Fountain Driven Accretion

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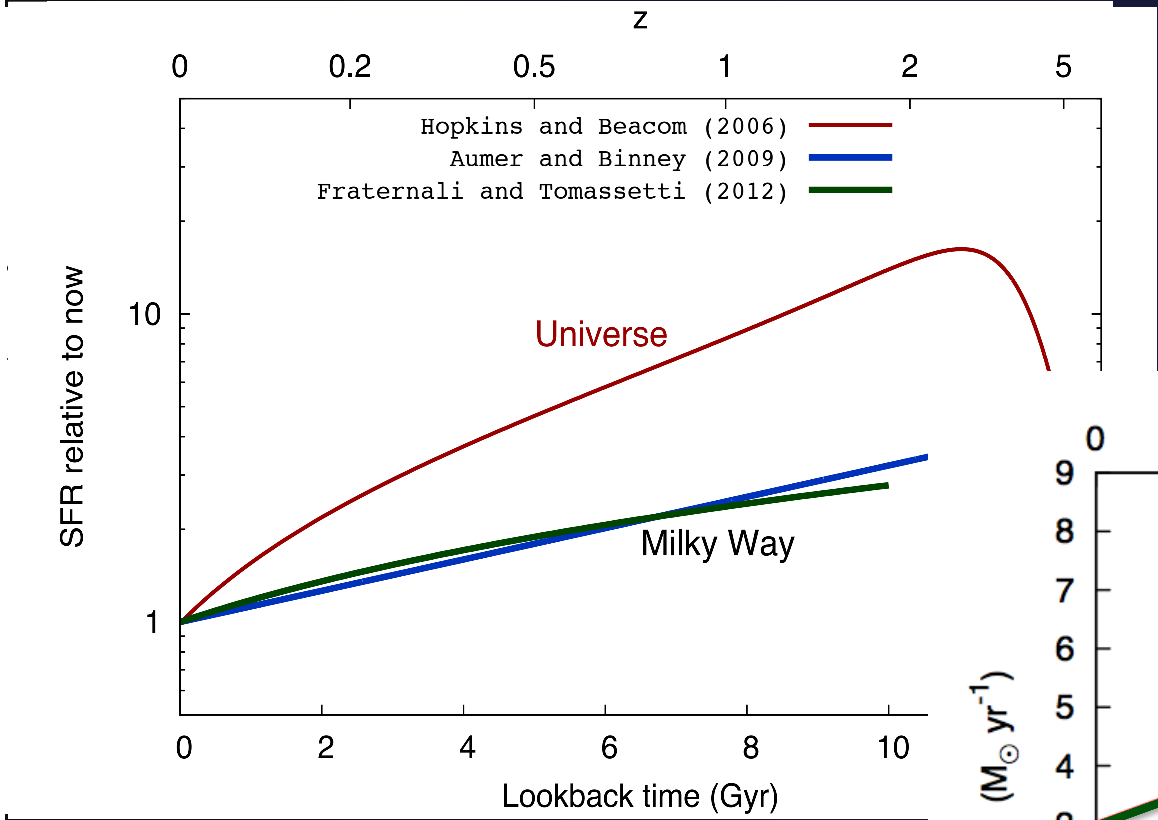
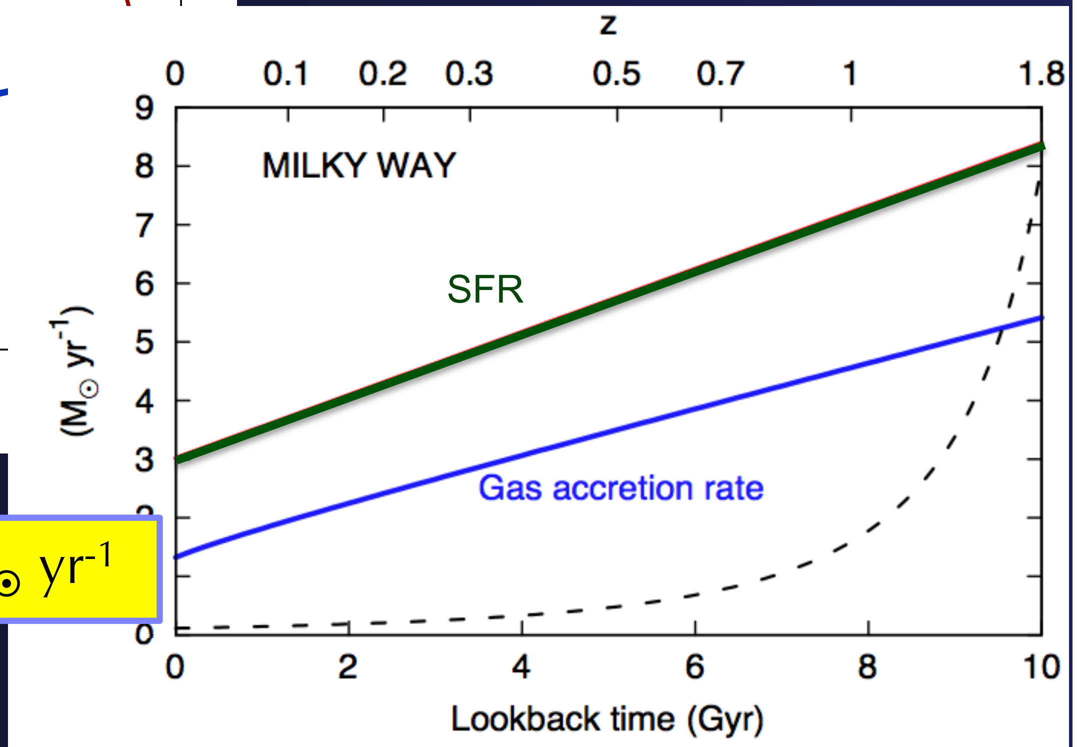
Gas accretion in disk galaxies





