How can star formation be sustained?

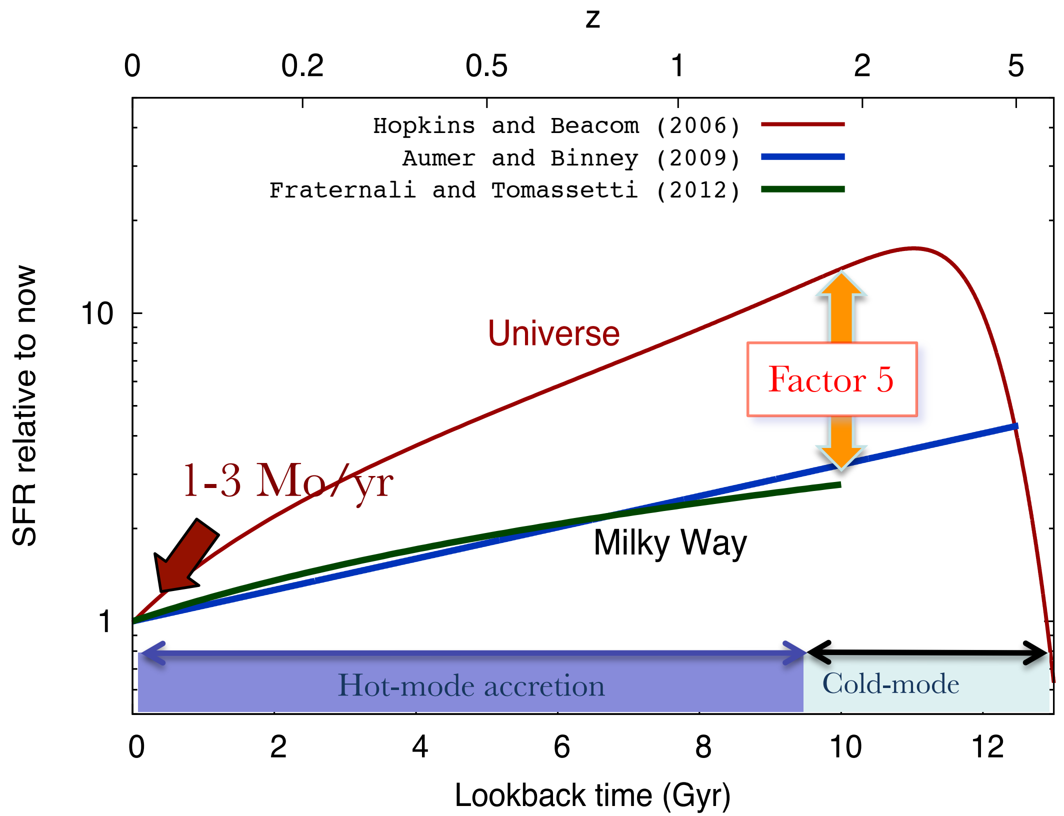
Filippo Fraternali

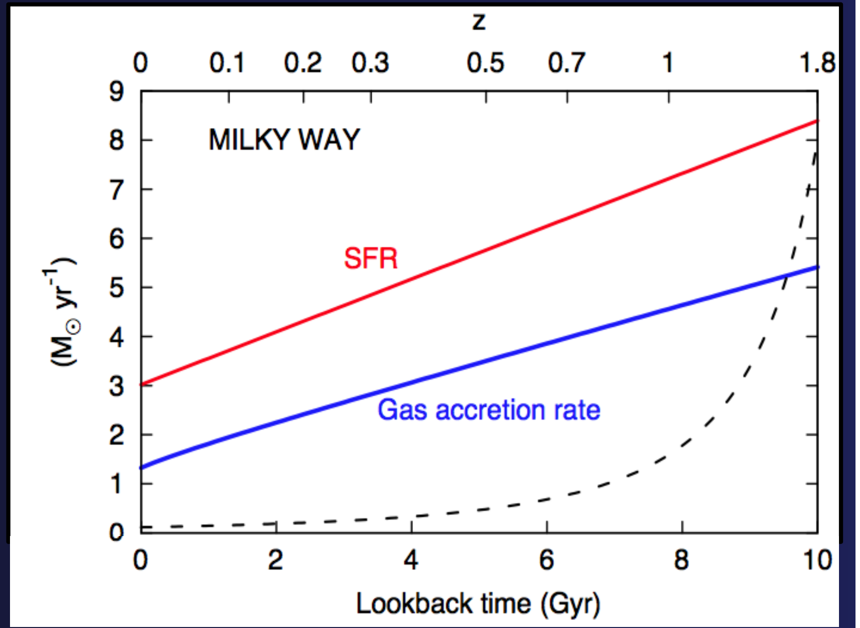
Department of Physics and Astronomy, University of Bologna, I
Kapteyn Institute, University of Groningen, NL

The case for gas accretion

SFH MW vs Universe

The Milky Way





Fraternali & Tomassetti 2012, MNRAS

Need for continuous accretion of cold gas at $\sim 1\ M_\odot/yr$

Disc evolution models

Chemical evolution models
(e.g., Larson 1972, Tinsley 80, Boissier & Pranzos 1999, Matteucci 2003, Chiappini+ 97, 01, Spitoni & Matteucci 2011, Colavitti+ 2008)

Need for accretion of gas with Z < 0.1 $Z_{\odot}$
(e.g., Tosi 88)

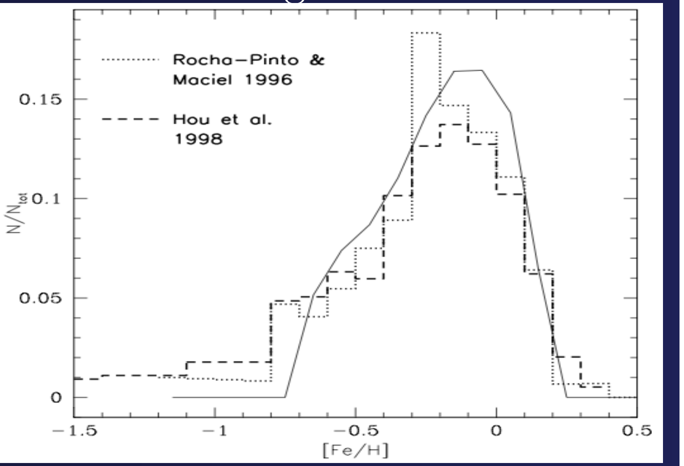
Importance of stellar migration
(Schoenrich & Binney 2009)

Conservation of angular momentum
(Bilitewski & Schoenrich 2012)

