Will we ever detect gas accretion?

(*Facts, opinions, puzzles & questions*)

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In this talk

Why gas accretion?

1. Can we detect it in HI emission?

2. Can we detect it in absorption?

3. Theoretical expectations

4. Have your say!

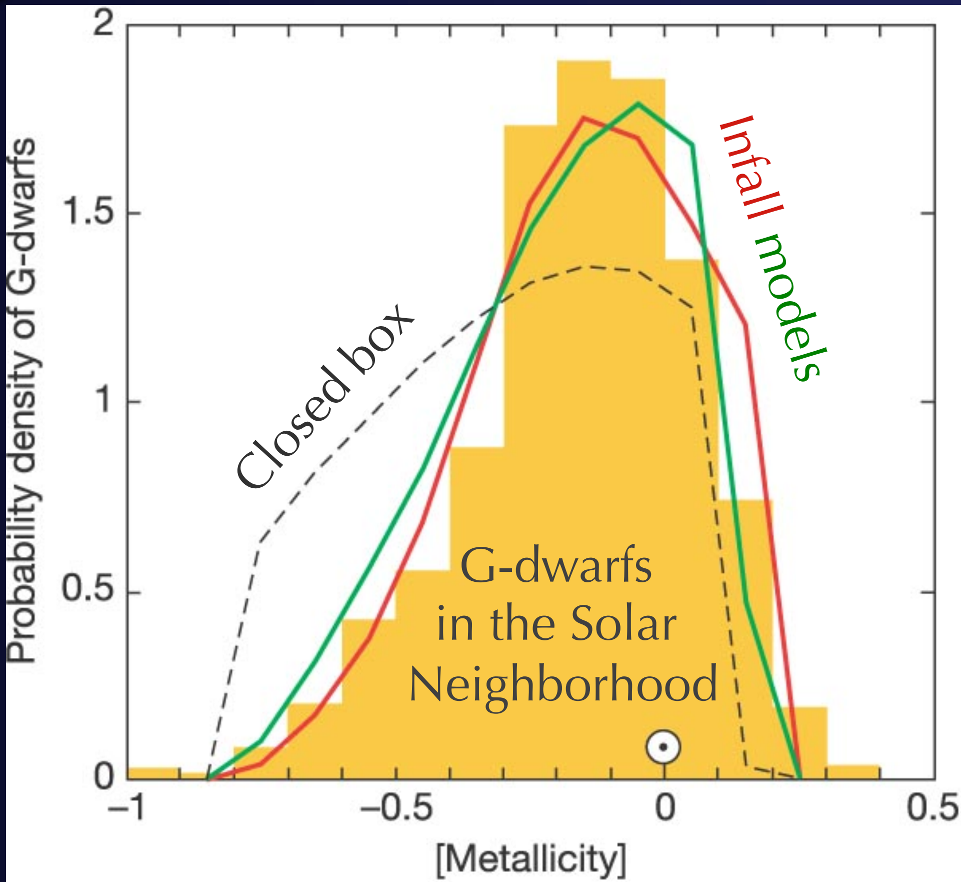
Why gas accretion?

Milky Way evidence

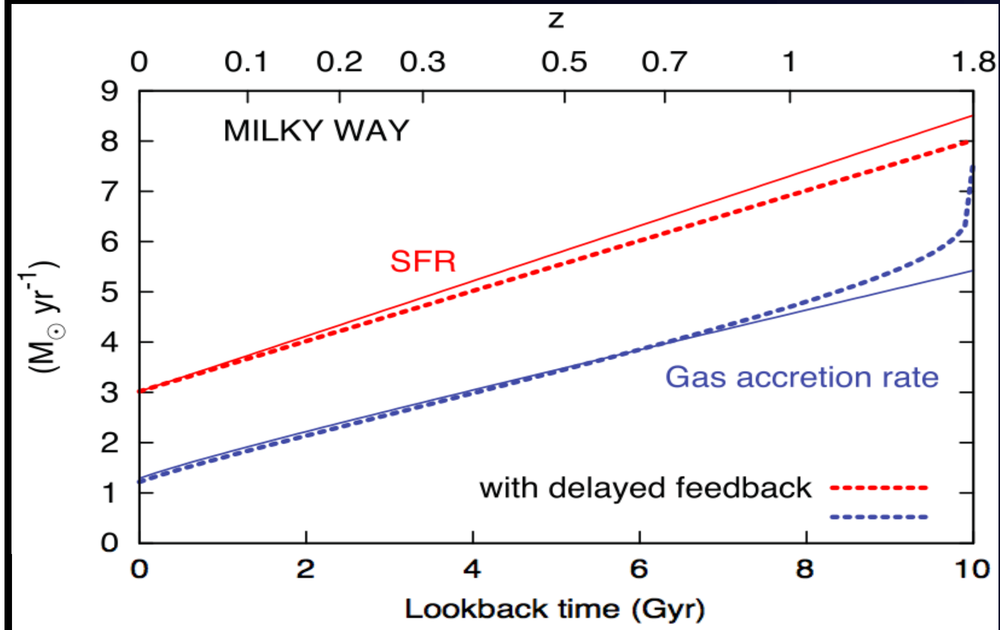
Chemical evolution models
G-dwarf problem
Larson 1972, Tynsley 80, Chiappini+ 97, 01; Schoenrich & Binney 09

Deuterium in local ISM appears to be re-supplied *Linsky et al. 2006*

Need for gas accretion at $Z<\sim 0.1\ Z_\odot$



Dauphas et al. 2005, Nature

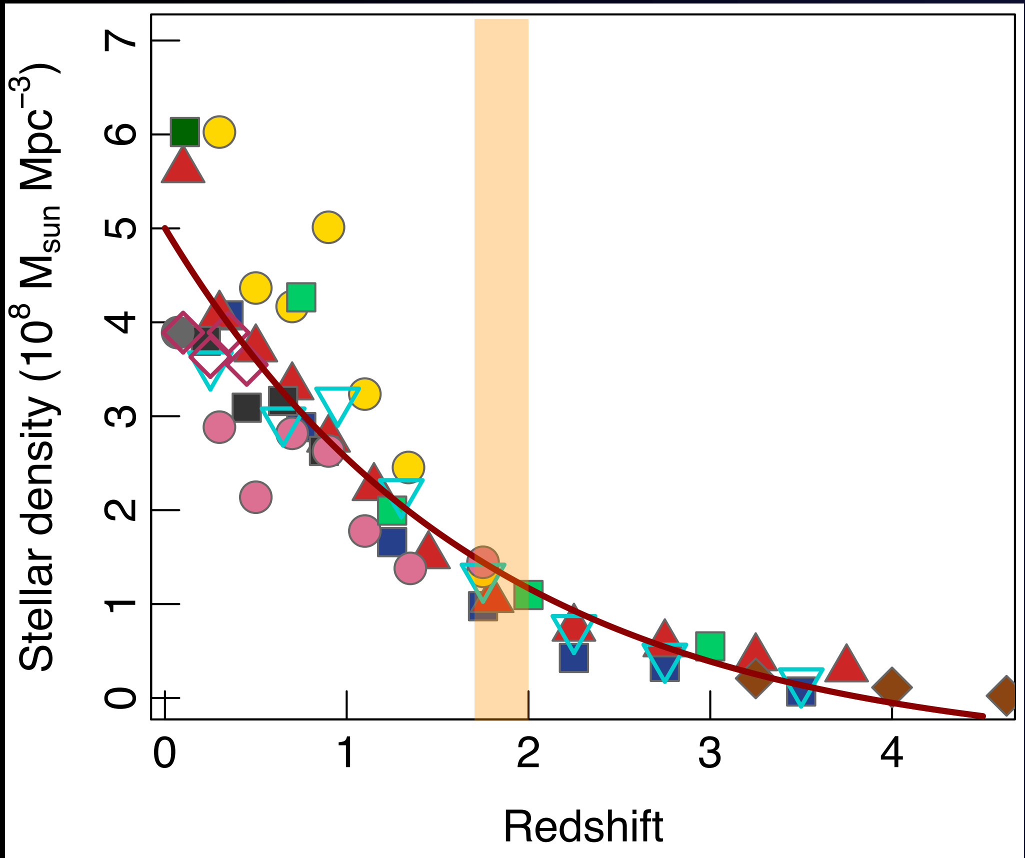


$\sim 1\ M_\odot/yr$

Fraternali & Tomassetti 2012, MNRAS

Cosmology evidence

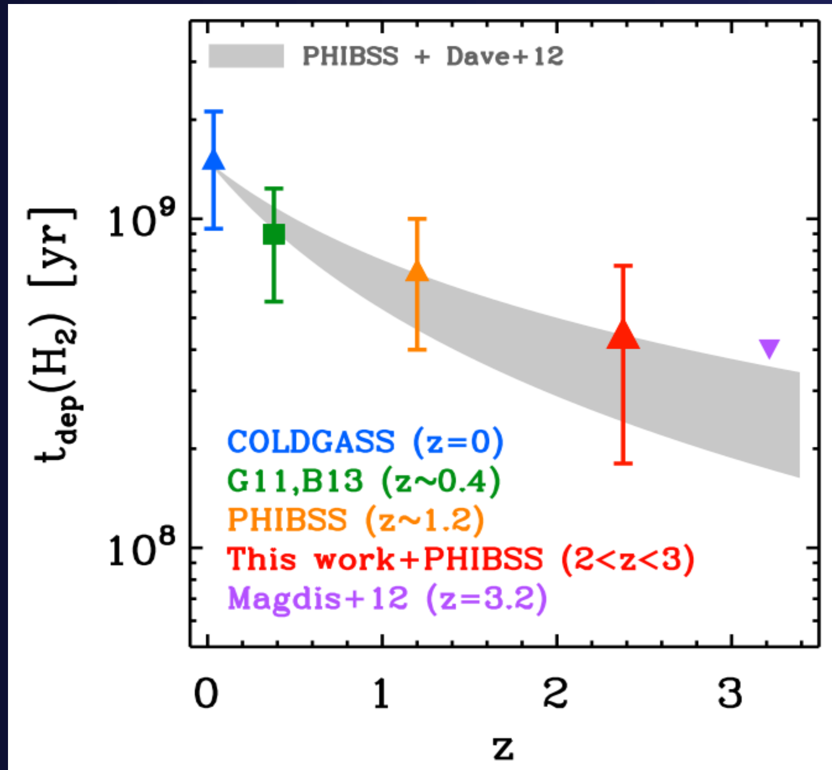
Assembly of stellar mass in the Universe



Compilation from *Madau & Dickinson 2014*

Gas depletion time ~ 1 Gyr

Gas depletion time $t_{depl} = M_{gas} / SFR$

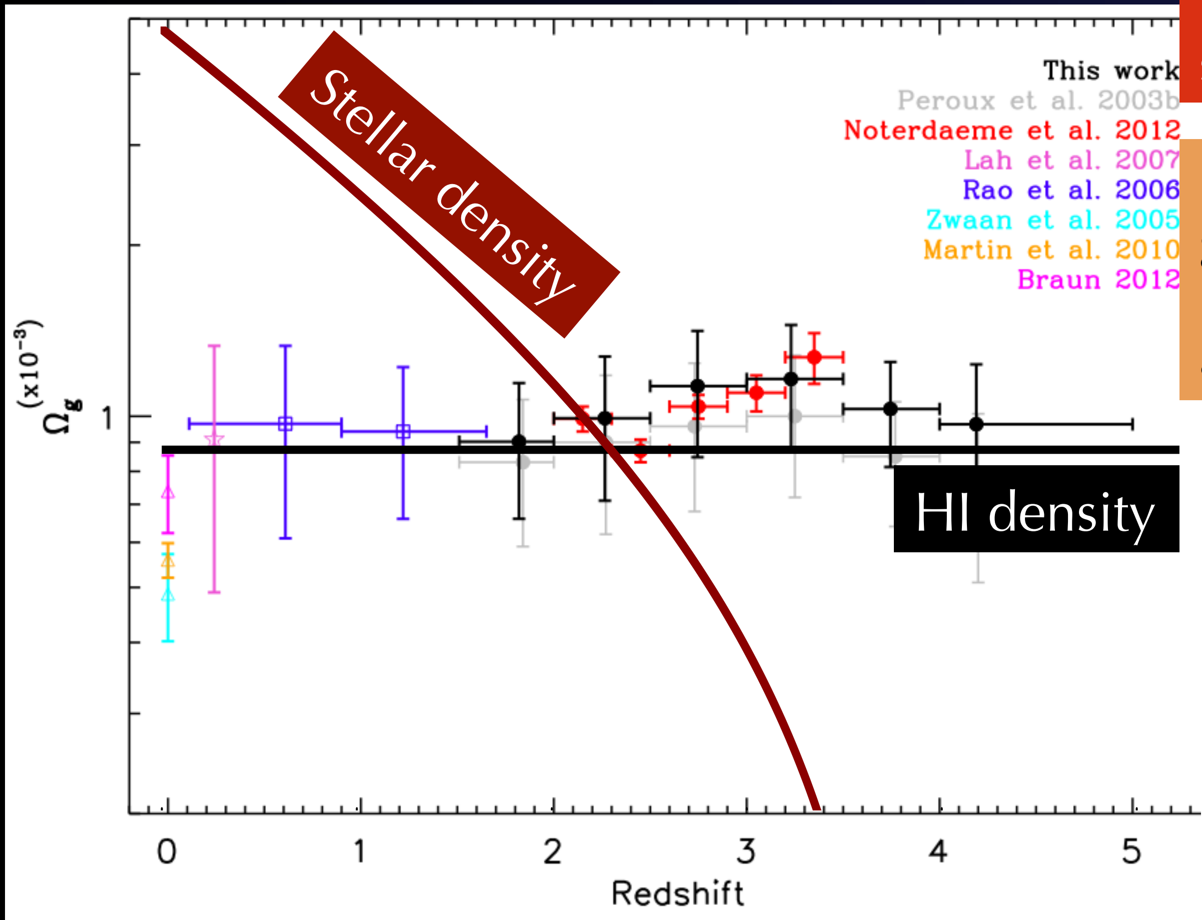


Saintonge+ 15

Kennicutt+83, Genzel+ 10, Bigiel+11, Genzel+15

Cosmology evidence

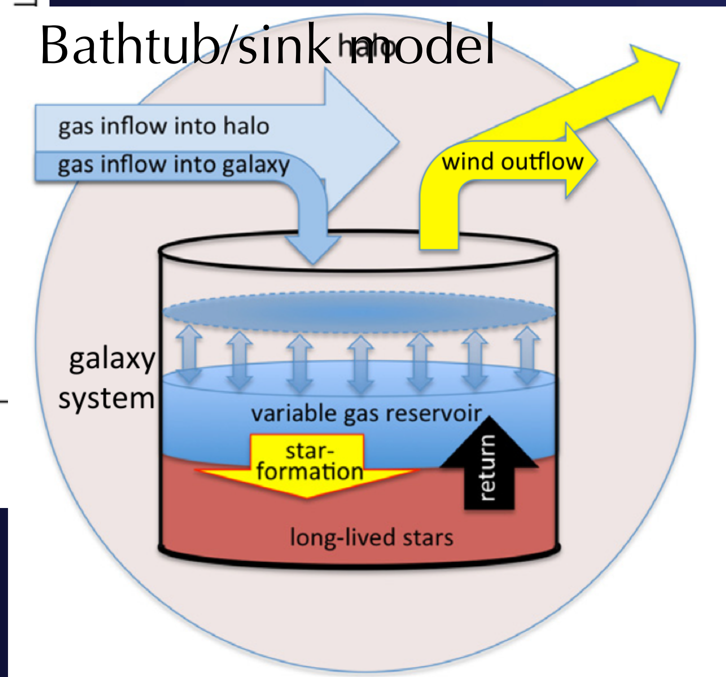
Constant HI in galaxies



The density of HI in galaxies is constant! The density of stars increases dramatically.

