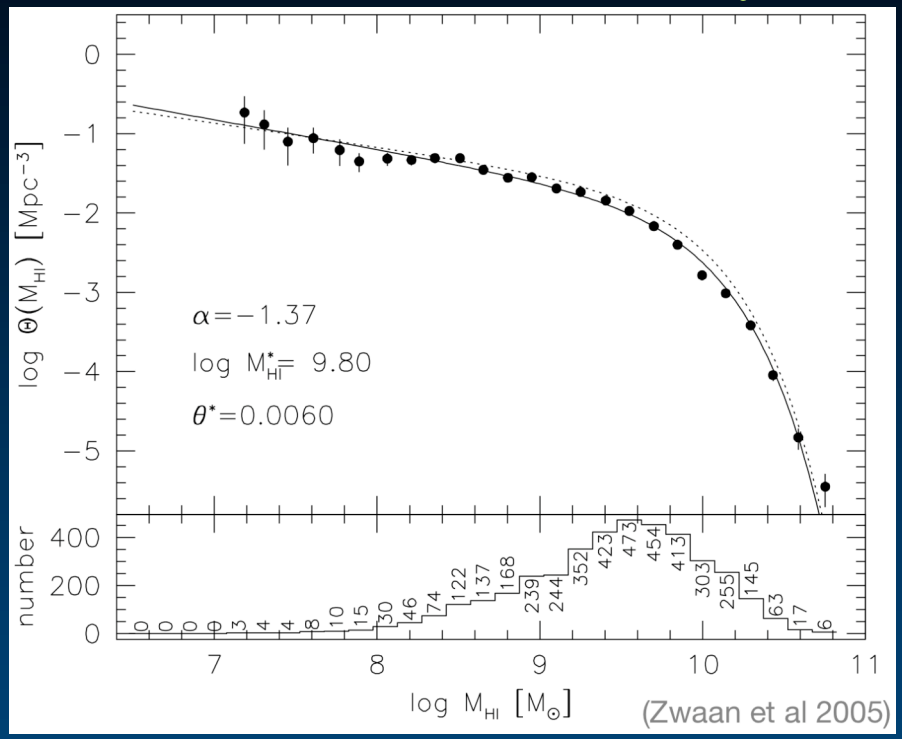
Fraternali 2008 (arXiv0807.3365)

Most of the accretion is missing!

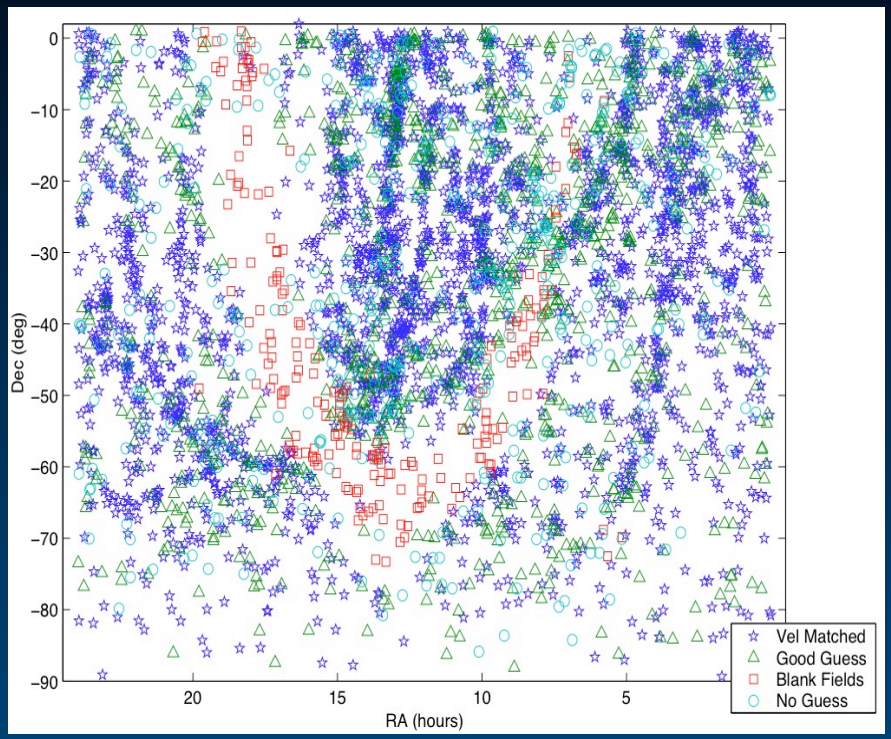
Floating clouds and minor mergers

No floating clouds

HIPASS - Blind HI survey



Zwaan et al. 2005, MNRAS



Doyle et al. 2006, MNRAS

First results from ALFALFA

Only 3% of all extragalactic HI sources cannot be identified with a stellar component.

Haynes et al. 2008, IAUS

"No isolated optically dark galaxies have been found within the limits of the HIPASS survey".

HVCs in M31

GBT total HI map

Halo Clouds around M31

Masses from 10^5 - 10^7 $M_\odot$

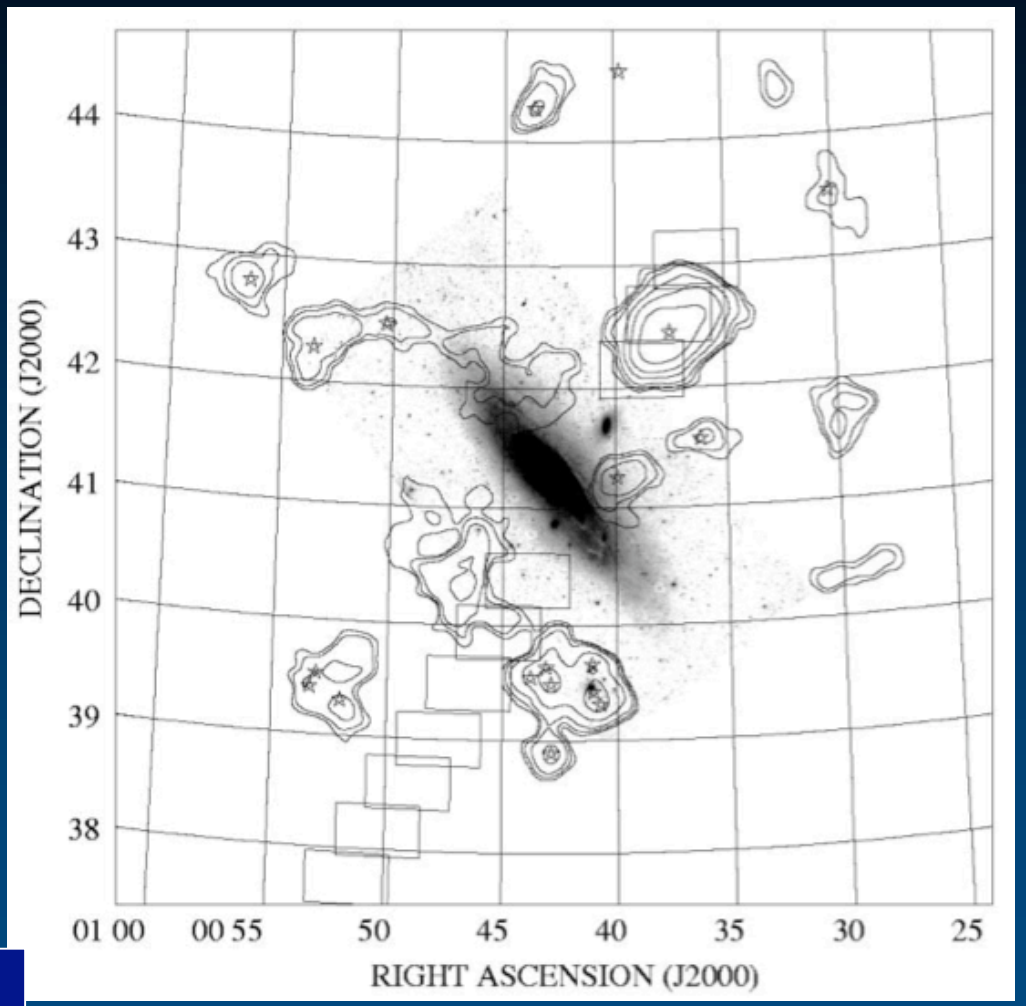
Total mass:

3-4 x 10^7 $M_\odot$

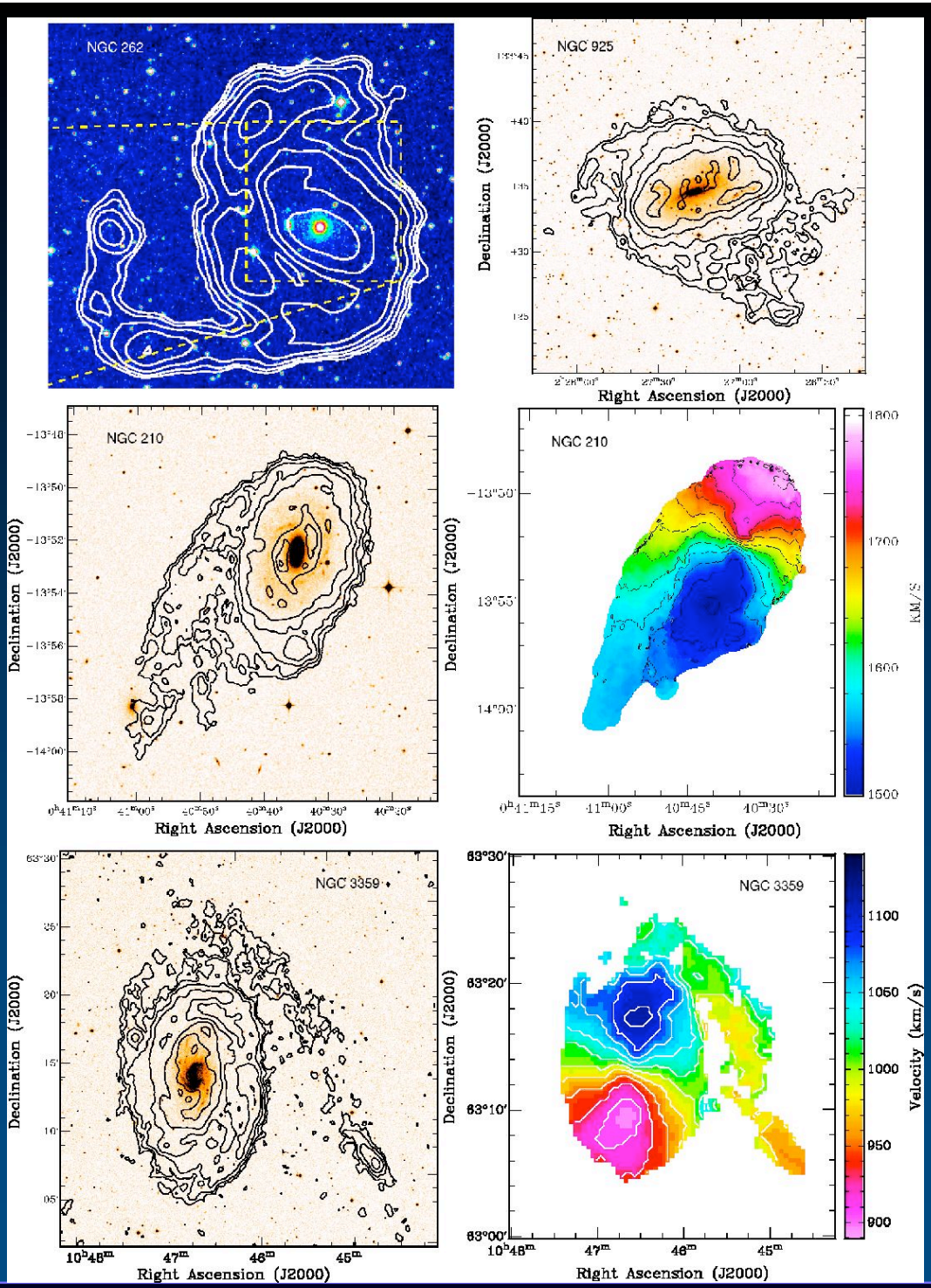
~1% of the total HI mass

All clouds are within 50 kpc

Clouds in the IGM?
Smaller than 10^5 $M_\odot$



Thilker et al. 2004, ApJL



Minor mergers?

Estimated from WHISP catalogue

Detected in ~25% of galaxies

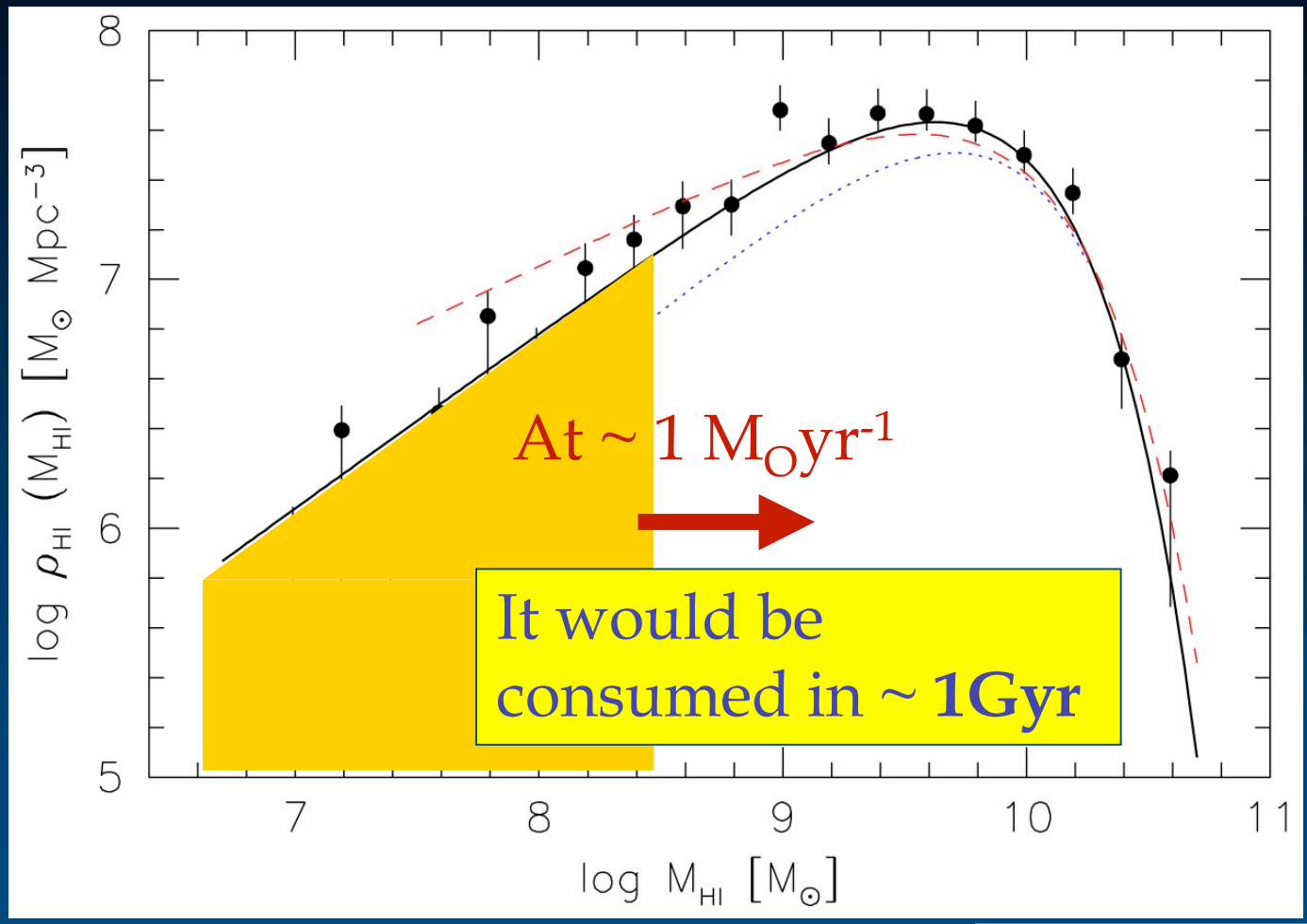
Masses ~ 1-10 x 10^8 M_O

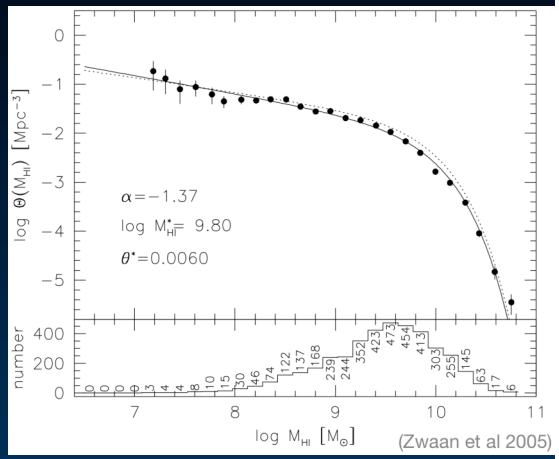
Life time ~ 1-2 dyn times

Global accretion rates ~ 0.2 M_O/yr

Sancisi et al. 2008, A&ARv

How many minor mergers?





Zwaan et al. 2005, MNRAS

Not enough small galaxies!