At low metallicity!

Chemical evolution models (e.g. *Chi*

G dwarf problem (e.g. *Haywood 200*

Deuterium abundance (e.g. *Steigman+ 2007*)

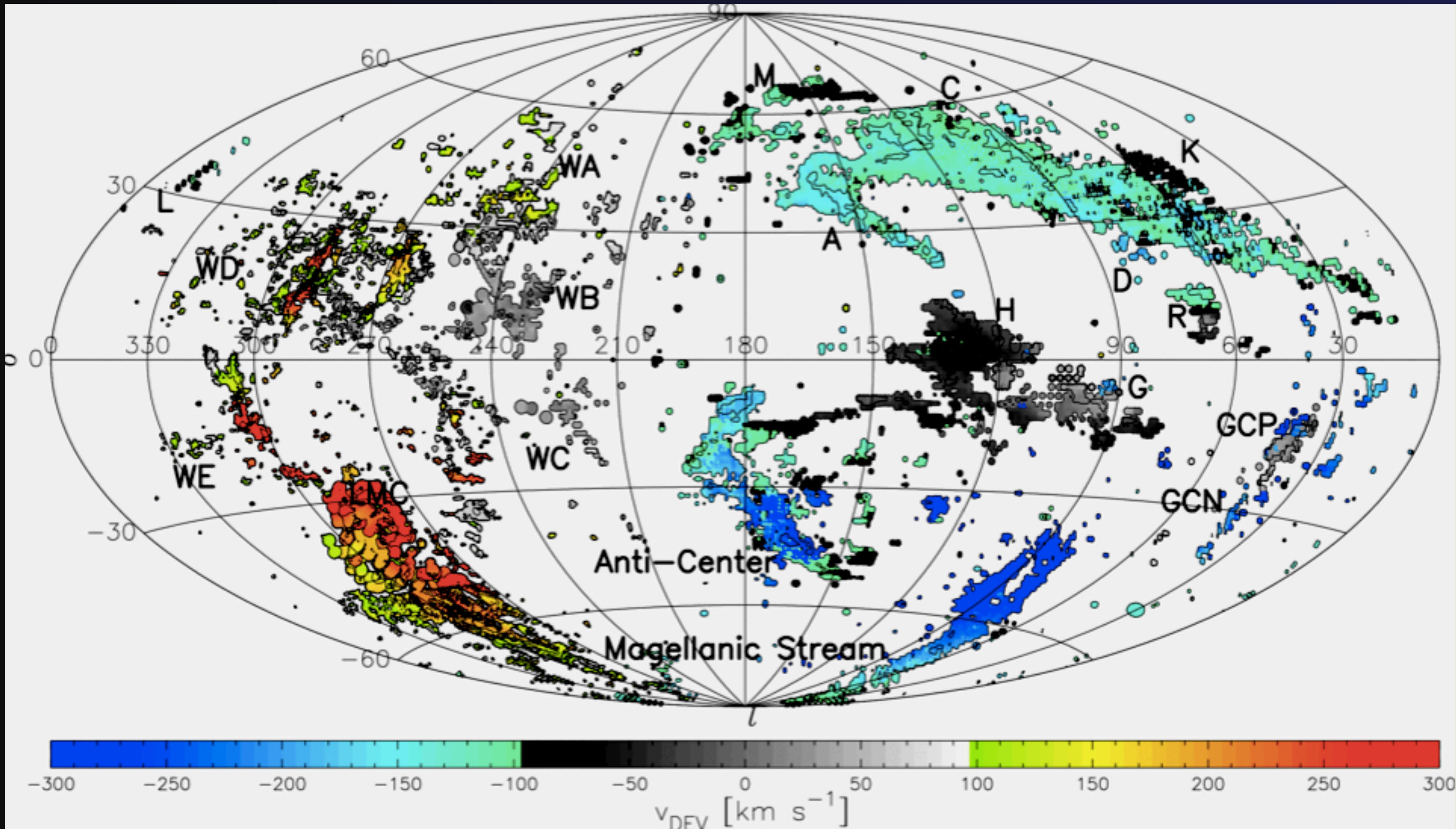
~1 $M_\odot$ yr^{-1}

Sánchez Almeida et al. 2014, A&ARv