→ Gas accretion is a parameter

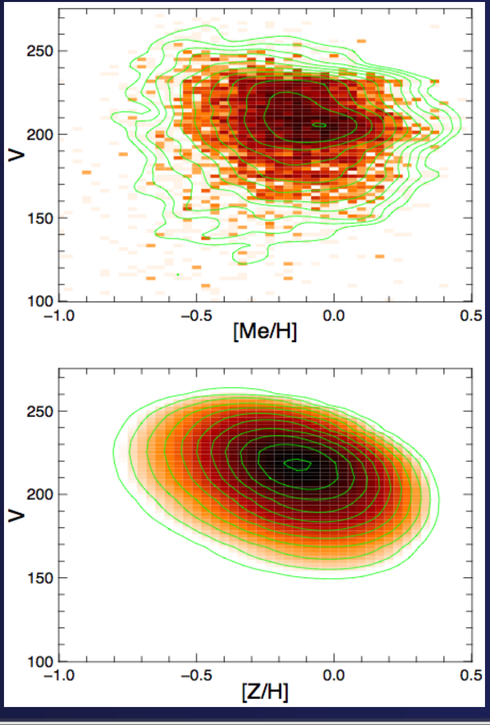
Z of Solar neighborhood stars

Chiappini et al. 2001



Z vs kinematics of stars

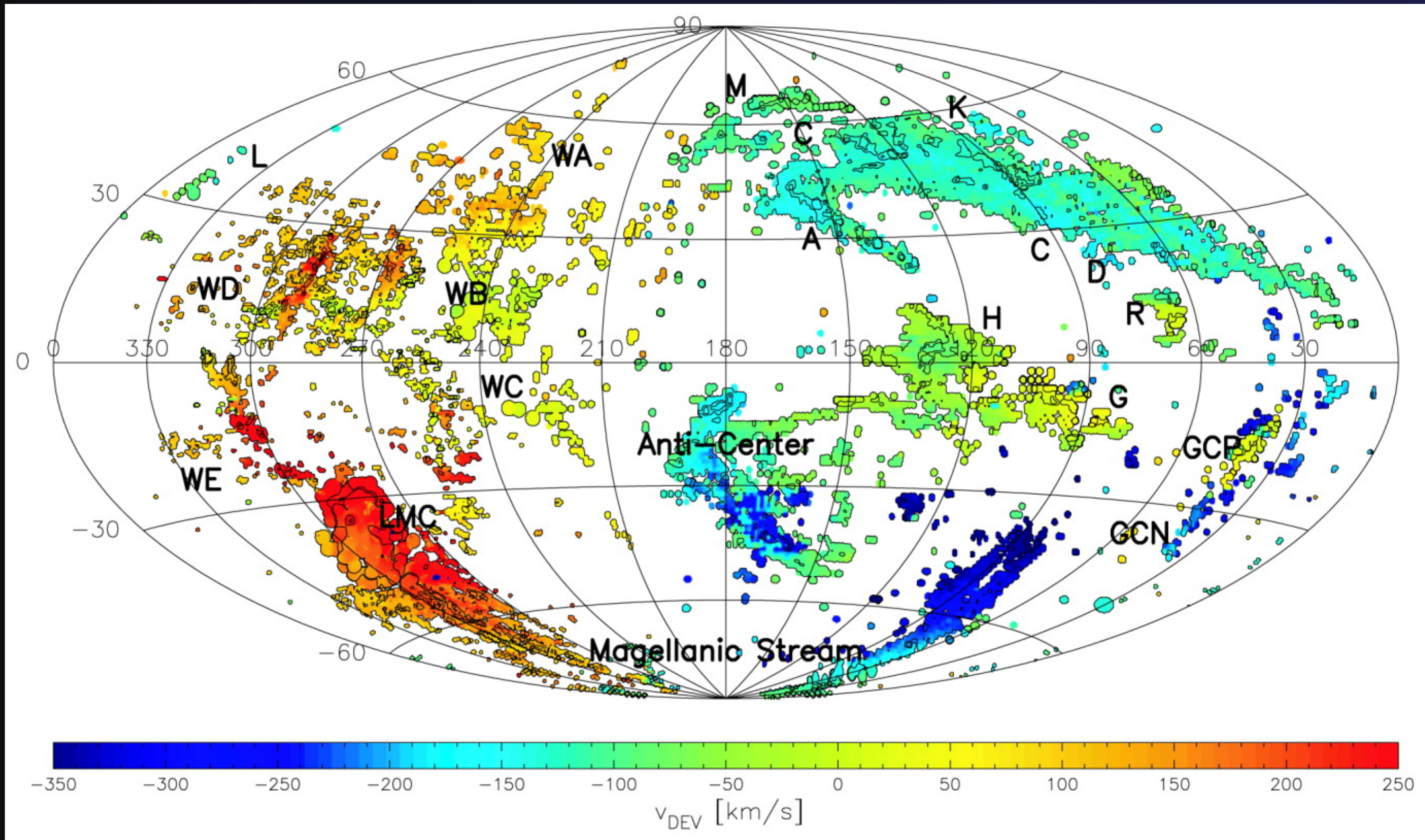
Schoenrich & Binney 2009



Inventory of gas accretion

1. High Velocity Clouds

HI High Velocity Clouds



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

Typical Distances: ~10 kpc

h~few-10 kpc

Z~0.1-0.4 $Z_\odot$

M<10^7 $M_\odot$

Accretion from High Velocity Clouds

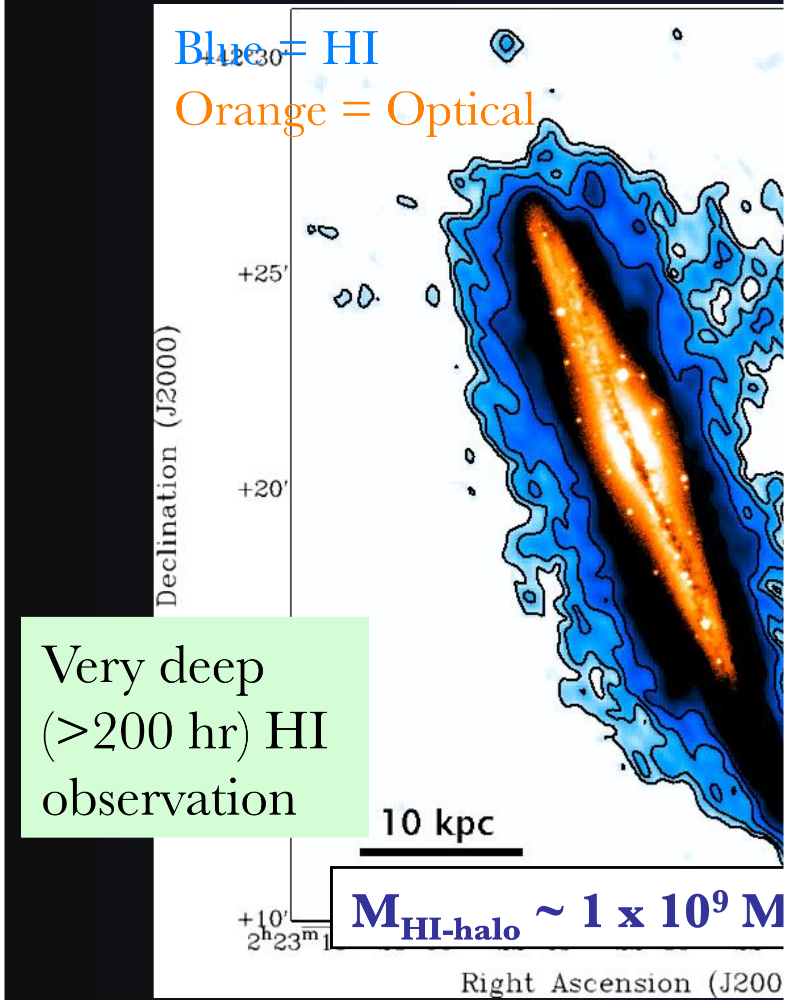
~ 0.08 $M_\odot$/yr

Putman, Peek, Joung 2012 ARA&A

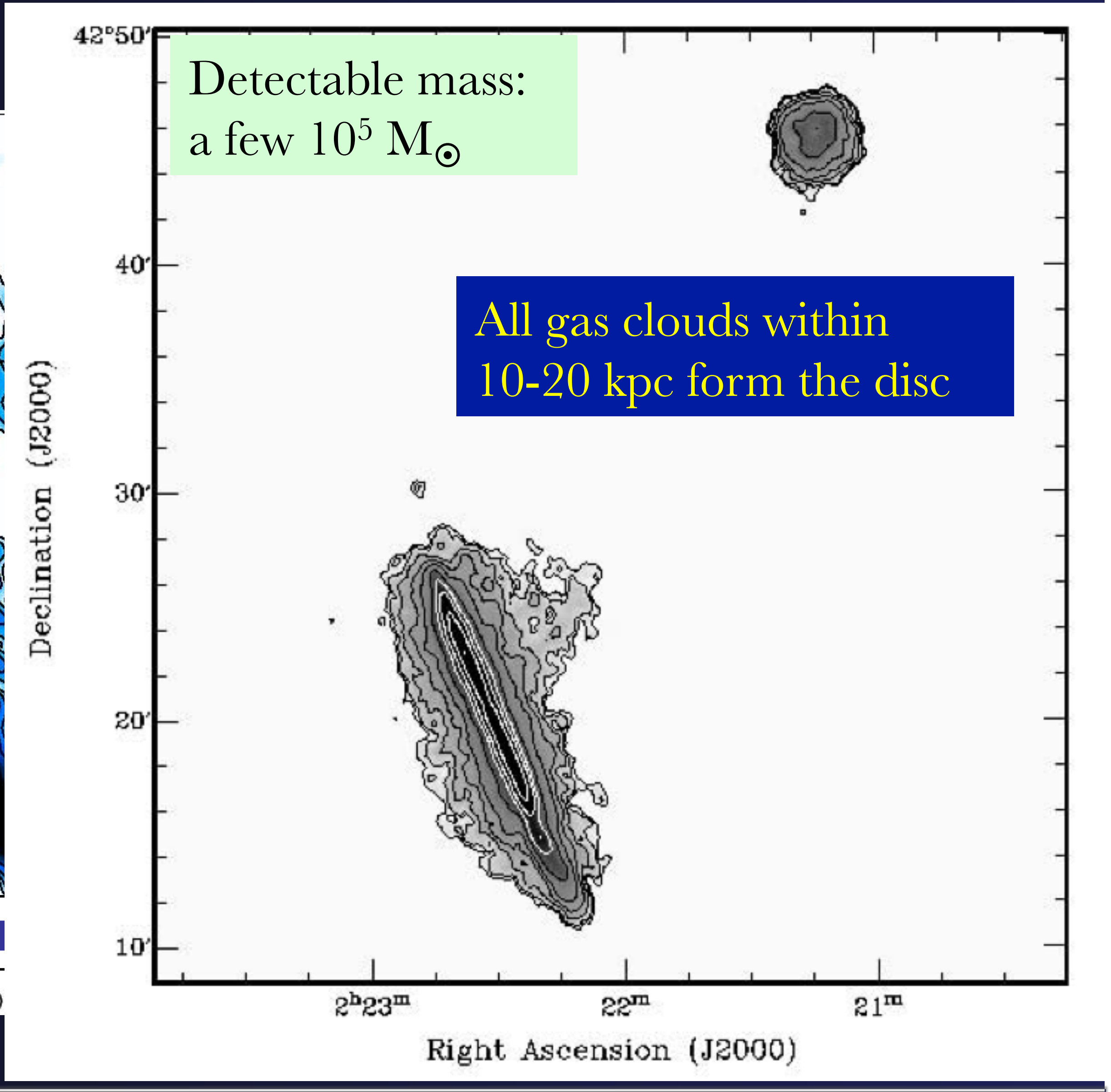
Includes He and factor 2 of ionised gas!

NGC 891: Halo gas and clouds

Extreme case



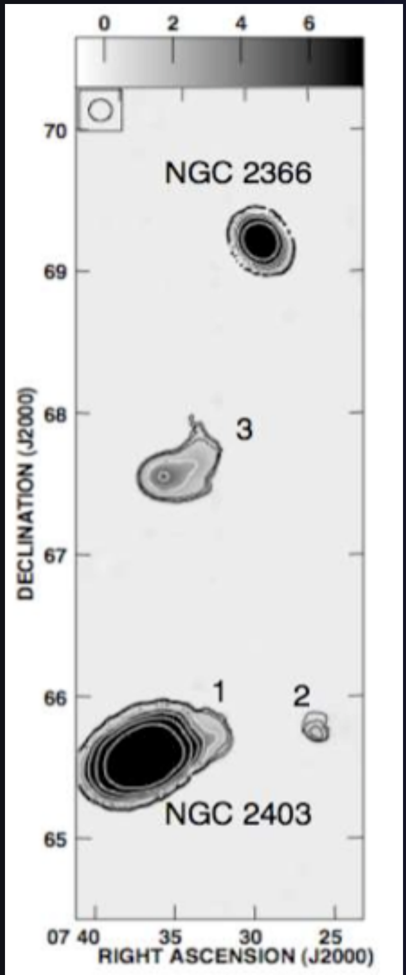
Oosterloo, Fraternali, Sancisi 2007



Single dish: NO floating HI clouds

Deep observations of galaxy groups

e.g. Pisano et al. 2004, Chynoweth et al. 2009



NO clouds of M_{HI} >~10^6 $M_\odot$

NO floating HI clouds away from galaxies with $M_{HI} > 10^6$ $M_\odot$

Large blind HI surveys

HIPASS - *Zwaan et al. 2005*

NO *isolated* HI clouds

WSRT - *Kovac et al. 2009*

Small region

No clouds down to 10^6 $M_\odot$

ALFALFA - *Heynes et al. 2011*

30000 detections

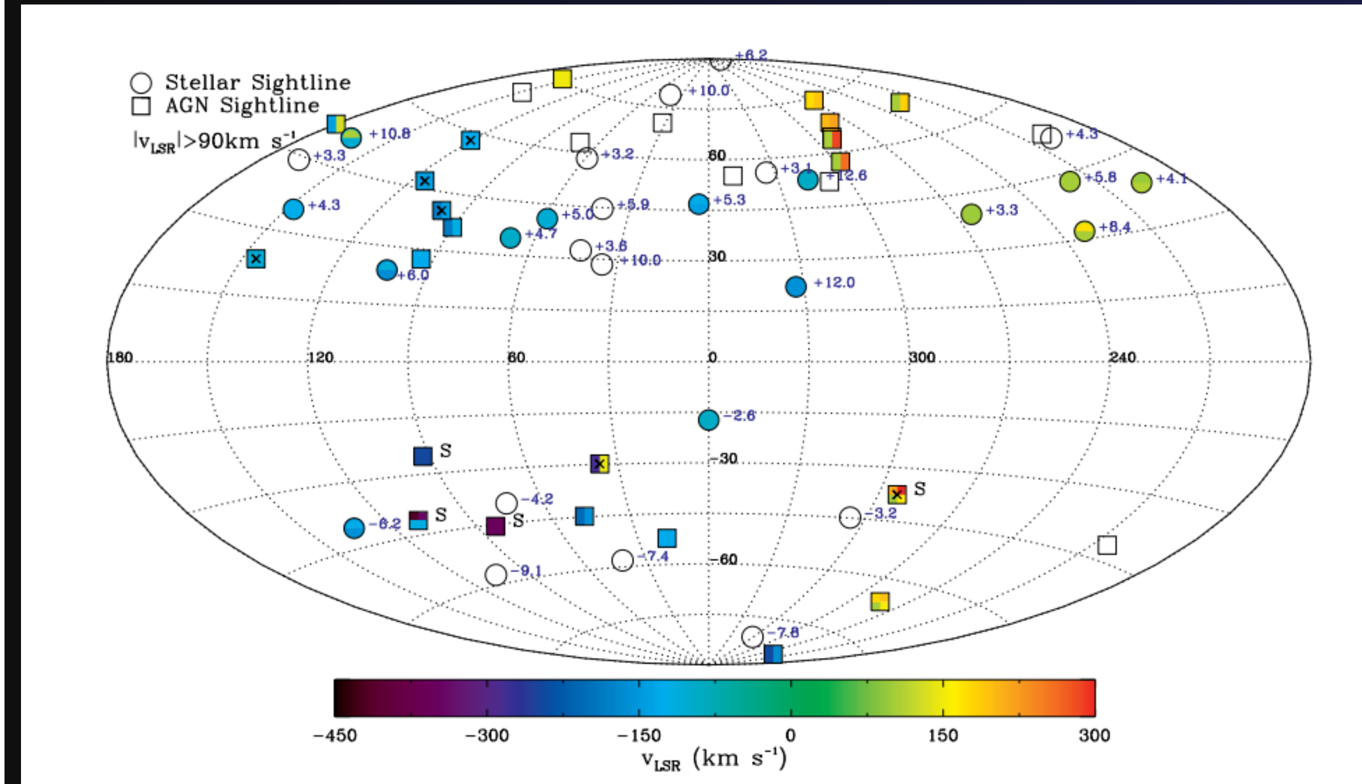
<2% of detections

without optical counterpart

Ionised HVCs

Highly Ionised species seen in absorption towards AGNs and halo stars

C II, Si II, Si III, …   logT ~ 4.5-5



HST and FUSE data

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

Distances known only for a subsample: *a few kpc*

Accretion from ionised HVCs

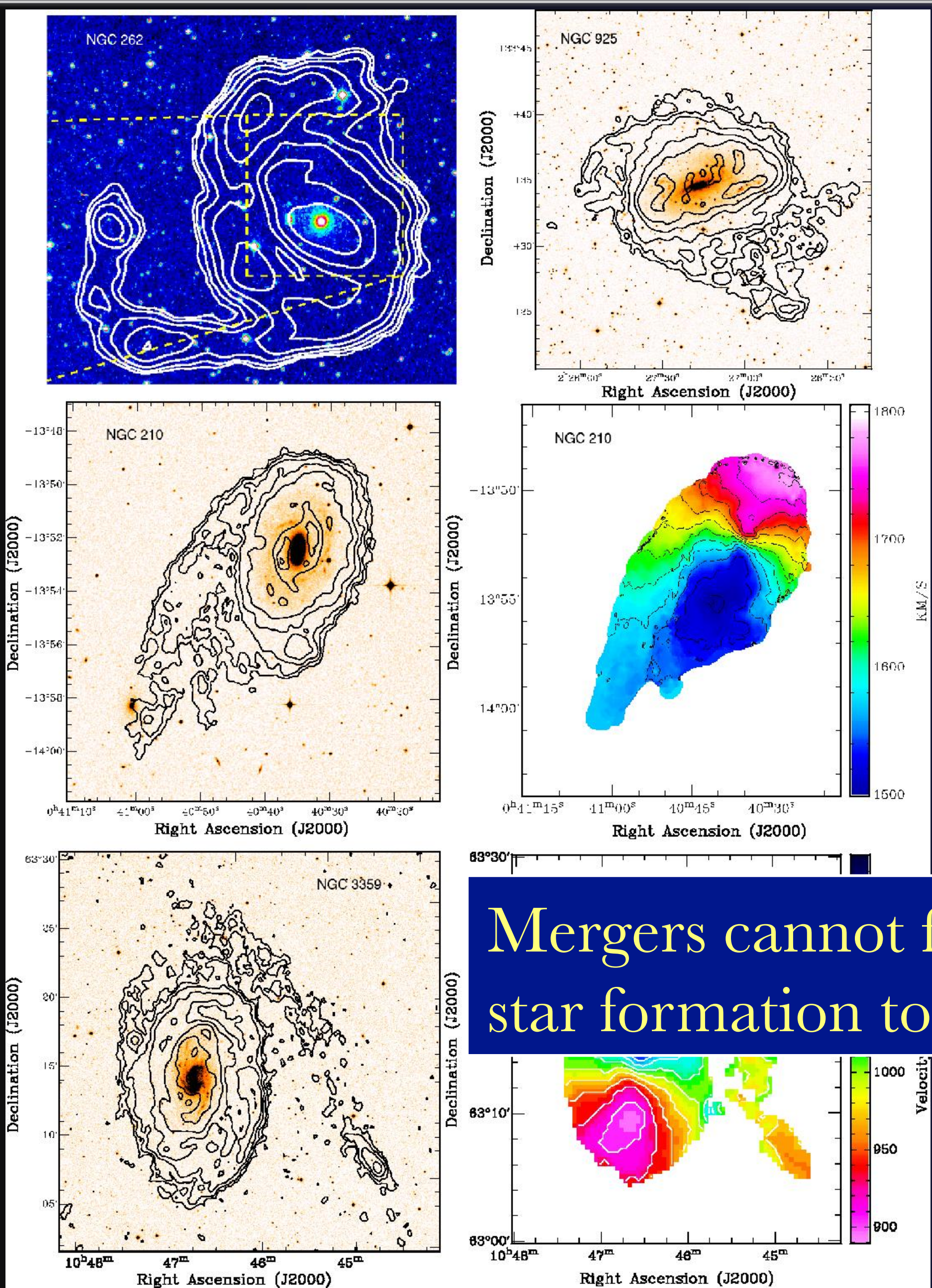
→ $\sim 1\ M_\odot/yr$

Quite uncertain estimate
Origin?