Exchange of gas between galaxies does not bring *new* gas in the picture, one needs accretion from the IGM

Bathtub/sink model

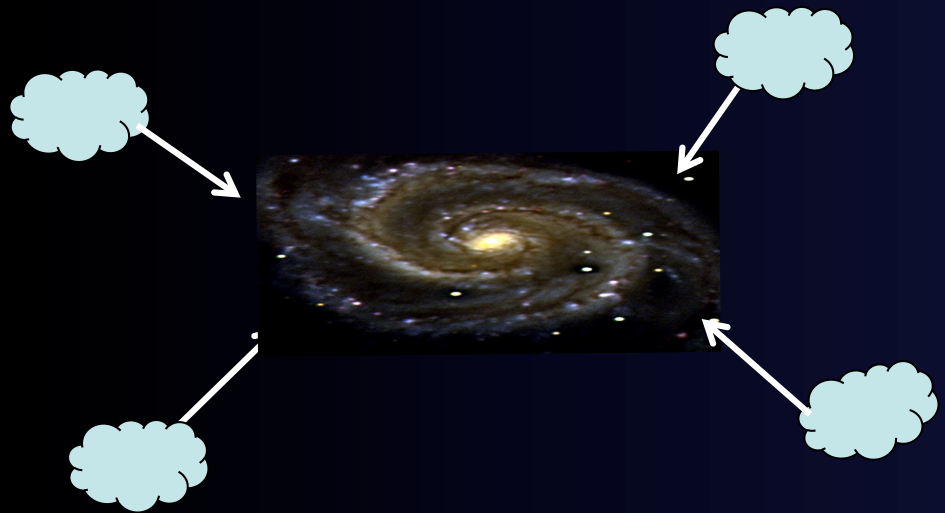


$$\mathrm{SFR} \sim \dot{M}_{\mathrm{acc}} - \dot{M}_{\mathrm{outflow}} + \mathcal{R}\mathrm{SFR}$$

Bouché+2010, Davé+ 2012, Lilly+13

Detection of gas accretion

Detect gas accretion

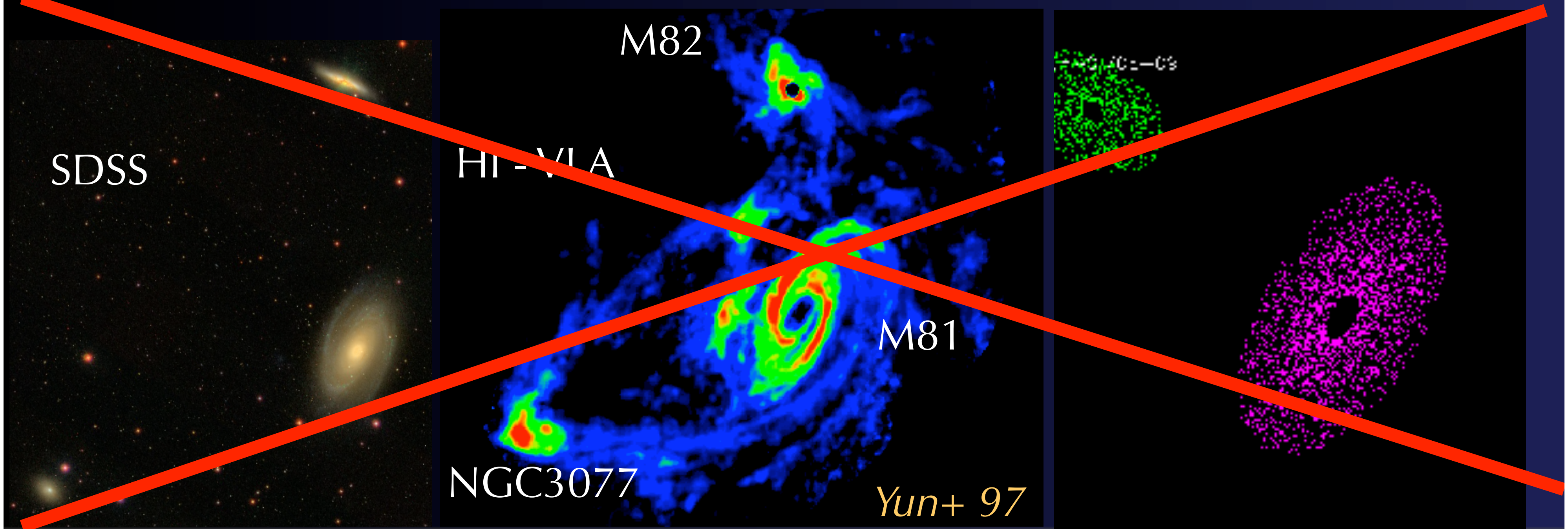


Needed:

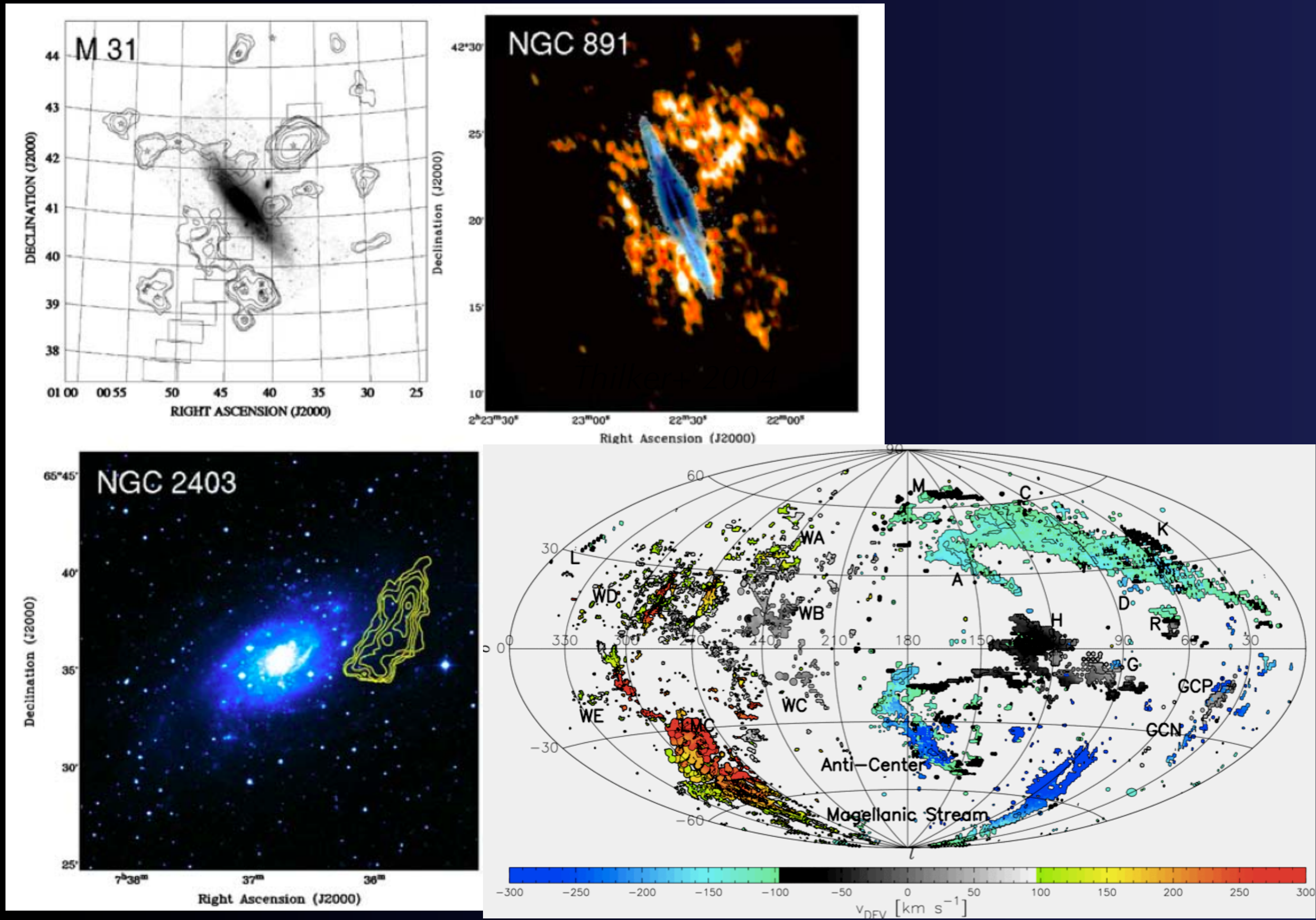
1. Mass gas around ($M_{in,\ gas}$)
2. *Evidence* for infall
3. Timescale of infall (t_{in})

Accretion rate

$(dM/dt)_{acc} \sim M_{in,gas}/t_{in}$



Genuine (?) HI clouds



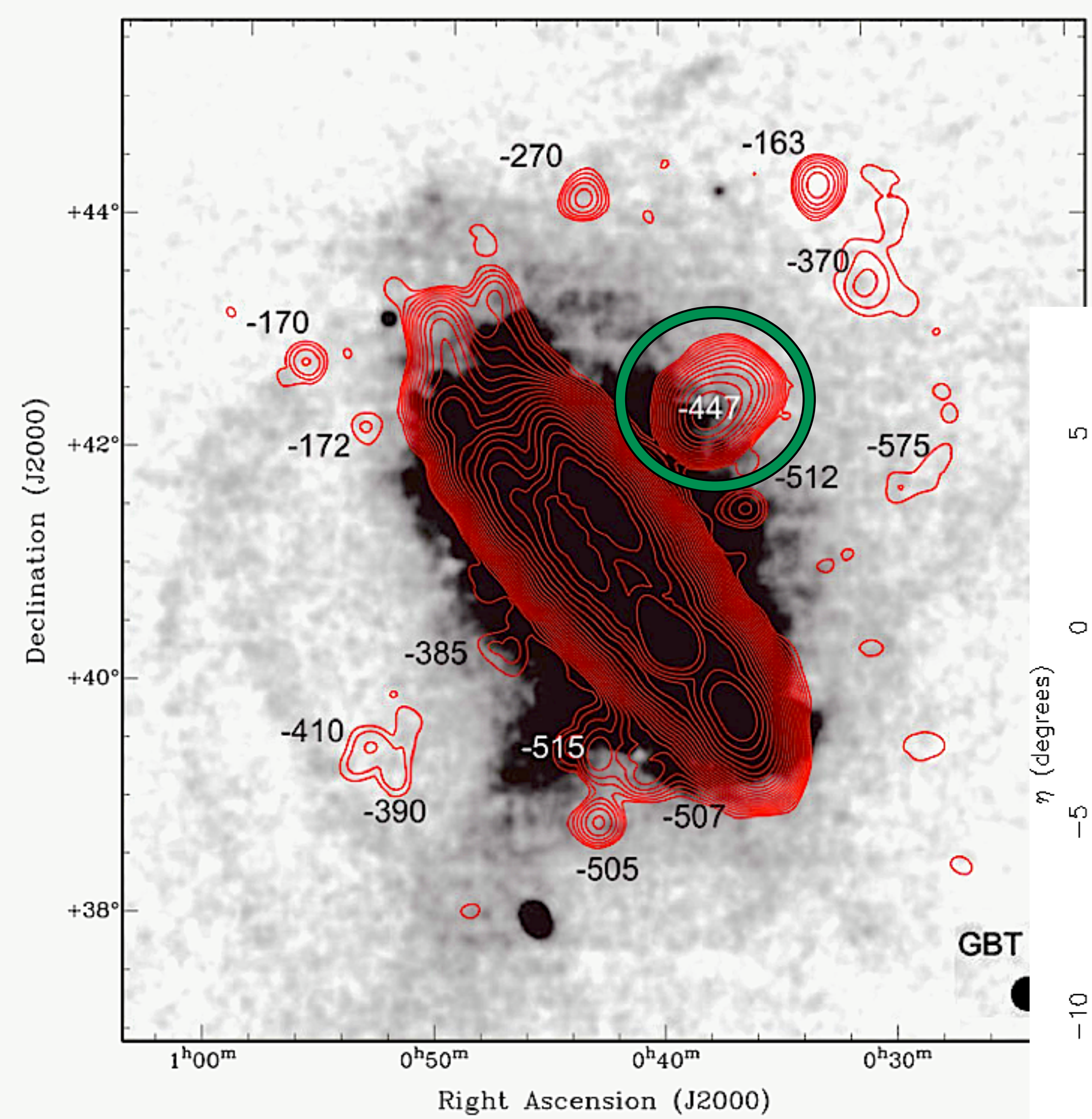
Sancisi, Fraternali+ 2008, A&ARv

M31 clouds

$M_{Davies\ cloud,HI}$ ~ 1-2 x 10^7 $M_\odot$

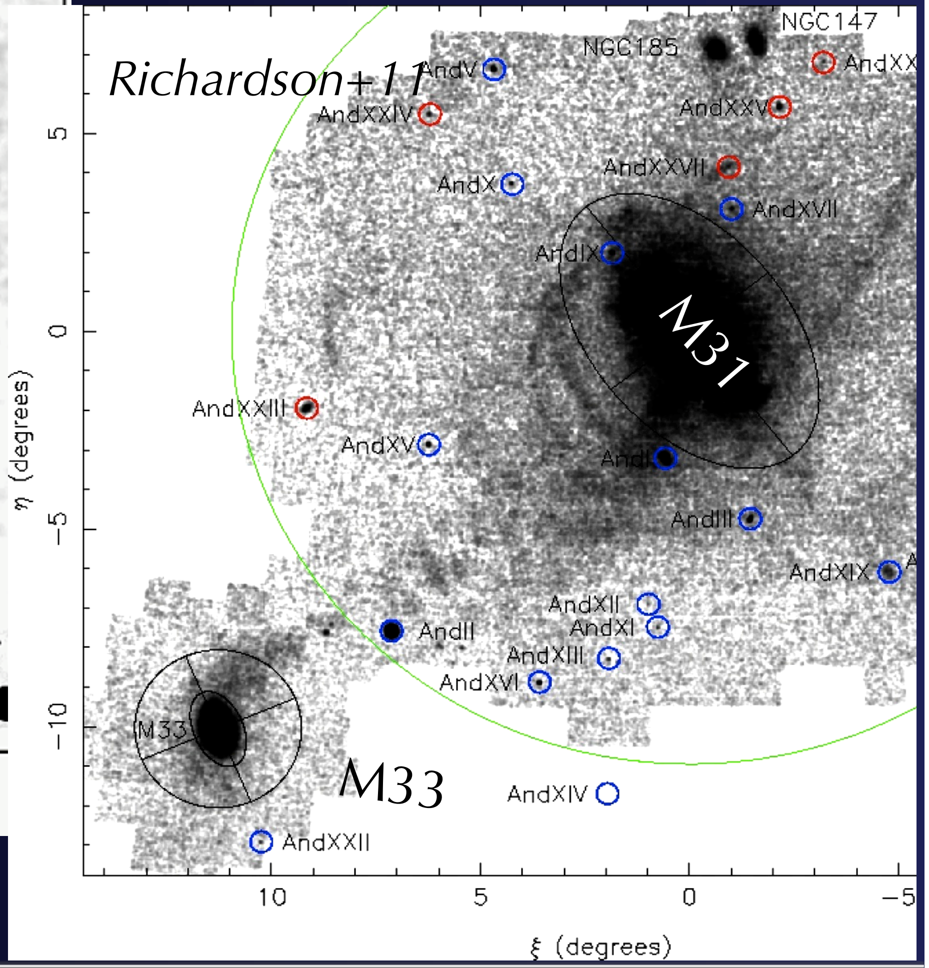
$Dist_{Davies\ cloud}$ ~ 10-20 kpc

$M_{other\ clouds,HI}$ ~ few x 10^5 $M_\odot$



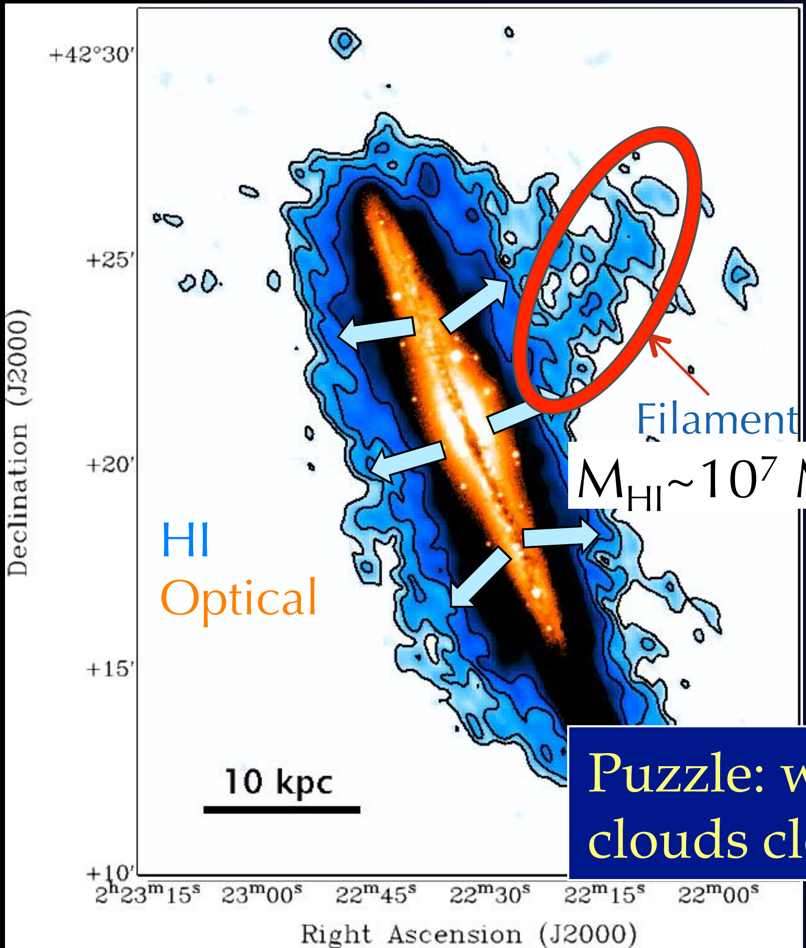
Lewis+ 2013

See R. Braun's talks



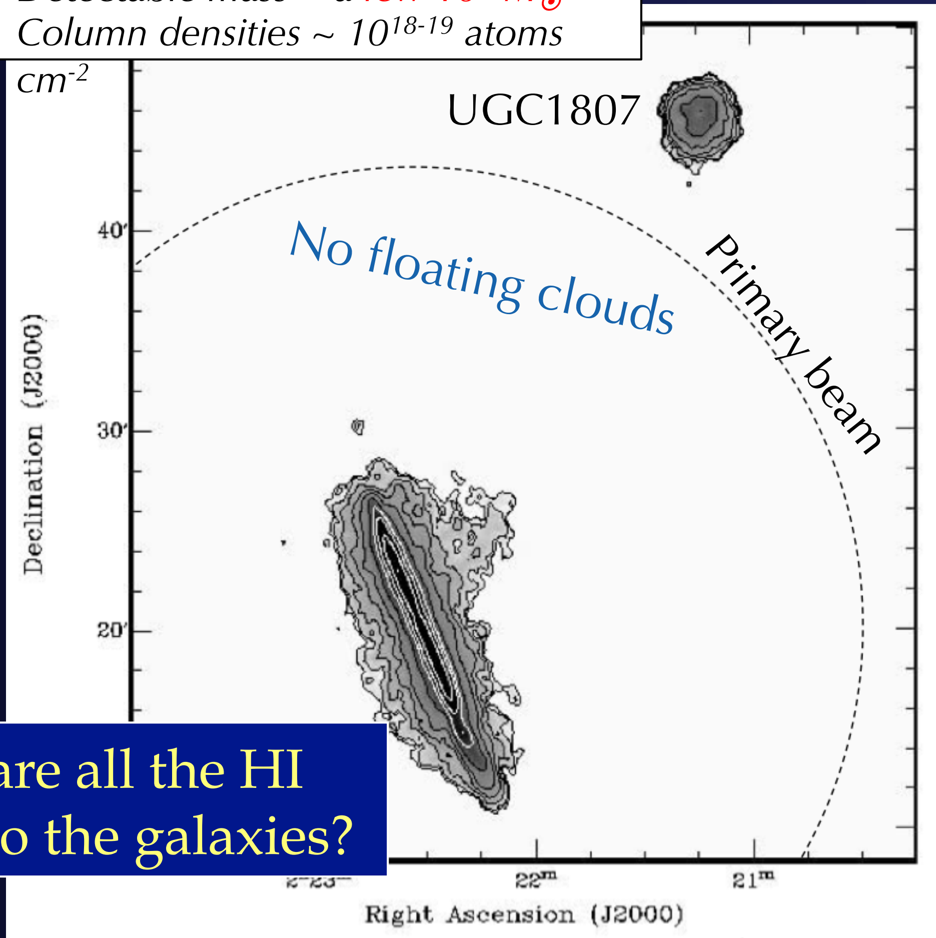
NGC891 filament

200 hrs with WSRT



$M_{HI} \sim 10^7 M_\odot$

Detectable mass = a few 10^5 $M_\odot$
Column densities ~ 10^{18-19} atoms cm^{-2}



Puzzle: why are all the HI clouds close to the galaxies?