Fraternali & Tomassetti 2012, MNRAS

Neutral gas accretion

HI High Velocity Clouds



Typical Distances: ~10 kpc

h~few-10 kpc

Z~0.1-0.4 $Z_\odot$

M<10^7 $M_\odot$

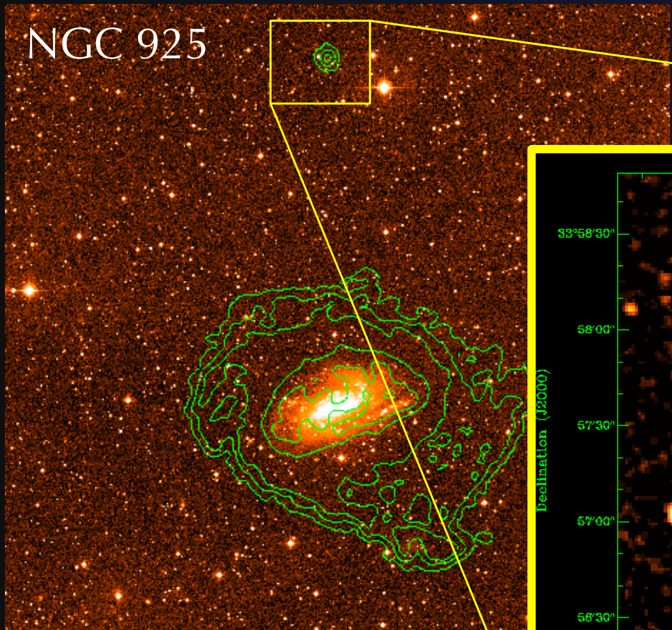
Wakker et al. 2007, 2008; Tripp et al. 2003