Summary so far

1. Large halos of cold gas out to r > ~50 kpc, no *large* HI clouds beyond

2. Most of the halo gas follows the disk kinematics

3. Some very anomalous clouds -> accretion rate 0.1 x SFR

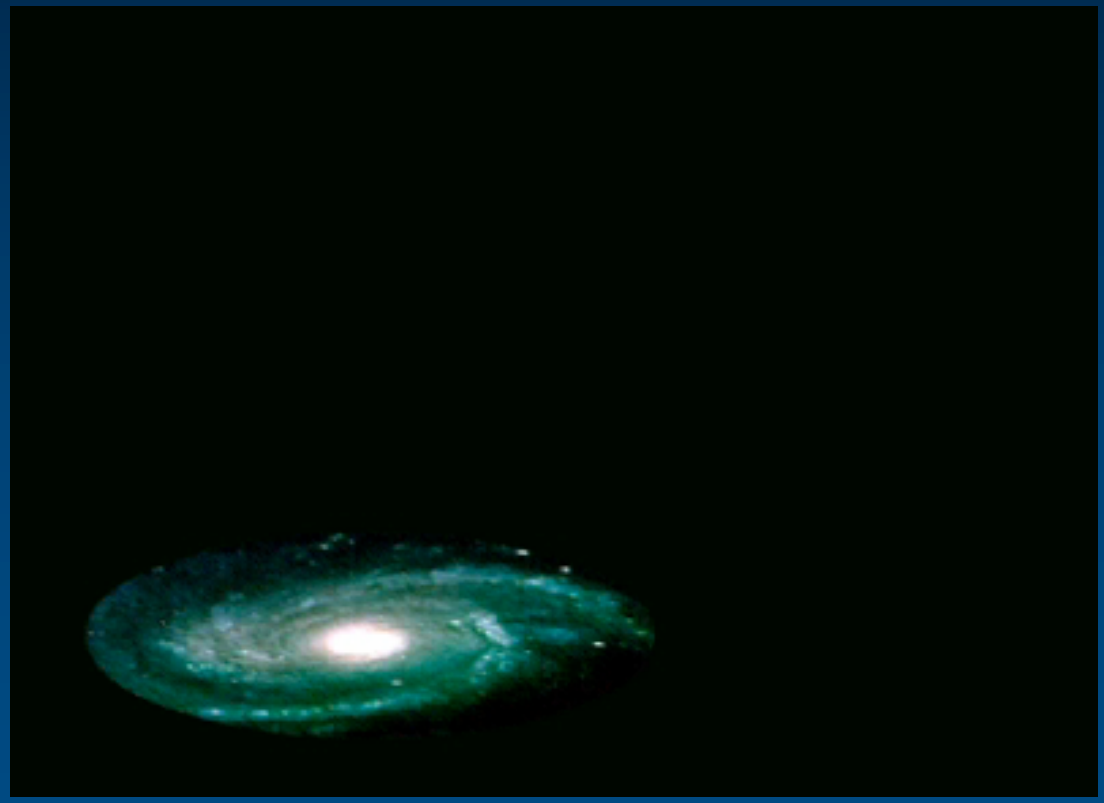
4. Minor mergers give ~ 0.2 M_O/yr

Modelling the halo gas

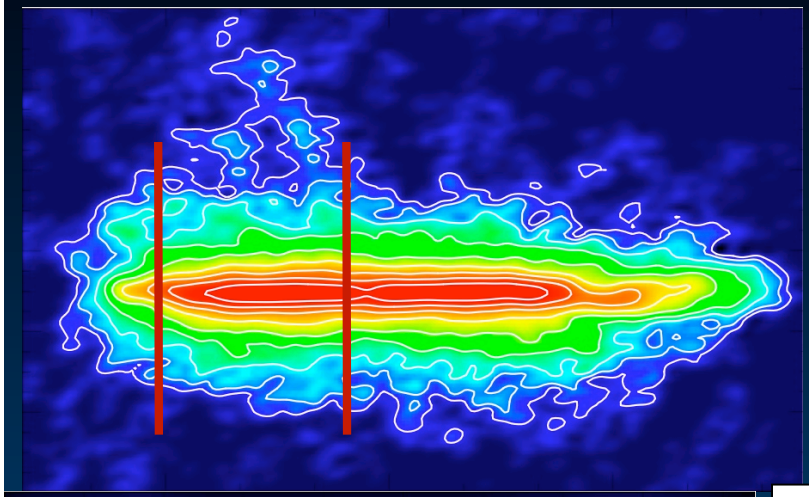
Fountain model for HI halo

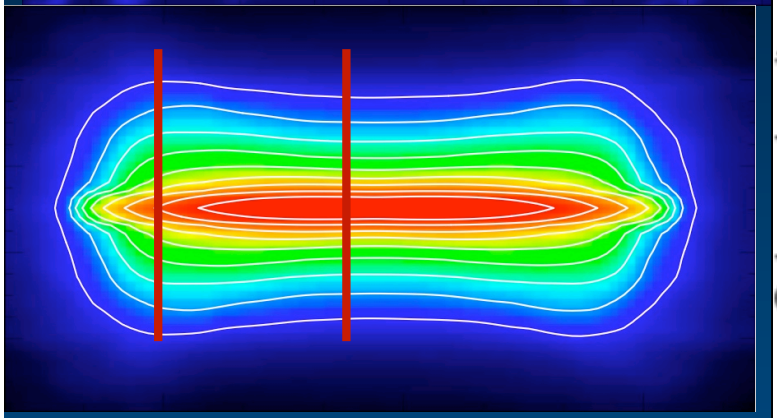
Fraternali & Binney 2006, MNRAS

- Potential of exponential disks + spheroids
- Family of orbits
- At each *dt* projection along the line of sight
- *Artificial cube* to be compared with HI data cube