Inventory of gas accretion

2. Minor mergers

Accretion from minor mergers



Sancisi et al. 2008, A&ARv

Mergers cannot feed star formation today

Using the WHISP catalogue

Detected in ~25% of galaxies
Masses ~ 1-10 x 10^8 M_O
Life time ~ 1-2 dyn times

→ Global accretion rate ~ 0.1-0.2 $M_\odot$/yr

New estimate with automatic
arch:

→ Firm upper limit < 0.1 $M_\odot$/yr

Di Teodoro & Fraternali, in prep.

Agreement with simulations (e.g., *Keres+ 2009*)

Inventory of gas accretion

3. IGM: cosmological corona

The missing baryon corona

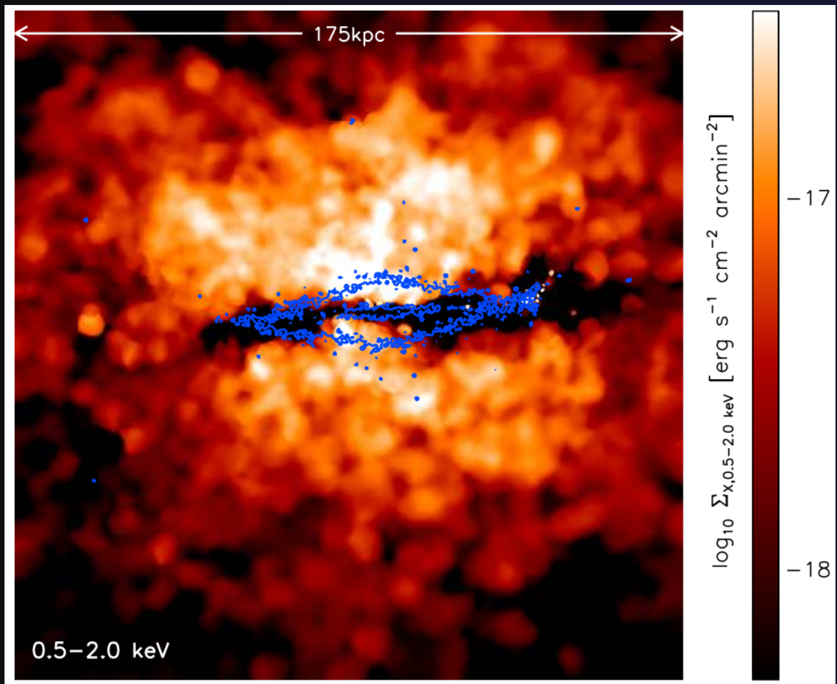
$$M_{\rm vir} \sim 2 \times 10^{12} M_\odot \xrightarrow{\frac{\Omega_{\rm b}}{\Omega_{\rm m}} = 0.17} M_{\rm b} \simeq 3.4 \times 10^{11} M_\odot$$

$$M_{*,\rm disc} \sim 5 \times 10^{10} M_\odot$$

$$M_{\rm cold\ gas} \sim 6 \times 10^{9} M_\odot$$

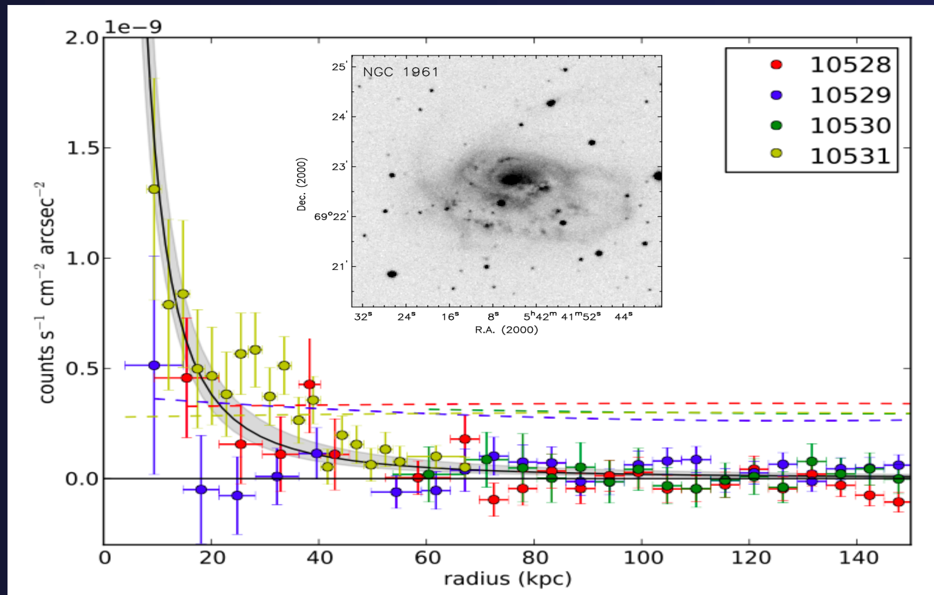
$$M_{\rm missing} \sim 2.8 \times 10^{11} M_\odot$$

Cosmological hydro simulation



Crain et al. 2010, MNRAS

X-ray observations



Anderson & Bregman 2011

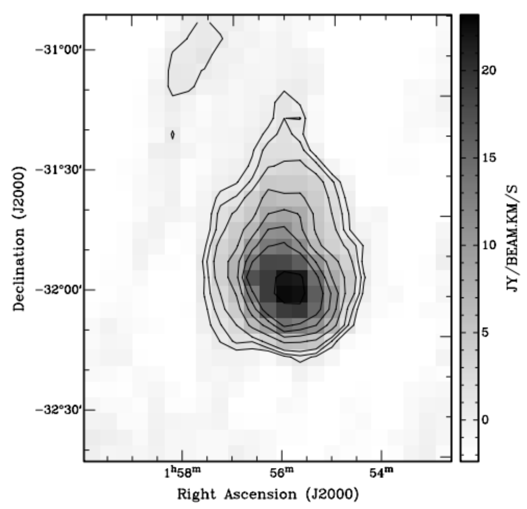
Only 10-20% of the missing baryons

The Milky Way's corona

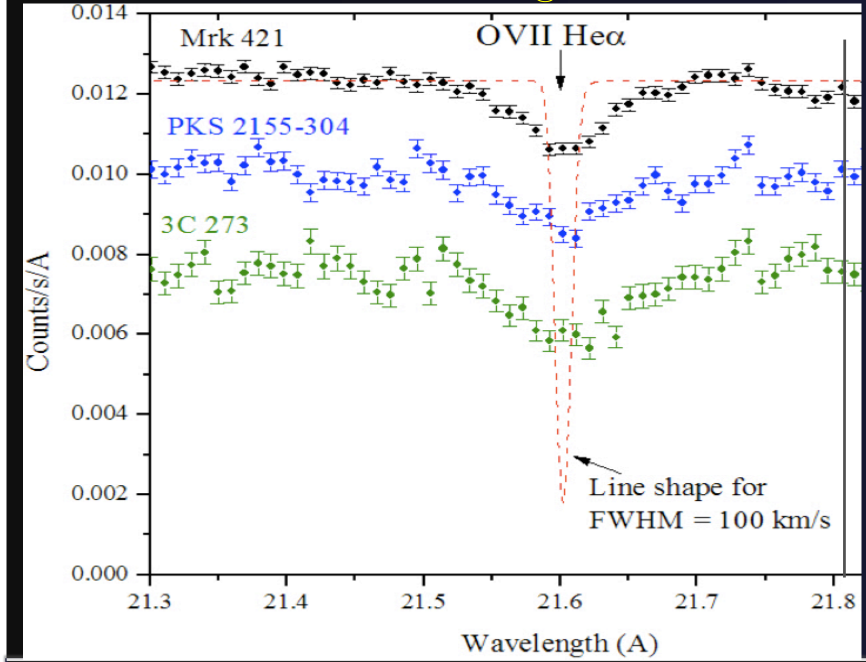
Indirect probes:

- Confinement of HVCs
- Cooling species: e.g. OVI, Si III, C IV
- Segregation of dSphs/dIrrs
- Head-tail shape of HVCs
- Asymmetry of the MS

Putman et al. 2011, MNRAS



Observations: OVII logT ~ 6

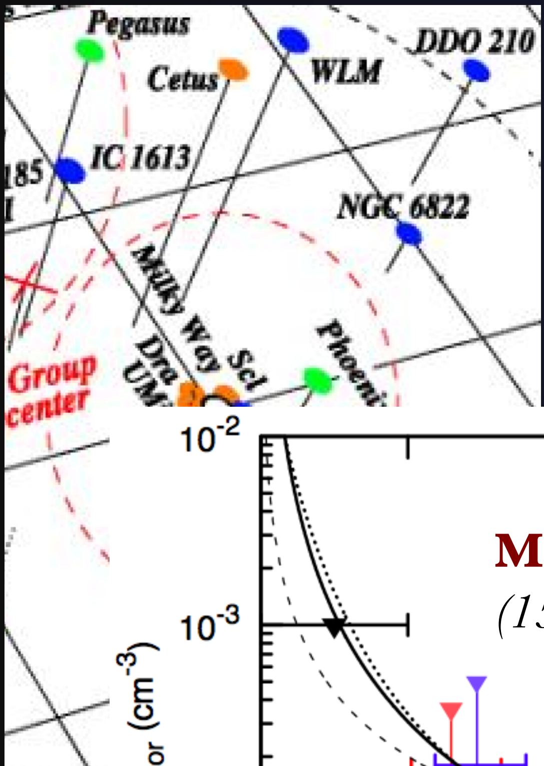


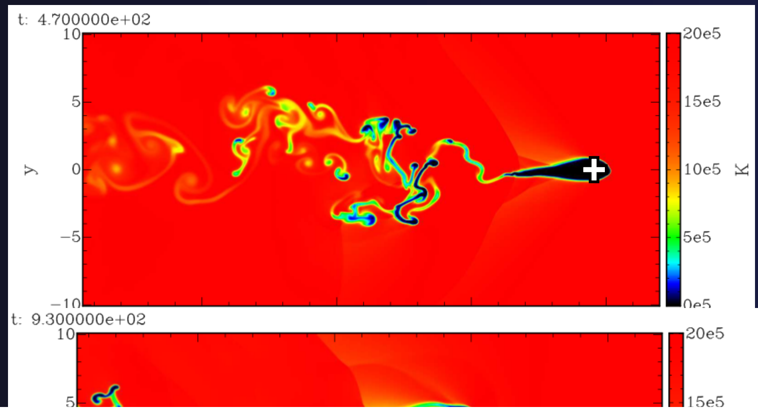
Controversial…

- ~1 Mpc → LG *Nicastro+ 02*
- >140 kpc → LG *Rasmussen+ 03*
- 15-100 kpc → corona *Bregman & Lloyd-Davies 07*
- ~2 kpc → thickDisk *Yao+ 08*

- corona: up 100% missing baryons *Gupta+ 12*
- corona: 10-50% missing baryons *Miller & Bregman 13*