Oosterloo, Fraternali, Sancisi 2007, AJ

Extraplanar HI: fountain origin

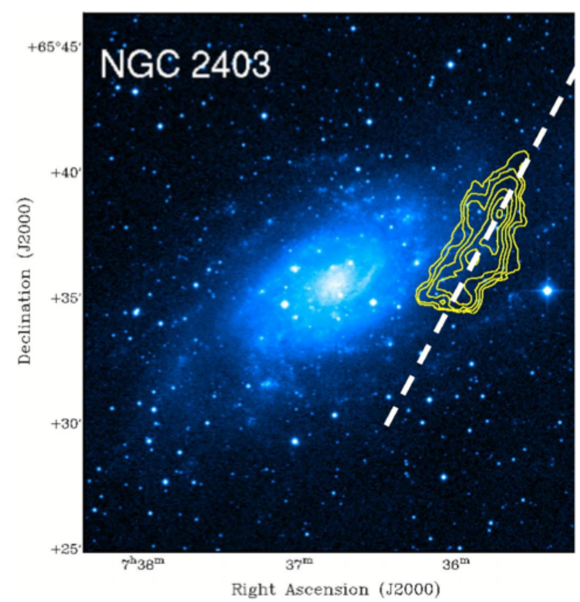
Fraternali & Binney 2008, MNRAS

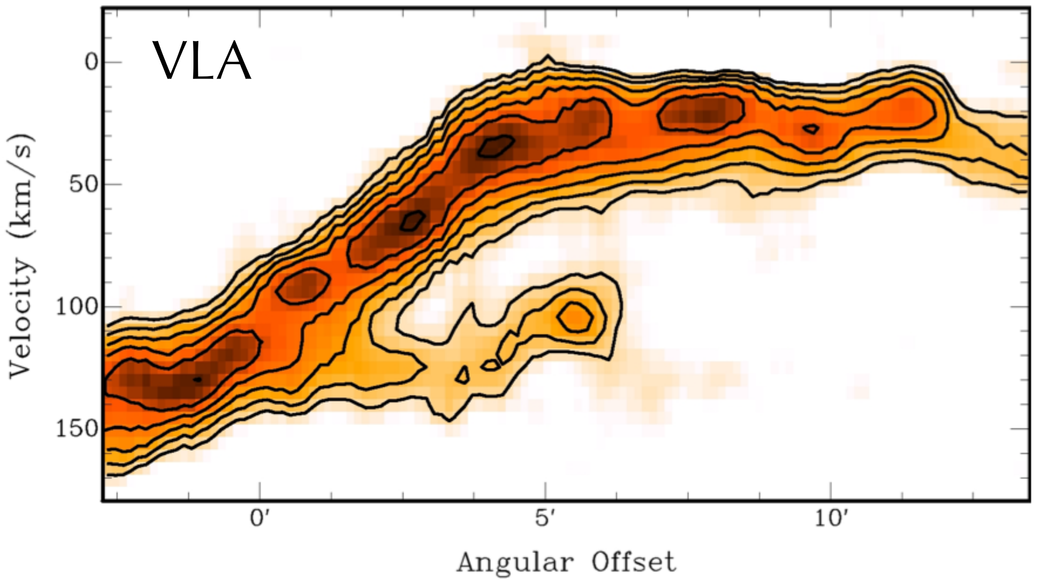
Z (HI) ~ $Z_\odot$ *Bregman et al. 2013, ApJ*

NO significant population of floating HI clouds ($M > 10^{6-7}$ $M_\odot$)

e.g. Pisano et al. 2004, Zwaan et al. 2005
Chynoweth et al. 2009, Haynes et al. 2011

NGC 2403 filament

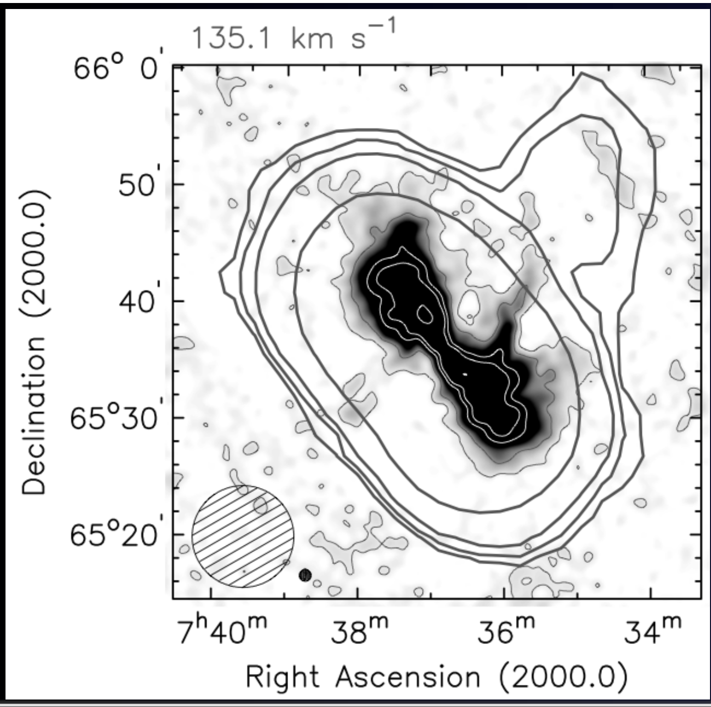


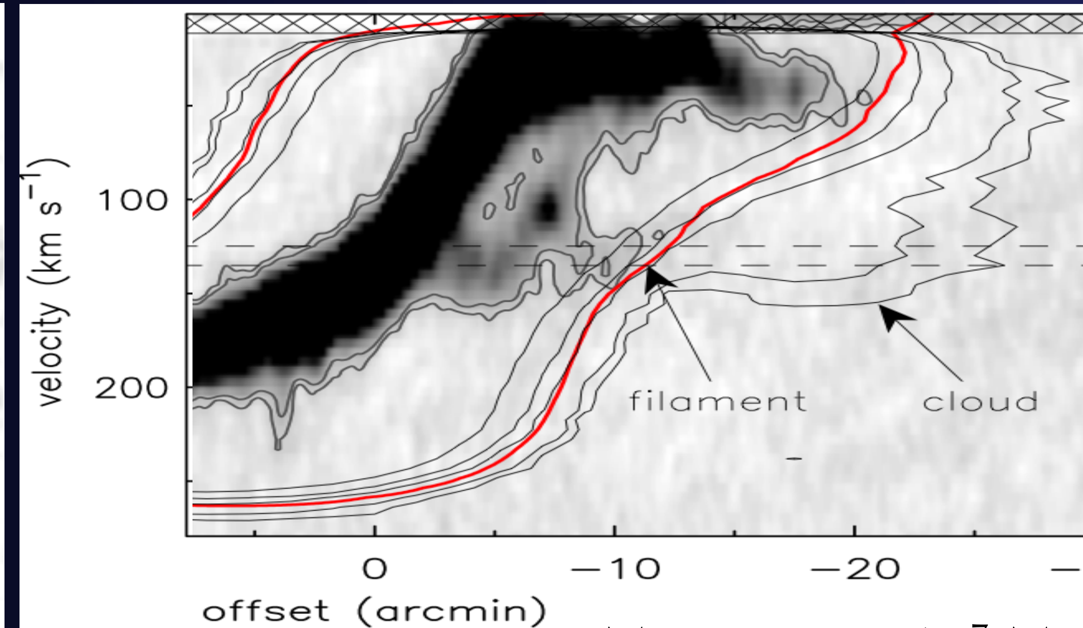


M_{HI}~10^7 $M_\odot$

Fraternali+ 2002

GBT
+
VLA

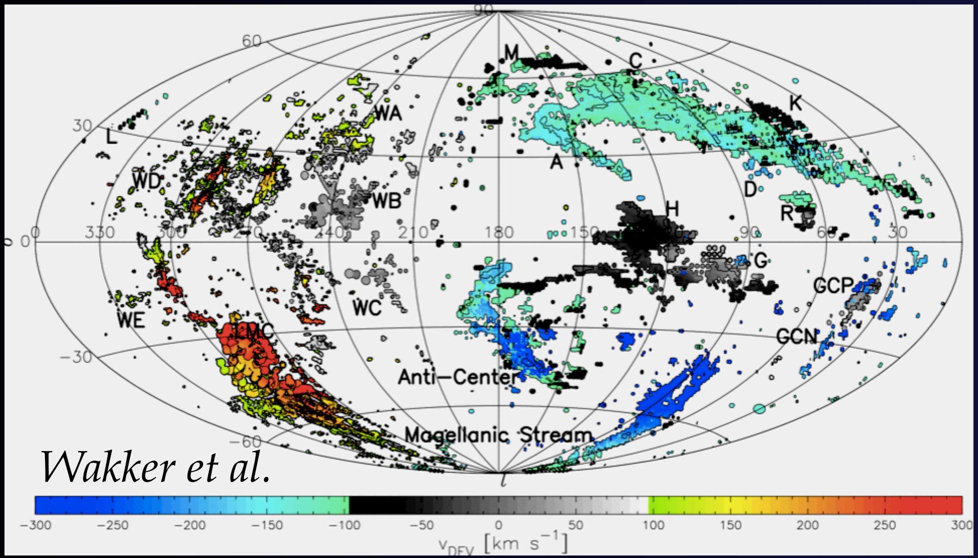




de Blok+ 14

$M_{HI,GBT}$~ 2 x 10^7 $M_\odot$

HI High Velocity Clouds



Typical distances: ~10 kpc

Z~0.1-0.5 $Z_\odot$

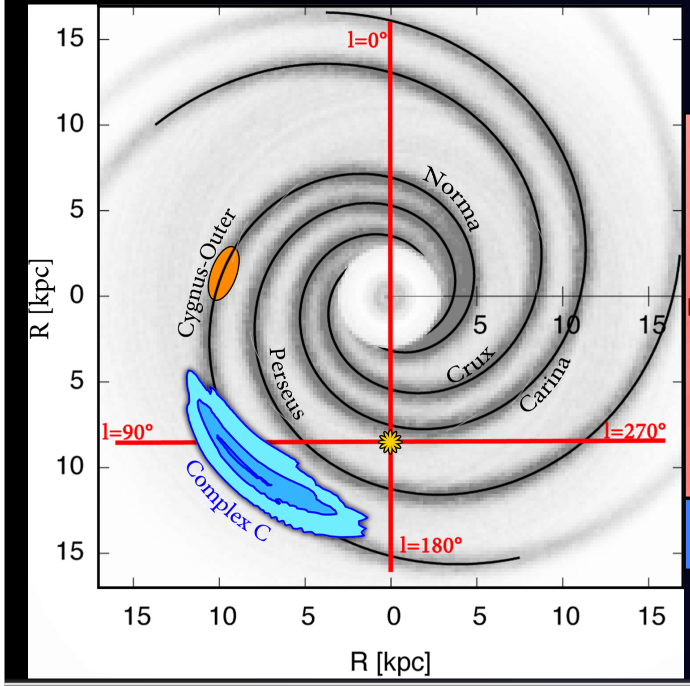
M ~< 10^7 $M_\odot$

Accretion from HVCs

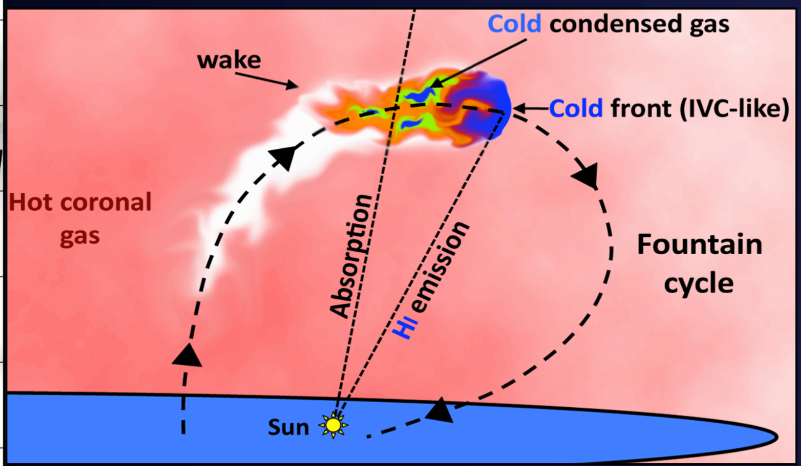
~ 0.08 $M_\odot$/yr

Includes He and factor 2 of ionised gas!

Putman, Peek, Joung 2012, ARA&A



Origin not clear



Fraternali+ 2015, MNRAS-L

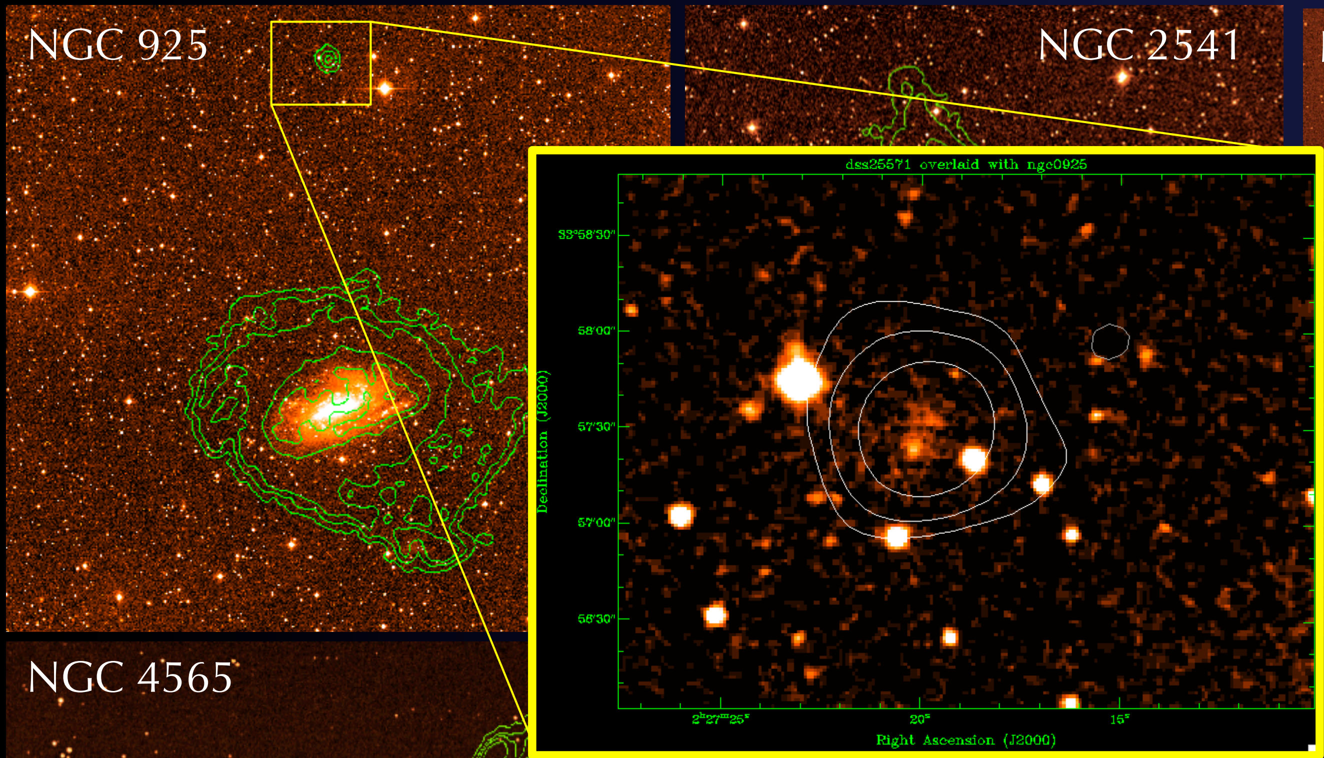
Complex C produced by a superbubble that triggered the cooling of the corona