Gas distribution

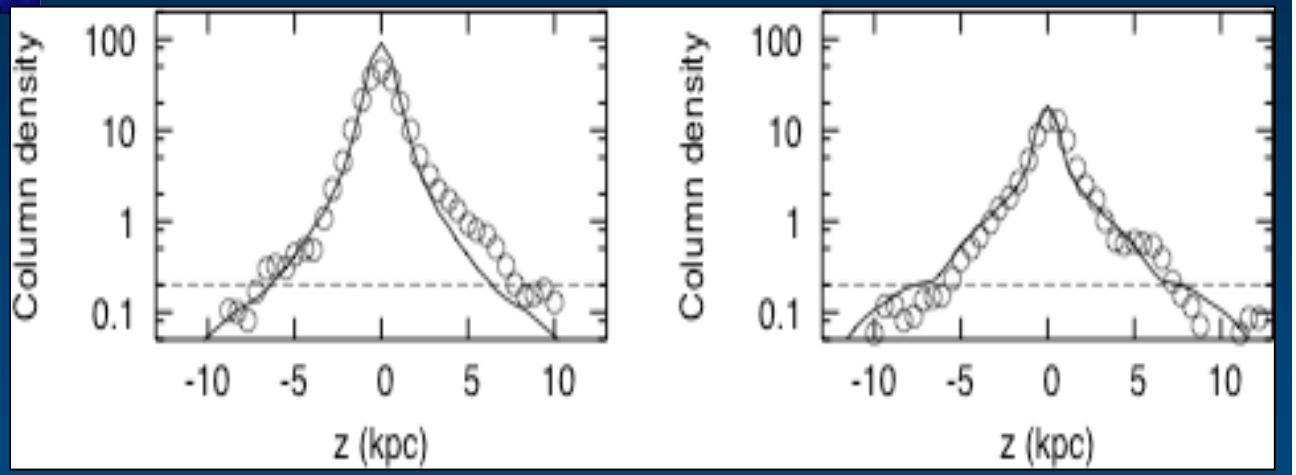




$V_{kick} \sim 75$ km s^{-1}

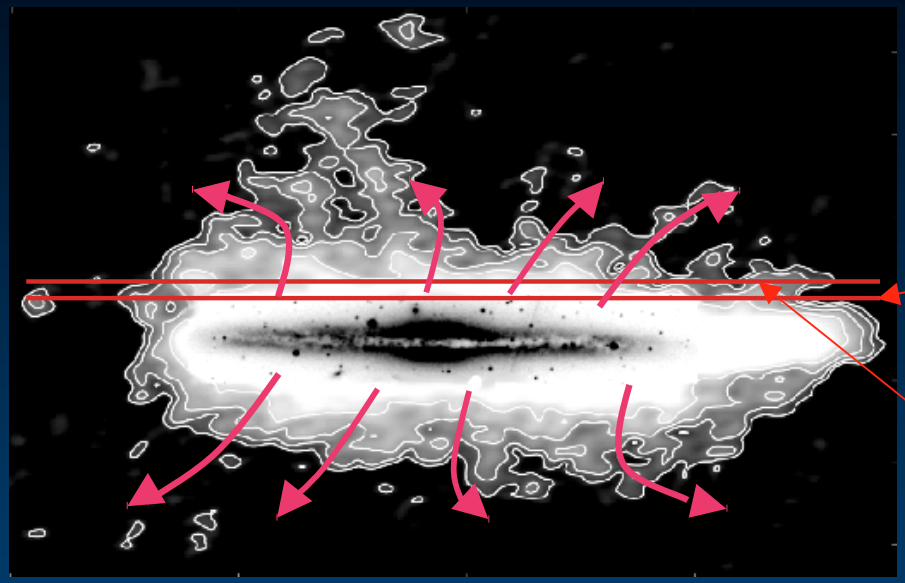
$M_{halo} \sim 2 \times 10^9 M_\odot$

Energy input
<4 % of energy from SNe

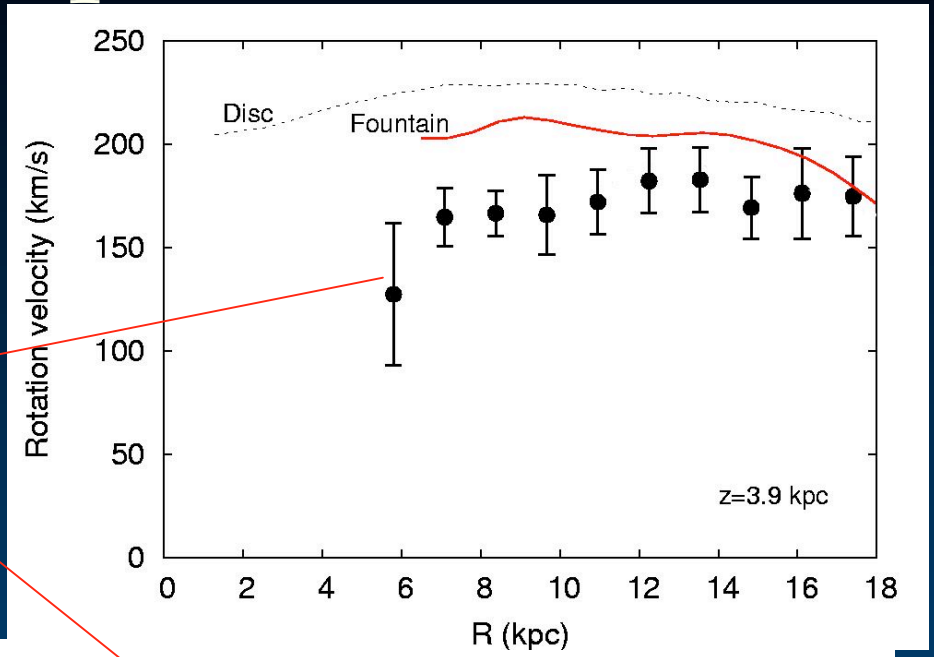


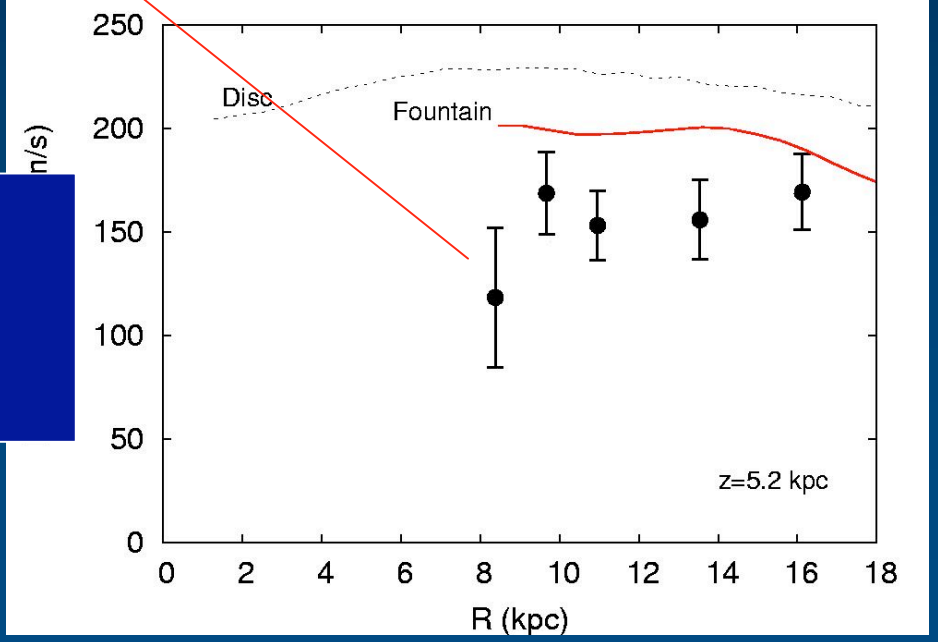
Fountain reproduces the halo gas distribution

Gas dynamics in a pure fountain



Fraternali & Binney, 2006





Fountain gas has too high angular momentum

Fountain sweeping up ambient gas

Sweeping-up Fountain model

Fraternali & Binney 2008, MNRAS

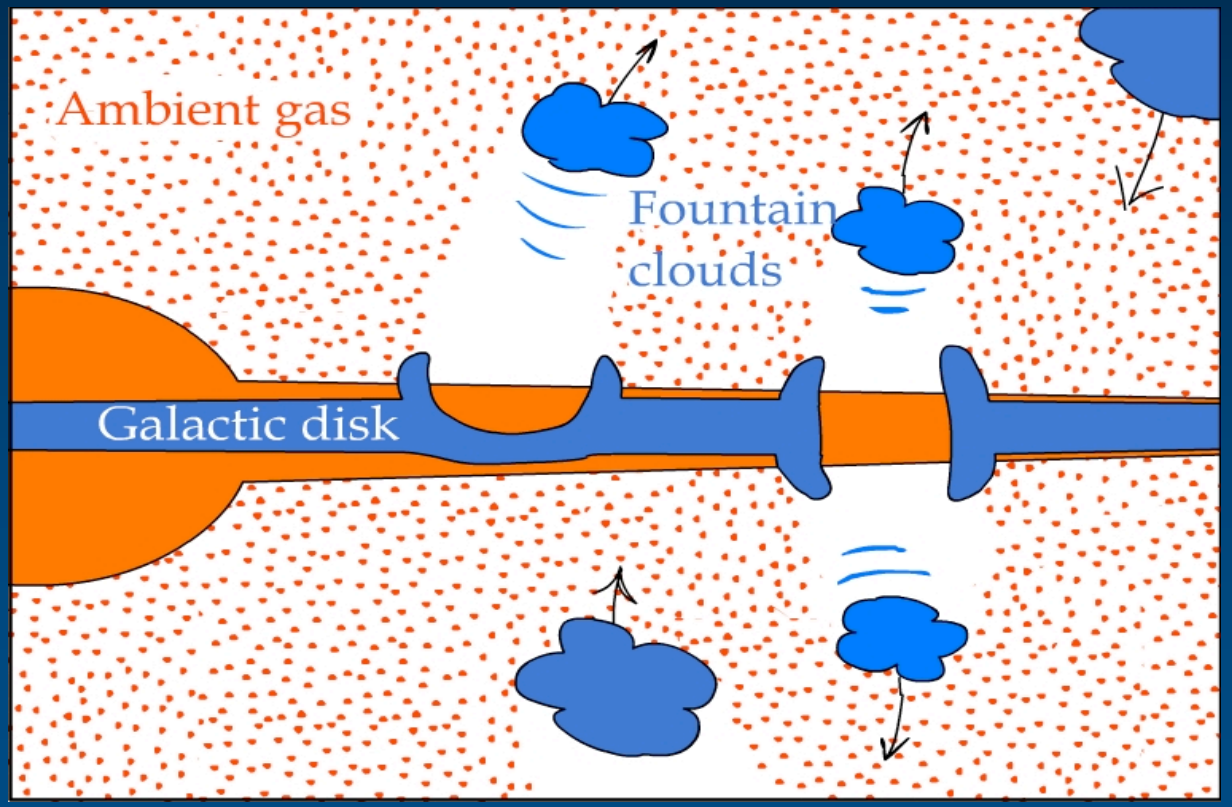
Accretion

- Fountain clouds sweep up gas from the surroundings
- Constant distribution of ambient gas
- Velocity distribution: low angular momentum about z-axis
- Accretion rate only free parameter