The Milky Way's corona

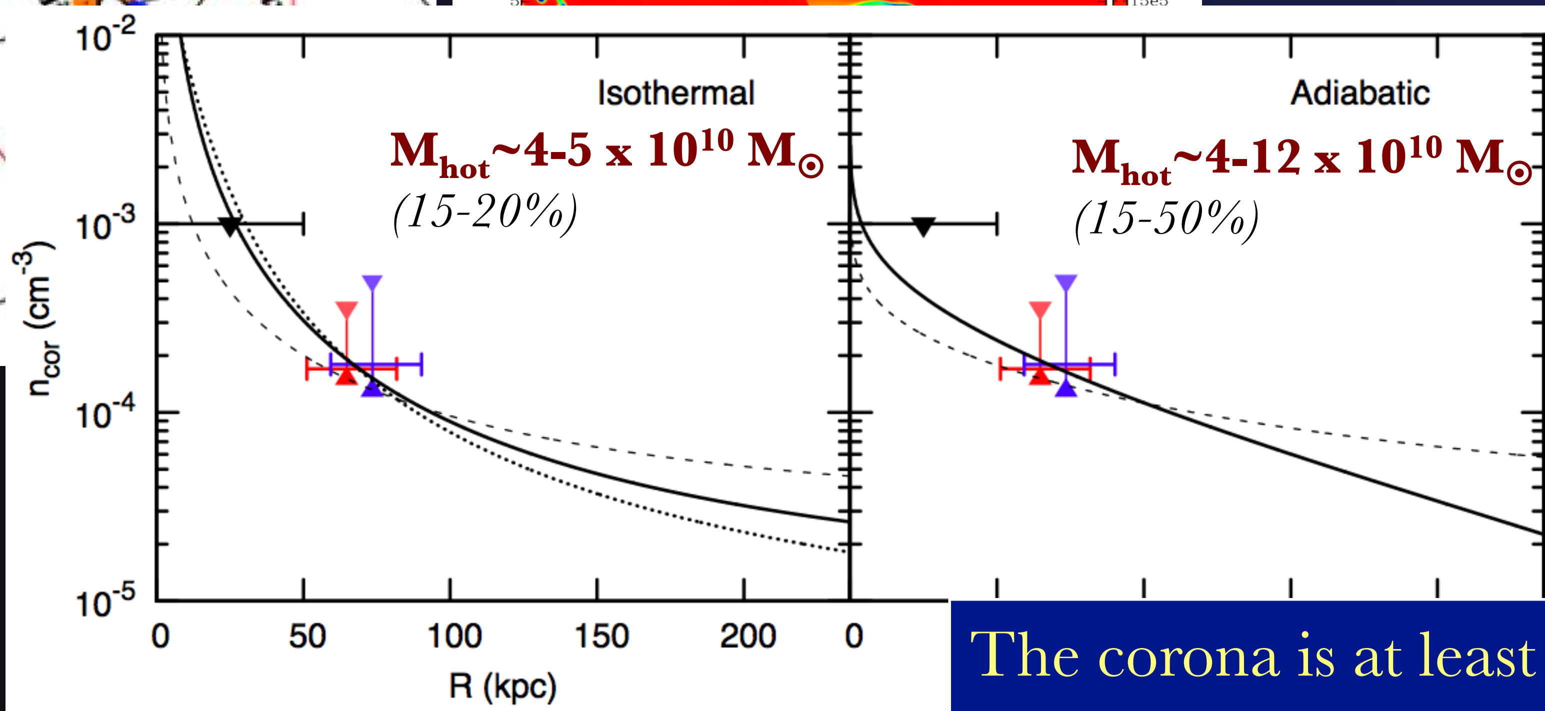




Gatto, Fraternali et al. 2013, MNRAS, in press

Gas lost by ram pressure stripping

n(50-90 kpc) ~ 2-3 $\times 10^{-4}$ cm^{-3}



M_{hot}~4-5 x 10^{10} $M_\odot$
(15-20%)

M_{hot}~4-12 x 10^{10} $M_\odot$
(15-50%)

The corona is at least as massive as the stellar disc!

Summary so far

1. Accretion needed ~ 1 $M_{\odot}$/yr
2. HI HVCs < 0.1 $M_{\odot}$/yr

   Minor mergers < 0.1 $M_{\odot}$/yr
3. Only possible reservoir: cosmological corona

Problem: how does it cool?

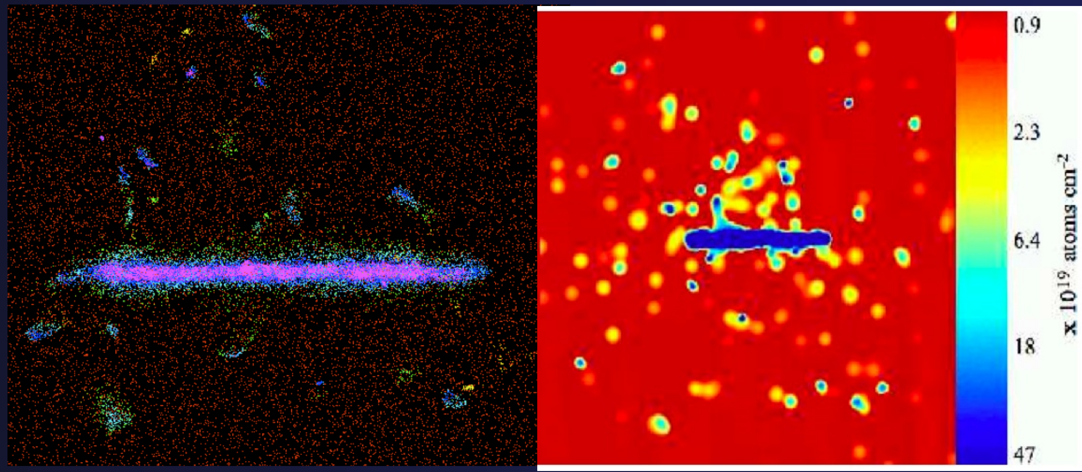
Cooling of the hot corona

1. spontaneous

How does the corona cool?

Thermal instability?

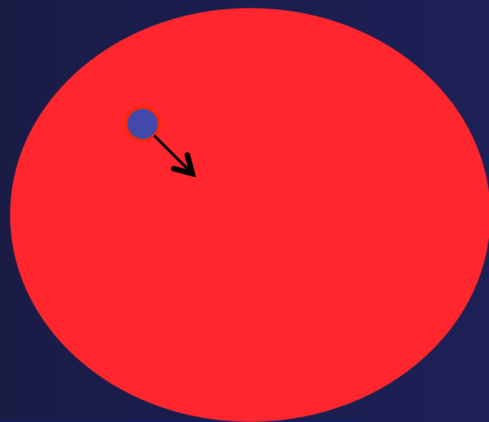
Maller & Bullock 2004, ApJ
Kaufmann et al. 2006, MNRAS
Peek, Putman & Sommer-Larsen, 2008, ApJ
Kaufmann et al. 2009, MNRAS



NO! Perturbations do not grow

Malagoli et al. 1987, ApJ — definition of the theory
Binney, Nipoti & Fraternali 2009, MNRAS — linear, non-rotating coronae
Nipoti 2010, MNRAS — linear, rotating coronae

Overdense regions move to equilibrium location faster than the instability can grow



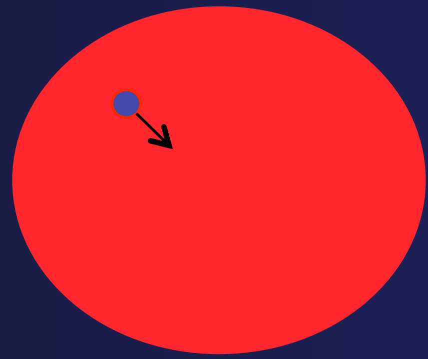
Coronae do not cool via thermal instability

AMR simulations

Joung, Bryan & Putman 2011, ApJ

AMR simulations -> NO growth of linear perturbations

-> only non-linear ones can grow

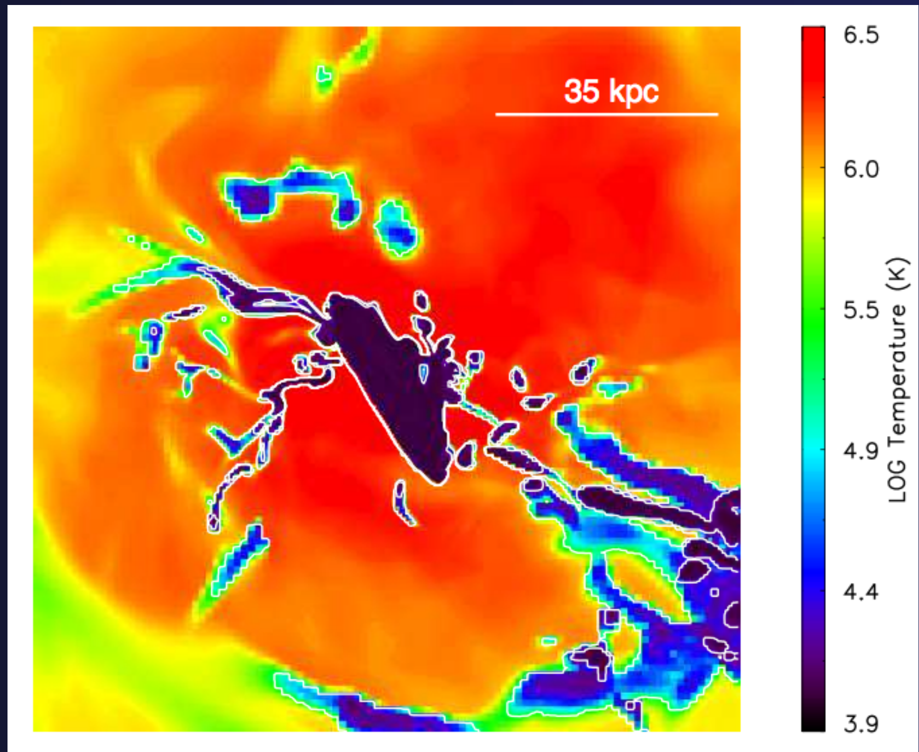


Fernandez, Joung, & Putman 2012, ApJ

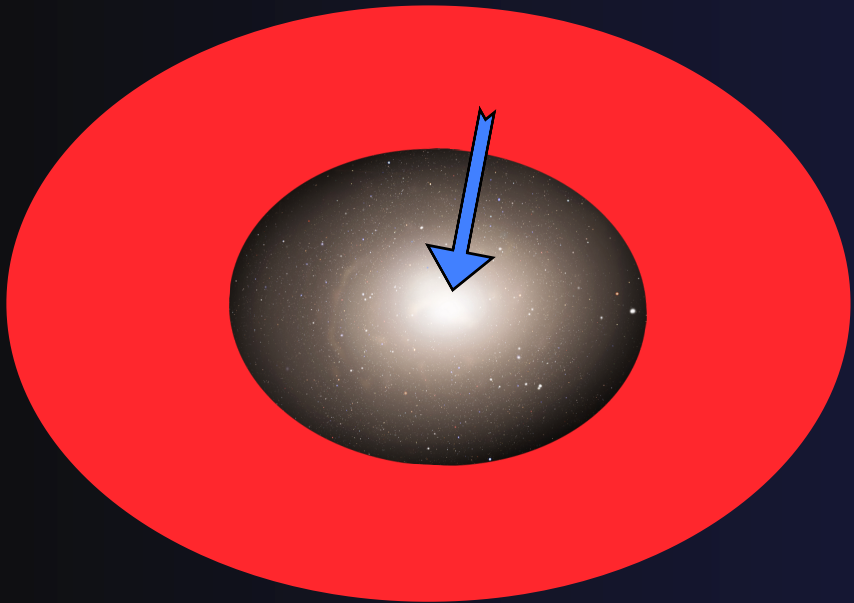
Cold stream penetrate the corona

HI accretion rate: 0.2 $M_{\odot}$/yr

BUT large amount of ionised gas



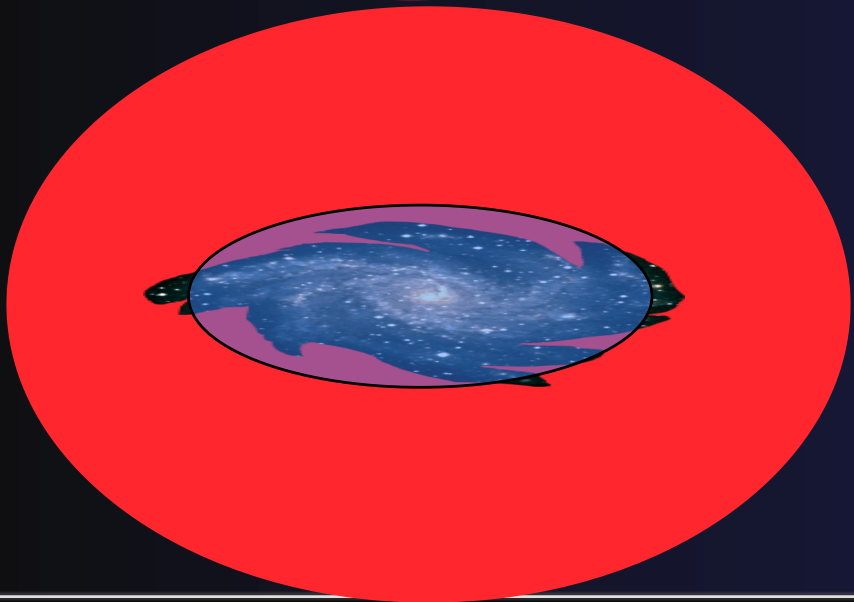
Why do early types have no cold gas?



Where are the streams?

