GAS ACCRETION AND THE EVOLUTION OF THE MILKY WAY

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EVIDENCE OF GAS ACCRETION

GAS ACCRETION: INDIRECT EVIDENCE

Chemical evolution models
G-dwarf problem
Larson 1972; Tynsley 80; Tosi 1988; Chiappini et al. 1997, 2001; Boissier & Prantzos 1999; Schoenrich & Binney 2009

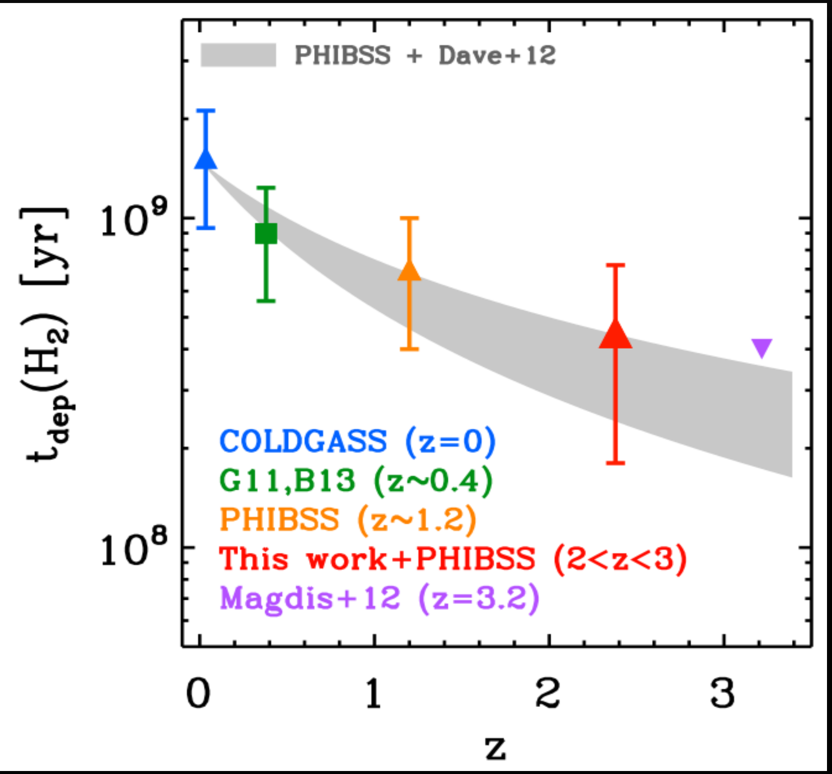
Deuterium in local ISM appears to be re-supplied *Linsky et al. 2006*

~ constant SFR in the MW (thin) disk
Aumer & Binney 2009; Fraternali & Tomassetti 2012; Haywood et al. 2016

Need for metal-poor gas accretion
At ~ 1 $M_\odot$/yr

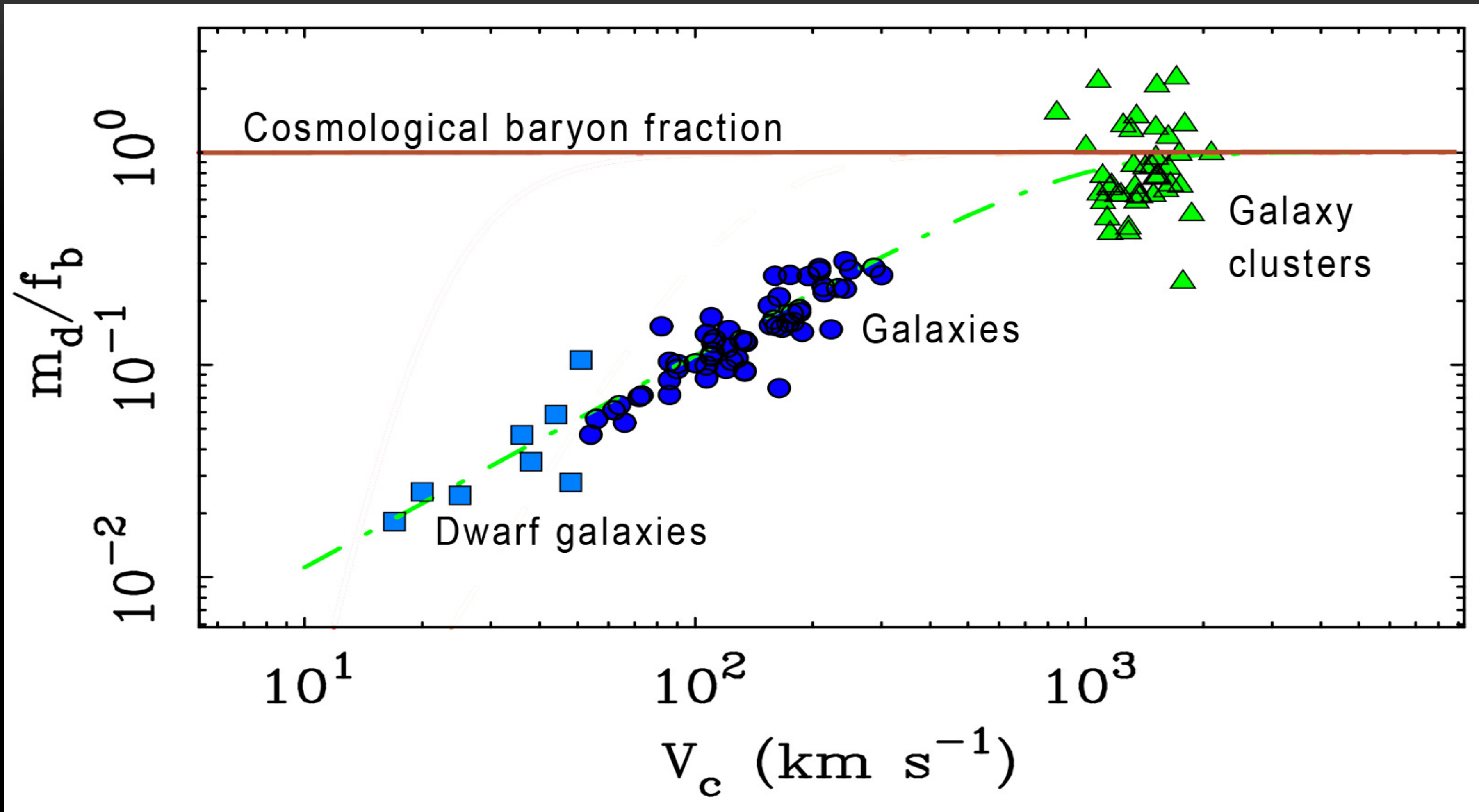
Gas depletion time ~ 1 Gyr

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



Saintonge et al. 2015; Kennicutt et al. 1983; Bigiel et al. 2011, Genzel et al. 2015

MISSING BARYONS

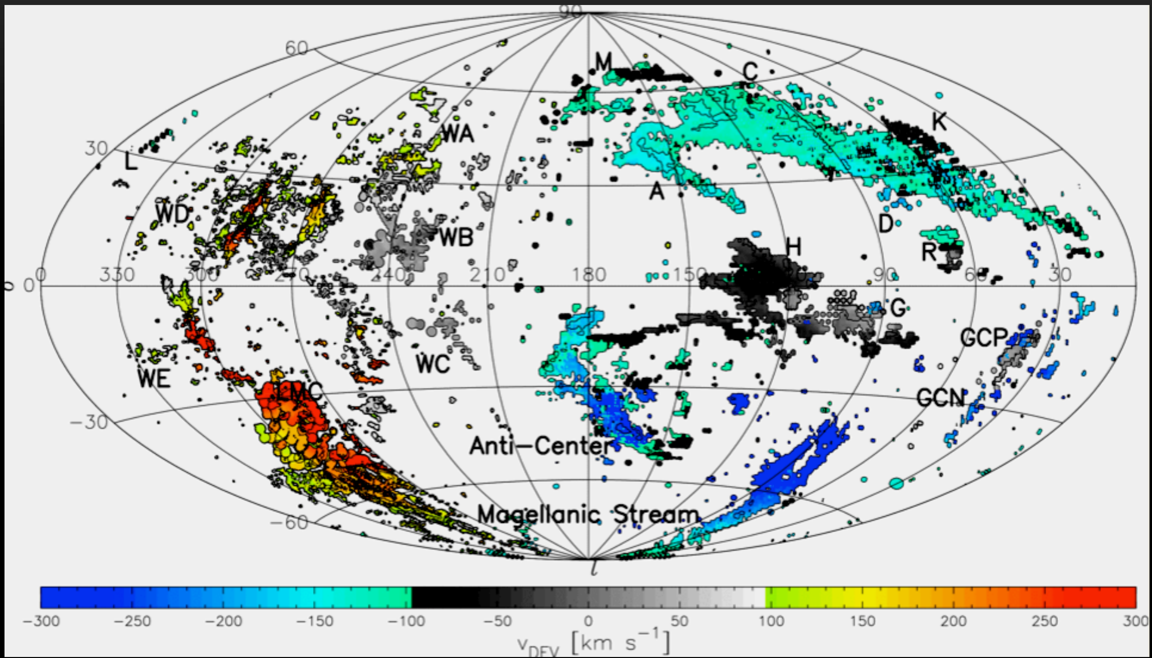


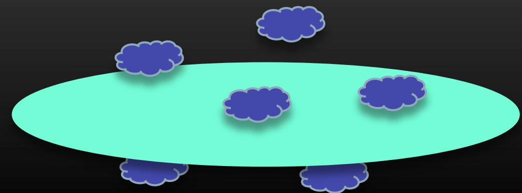
Adapted from McGaugh 2008, see also Dai et al 2010

For the MW: $M_{missing}$ = 1-2 x 10^{11} $M_\odot$

WHAT'S OUT THERE: COLD DENSE GAS

High-velocity clouds





Masses < few x 10^6 $M_\odot$

Accretion from HVCs

~ 0.08 $M_\odot$/yr

Includes He and factor 2 of ionised gas!

Putman, Peek, Joung 2012, ARA&A

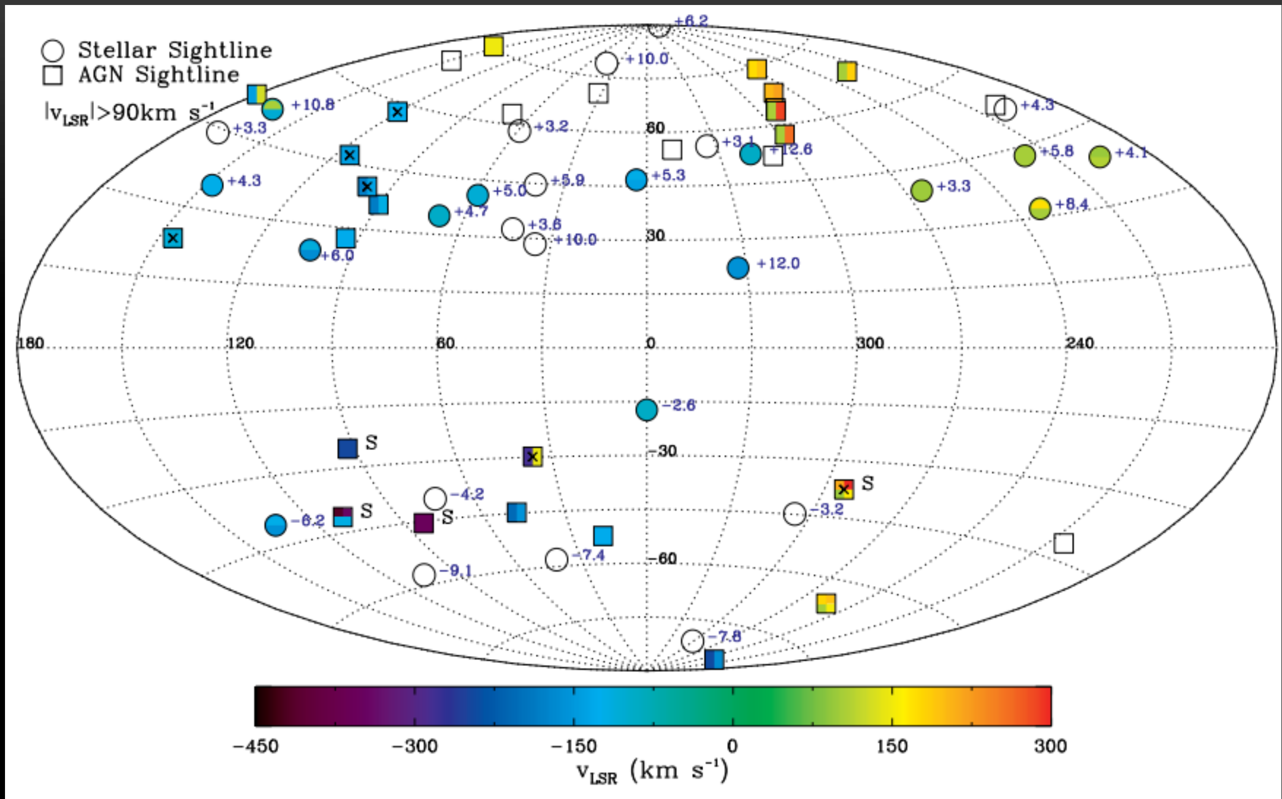
Accretion of Magellanic Stream (see Ricther's talk)
BUT it happens once!