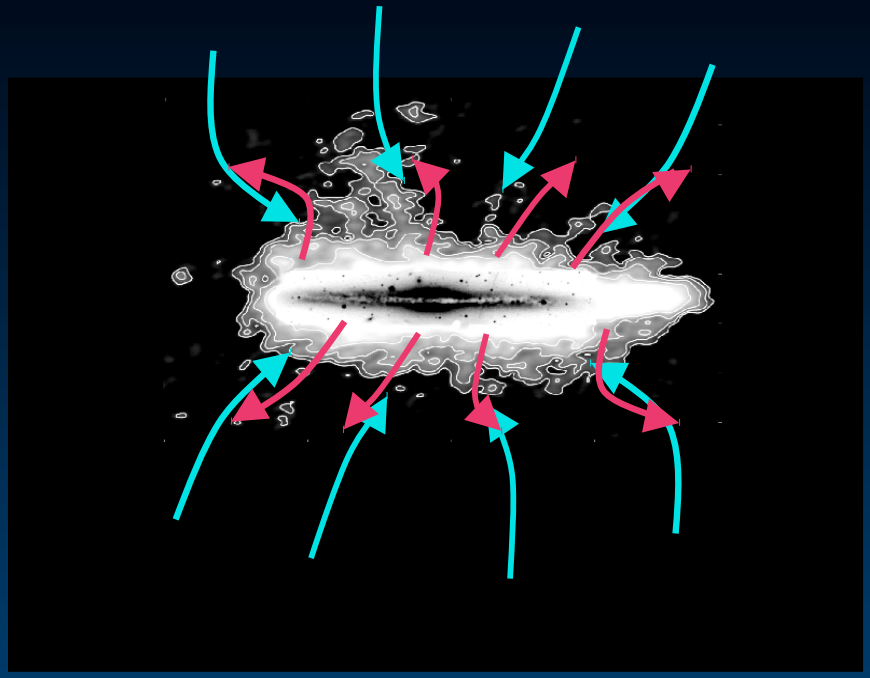
Non-elastic collisions

$$\dot{m} = \alpha m$$

$$v_1 = \frac{m_0 v_0 + \delta m v_i}{m_0 + \delta m}$$



Fountain + Accretion in NGC891



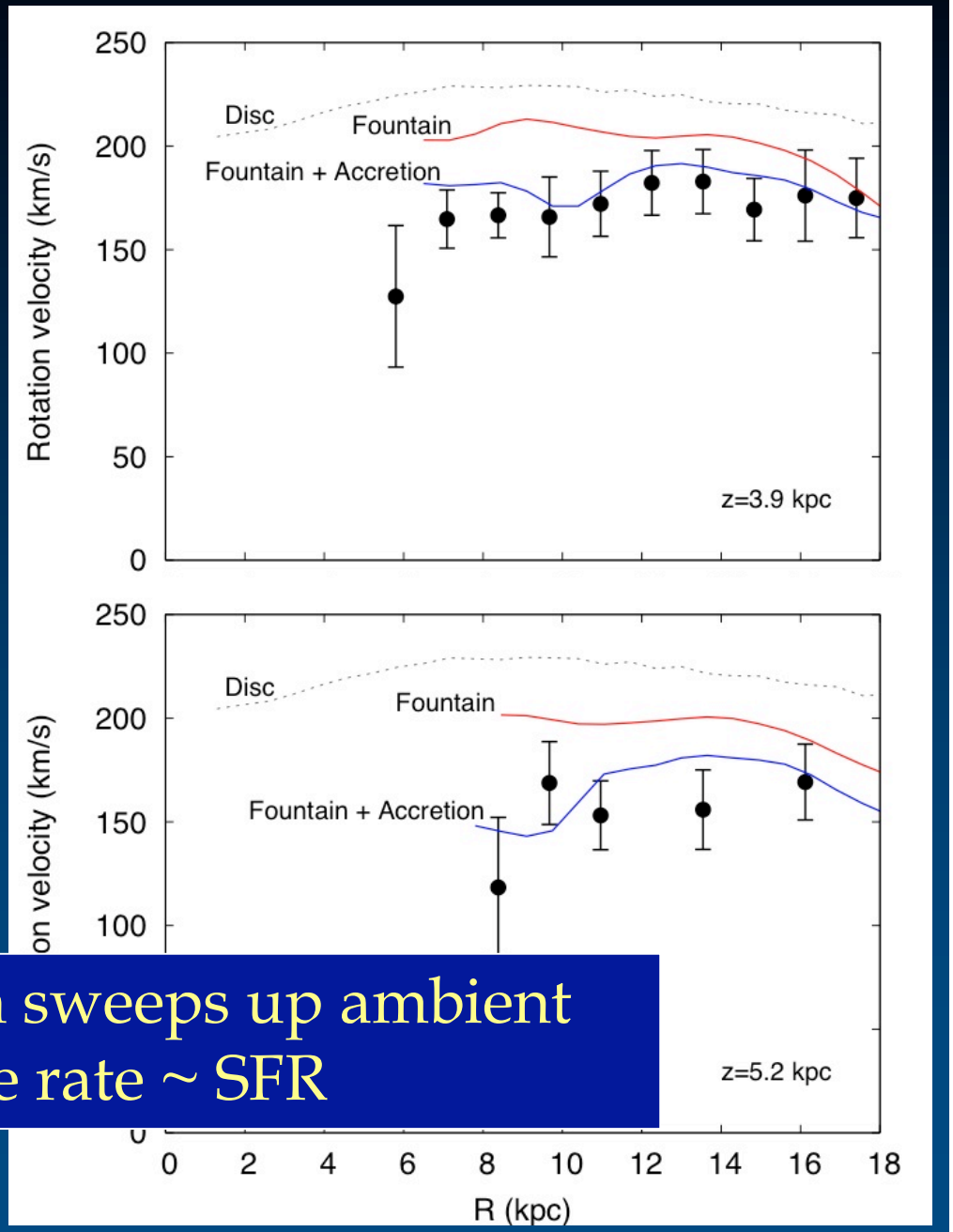
Best-fit Accretion Rate ~ 3 $M_\odot yr^{-1}$

Compare to SFR ~ 4 $M_\odot yr^{-1}$

Halo gas:

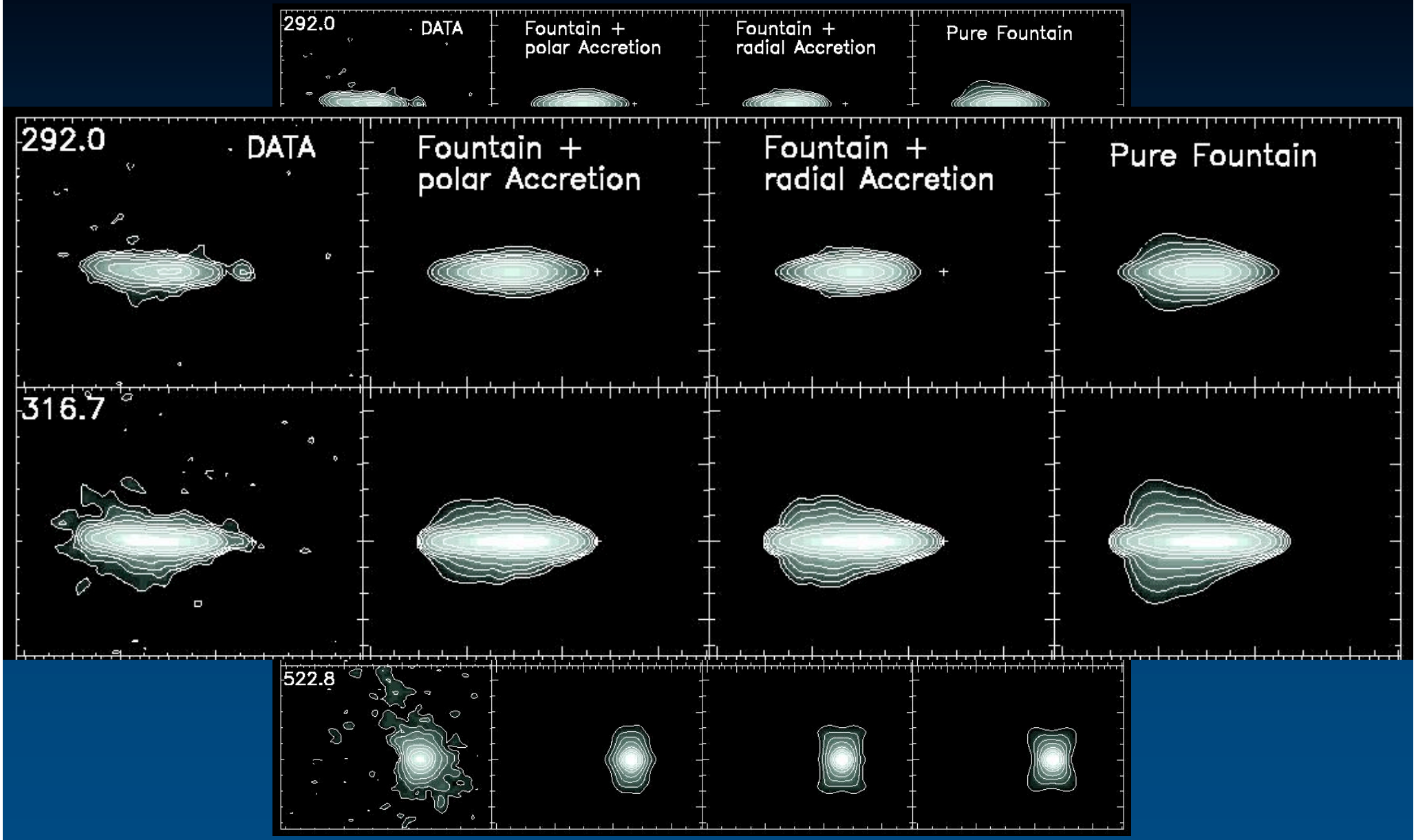
~90% from fountain

~10% accreted

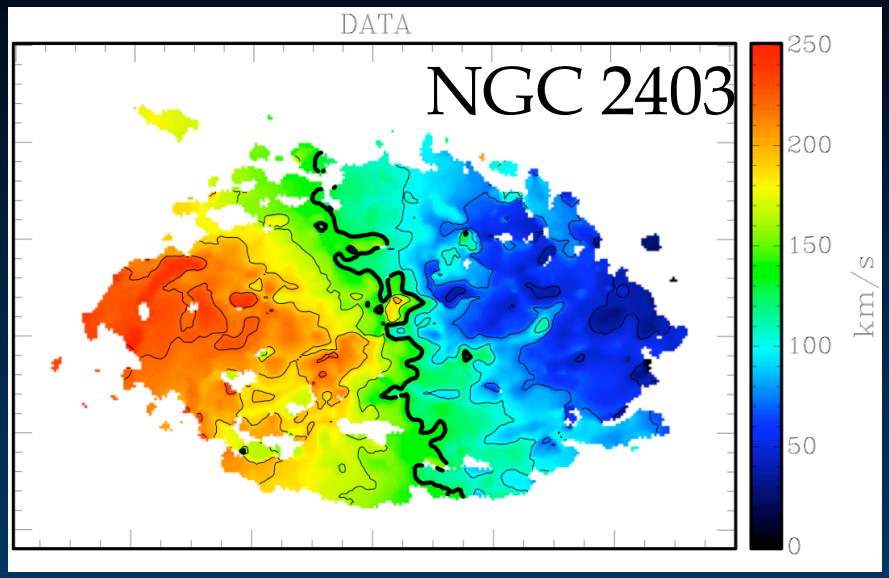


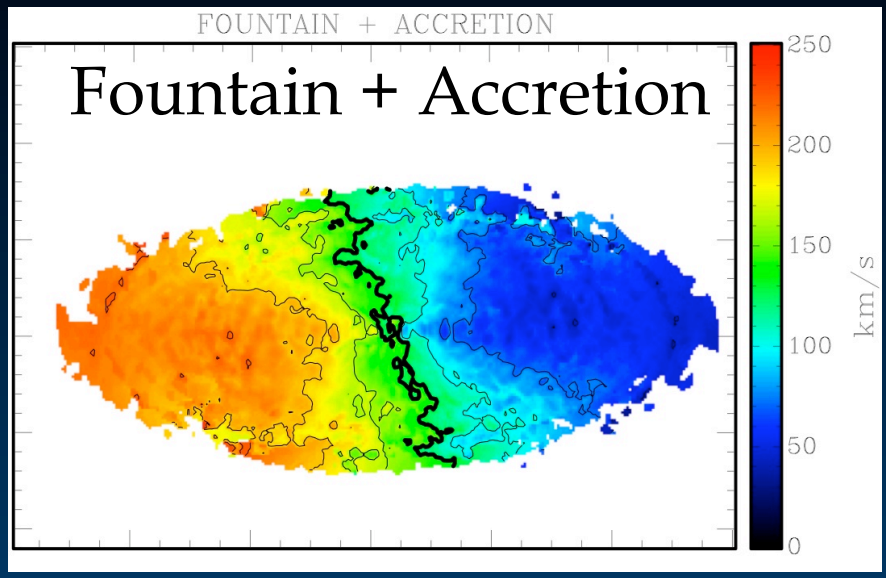
Fountain sweeps up ambient gas at the rate ~ SFR

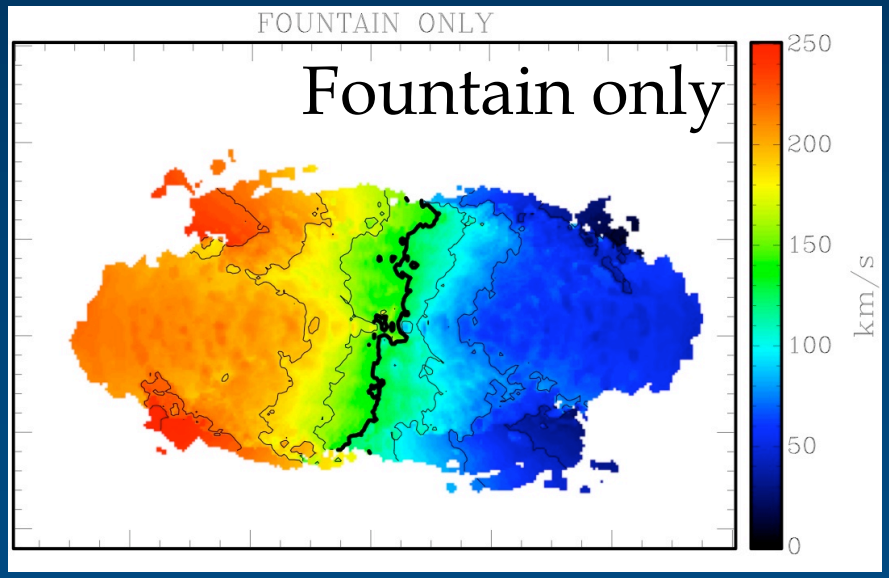
The whole data cube is reproduced



Fountain+Accretion in NGC 2403







Best-fit Accretion Rate ~ 0.8 $M_\odot yr^{-1}$

Compare to SFR ~ 1.3 $M_\odot yr^{-1}$

Halo ga

~85%

~15%

Fountain + accretion reproduces the gradient and the infall pattern!

Fat fountain model

Most (90%) halo gas is disk gas pushed up by the galactic fountain

Roughly 10% of halo gas is ambient gas mixed with the fountain -> accretion rate ~ 1 SFR

Accretion rate proportional to the SNR

Natural link between SFH and GAH

(cf. A. Hopkins' talk)

1-3% of halo gas is in HVCs -> accretion rate ~ 0.1 SFR

Thermal instability?