In early types the WHIM corona cools in the very centre (high density, low t_{cool})

-> feeds BH, NOT star formation



INSTEAD in disc galaxies it cools:

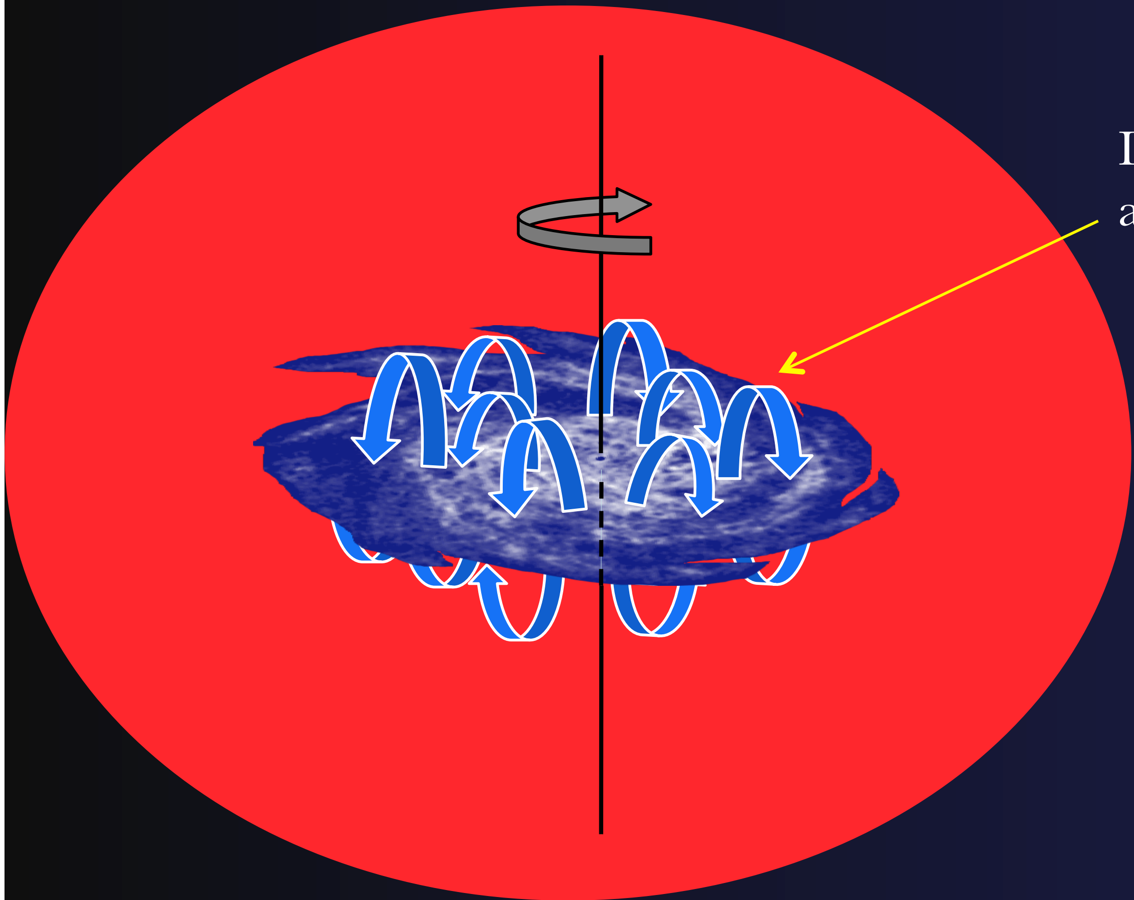
1. All over the disc
2. Not too far above the disc

Cooling of the hot corona

2. disc-corona interaction

(James Binney, Antonino Marasco, Federico Marinacci)

Interplay between disc and corona



Interface layer where disc and coronal materials mix

Cooling time of the corona (typically very long) decreases dramatically because mixed with:

1. *cold* gas
2. High Z gas

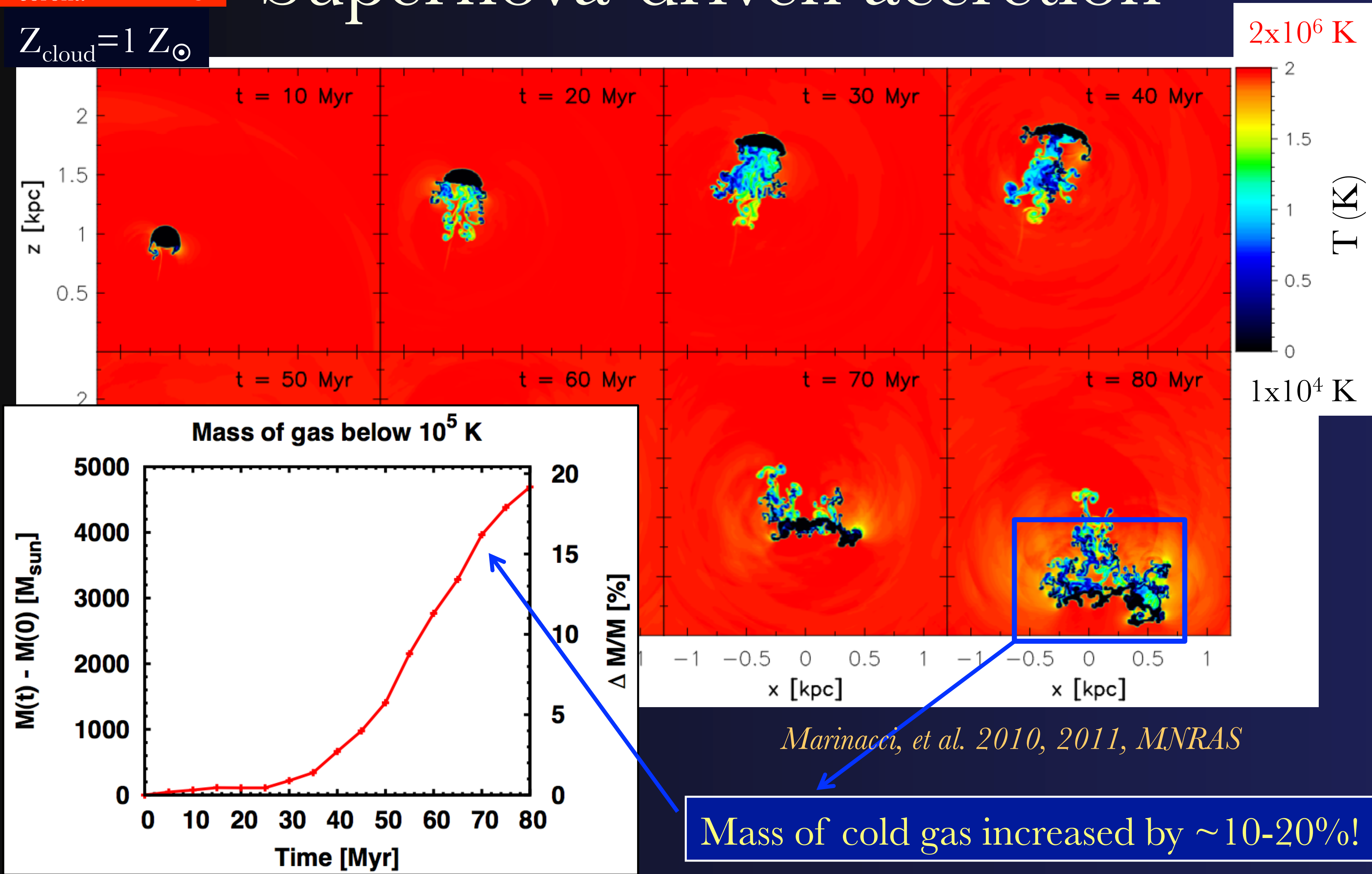
Galactic fountain models

Shapiro & Field 1976, Bregman 1980, Houck & Bregman 1990, Collins et al. 2002, Fraternali & Binney 2006/08, Melioli et al. 2008/09

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

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

Supernova-driven accretion

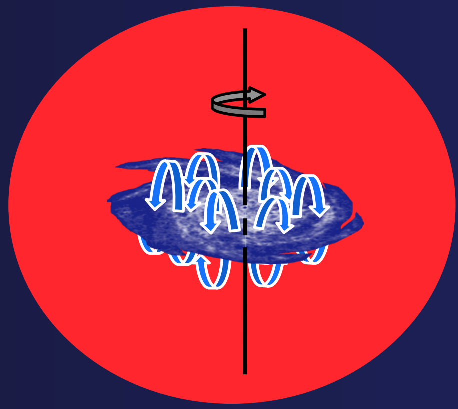


Marinacci, et al. 2010, 2011, MNRAS

Mass of cold gas increased by ~10-20%!

Supernova-driven accretion in the Milky Way

Global fountain model

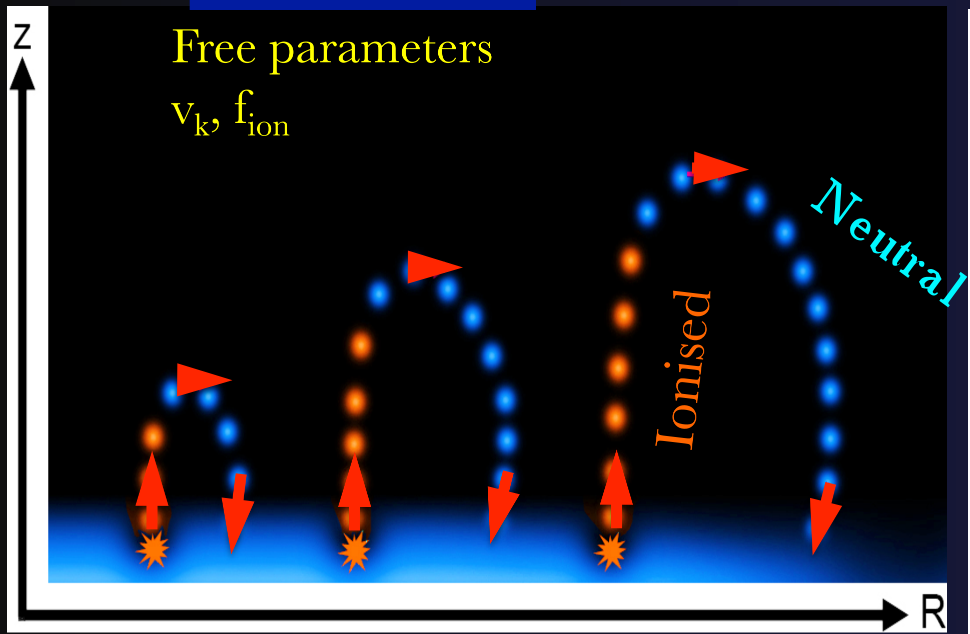


Corona lags with respect to cold gas by 75 km/s
Building of several model cubes -> minimization residuals with LAB

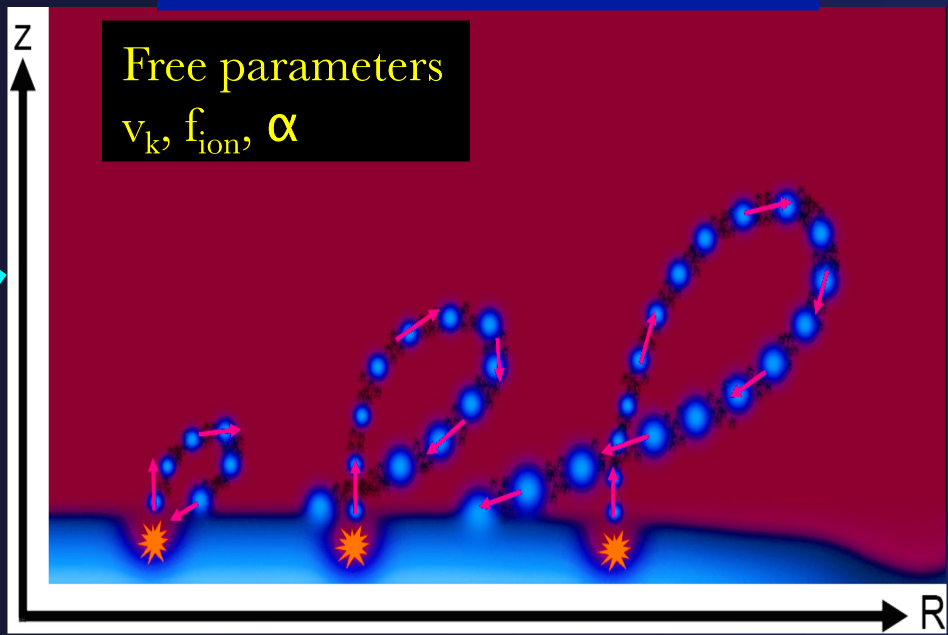
We fit:
1. kick velocities (v_k) → scaleheight
2. Ionised fraction (f_{ion}) → vertical motions
3. Accretion coefficient (α) → radial motions