Minor mergers NOT suitable channel for gas accretion

If all dwarfs merged in shortest time $M_{acc, HI}$ << 0.28 $M_\odot$/yr

Di Teodoro & Fraternali 2014, A&A

WHAT'S OUT THERE: IONISED GAS



C II, Si II, Si III, Si IV, C IV…

Warm

4.3<logT<5.3 K

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

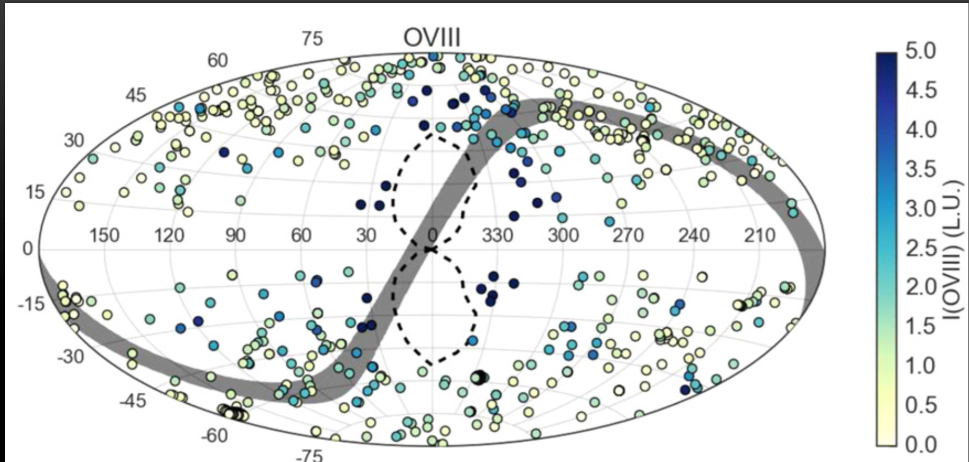
Mass quite uncertain

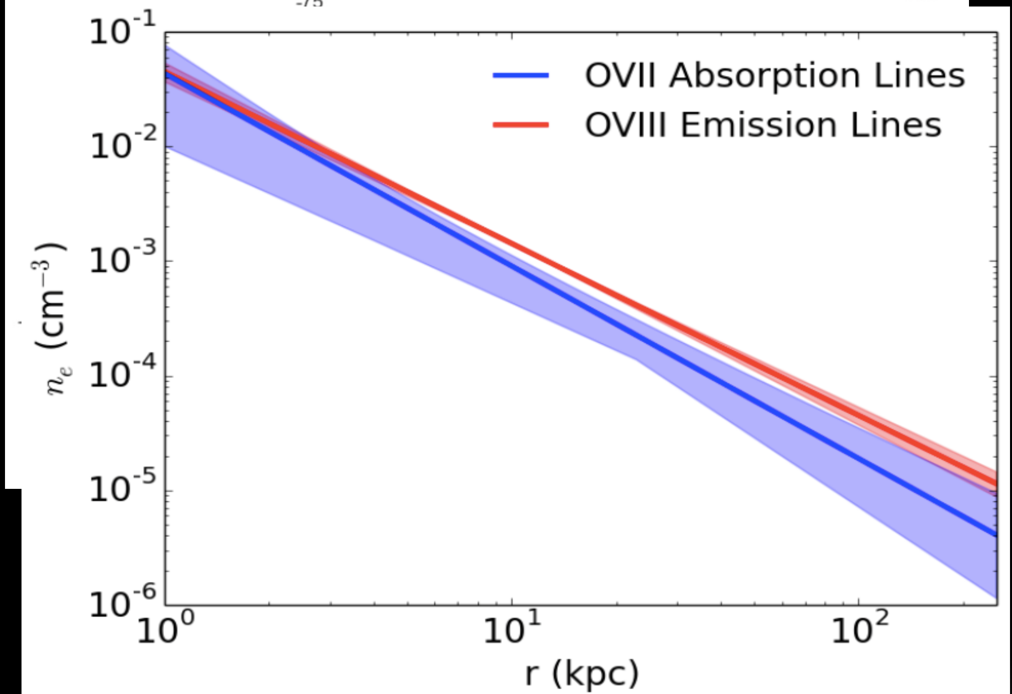
$$M_{\rm iHVC} \approx 1.1 \times 10^8 (d/12\,{\rm kpc})^2 (f_c/0.5)(Z/0.2Z_\odot)^{-1}\ {\rm M}_\odot$$

If they fall at 100 km/s -> t_{fall} ~ 120 Myr -> $M_{acc\ ,ion}$ ~ 1 $M_\odot$/yr

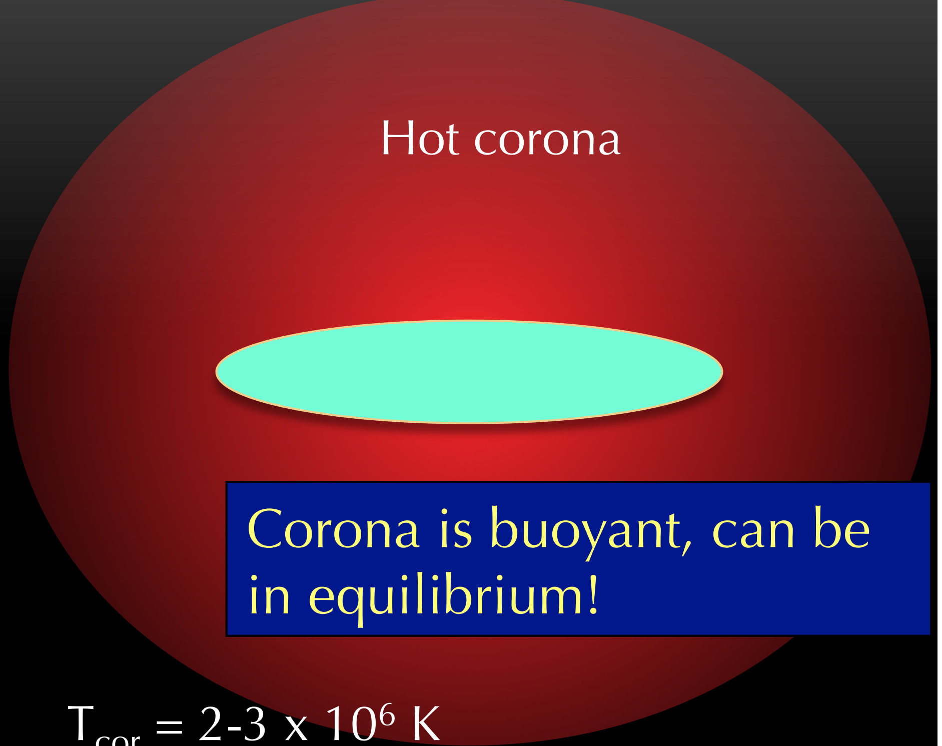
Origin? See later

WHAT'S OUT THERE: HOT GAS





Miller & Bregman 2015, ApJ
Gatto, Fraternali et al. 2013, MNRAS



Corona is buoyant, can be in equilibrium!

T_{cor} = 2-3 x 10^6 K

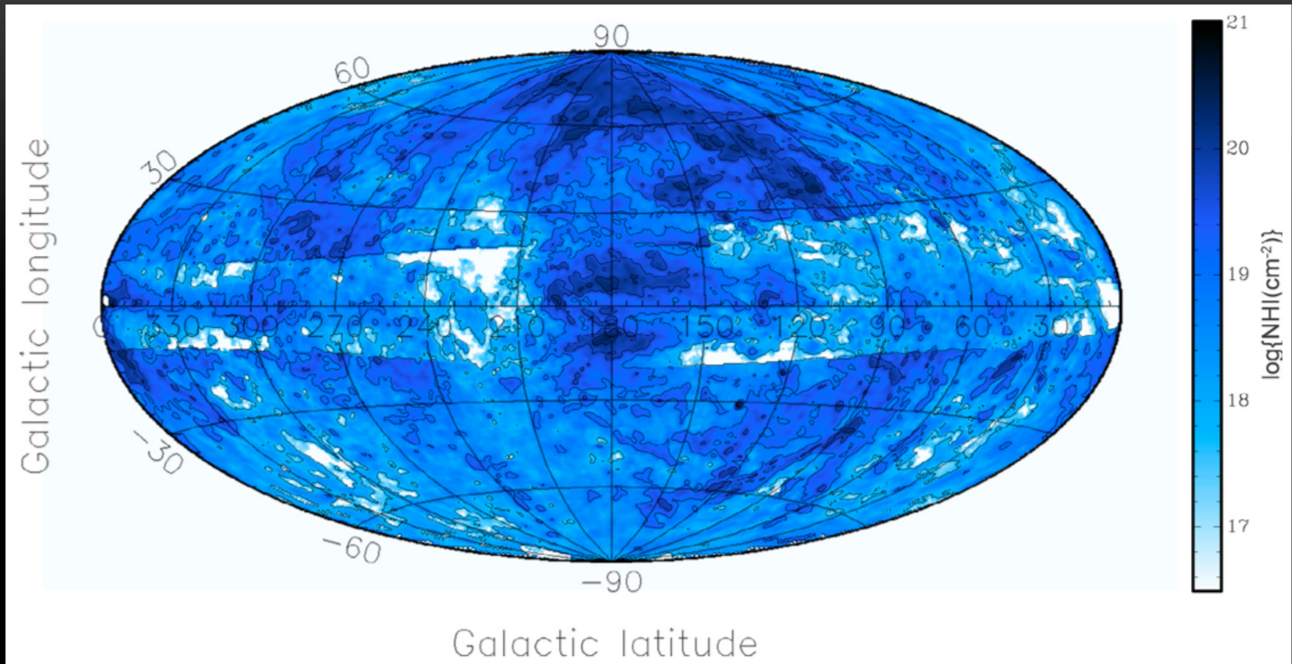
Z ~ 0.3 Solar, in other galaxies: 0.1 (*Hodges-Kluck & Bregman 2012, ApJ; Bogdan at al. 2013, ApJ*)

If R~R_{vir} -> M_{hot} ~ 2-6 x 10^{10} $M_\odot$ (10-50% of missing)