Binney, Nipoti & Fraternali (2009), MNRAS, in press

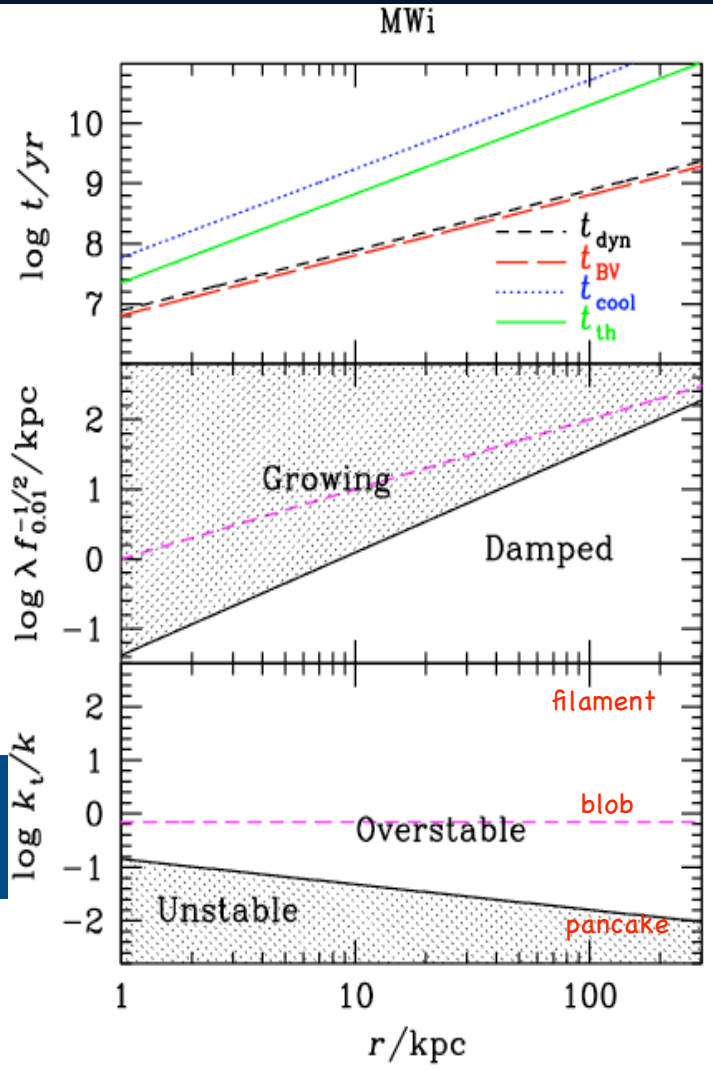
Isothermal corona

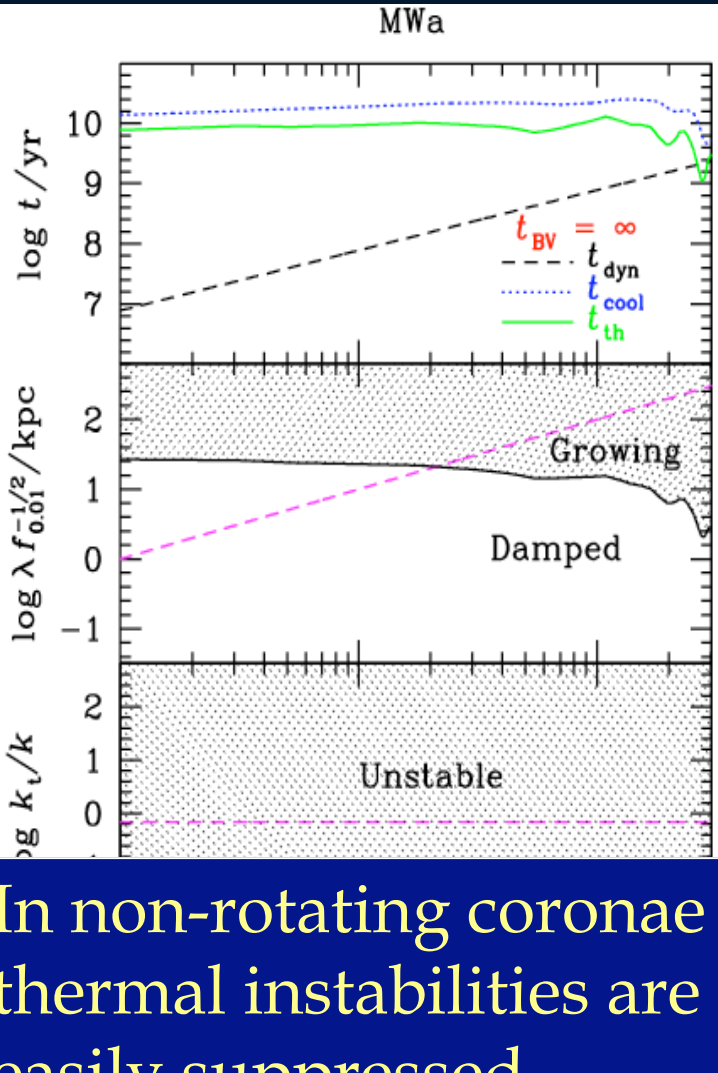
Adiabatic corona

Timescales

Thermal conduction damping

Suppression by buoyancy





In non-rotating coronae thermal instabilities are easily suppressed

Future

Near Future: HALOGAS survey

Hydrogen Accretion in LOcal GAlaxieS

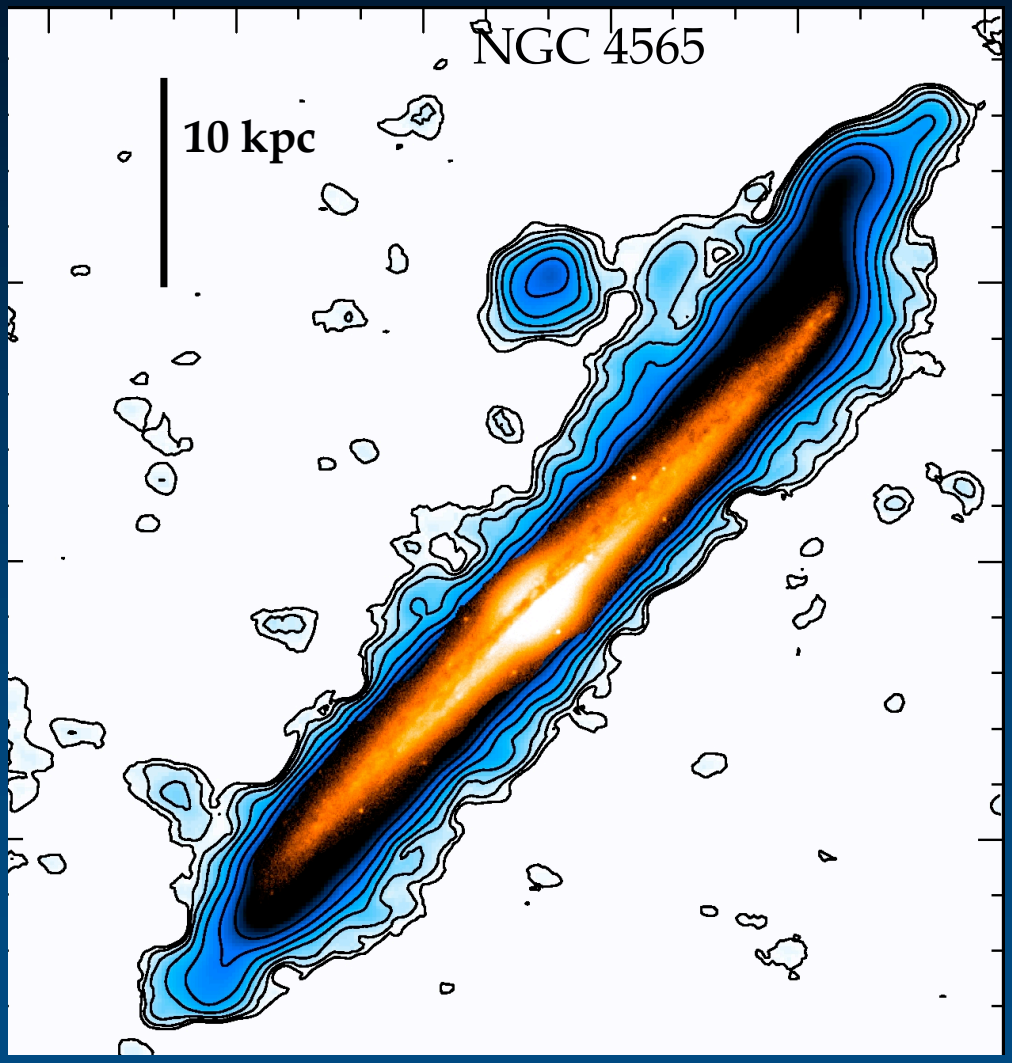
George Heald (ASTRON) (PI), Filippo Fraternali (Bologna University), Gianfranco Gentile (Ghent University), Gyula Jozsa (ASTRON), Eva Jütte (Ruhr-Universität Bochum), Tom Oosterloo (ASTRON), Rich Rand (University of New Mexico), Renzo Sancisi (Osservatorio Astronomico di Bologna), Paolo Serra (ASTRON), Rene Walterbos (New Mexico State University)