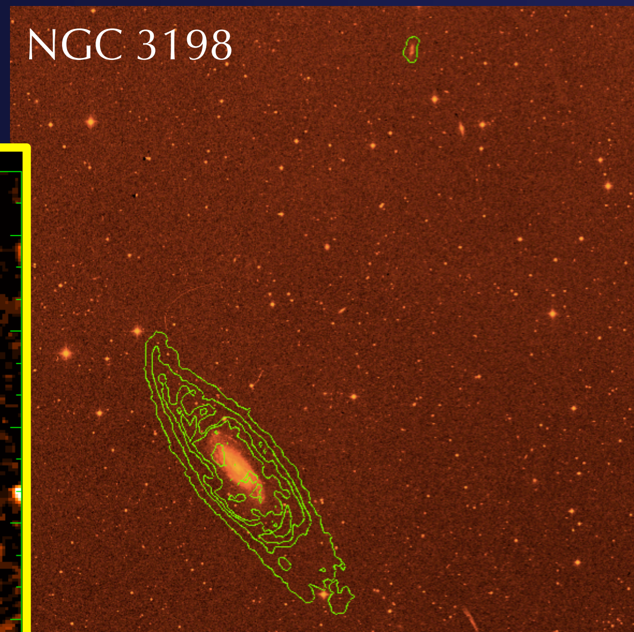
M_{HI} = 7 x 10^6 $M_\odot$

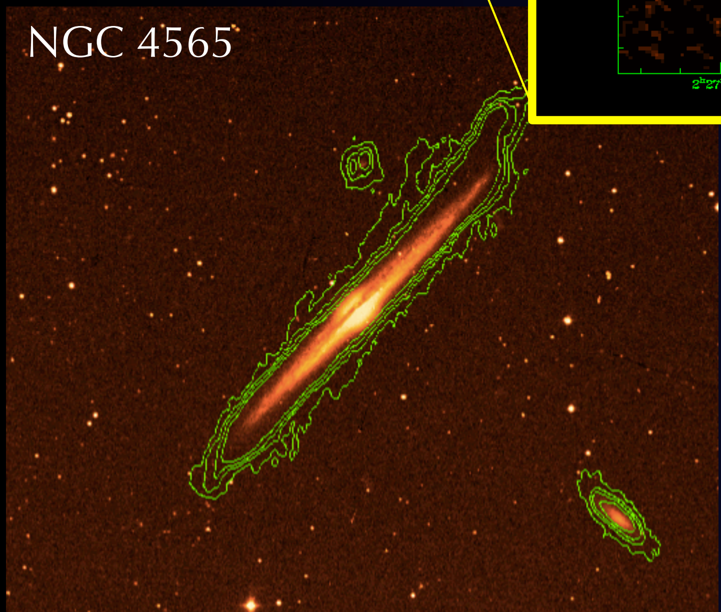
Z = 0.27 Solar

E ~ 10^4 SNe

Several galaxies without large HVCs







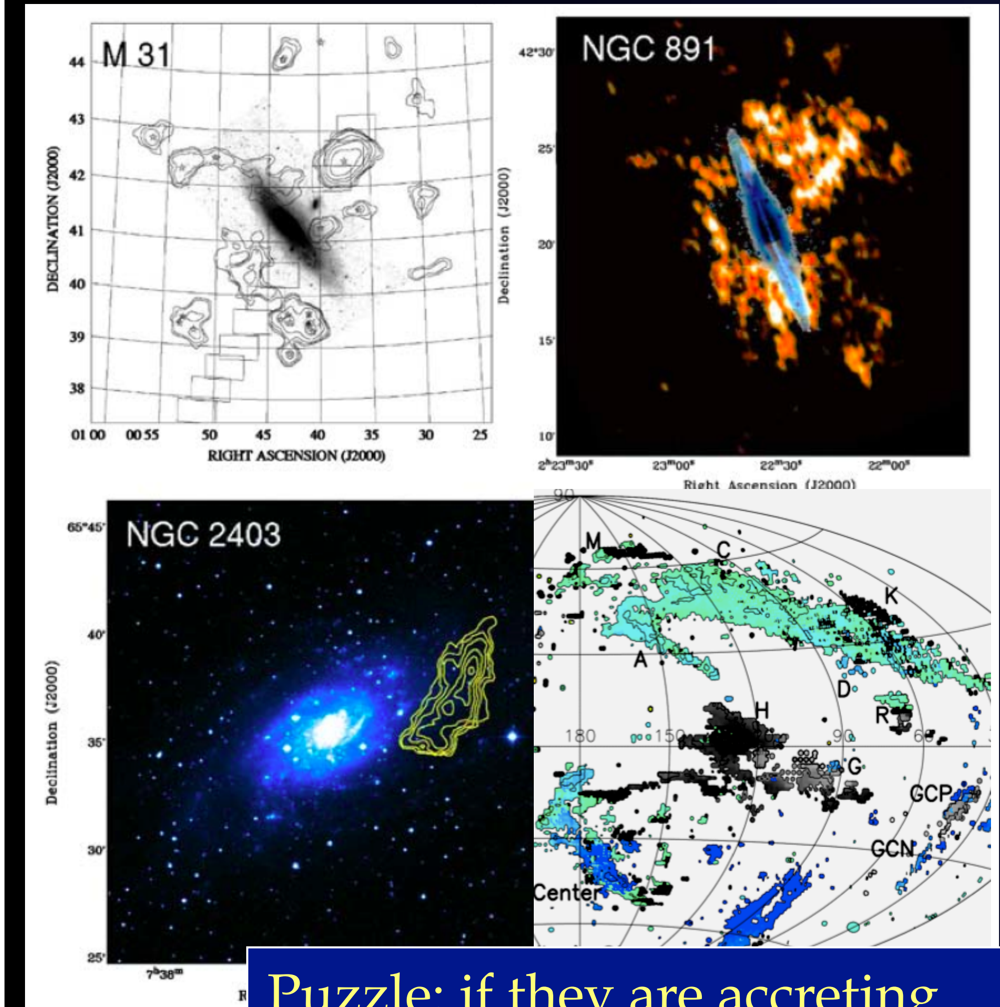
Minimum detectable mass: ~ few 10^5 $M_\odot$

Minimum detectable column density: ~ 10^{18-19} atoms cm^{-2}

HALOGAS survey
Heald et al. 2011, A&A
Juette et al., in prep

Minor mergers cannot feed star formation
Di Teodoro & Fraternali 2014, A&A

Accretion rates



Puzzle: if they are accreting clouds what's their origin?

Let's assume that they are genuine accreting clouds

$M_{cloud,HI} \sim 10^7\ M_\odot$

$R \sim 10$ kpc

$t_{acc} > 10$ kpc / 100 km/s $\sim 10^8$ yr

$M_{acc\ ,HI} \lesssim 0.1\ M_\odot/yr$

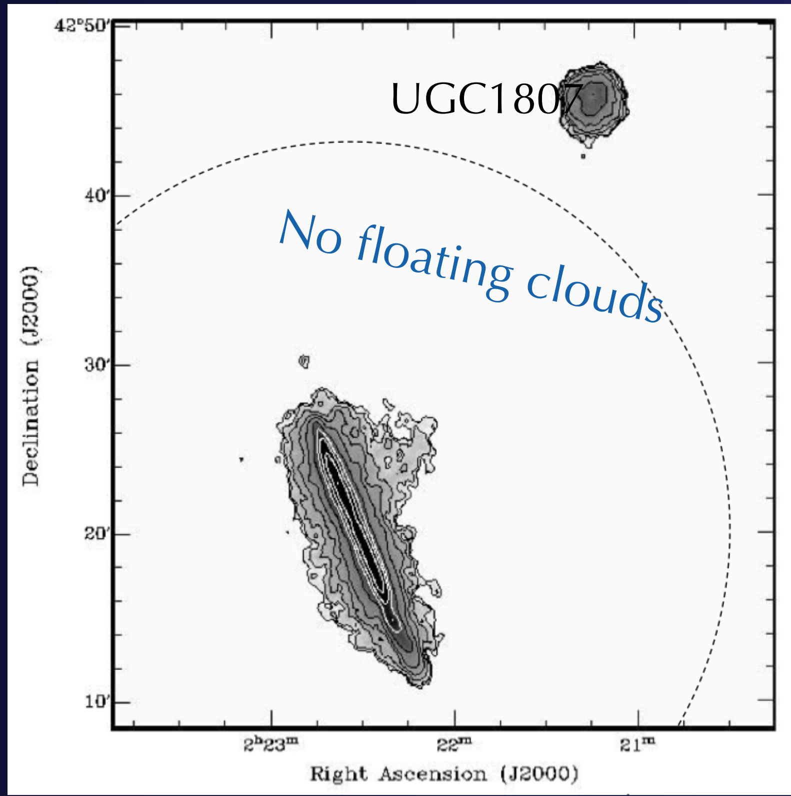
Puzzle: why is HI accretion missing?

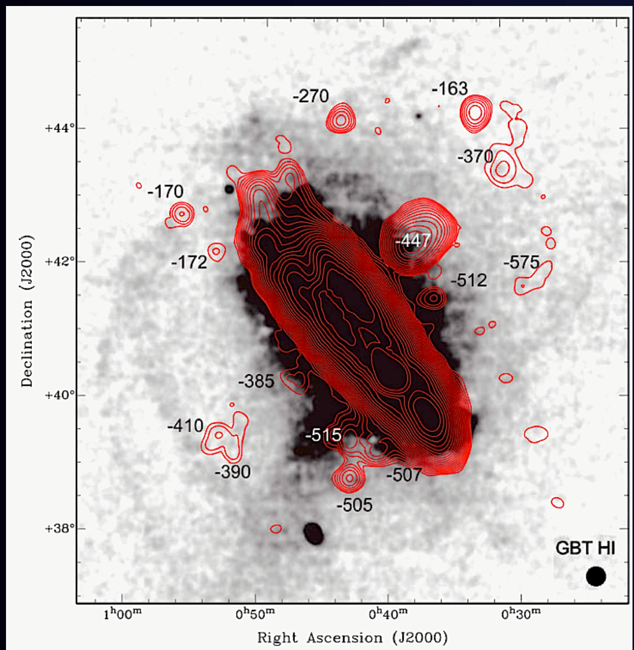
Possible solutions:

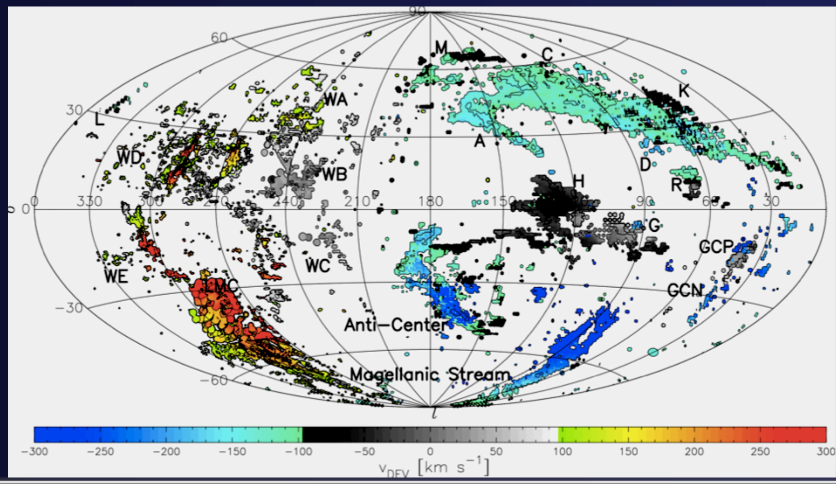
1. Assume most gas is ionised
2. Postulate many clouds under detection limit
3. or *hidden*

First questions

1. Why is HI accretion missing?
2. Why are all the *clouds* closeby?
3. What's their origin?



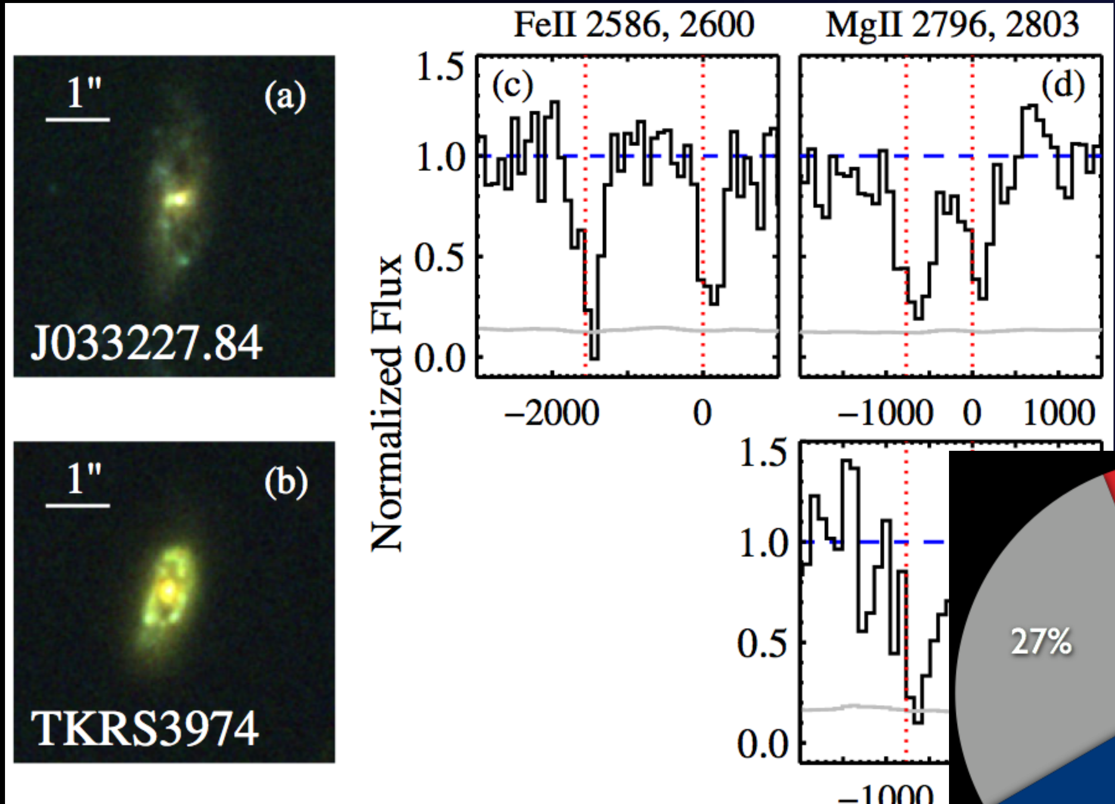




Absorption studies

It's not easy to *see* accretion

Redshifted ISM absorptions

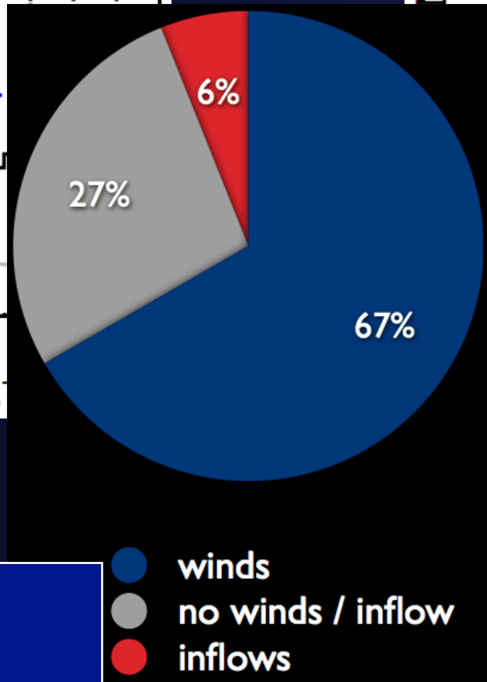


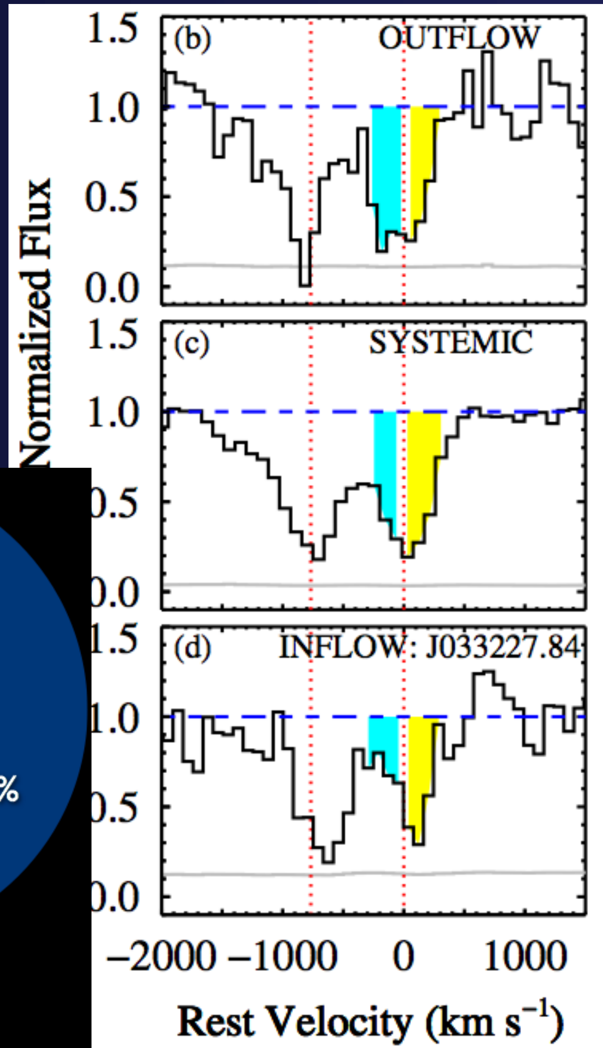
101 galaxies, z~0.3-1

Rubin+ 2012, ApJ

$\dot{M}_{in}$ ~ 0.2–3 $M_\odot$ yr^{-1} ?

SFR ~1-40 $M_\odot$ y





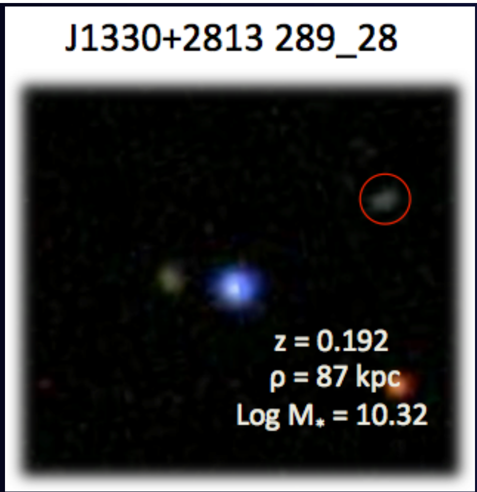
Puzzle: why is inflow not seen?