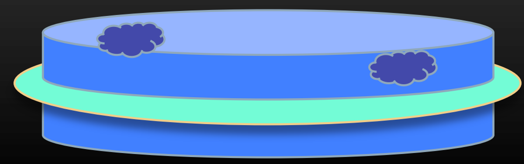
$\dot{M}_{cool}$ ~ 0.2 $M_\odot$/yr

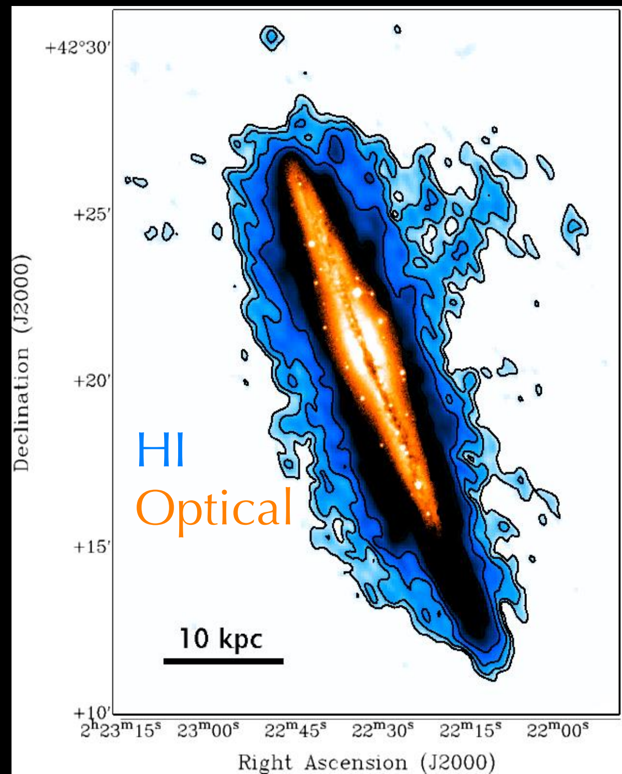
ENTER EXTRAPLANAR GAS

EXTRAPLANAR HI



Marasco & Fraternali 2011, A&A





Oosterloo, Fraternali+ 2007, AJ

Extraplanar HI mass = 4 x 10^8 $M_\odot$ (10% of total)

Falls in few x 10^7 yr

-> galactic fountain circulates ~ 10 $M_\odot$/yr

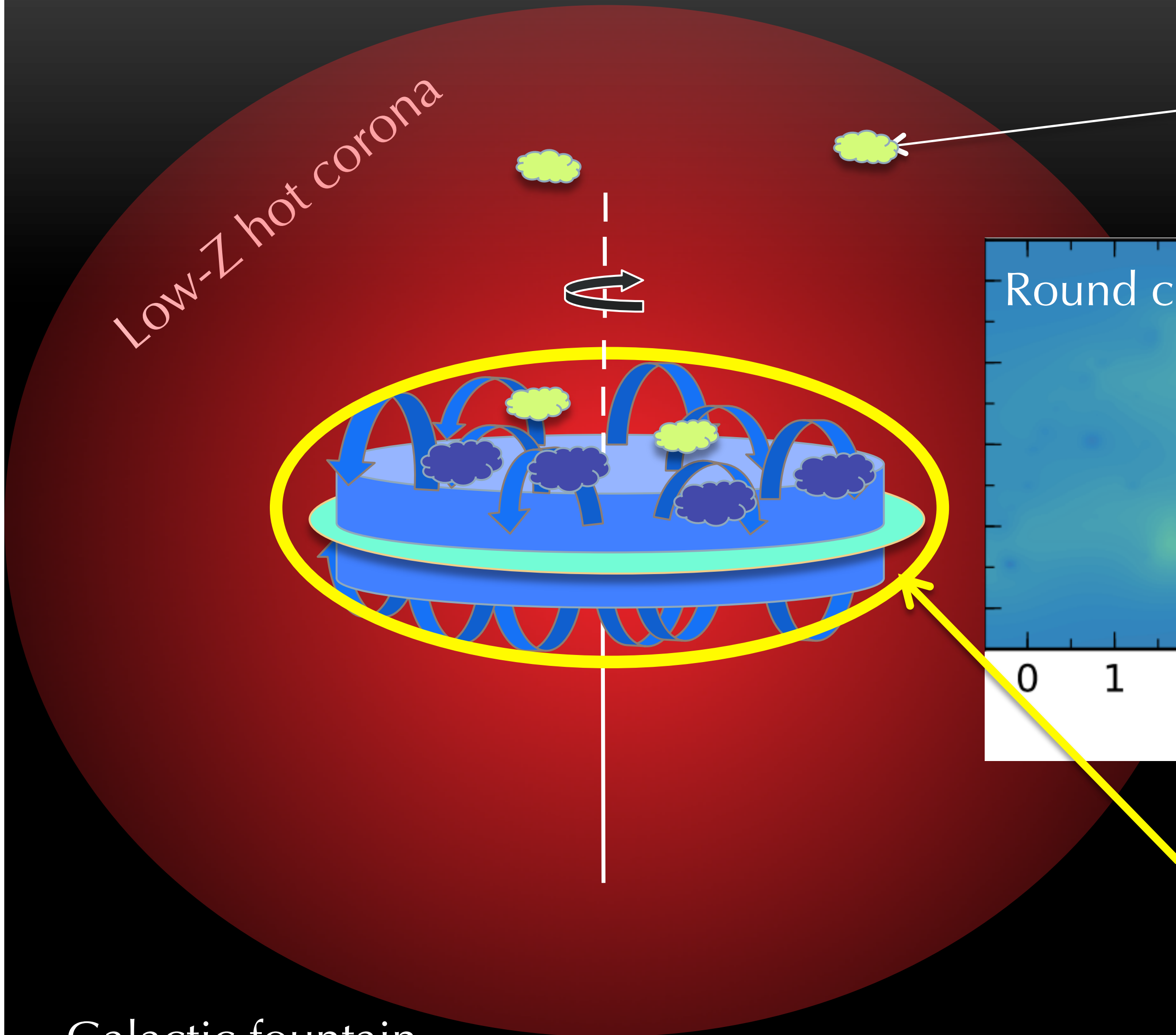
Typical velocities 70-80 km/s

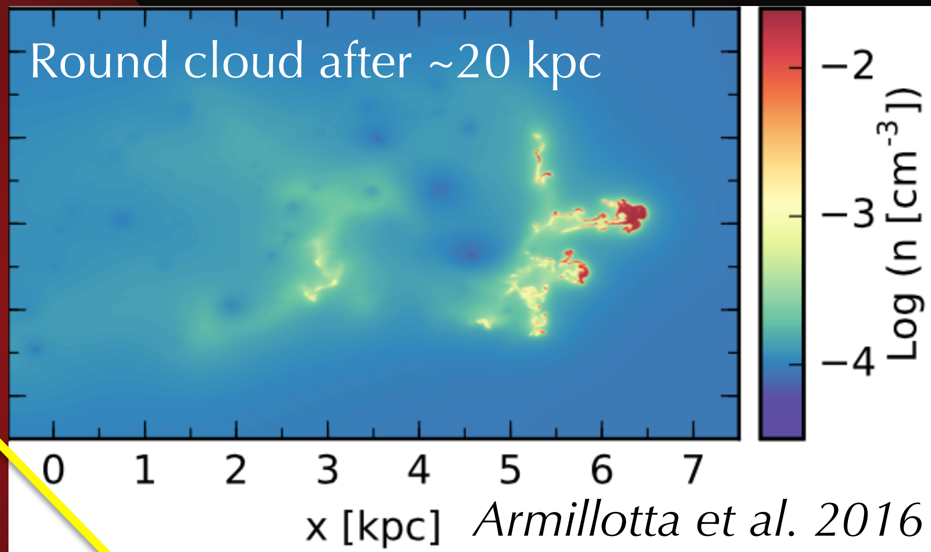
For SFR=2 $M_\odot$/yr only 2% of SN energy

HI mass ~ 1 x 10^9 $M_\odot$ (25% total)

INTERPLAY DISC-CORONA

Distant clouds contribute very little:
1. unlikely to make it to the disc, 2. long accretion time





Armillotta et al. 2016

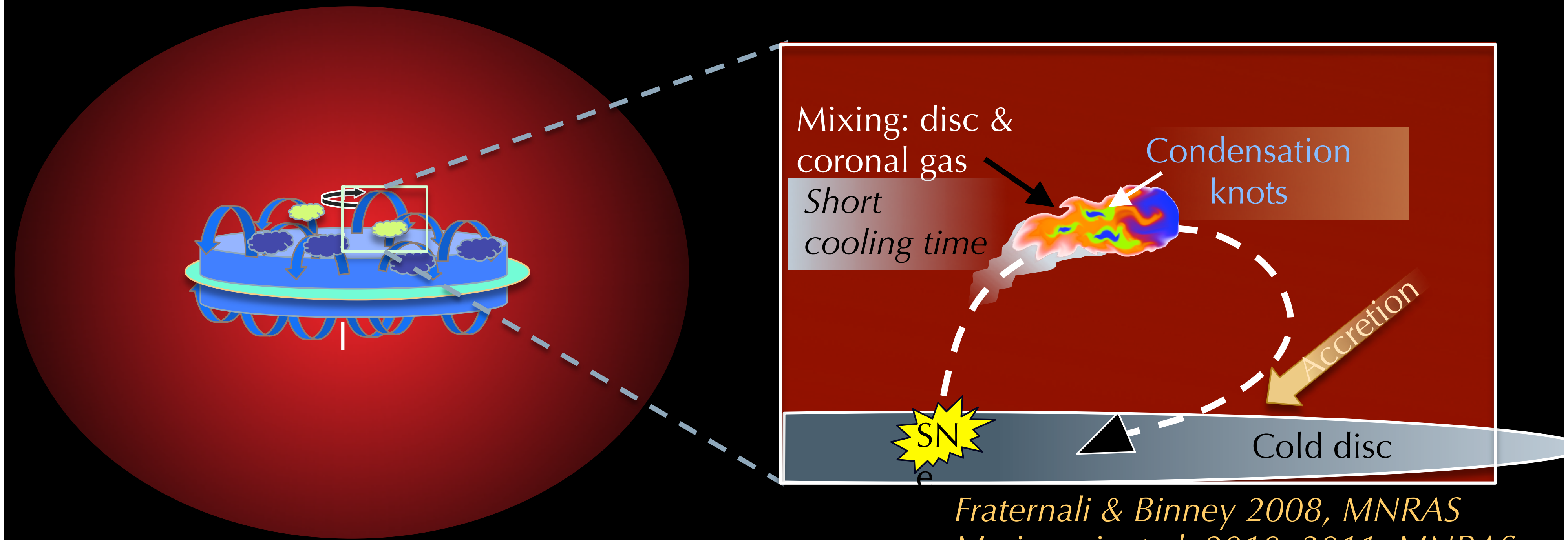
Interface: here accretion takes place!