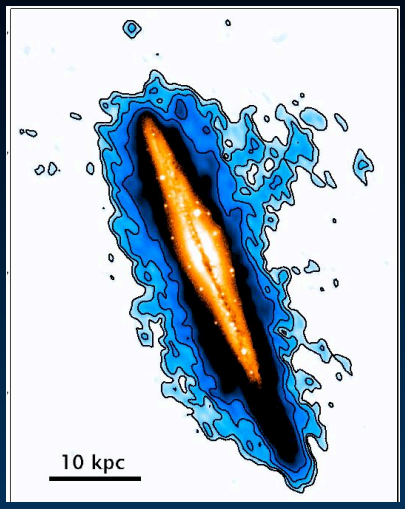
22 galaxies
> 100 hr per target

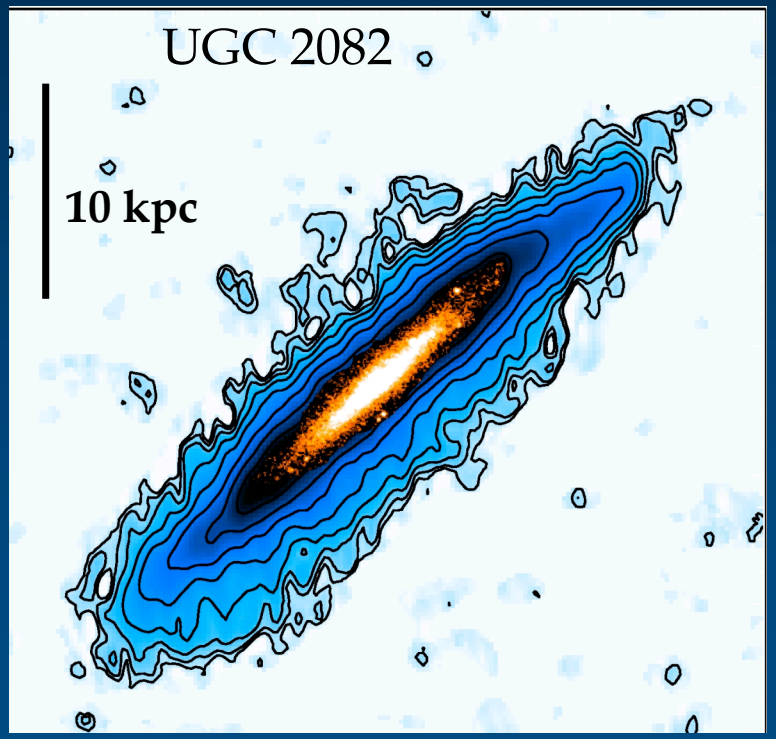
Galaxy ID	Type	D (Mpc)	v_{sys} (km s^{-1})	i (°)	D_{25} (arcmin)	M_B (mag)	v_{rot} (km s^{-1})	SFR ($M_\odot$ yr^{-1})	Observational status
UGC 2082	SAc	10.7	710	89	5.8	-18.55	86.6	0.022[a]	Complete
UGC 4278	SAd	10.6	565	90	4.3	-17.45	79.2	0.046[b]	
NGC 4244	SAcd	3.1	247	90	15.8	-17.60	89.0	0.045[a]	4 × 12hr [archive]
NGC 4565	SAb	9.7	1228	90	16.2	-20.34	244.9	2.7[a]	Ongoing
UGC 7774	SAd	6.8	526	90	3.5	-15.57	79.4	0.0068[b]	
NGC 4631	SBd	6.9	613	85	14.7	-20.12	138.9	4.2[a]	
NGC 5023	SAc	6.0	400	90	6.8	-17.29	80.3	0.019[b]	
NGC 5229	SBc	6.4	365	90	3.5	-15.82	57.3	0.0069[b]	
NGC 0672	SBcd	7.5	425	70	6.4	-18.65	130.7	0.15[b]	Complete
NGC 0925	SABd	9.4	554	54	11.3	-19.66	102.4	0.79[a]	Complete
NGC 0949	SAd	10.3	610	52	3.5	-17.85	90.9	0.13[b]	
NGC 1003	SAcd	10.7	626	67	6.3	-18.61	95.5	0.20[b]	
NGC 2541	SAcd	10.6	553	67	7.2	-18.37	92.1	0.24[b]	
NGC 3198	SBc	10.8	660	71	8.8	-19.62	148.2	0.46[a]	
NGC 4062	SAc	9.7	769	68	4.5	-18.27	140.5	0.39[b]	
NGC 4258	SABbc	6.8	449	71	17.1	-20.59	208.0	0.98[a]	
NGC 4274	SBab	9.7	922	72	6.5	-19.22	239.9	0.15[b]	
NGC 4414	SAc	9.7	720	50	4.5	-19.12	224.7	1.0[b]	
NGC 4448	SBab	9.7	693	71	3.8	-18.43	221.6	–	
NGC 4559	SABcd	9.7	816	69	11.3	-20.07	113.4	0.84[a]	
NGC 5055	SAbc	7.2	497	55	13.0	-20.14	215.5	2.1[a]	
NGC 5585	SABd	7.0	303	51	5.5	-17.96	79.1	0.065[b]	

Preliminary results from HALOGAS

Total HI maps of the first 2 edge-on galaxies observed



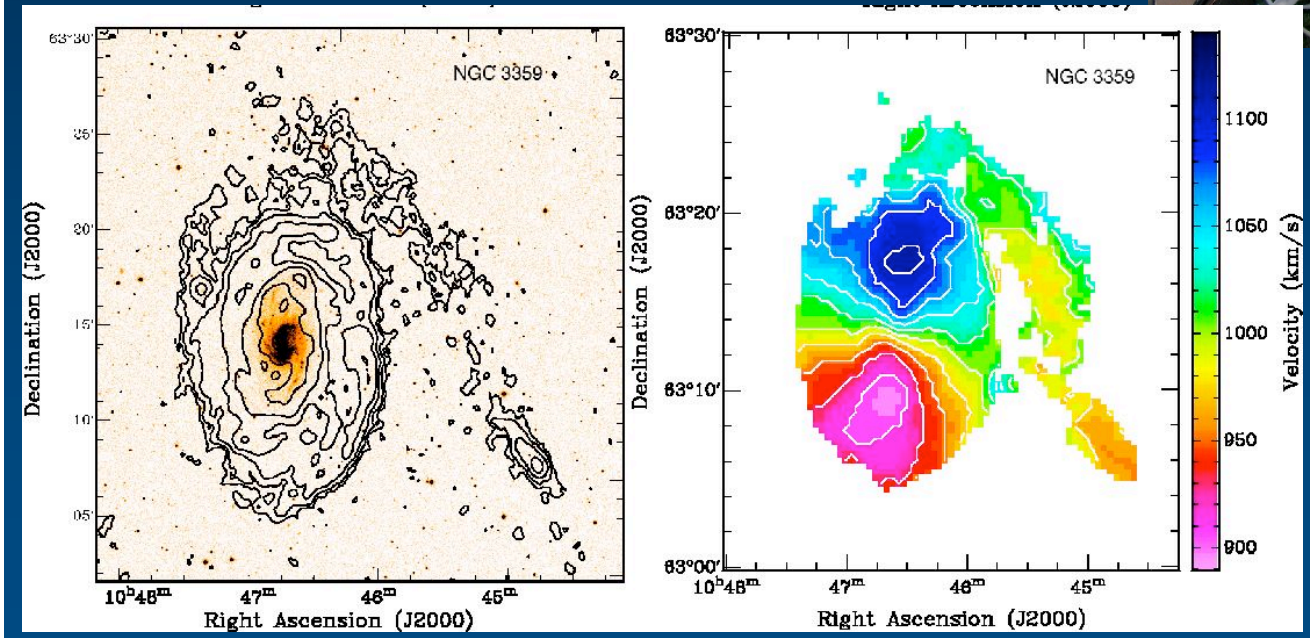




Apertif, ASKAP, MeerKAT

Study of minor mergers in a sample of thousands of galaxies

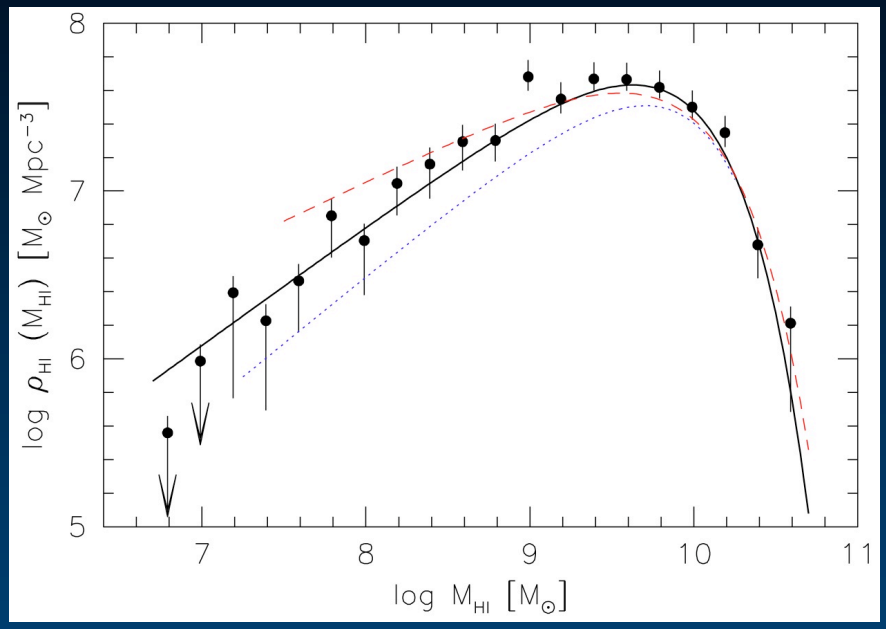
Apertif prototype

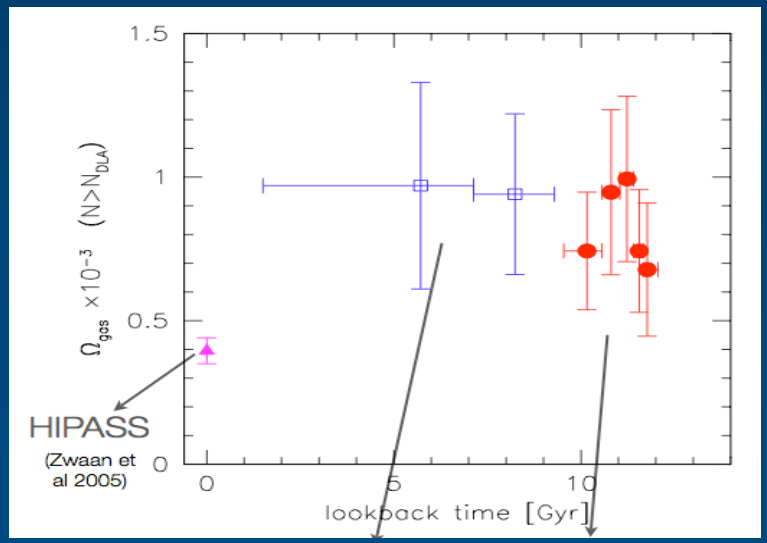


Precise estimate of gas accretion from mergers

Apertif, ASKAP, MeerKAT

Evolution of the HI mass function





Parkes Testbed for ASKAP

Is there room for more minor mergers at higher z?

Conclusions

1. HI clouds detected are always in the vicinity of galaxies

2. Measured HI accretion rate is ~ 0.1 SFR

3. Most of the accreting gas may be dragged down by galactic fountains