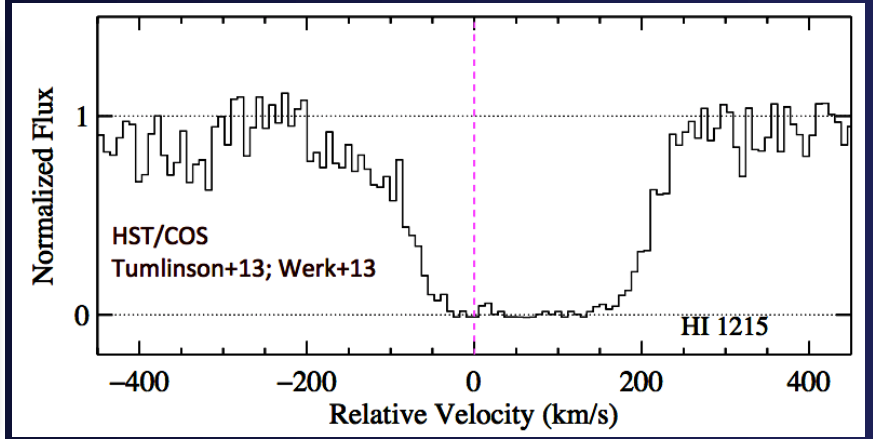
SEE also Martin+ 12

COS-Halos

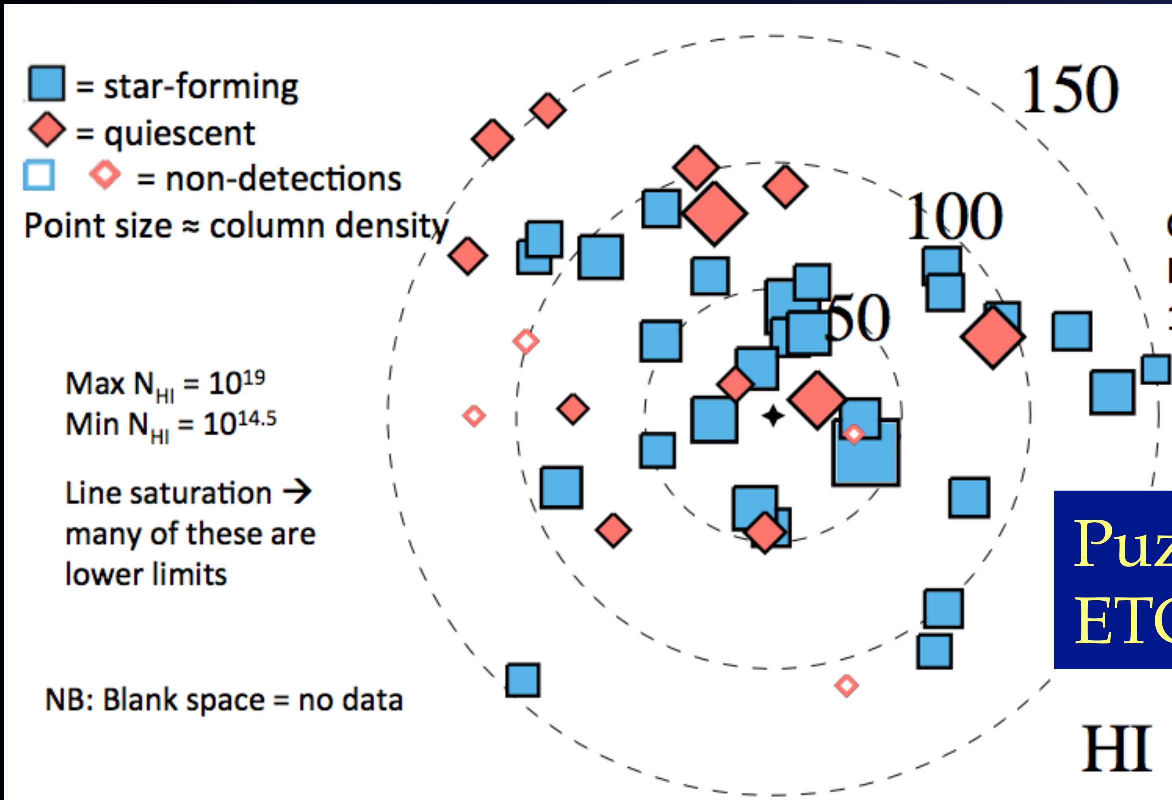
PI: Jason Tumlinson
134 orbits with HST/COS
44 galaxies

0.14 < z < 0.35





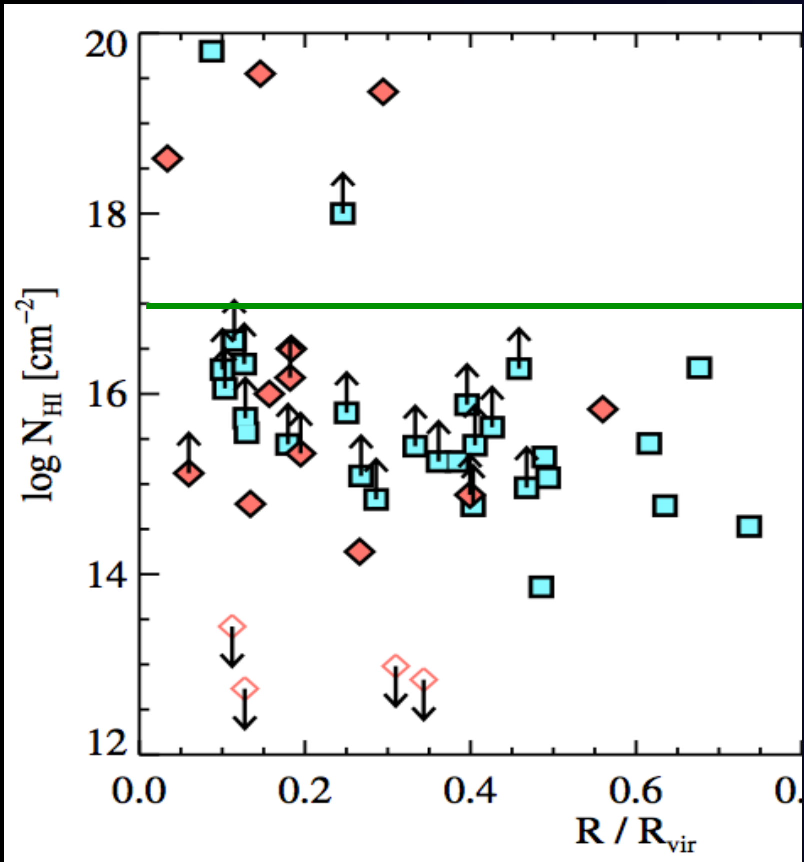
Ly alpha – cold gas (T ~ 1-3 10^4 K)



Puzzle: why do ETGs have cold gas?

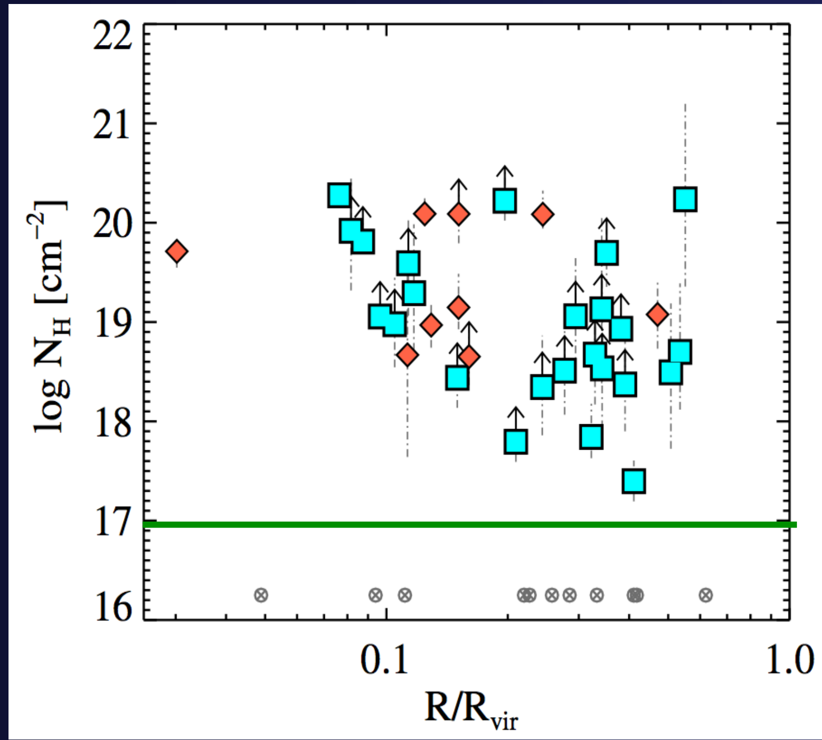
Huge correction for ionised fraction

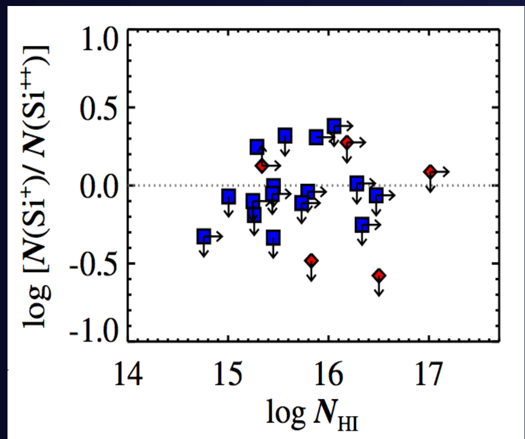
N_{HI} before correction



CLOUDY
Assuming
EUVB

N_H after correction

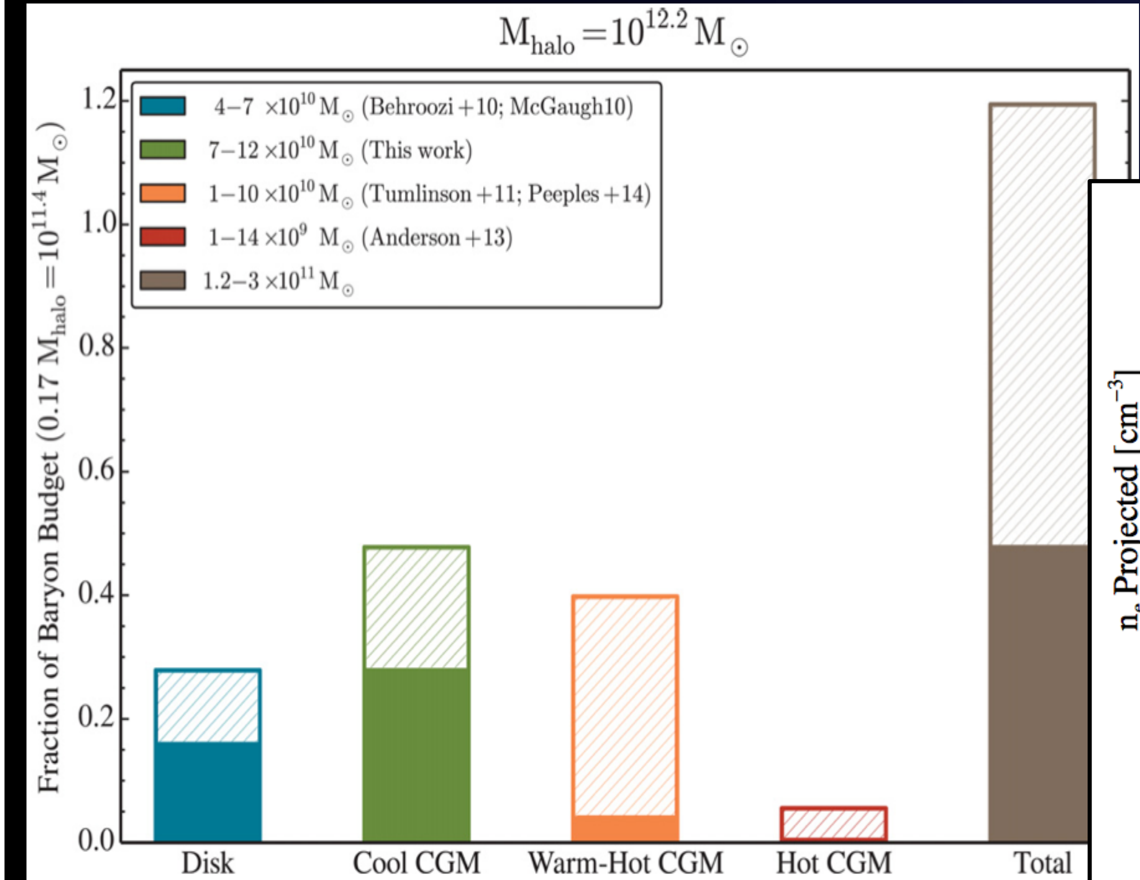




Gas >99% ionised
Very large mass

Masses and densities

Components of the Circum Galactic Medium

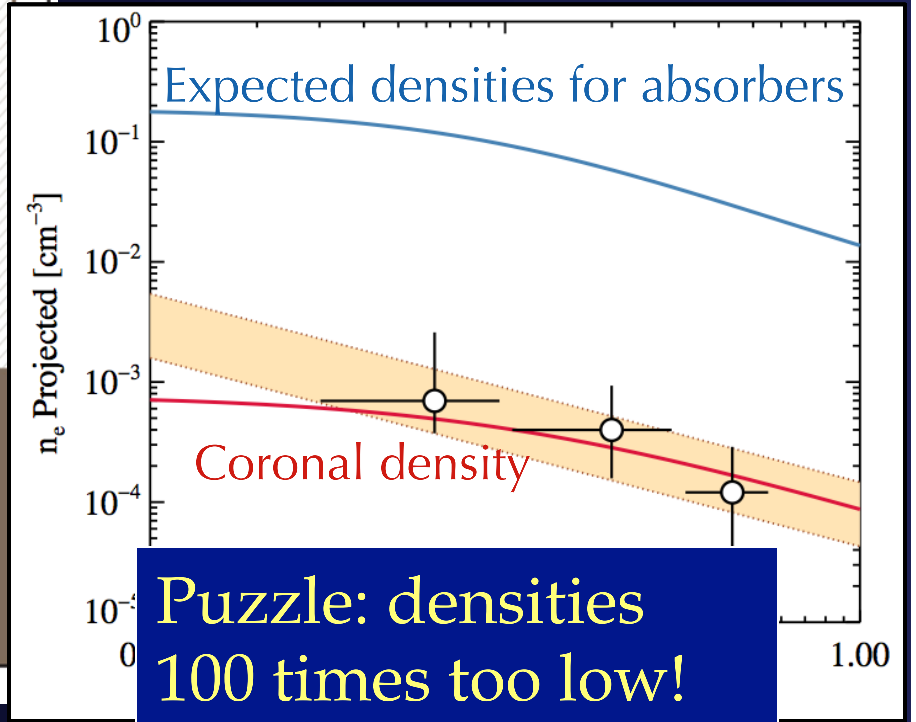


Werk+ 2014

Puzzle: can there be so much cold gas?

Are they in pressure equilibrium with the corona?

Volume densities



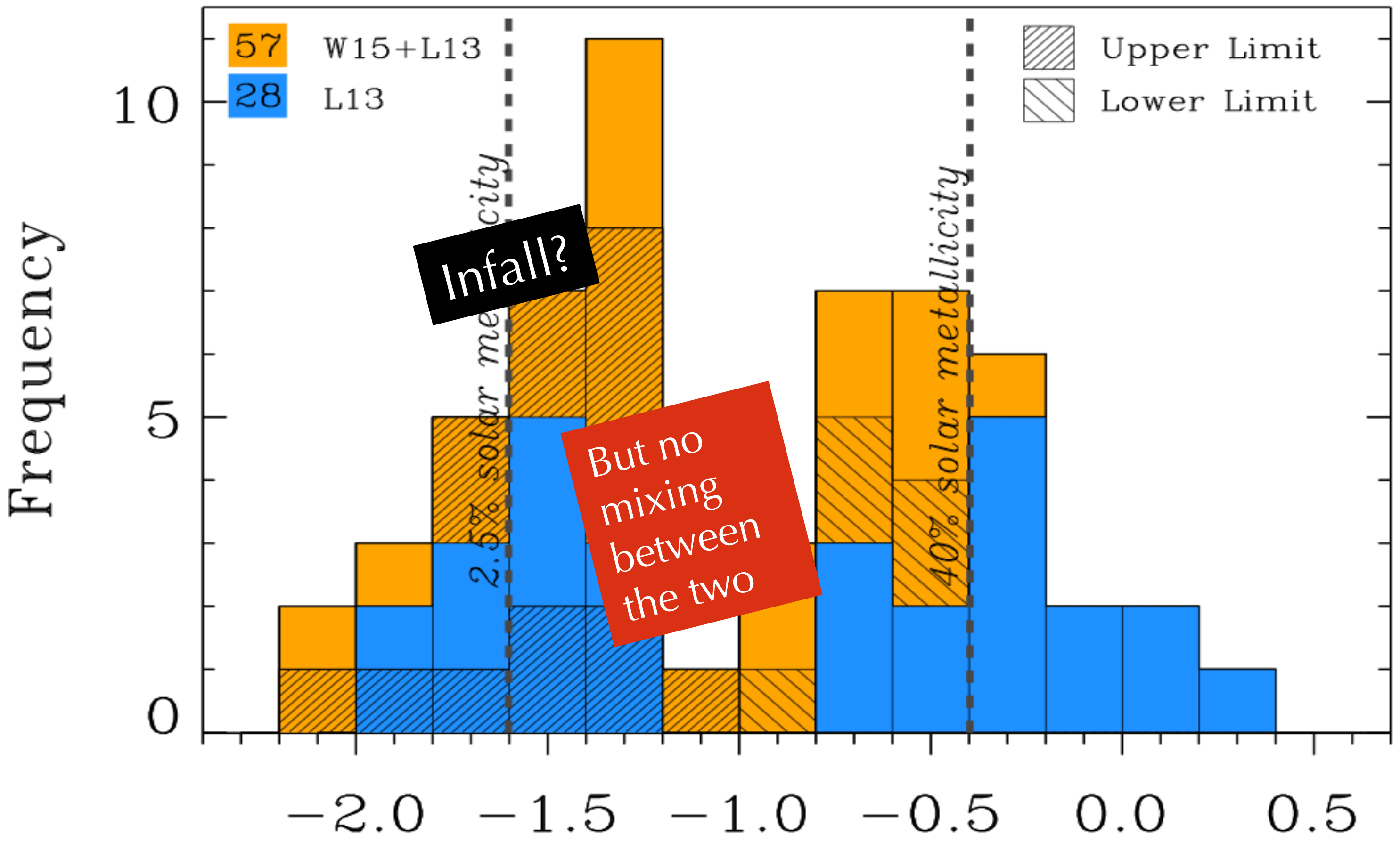
Puzzle: densities 100 times too low!