Galactic fountain

Bregman 1980; Houck & Bregman 1990; Fraternali & Binney 2006; Melioli et al. 2008; Spitoni et al. 2009

SUMMARY SO FAR

1. Gas accretion must come from cooling of the corona
2. The Milky Way keeps 10% of HI above the plane (extraplanar gas)
3. Interaction between fountain gas and corona inevitable

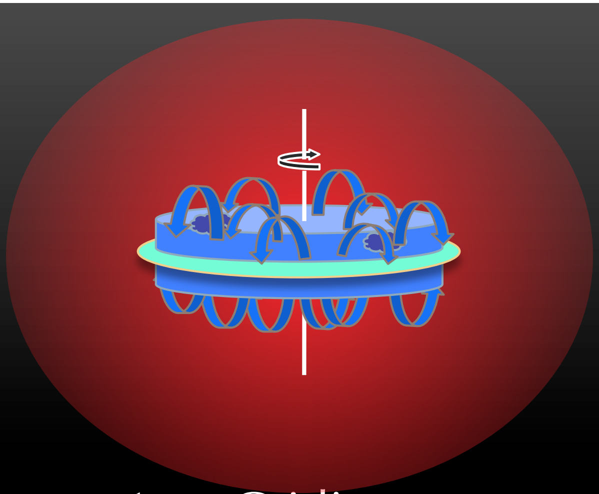


Fraternali & Binney 2008, MNRAS
Marinacci, et al. 2010, 2011, MNRAS

➡ Study with idealized simulations combined with galactic fountain model

FOUNTAIN-DRIVEN ACCRETION

DISC-CLOUD CORONA INTERACTION

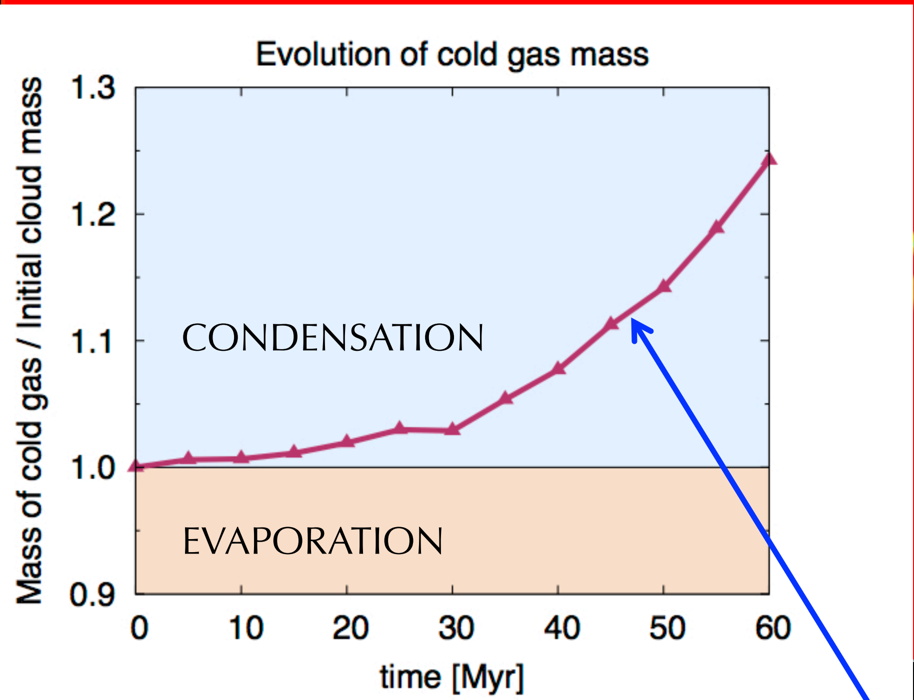


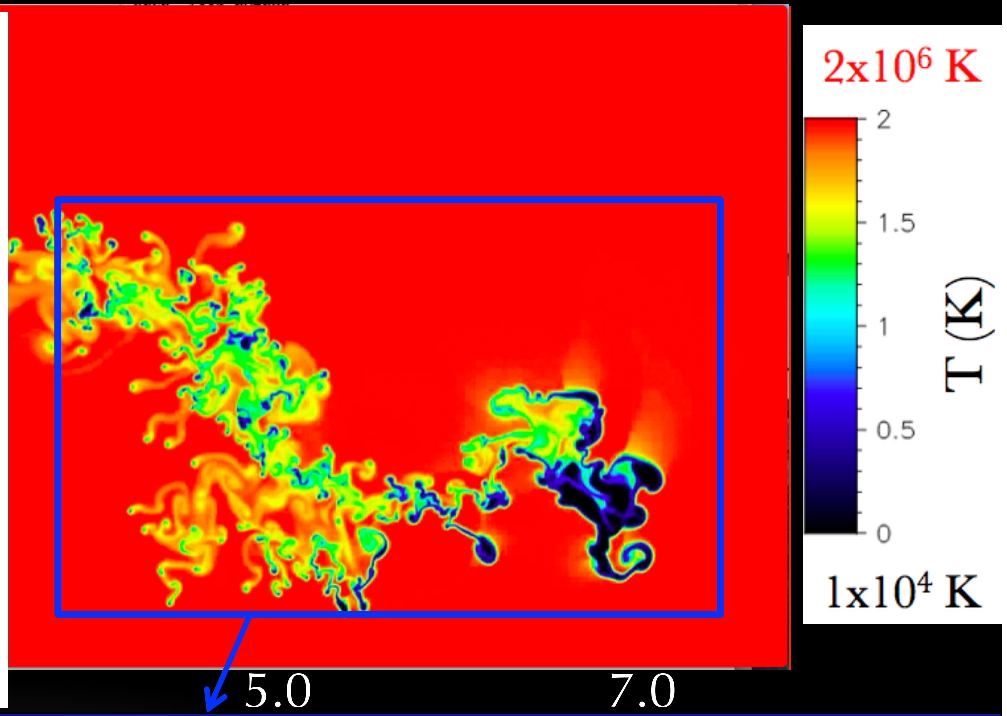
1 pc x 1 pc Grid!

T_{corona}=2x10^6 K

Z_{corona}=0.1 $Z_\odot$

Z_{cloud}=1 $Z_\odot$

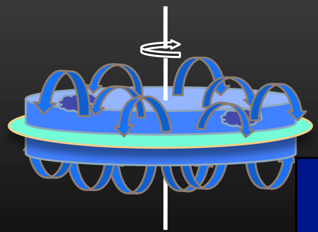


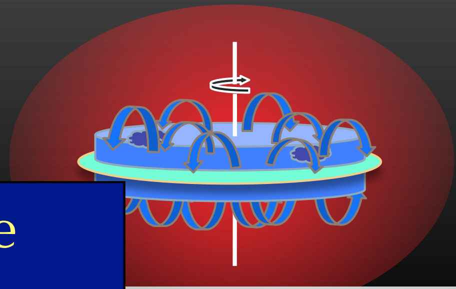


Mass of cold gas increased by ~20%!