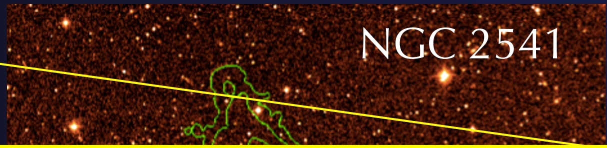
Accretion from High Velocity Clouds

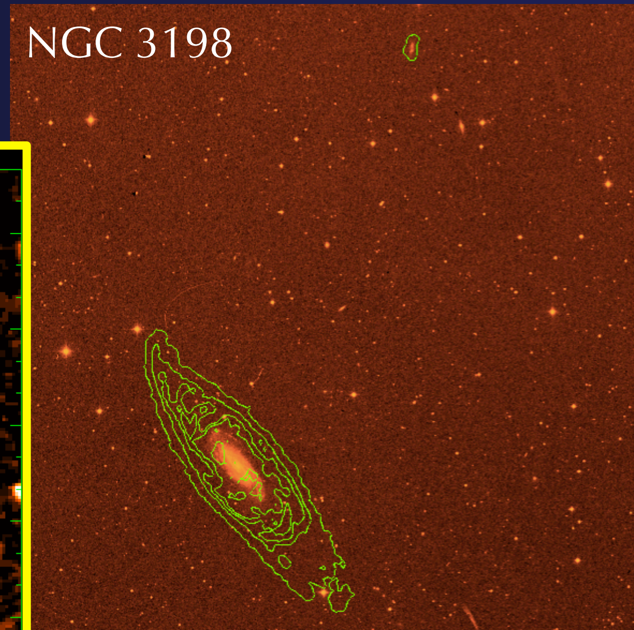
→ ~ 0.08 $M_\odot$/yr   Includes He and factor 2 of ionised gas!