Possible solutions:

1. Too simplistic assumptions
2. Ionization from galaxies/shocks
3. Corona not isothermal

Metallicity vs N_{HI}

16 < Log N_{HI} < 19 : Bimodality

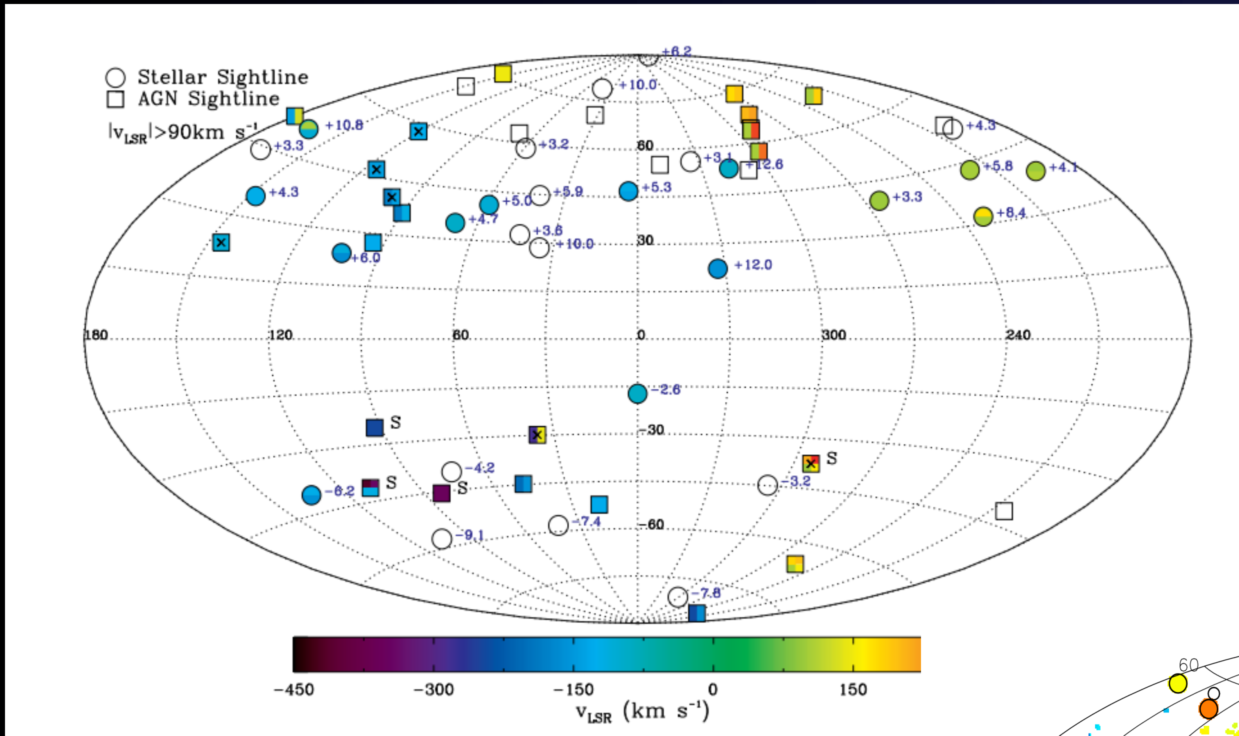


Wotta+ 2015

[X / H]

Puzzle: why is the metallicity of the low N_{HI} gas bimodal ?

Absorbers around the MW



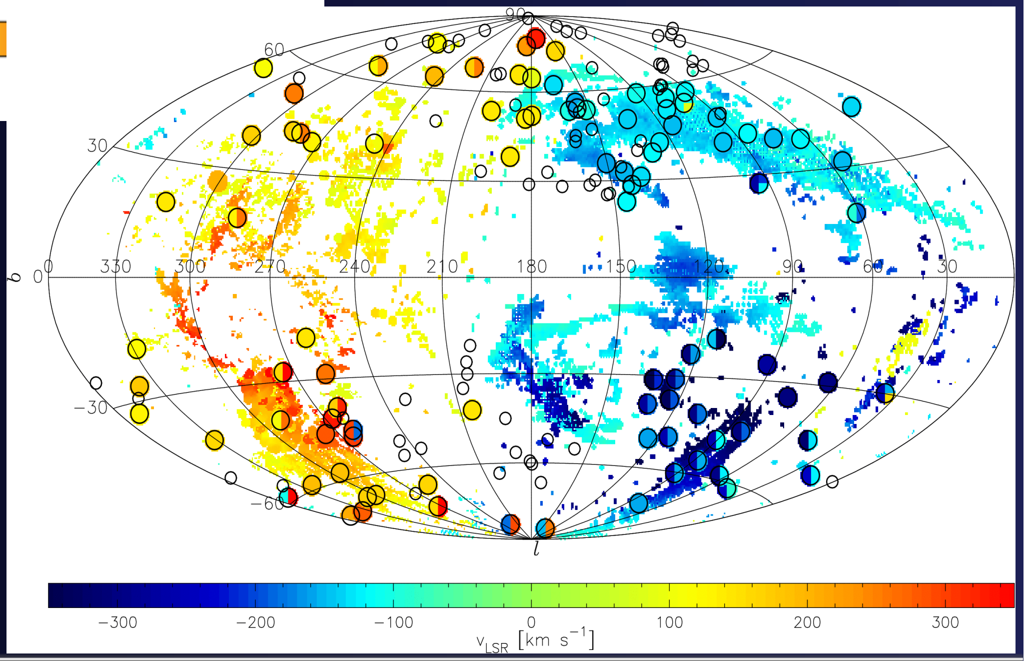
Shull+ 2009, ApJ
Lehner & Howk 2011, Science
Lehner et al. 2012, MNRAS

C II, Si II, Si III, …

$4.3 < \log T < 5.3$ K

OVI $T \sim 3 \times 10^5$

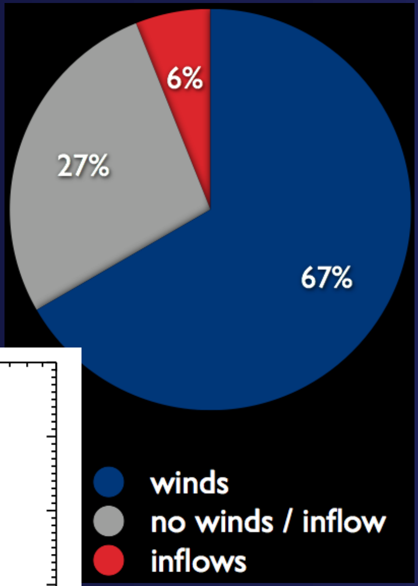
- $13.8 < N_{OVI} < 14.8$
- $-400 < v_{los} < +400$
- Every directions

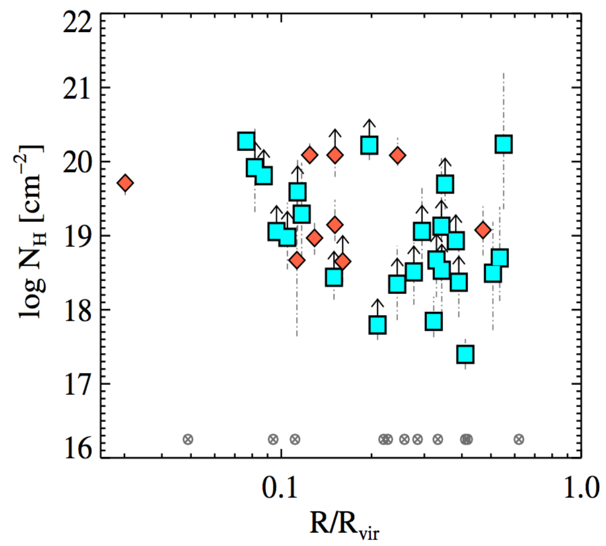


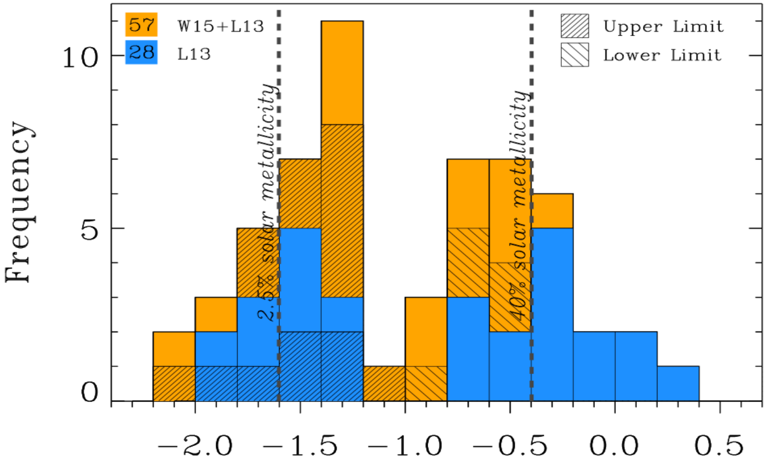
Sembach+ 03, ApJS; Savage+ 03, ApJS

More questions

1. Why is HI accretion missing?
2. Why are all clouds closeby?
3. What's their origin?
4. Why is inflow generally not seen?
5. What are the COS-Halos *cold* absorbers?
6. How do they survive, do they accrete?
7. Why Z bimodality in absorbers?







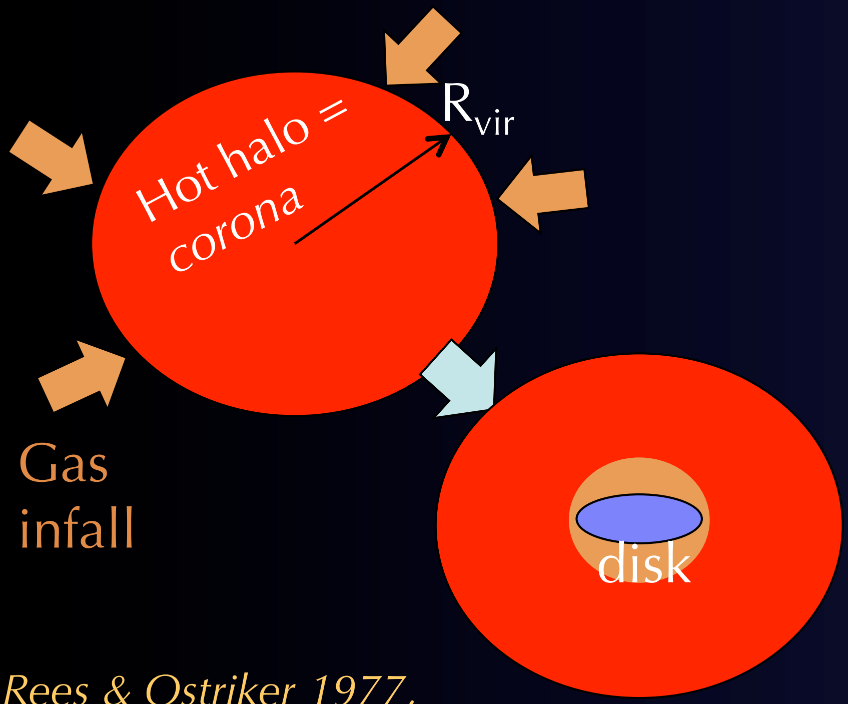
Theoretical expectations

Hot and cold modes

Classical theory

- Gas falls into a dark matter halos
- Shock heats to the virial temperature

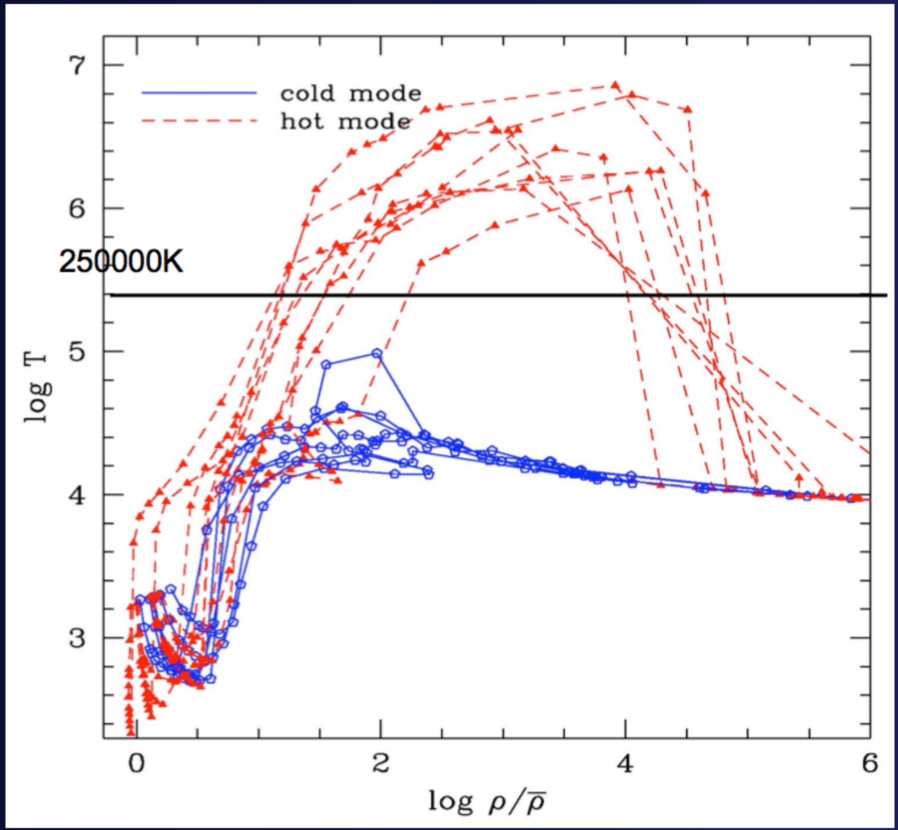
- Quasi-hydrostatic equilibrium corona cools inside-out and settle into a disk



Rees & Ostriker 1977, White & Rees 1978

Modern revision

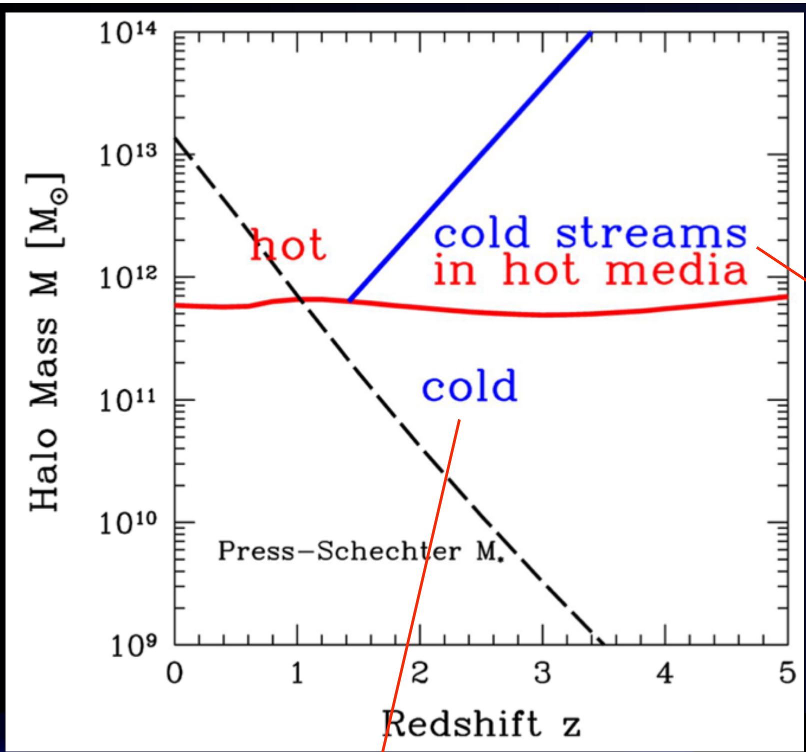
- In small halos gas does not thermalize
- Falls in *cold* filaments
- Rapid collapse and disk formation



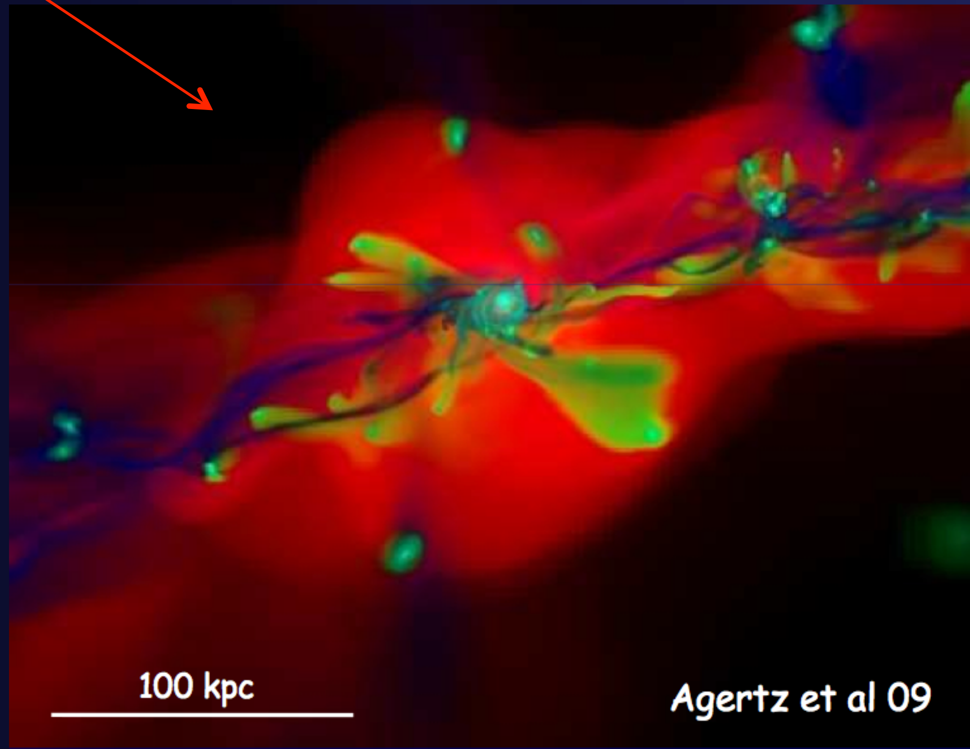
Binney 1977, Katz+ 2002, Dekel & Birnboim 2003, Keres+ 2005