Marinacci, et al. 2010, MNRAS; Armillotta et al. 2016, MNRAS

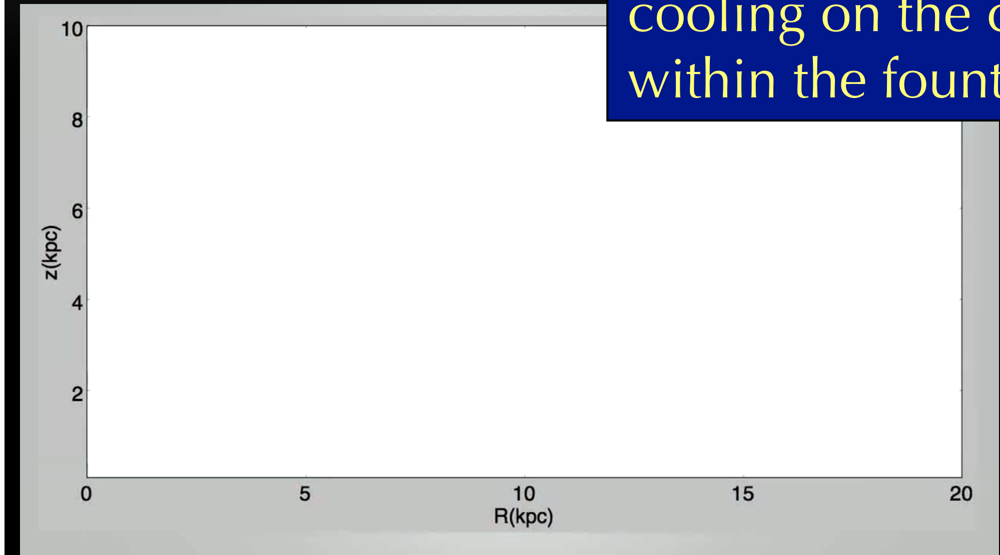
MODIFICATION OF ORBITS

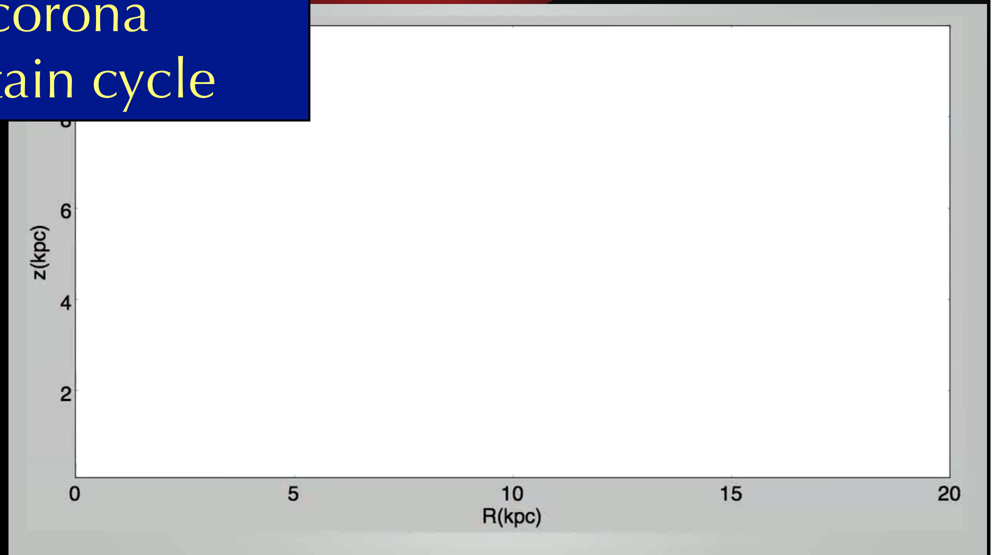


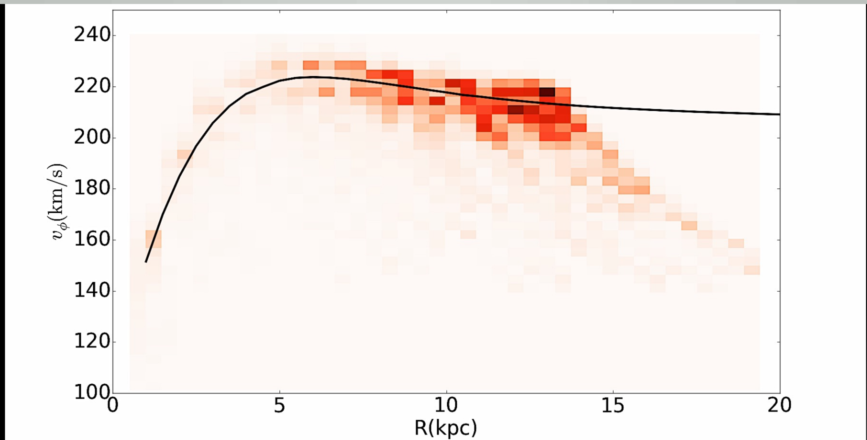


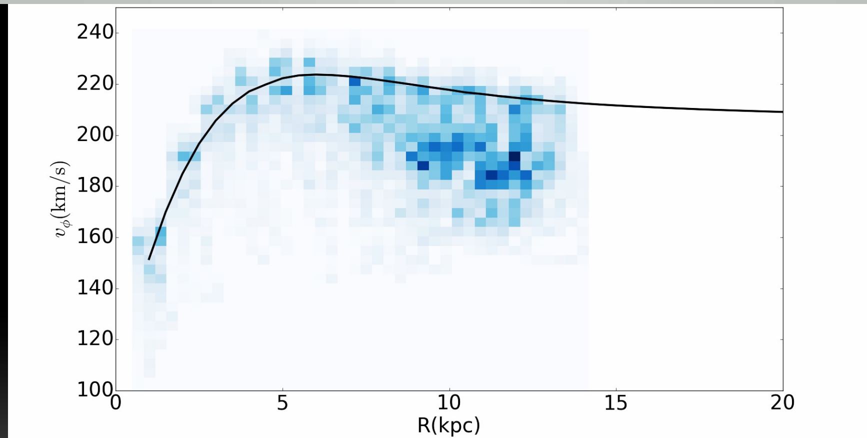
Corona rotates with a lag of ~ 75 km/s

Kinematic imprint of the cooling on the corona within the fountain cycle



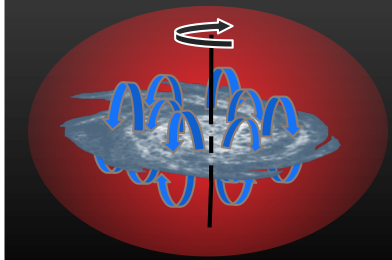




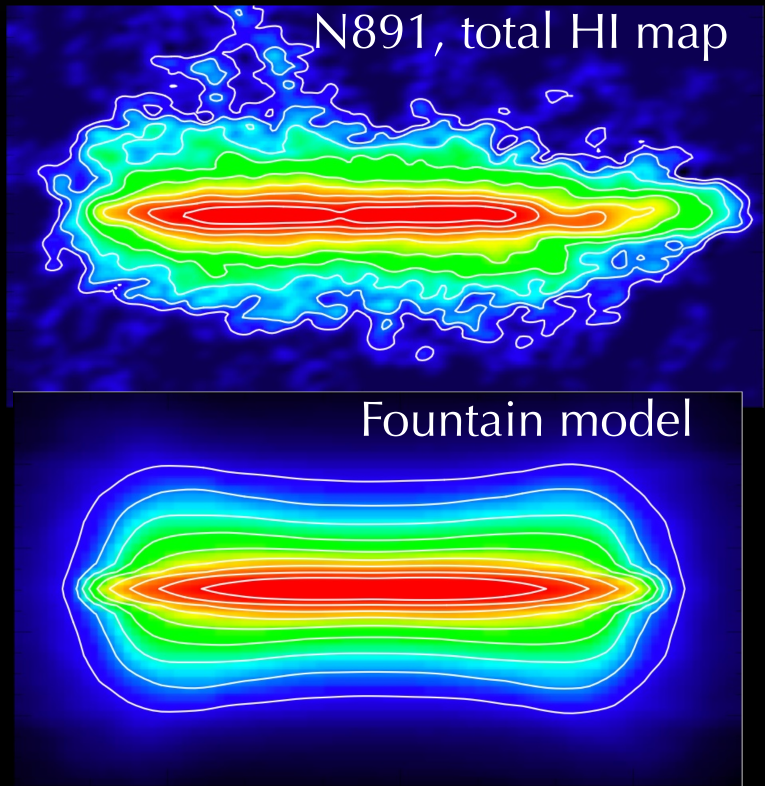


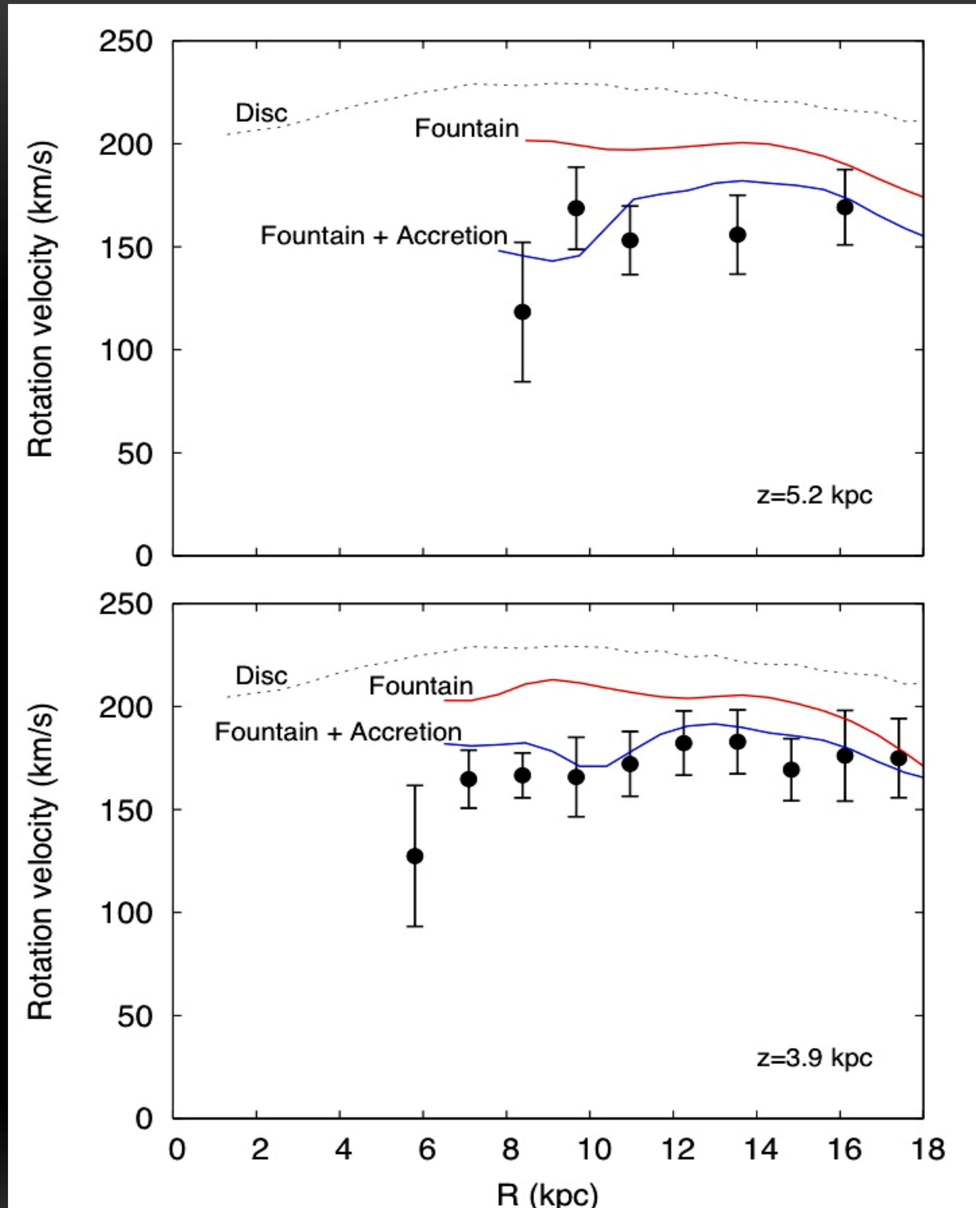
Rotation of the corona (*Marinacci, Fraternali et al. 2011, MNRAS*)

FOUNTAIN-DRIVEN ACCRETION MODEL



1. kick velocities (v_k)
2. Ionised fraction (f_{ion})
3. Accretion rate (dM/dt)



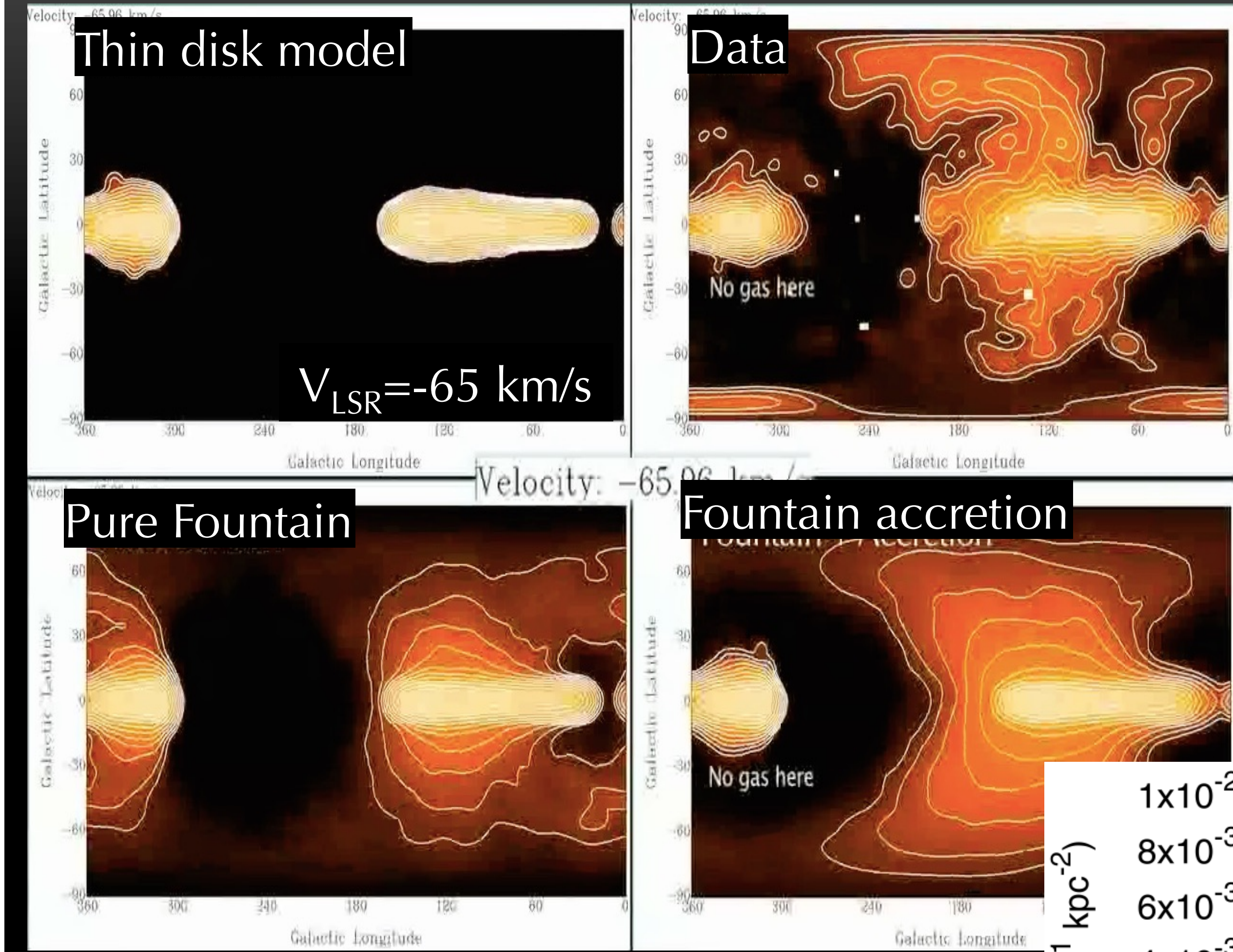


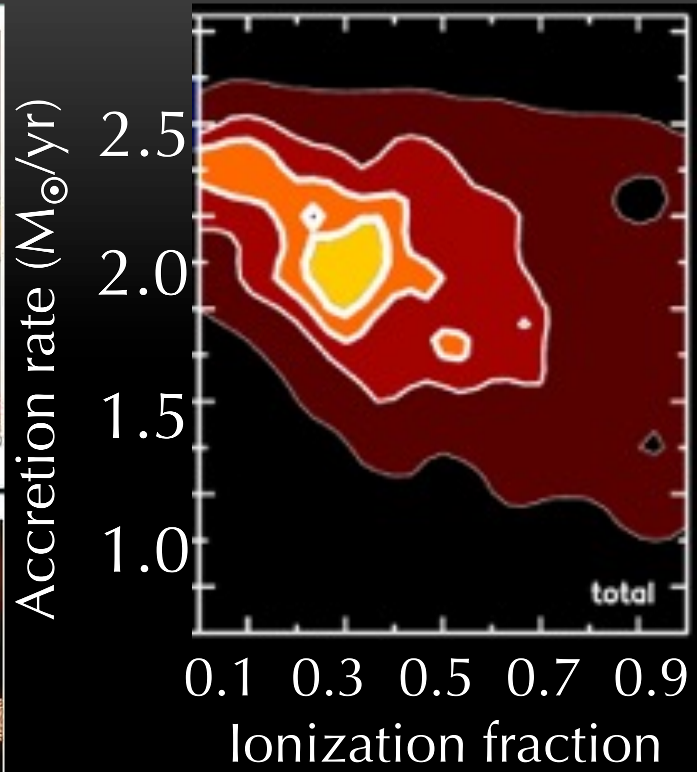
Best-fit Accretion Rate ~ 3 $M_\odot yr^{-1}$