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

Pure fountain

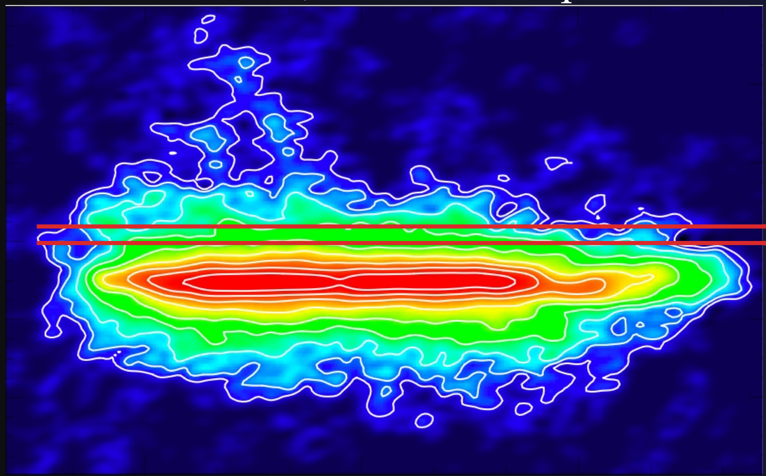


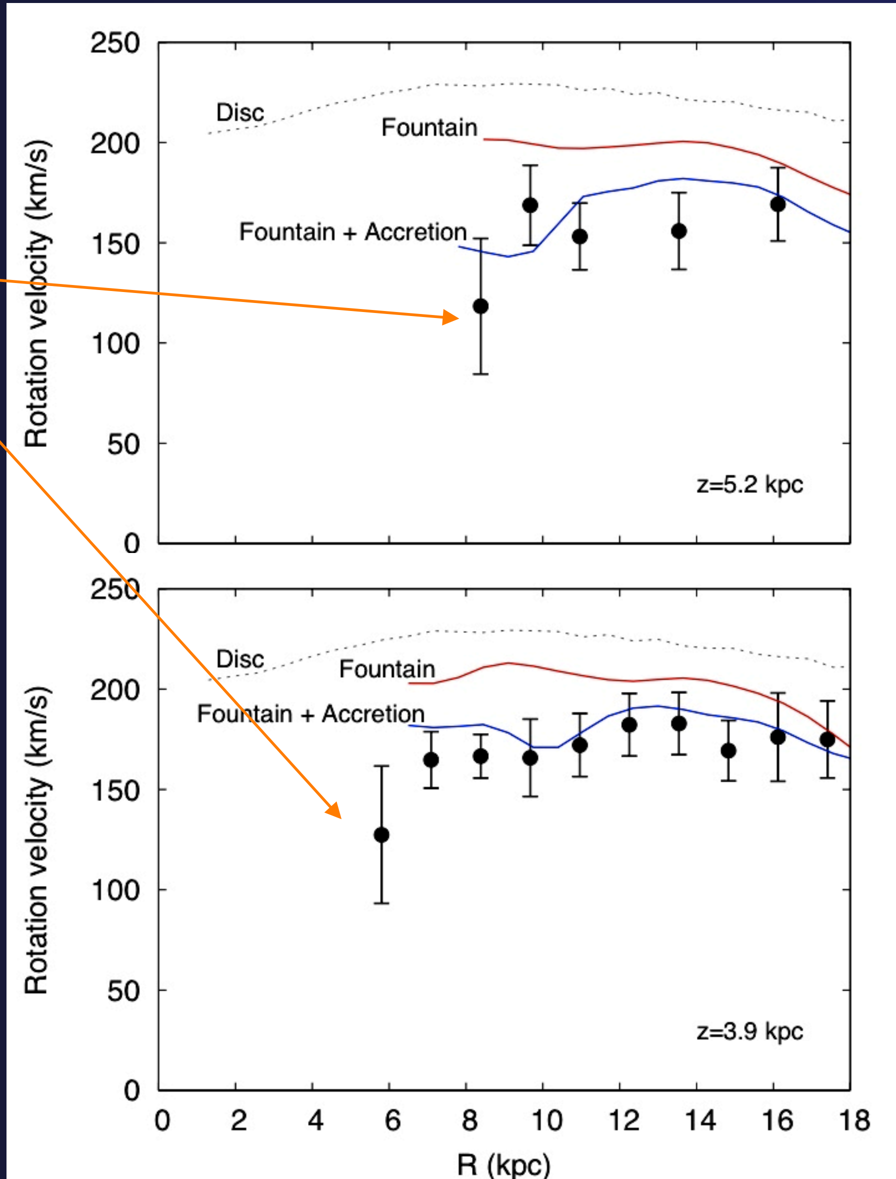
Fountain + condensation



Fountain + condensation: NGC 891

NGC 891, total HI map



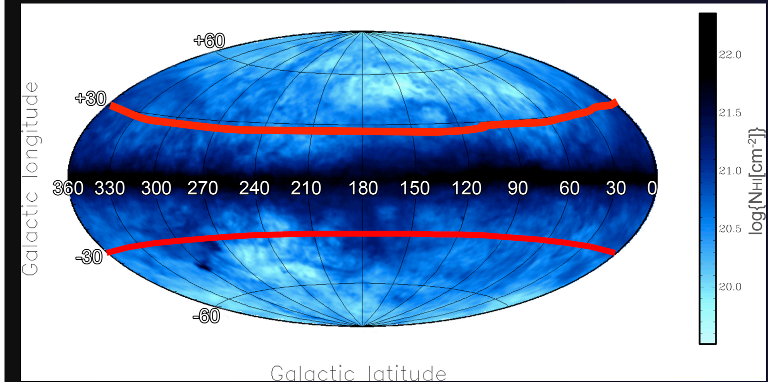


Best-fit Accretion Rate ~ 3 $M_\odot yr^{-1}$

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

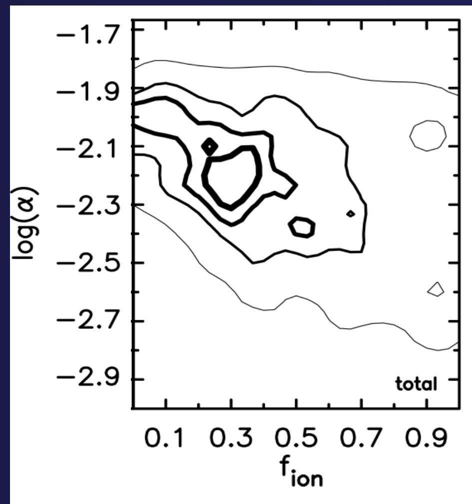
Fraternali & Binney 2008, MNRAS

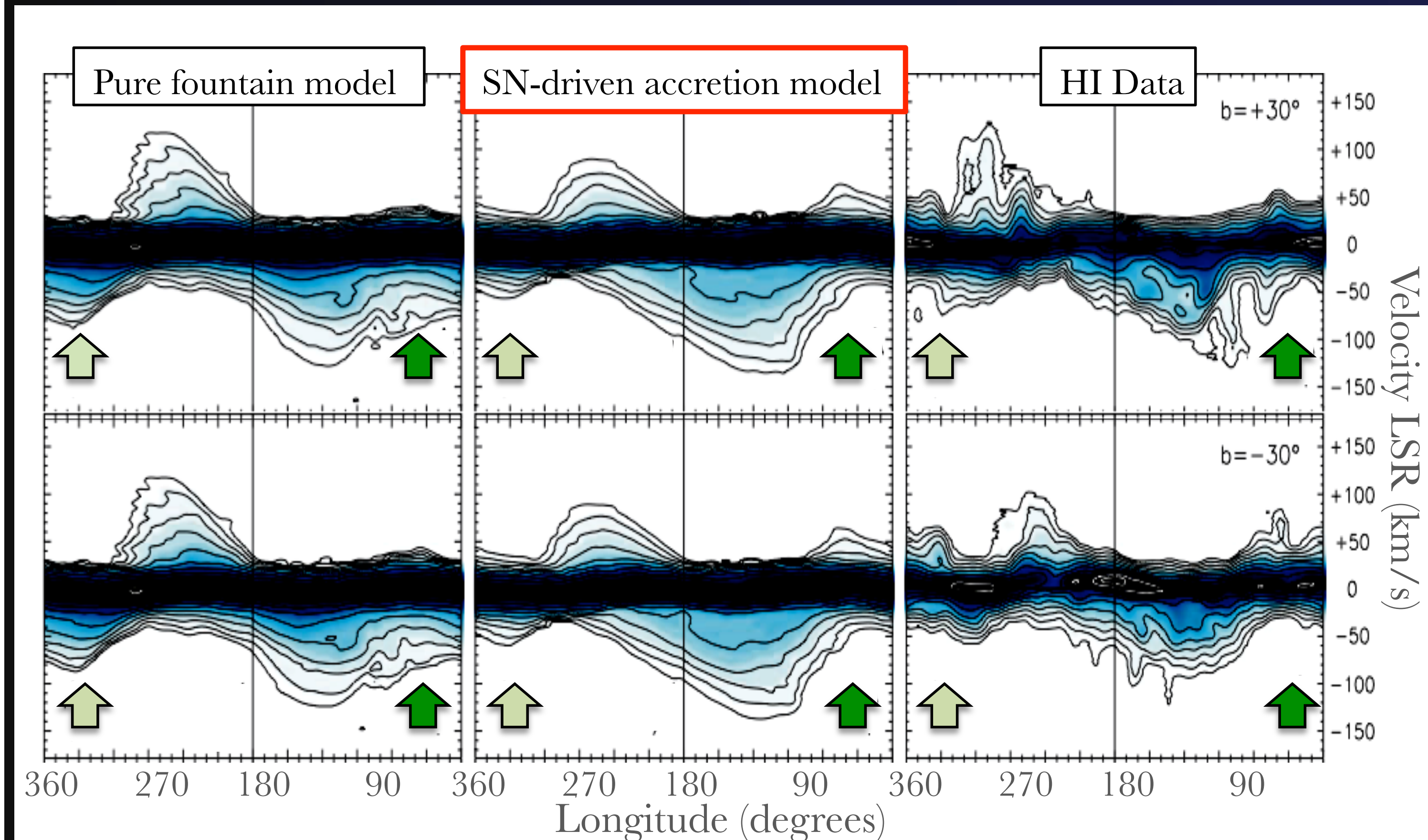
Milky Way's HI halo



Marasco, Fraternali & Binney 2012

Best fit





$v_k = 75$ km/s

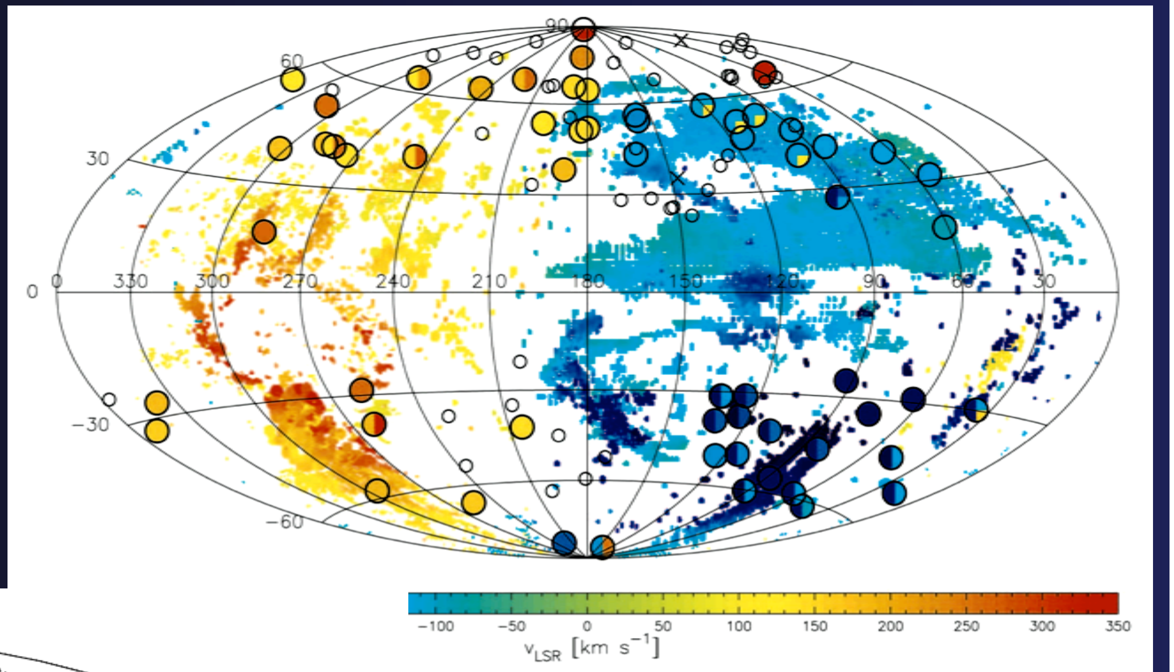
$f_{ion} = 0.3$

$\dot{M}_{cor} \sim 2\ M_\odot/yr$

Supernova-driven cooling

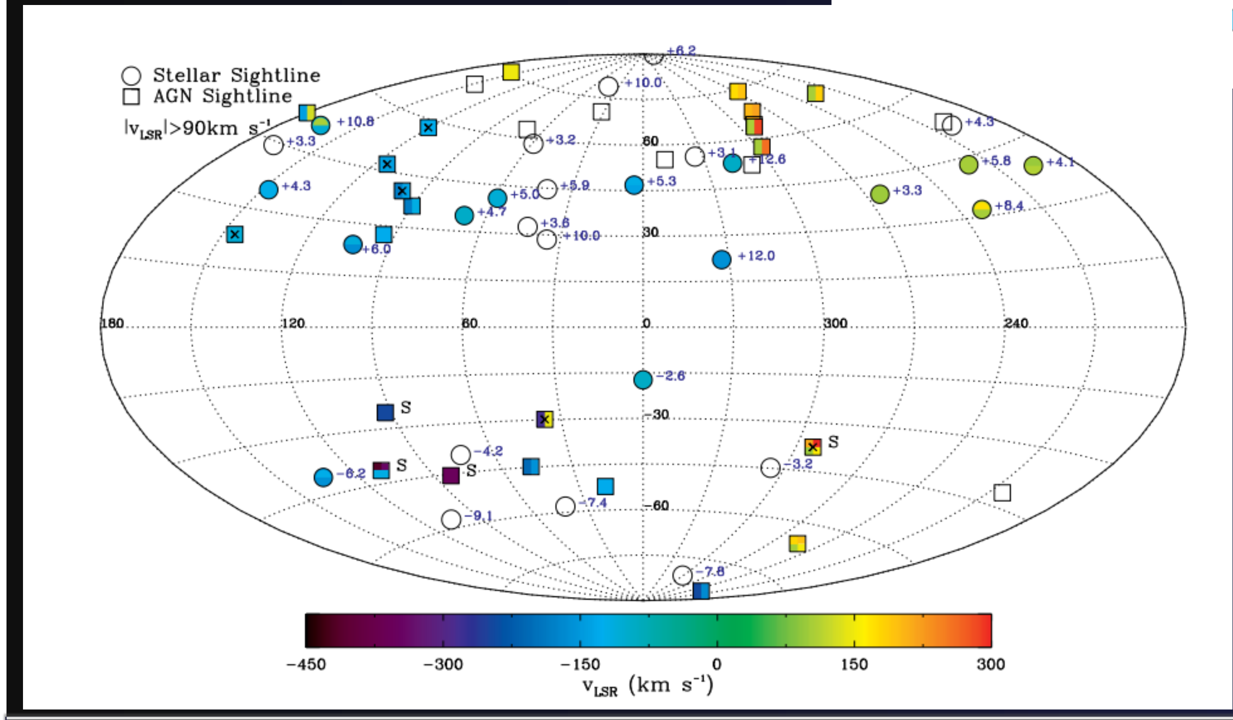
Ionised species