Cold mode

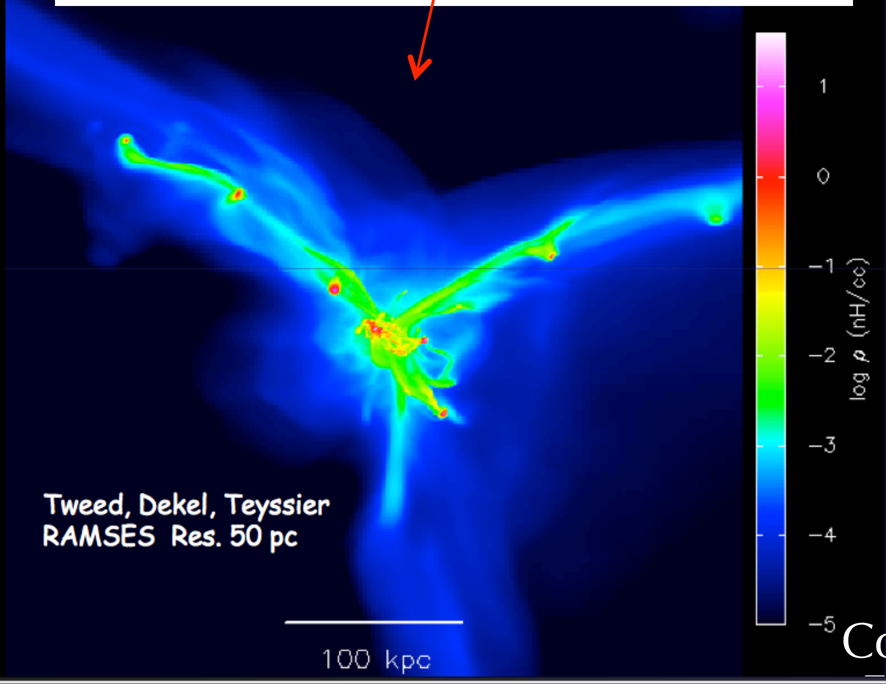
Dekel & Birnboim 2006



High z, large halos



Cold streams in hot corona

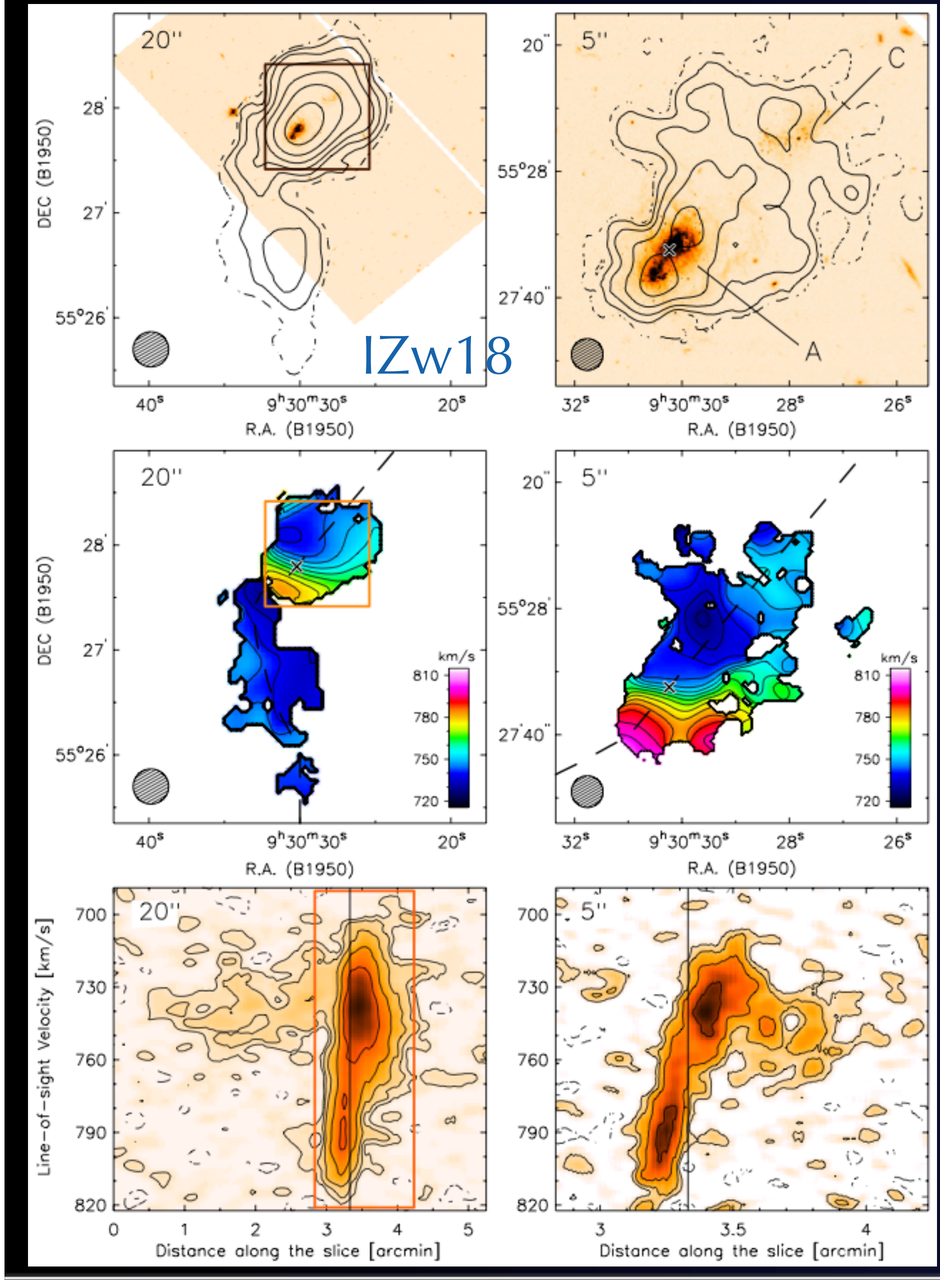


$$\dot{M}_{\rm h} \approx 30 \left(\frac{M_{\rm h}}{10^{12} M_\odot}\right)^{1.14} (1+z)^{5/2}\, M_\odot\, {\rm yr}^{-1}$$

Cold streams

Nearby cold flows?

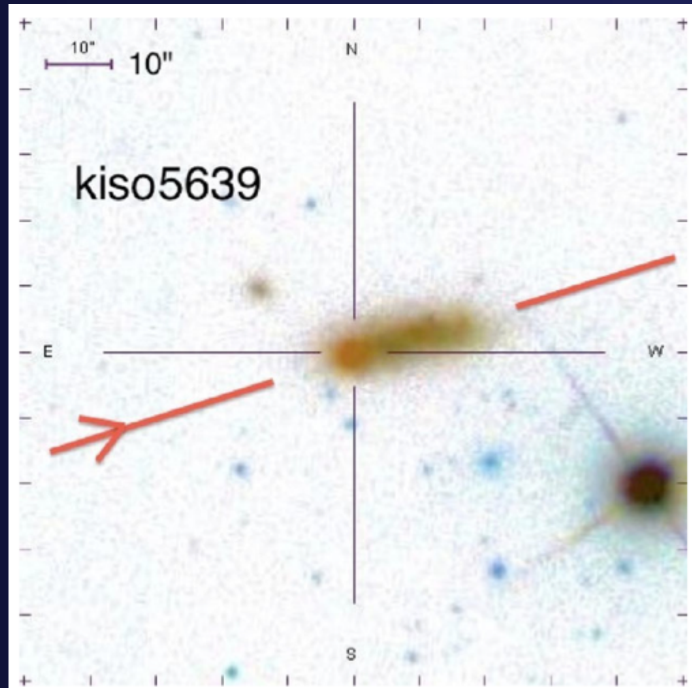
Starbursting dwarf

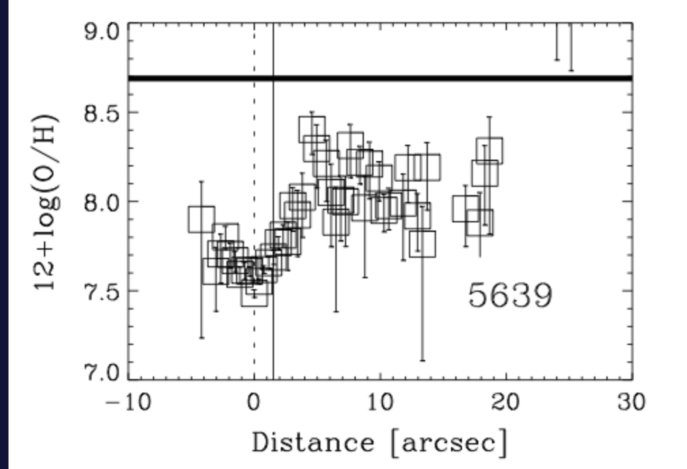


Lelli+ 2012

KISO survey
Elmegren+ 2012

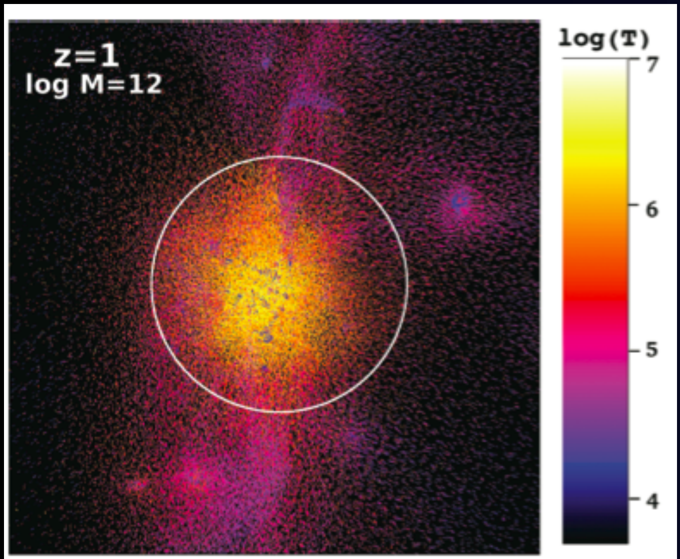
Tadpole galaxies with offset star formation





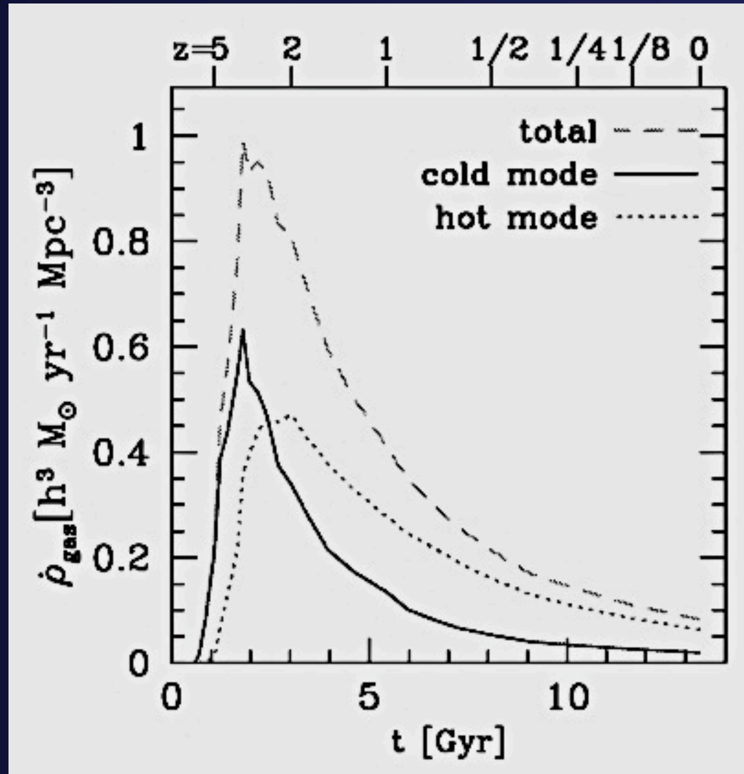
Sanchez-Almeida+ 2014

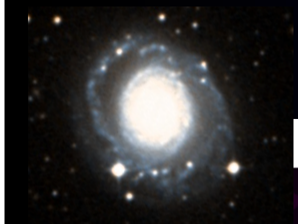
Hot mode



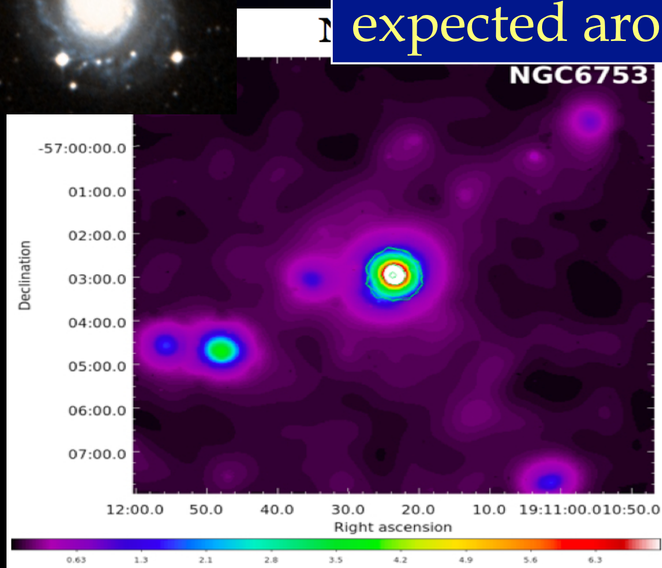
Keres+ 2005, 2009

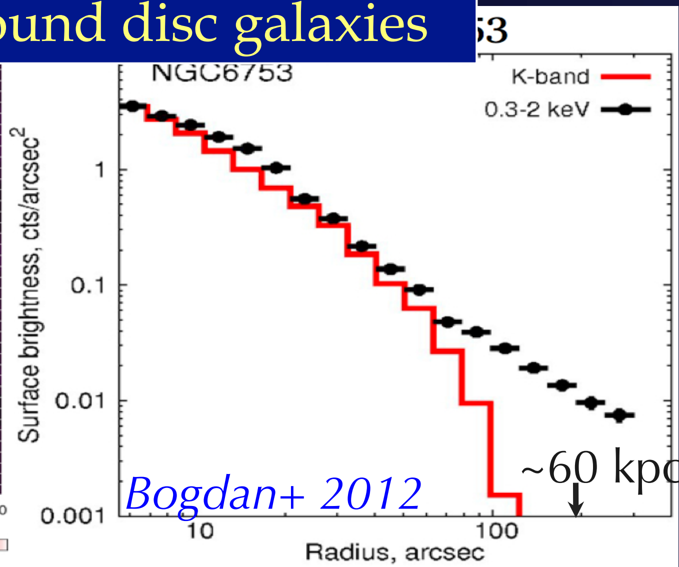
For MW halos
z>2 : cold mode
z<2 : hot mode
dominates





Puzzle: Less hot gas than
expected around disc galaxies





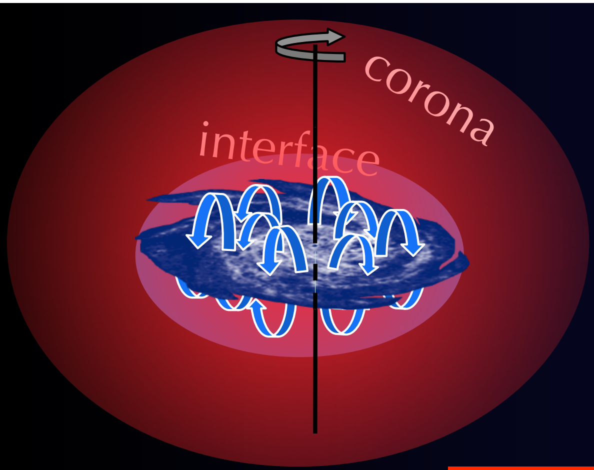
Bogdan+ 2012

Anderson & Bregman 2012
Dai+ 2012, Anderson+ 2013
MW *Miller & Bregman+ 2013, Gatto+13*

Mass corona
~ 10-50% missing baryons

Cooling time >2 Gyr
Cooling rate ~ 0.1 Mo/yr

Induced cooling

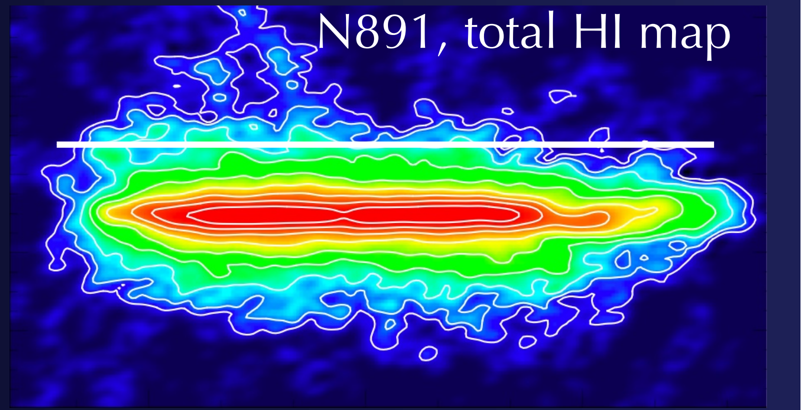


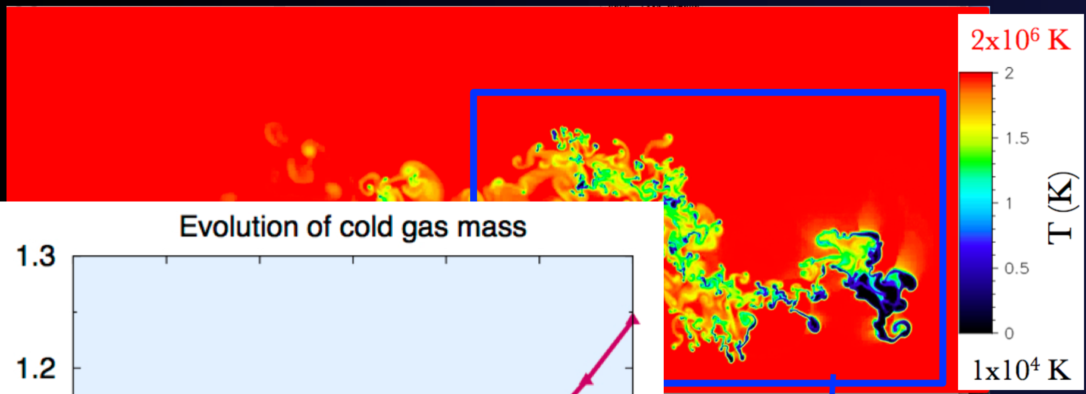
$Z_{corona}=0.1\ Z_\odot$

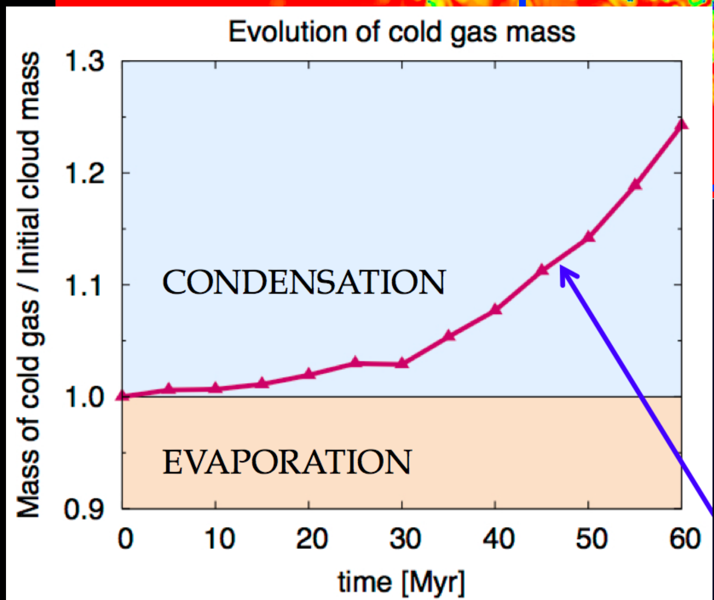
1 pc x 1 pc Grid!