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

Fraternali & Binney, 2008

EXTRAPLANAR HI IN THE MILKY WAY

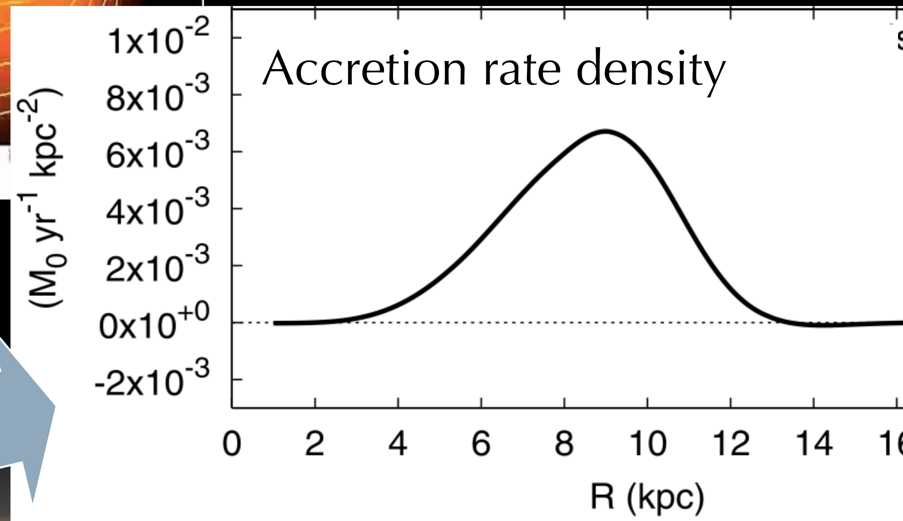




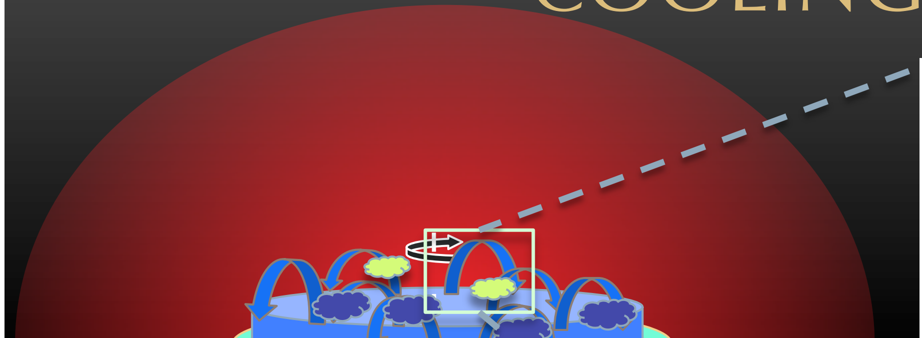
Marasco, Fraternali & Binney 2012, MNRAS

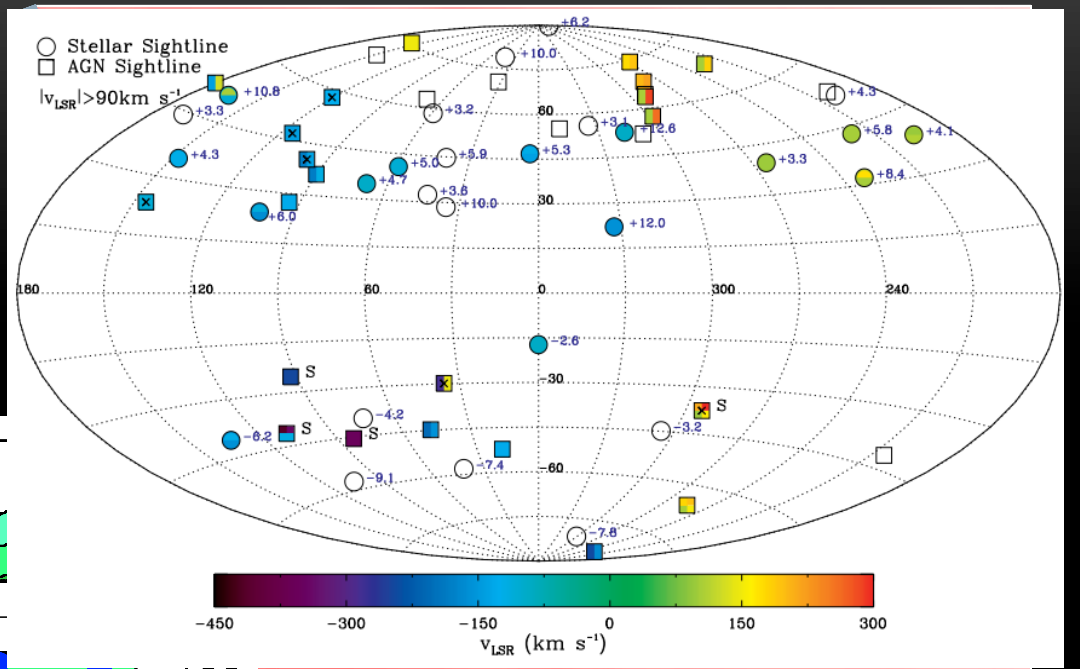
Best-fit Accretion Rate ~ 2 $M_\odot yr^{-1}$