O VI absorptions logT~5.5 K



Sembach+ 2003, ApJ

C II, Si II, Si III, … 4.3<logT<5.3 K

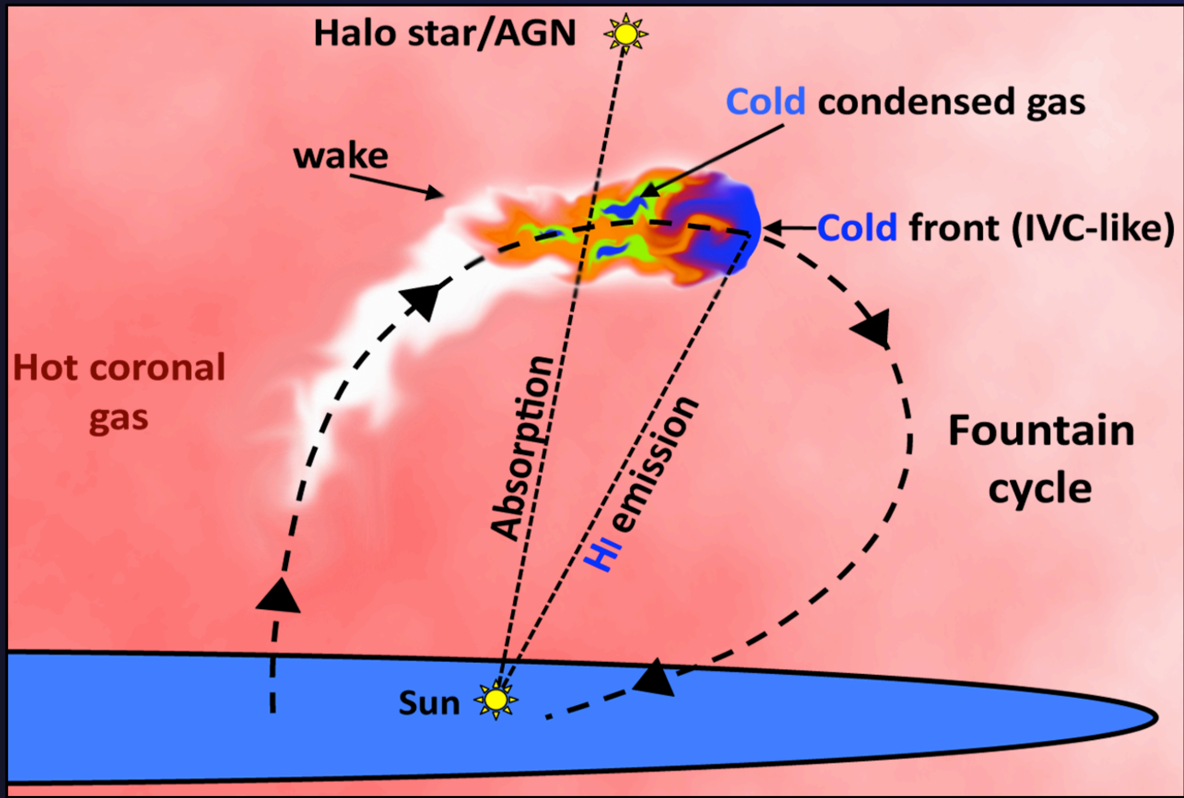


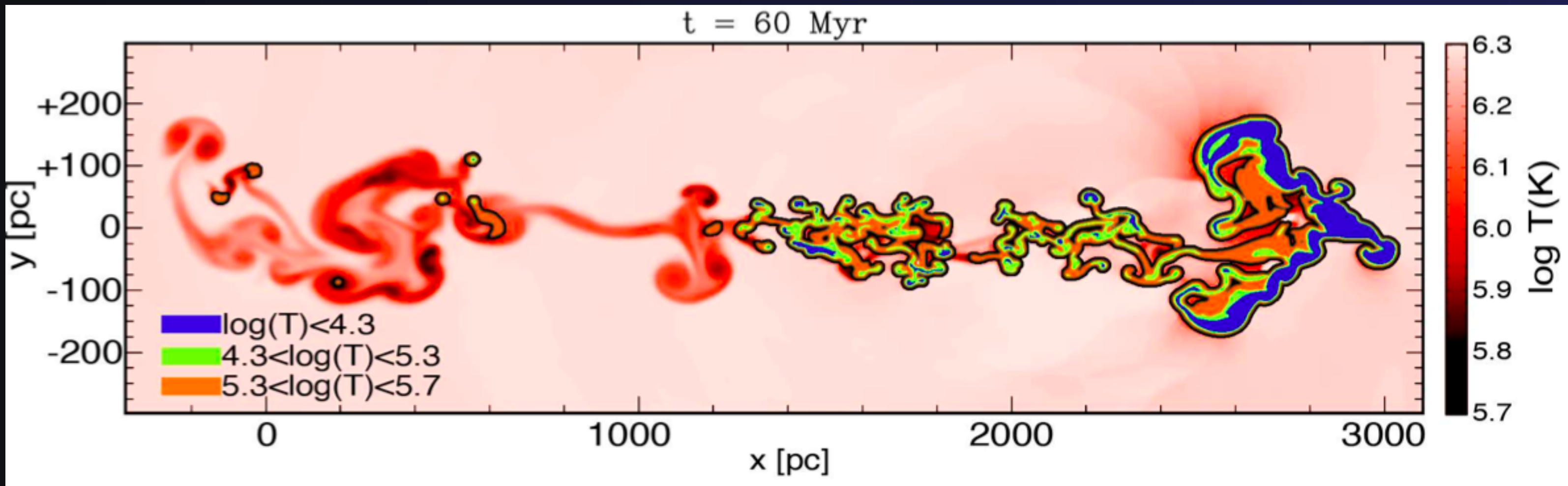
Distances unknown

Shull+ 2009, ApJ

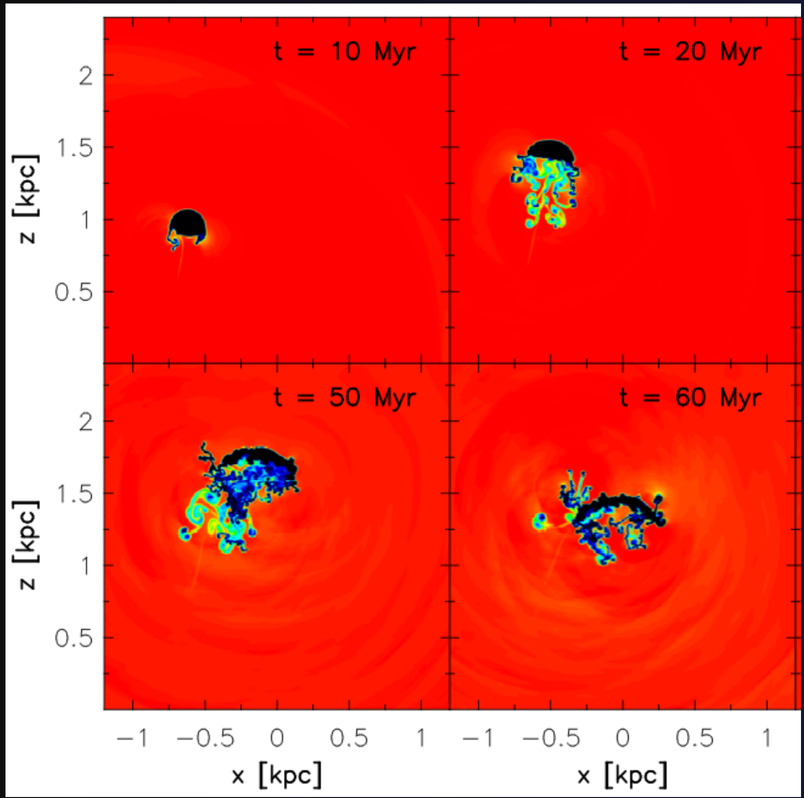
Lehner & Howk 2011, Science

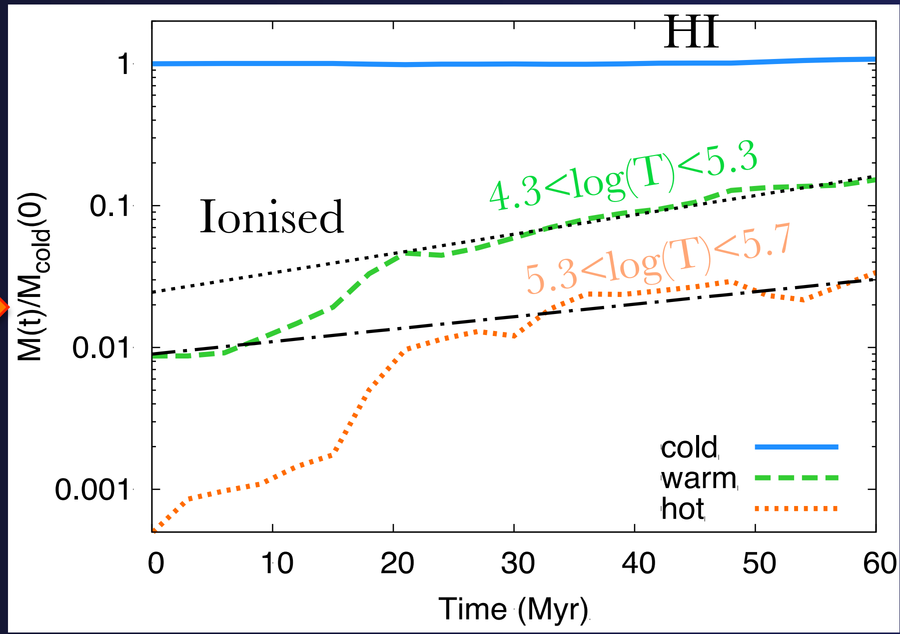
Cooling in the wake

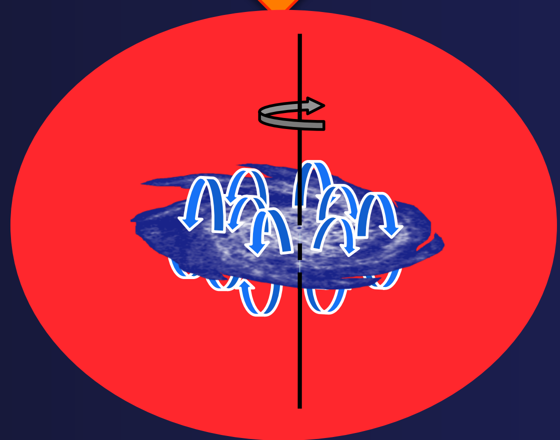




Evolution of the wake



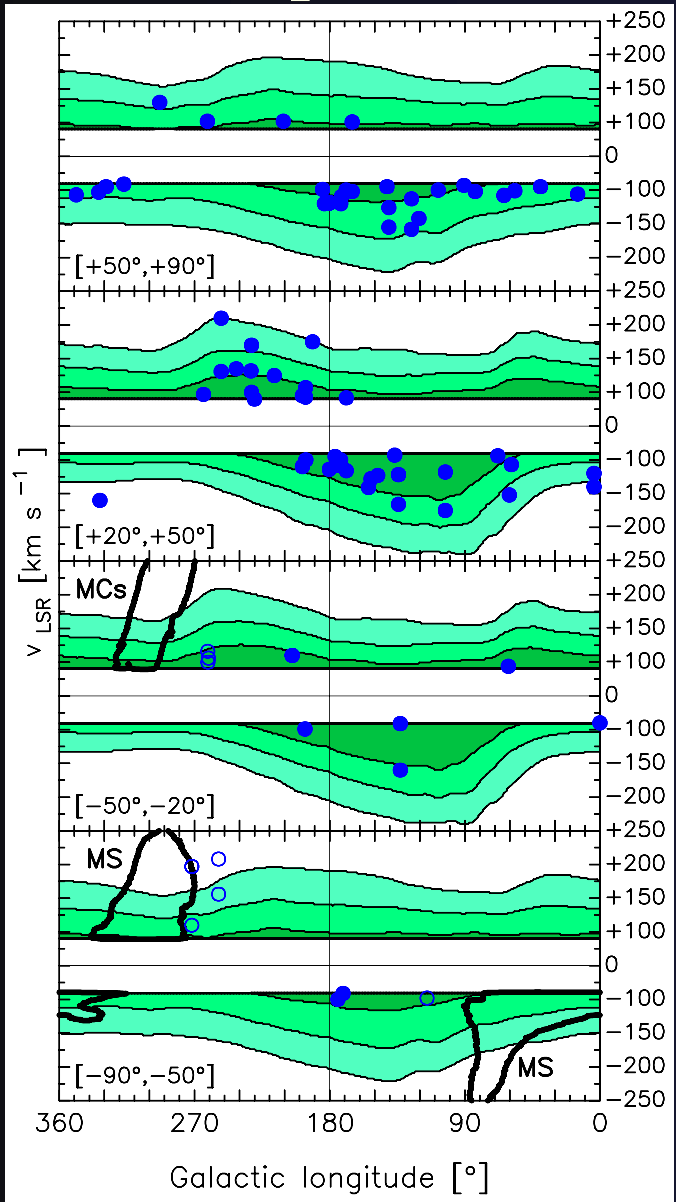




DYNAMICAL MODEL
OF IONISED GAS
(no free parameters)

Marasco, Marinacci & Fraternali 2013, MNRAS

Supernova-driven cooling of the corona

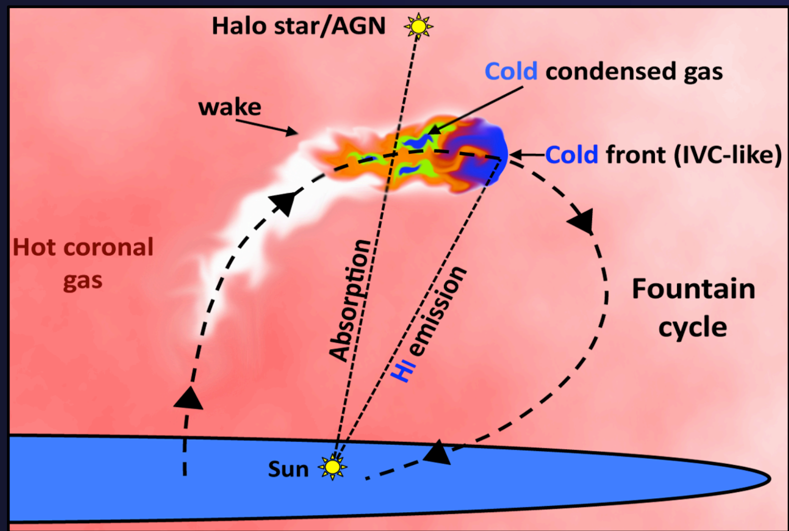


Marasco et al. 2013, MNRAS

The model reproduces:

- Positions-velocities of 95% absorbers
- Average column density
- Number of absorbers along the l.o.s.