$T_{corona}=2\times10^6$ K

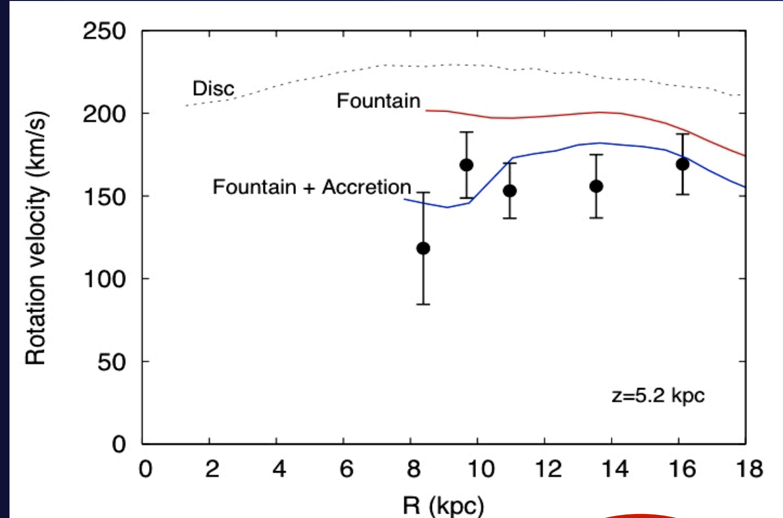
$Z_{cloud}=1\ Z_\odot$







Mass of cold gas increases



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

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

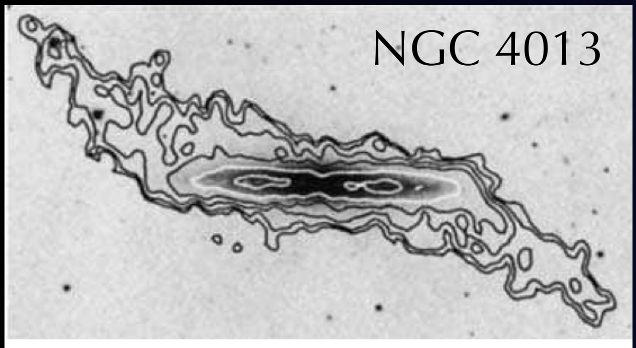
Fraternali & Binney 2008

Lucia Armillotta, in prep.; Marinacci, et al. 2010, 2011, MNRAS

Questions/puzzles

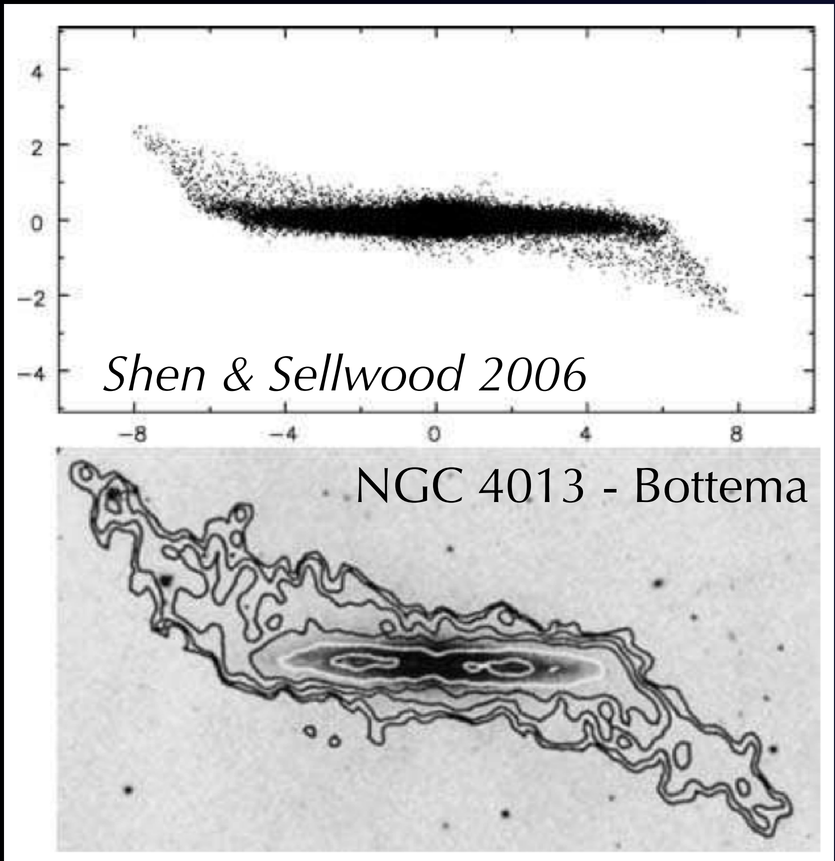
Accretion in what form?

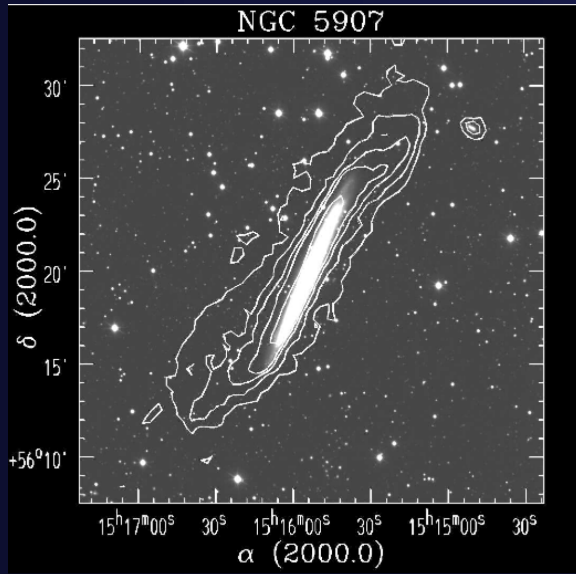
1. *Cold* gas clouds/filaments ($T<10^5$ K) directly from the IGM
    1. Mostly neutral
    2. Mostly ionized
2. Cooling of a hot corona (T_{vir})
   Spontaneous or induced?
3. Drizzle?
4. Minor mergers??
5. Outer discs, just flowing in



1. Why is HI accretion missing?
2. Why are all clouds closeby?
3. What's their origin?
4. Why is inflow generally not seen?
5. What are the COS-Halos *cold* absorbers?
6. How do they survive, do they accrete?
7. Why Z bimodality in absorbers?
8. Can we see cold mode at z=0?
9. Why coronae have low masses? Can they cool efficiently?

Galaxy warps and accretion





Very common

Garcia-Ruiz+ 2001

But gas is needed for star formation in the central parts!

Galaxy discs should act as accretion discs (?)

Forbes+ 12, Golbaum+ 15

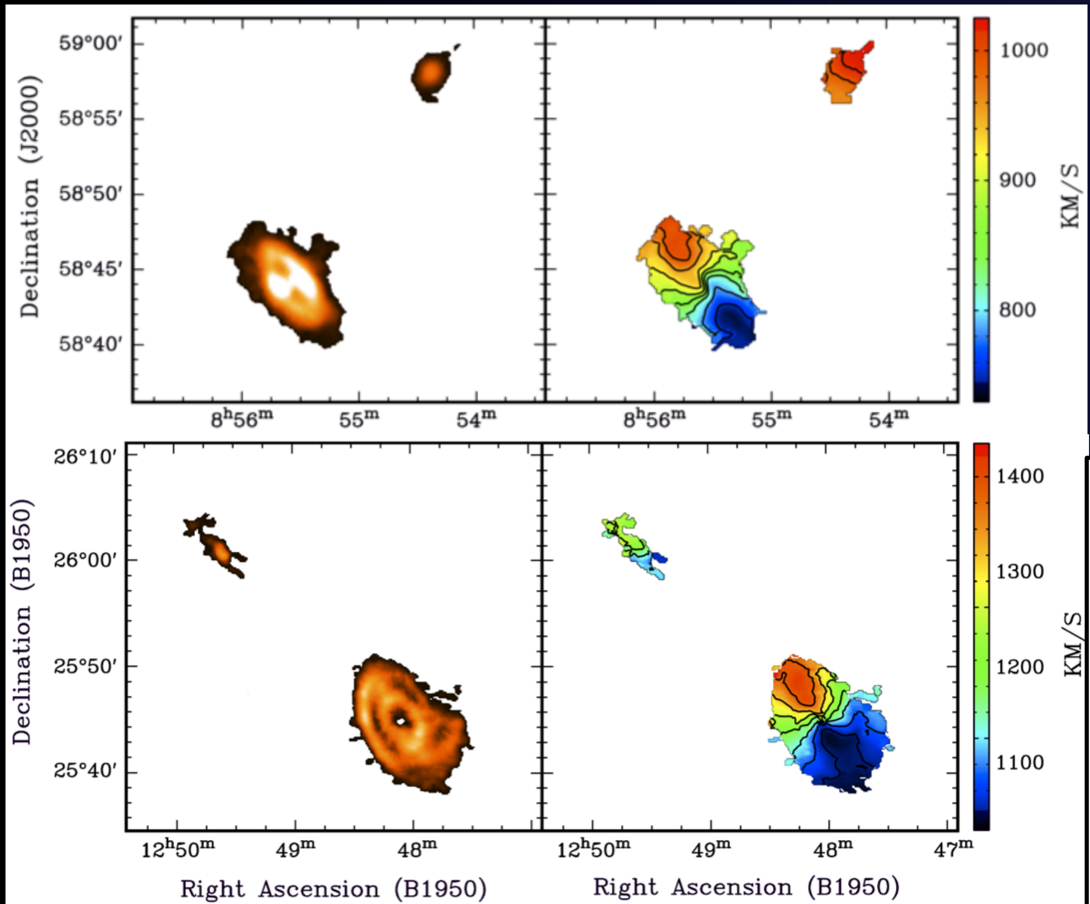
Is this distinguishable from satellite accretion?

Ostriker & Binney 1989, Jiang & Binney 1999

Galaxy pairs in HI

WHISP catalogue: ~150 datacubes

Algorithm identifies main galaxies & satellites

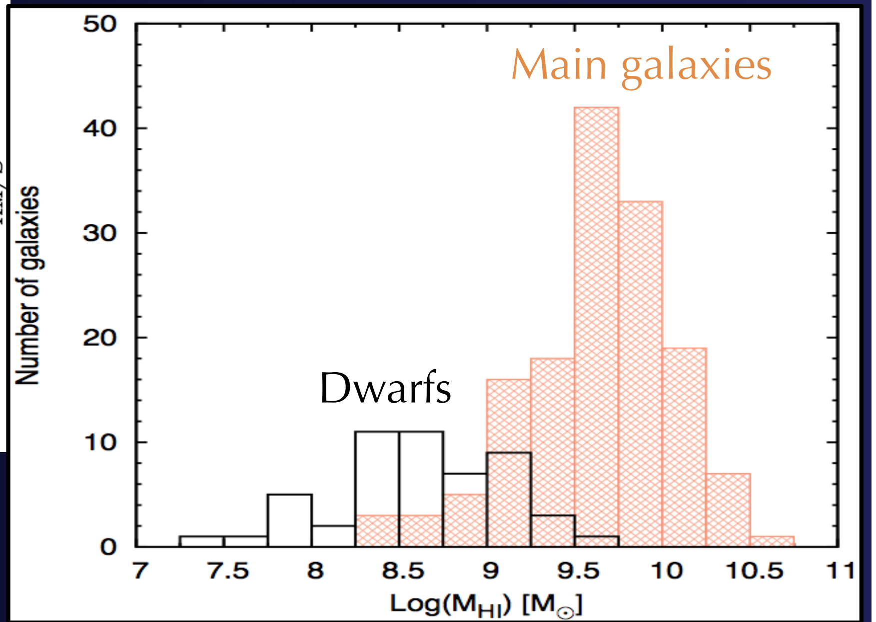


Di Teodoro & Fraternali, A&A, submitted

21% have dwarf companions

47 dwarfs: 40 already known, 7 new

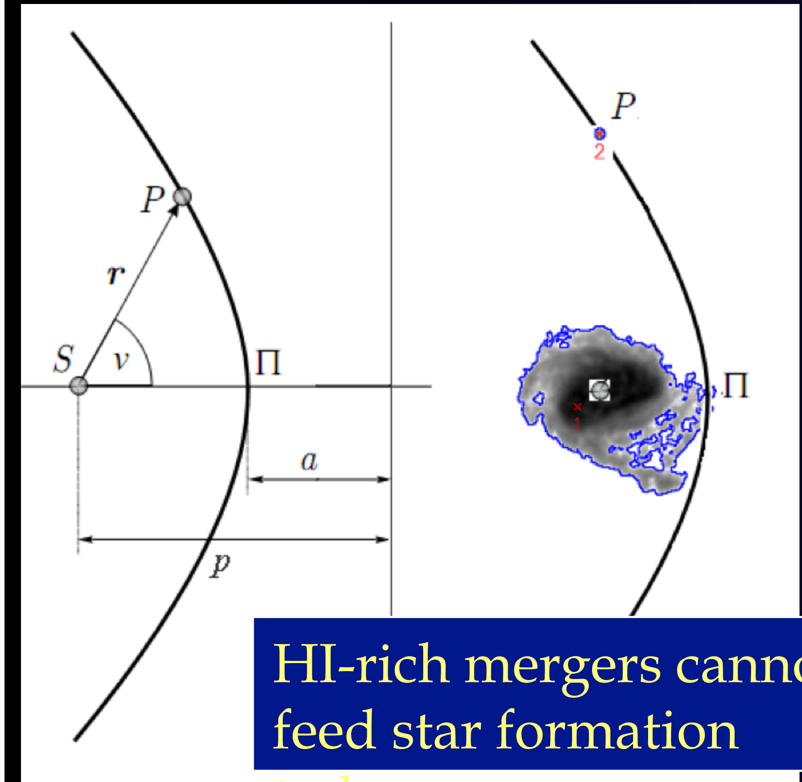
All with optical counterparts



Accretion from minor mergers (revisited)

Very conservative assumption:
all satellites merge in the shortest time possible

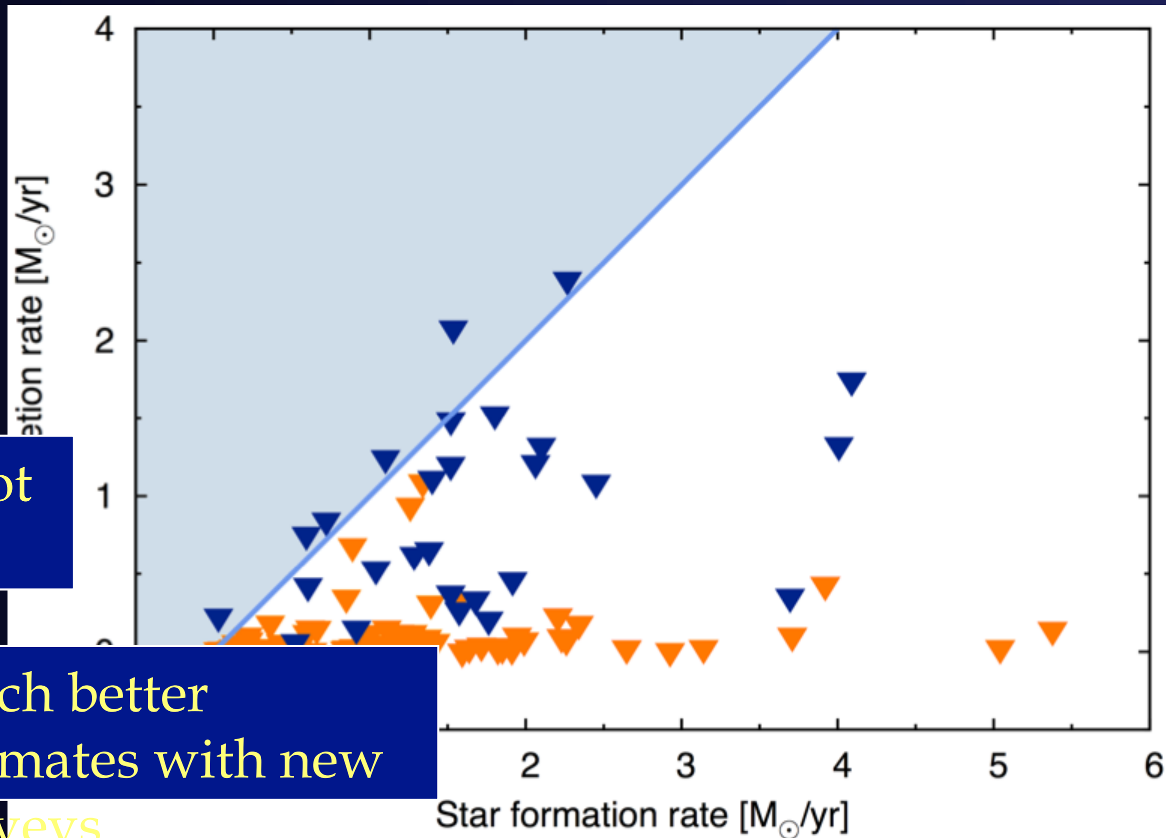
→ Upper limit to accretion << 0.23 $M_\odot$/yr



HI-rich mergers cannot feed star formation today

$$\dot{M}_{\rm acc} < M_{\rm HI}/t_{\rm min}$$

Compare to average SFR = 1.35 $M_\odot$/yr



Much better estimates with new surveys

Di Teodoro & Fraternali, A&A, submitted