Compare to SFR ~ 1-3 $M_\odot yr^{-1}$

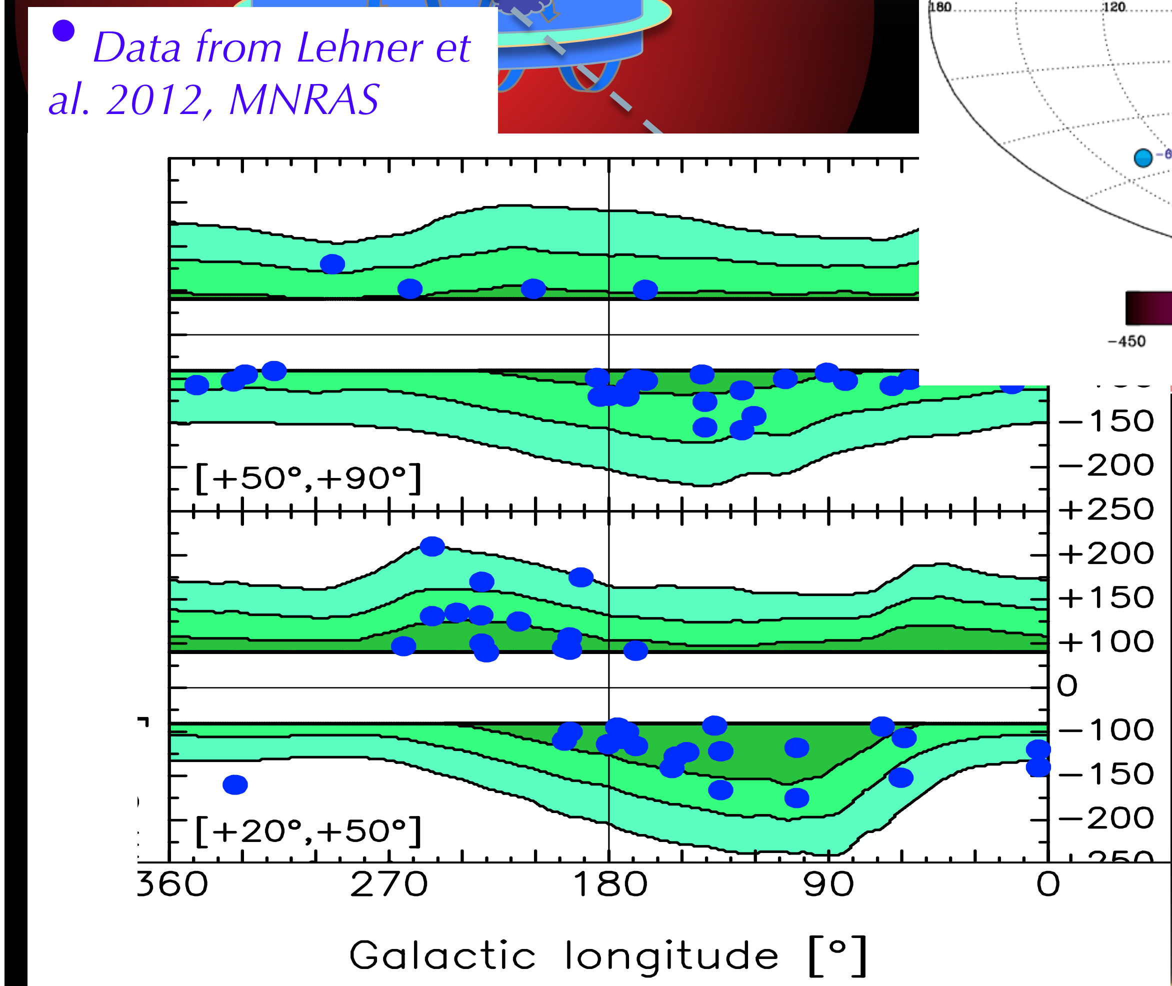


COOLING IN THE WAKE





Fraternali et al. 2013, ApJL

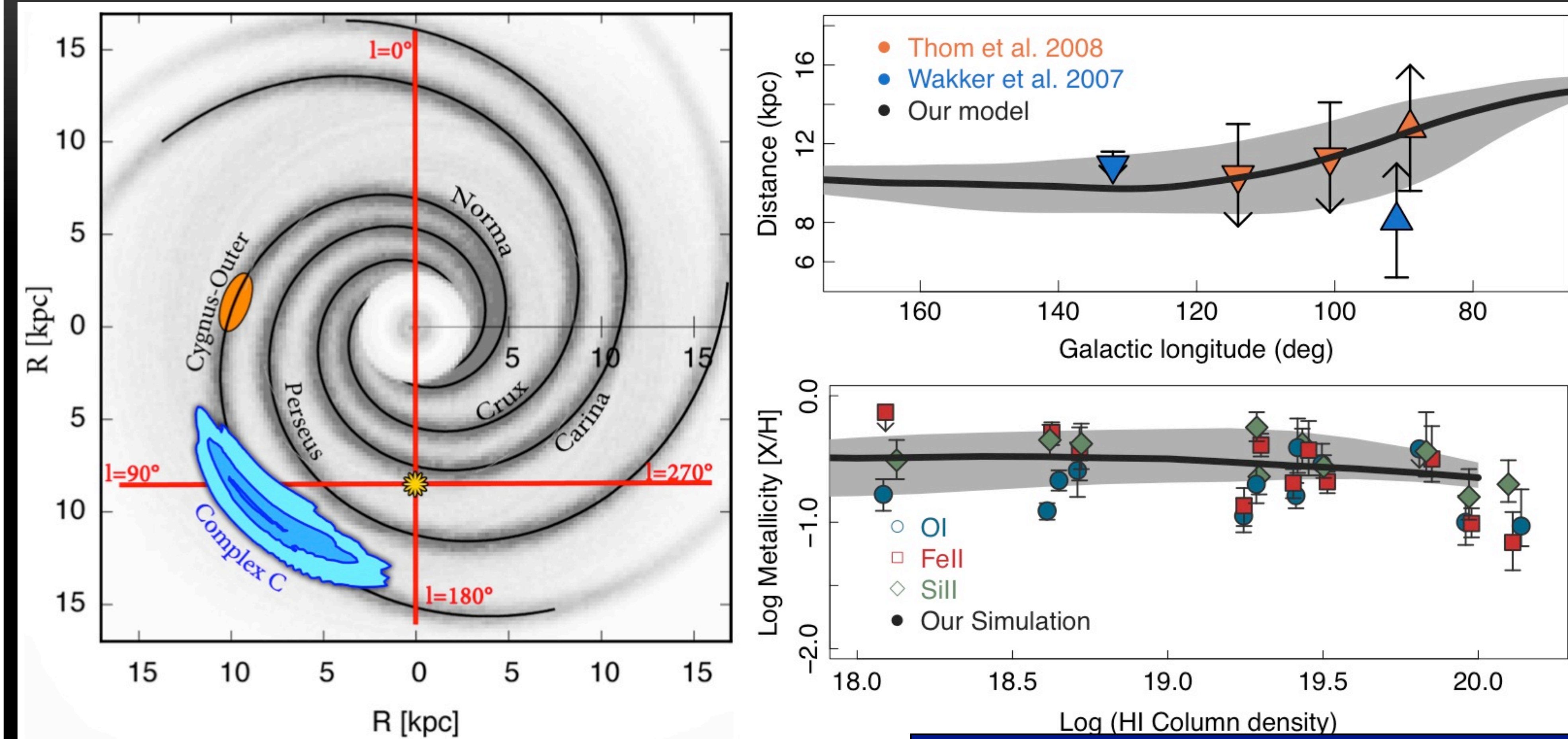


C II, Si II, Si III, … 4.3<logT<5.3 K

This model reproduces:

- Positions & velocities 95% absorbers
- Average column density
- Number of absorbers along the l.o.s.
- High velocity dispersions of features

HIGH-VELOCITY CLOUD COMPLEX C



Fraternali et al. 2015, MNRASL

Distance and Z are independent confirmations not used in the fit!

Half gas from the disc, half from the corona

Als

Mar

Fountain-driven accretion:

1. Kinematics of extraplanar gas
2. Ionised absorbers
3. HCVs

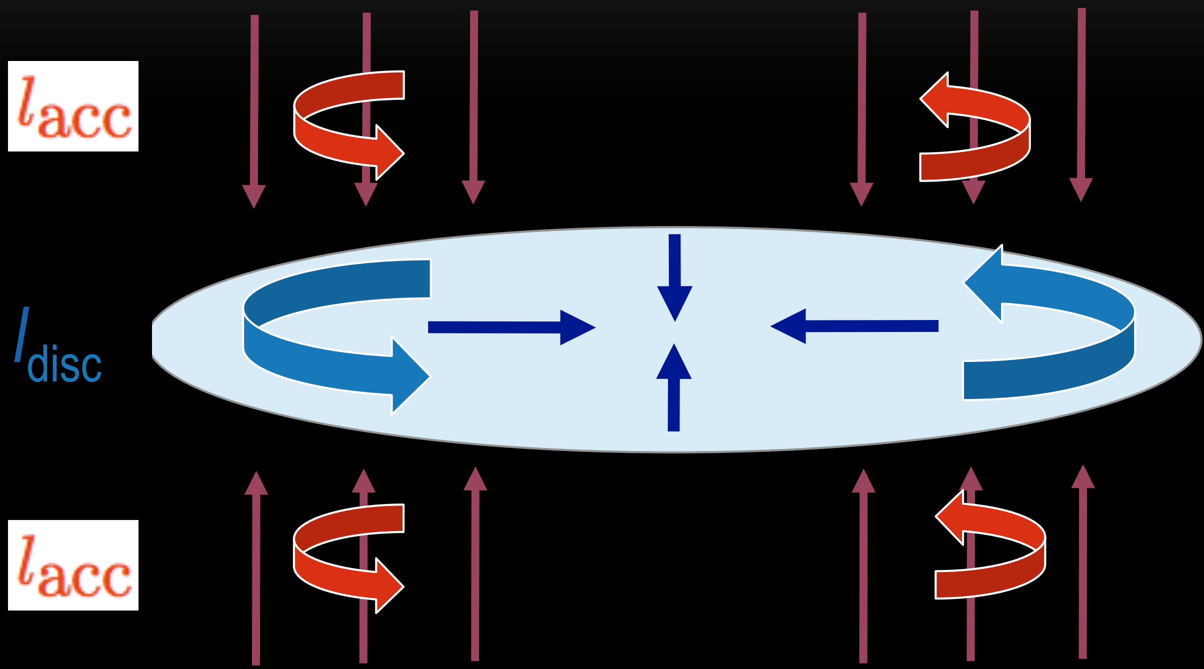
-> Accretion rate to sustain SFR

CLUES FROM ANGULAR MOMENTUM

Pezzulli & Fraternali 2016, MNRAS, 455, 2308

LOCAL ANGULAR MOMENTUM MISMATCH

Inside-out growth today (see *Pezzulli, Fraternali et al. 2015*)
-> corona must rotate



Effective accretion rate

$$\dot{\Sigma}_{\rm eff} = \dot{\Sigma}_{\rm acc} - \frac{1}{2\pi R}\frac{\partial \mu}{\partial R}$$

Pitts & Tyler 1989

$l_{acc} < l_{disc}$ ⇒ Radial inflow ⇒ Influence on metallicity gradients

Mayor & Vigroux (1981); Lacey & Fall (1985)

See also Bilitewski & Schoenrich 2012, MNRAS

MODEL OF DISC EVOLUTION

Hypotheses

1. Exponential disc (at all times)
2. Kennicutt-Schmidt law valid
3. Exponential SFH

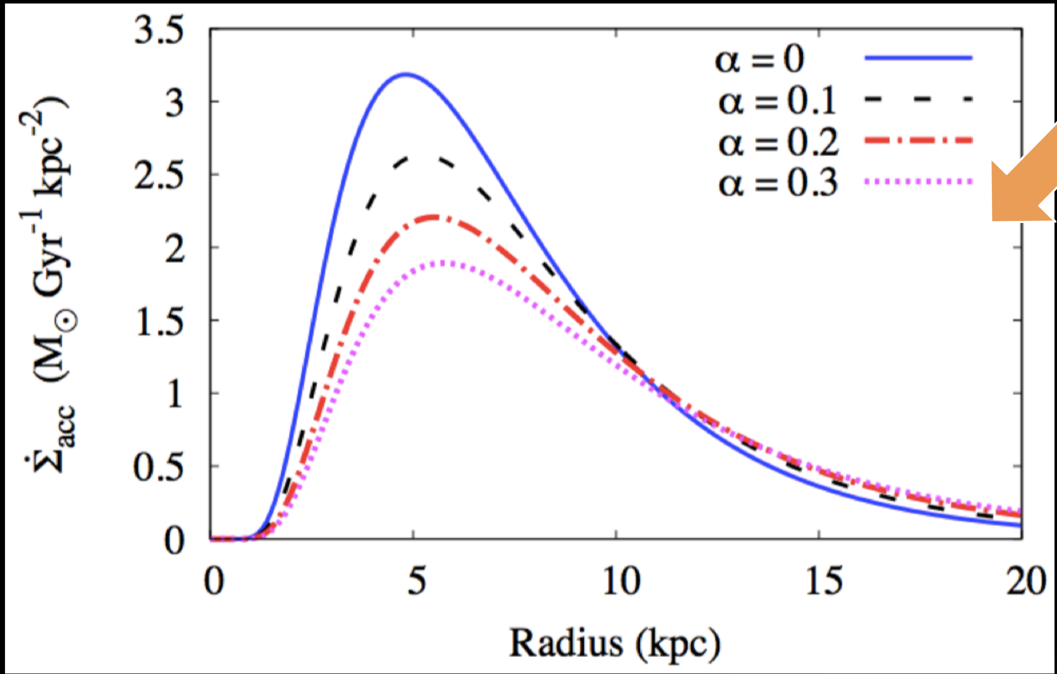
4. Conservation of angular momentum

$\dot{\Sigma}_{\rm eff}(t, R)$

$$\dot{\Sigma}_{\rm eff} = \dot{\Sigma}_{\rm acc} - \frac{1}{2\pi R}\frac{\partial \mu}{\partial R}$$