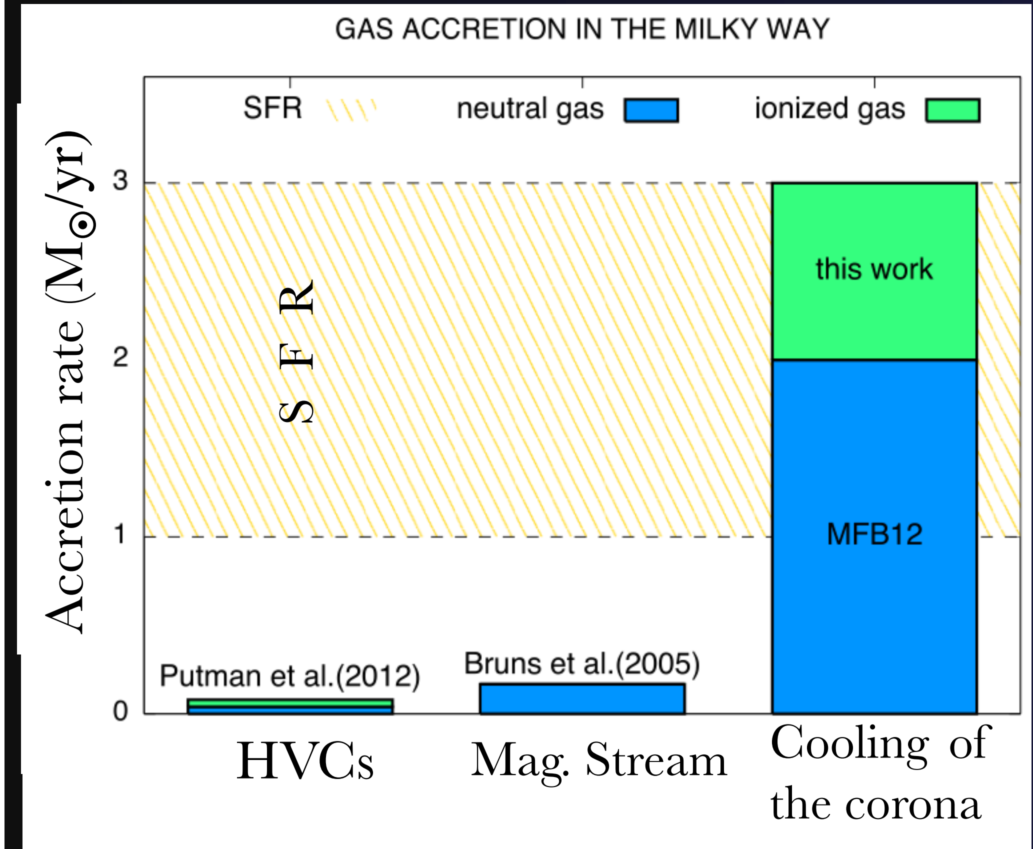
'warm' accretion: ~1 $M_\odot$/yr



Fraternali et al. 2013, ApJL

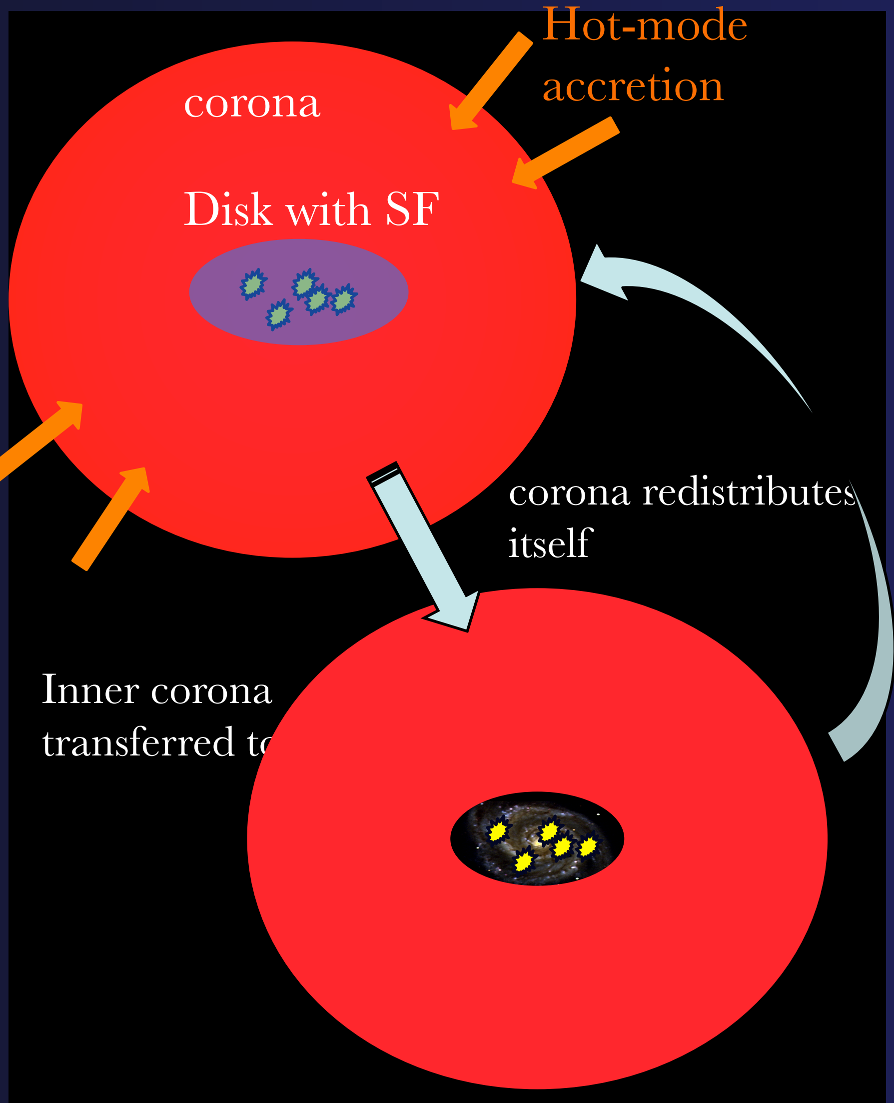
Corona accretion sustaining SF

Today



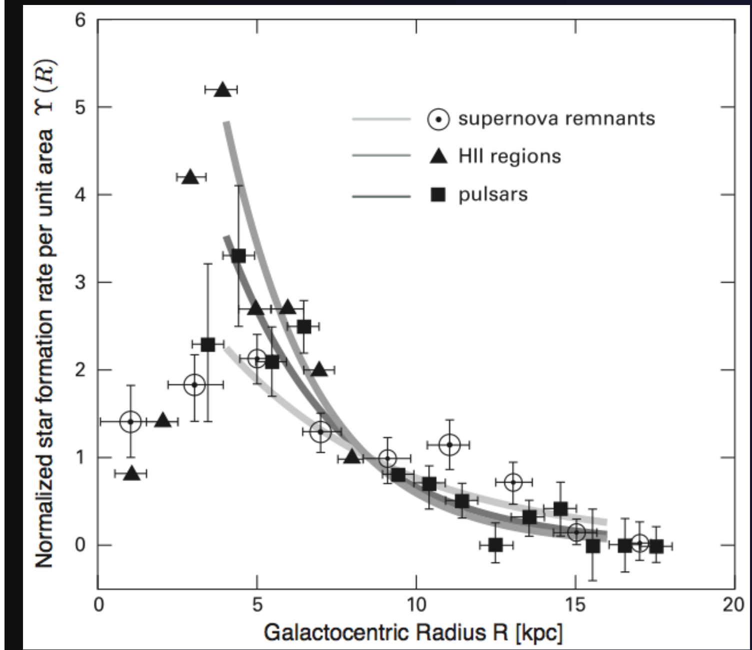
Fraternali et al. 2013, ApJL

Evolution

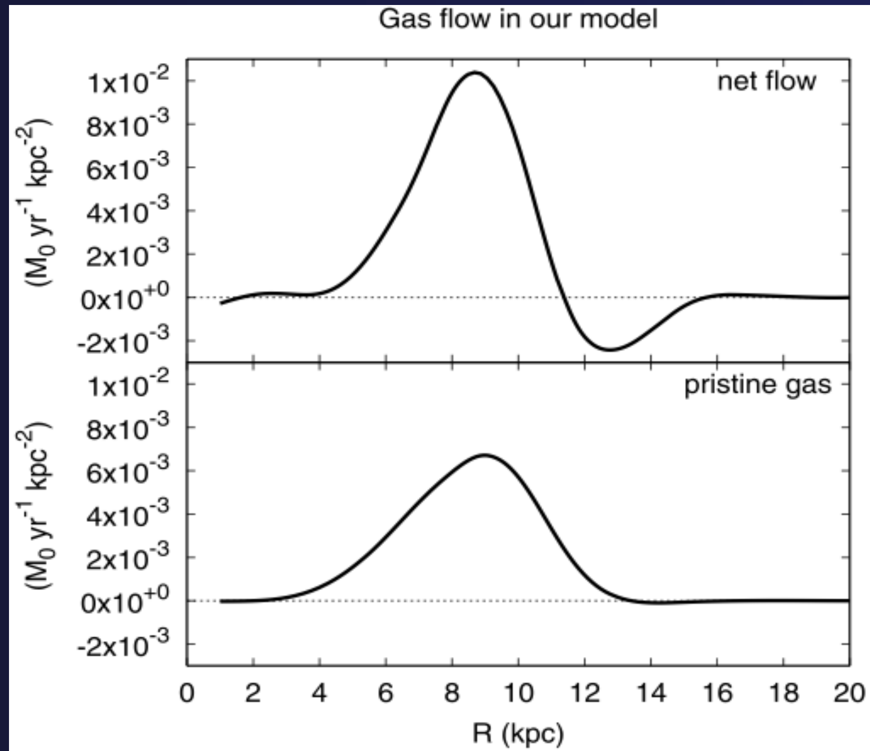


Disc evolution models

Connection between supernova feedback and gas accretion



SN-driven accretion



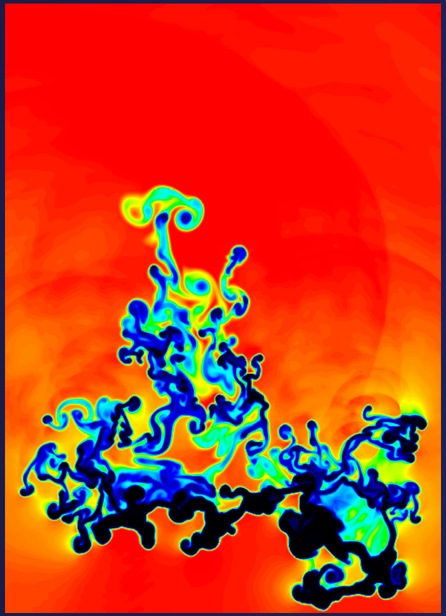
FUTURE WORK

Include in a chemical evolution model a self-consistent and physically motivated treatment of gas accretion

Constraints: stellar abundances and kinematics + ISM metallicity + gas kinematics (flows)

Conclusions

- Star formation must be matched by gas accretion
- Very few infalling HI *clouds*
- Star formation sustained by the cosmological corona
- Supernova-driven corona cooling produces $\dot{\mathrm{M}}_{\mathrm{acc}} \sim 2\, M_{\odot}\, \mathrm{yr}^{-1}$
- Accretion can be included self-consistently in galaxy models
  -> GAIA & LAMOST!



Thanks to:
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A. Gatto, T. Oosterloo, J. Read, R. Sancisi

谢谢!