Radial mass flux $\mu = -2\pi\alpha R^2 \dot{\Sigma}_{\rm acc}$

Angular momentum mismatch $\alpha = 1 - \frac{V_{\rm acc}}{V_{\rm disc}}$



Pezzulli & Fraternali 2016, MNRAS

Approximations

1. Instantaneous recycling: ok for α elems
2. No stellar migration: ok for gas/ Cepheid abundance gradient

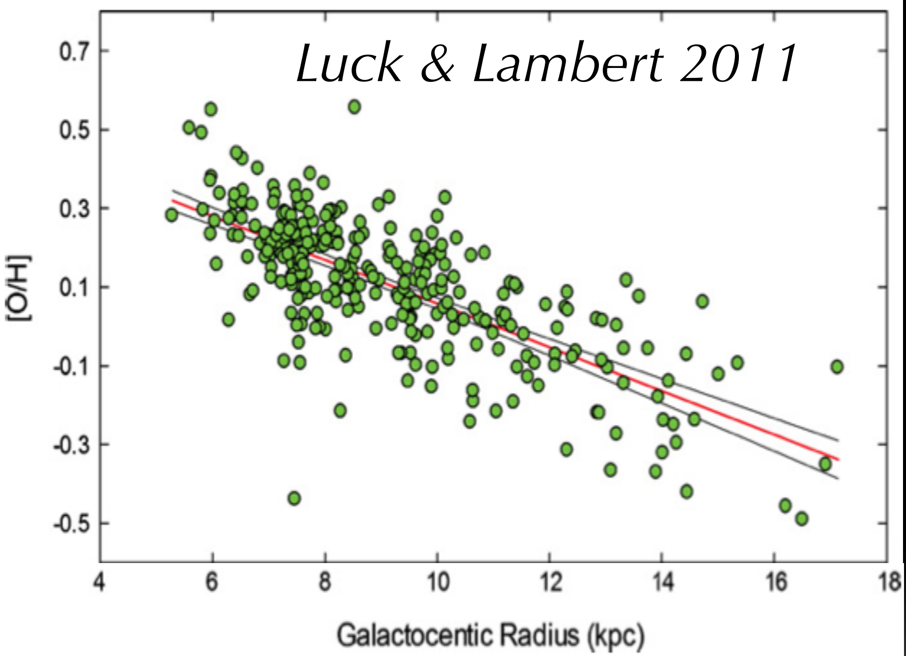
CHEMICAL EVOLUTION

Hypothesis

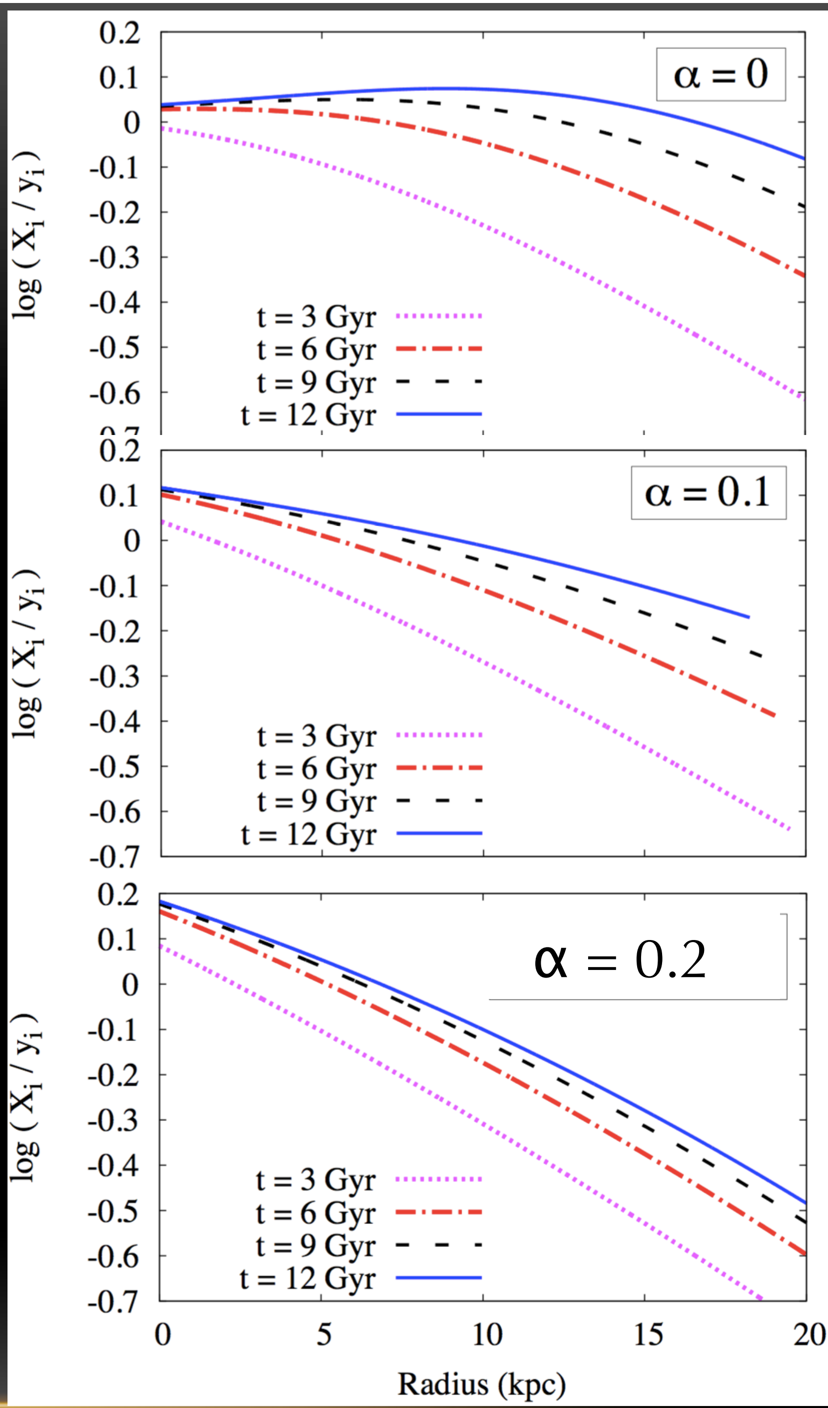
Structural disc evolution fixed as above

Chemical evolution → 1 paramenter $\alpha = 1 - \frac{V_{acc}}{V_{disc}}$

Metallicity gradients as a function of angular momentum mismatch (α)



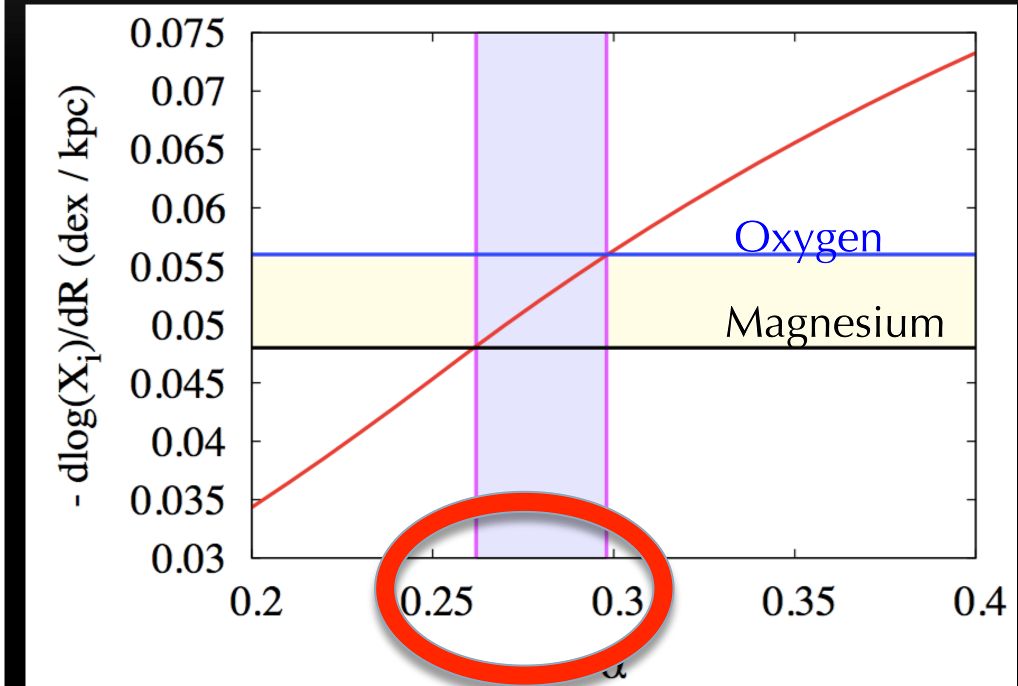
See also Bono's talk



ANGULAR MOMENTUM VS α

$$\alpha = 1 - \frac{V_{\rm acc}}{V_{\rm disc}}$$

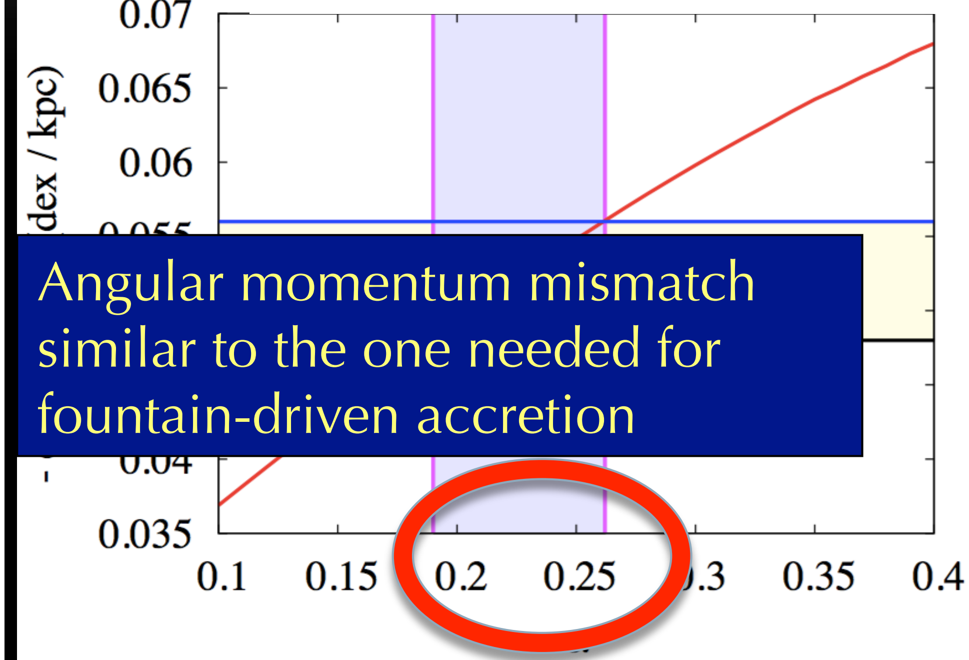
Without inside-out growth



Pezzulli & Fraternali 2016, MNRAS

With inside-out growth

See Matteucci & Francois 1989



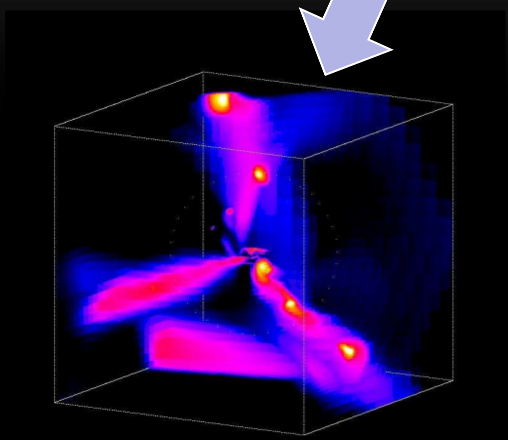
For MW: $v_{\rm rot,\, corona}$~170-195 km/s

➡ Accreting gas rotates 70-80% more slowly than the disc

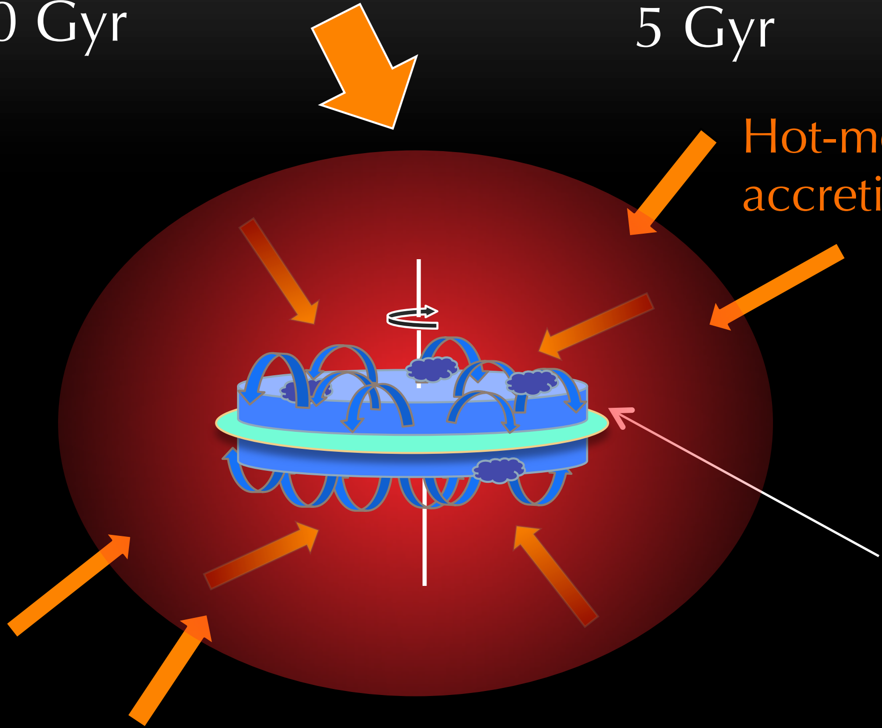
Then it was observed!
$V_{\rm rot}$ = 183 ± 41

Hodges-Kluck et al. 2016, ApJ

POSSIBLE EVOLUTION OF THE MW



Dekel et al. 2009



Interface where corona can cool also thanks to the fountain *(refrigerator)*

Thick disk/bulge formation?
First accretion episode (*Chiappini et al. 2001*)

Thin disk growth

Depletion time ~ Gyr

Need of accretion BUT
Corona is hot: long cooling time

CONCLUSIONS

1. The disc-corona interface is key for accretion (fountain region)
2. Fountain-driven accretion explains many observables
   -> accretion rate of ~1 $M_{\odot}$/yr
3. Radial flows of gas inevitable -> but they can be constrained!
4. Thin disc grows through the cooling of the corona triggered by fountain