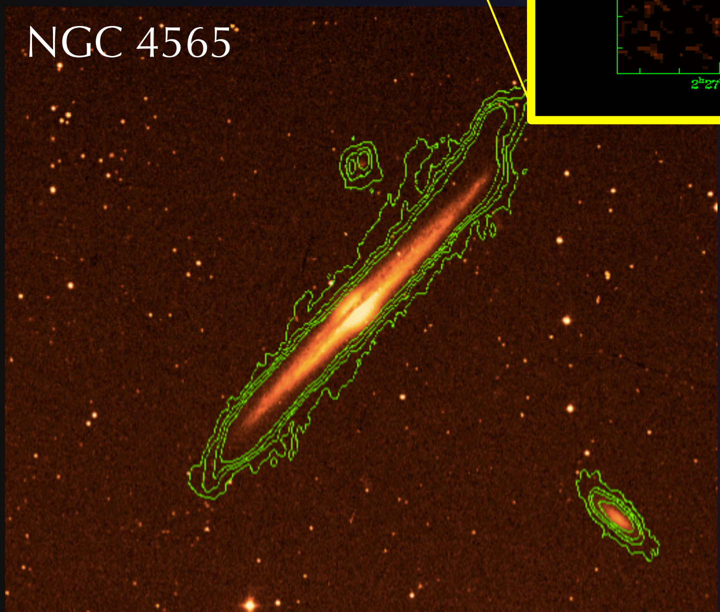
Putman, Peek, Joung 2012, ARA&A

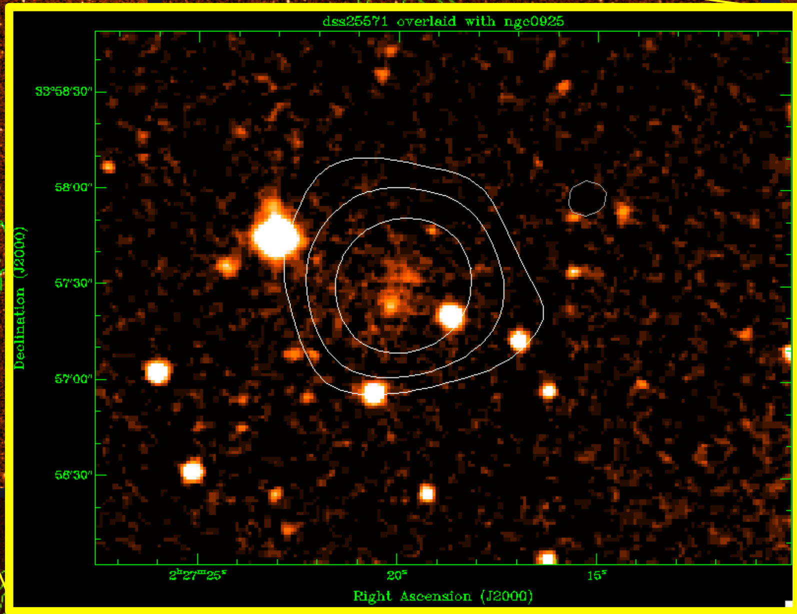
No floating HI clouds











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

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

HALOGAS survey

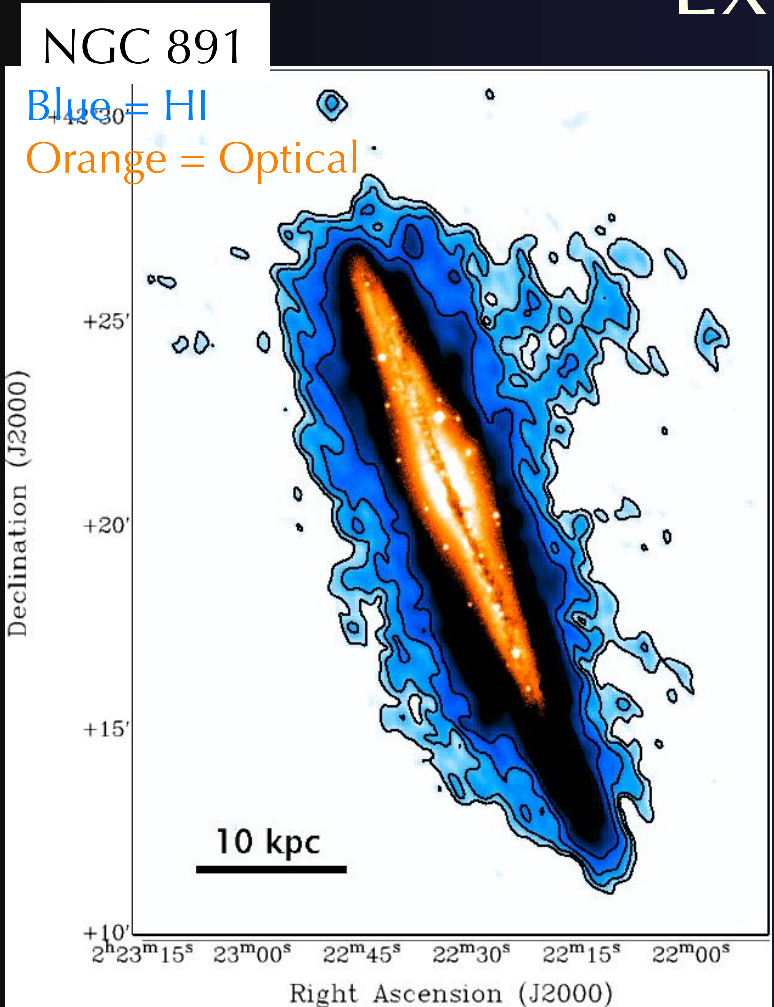
Heald et al. 2011

Juette et al., in prep

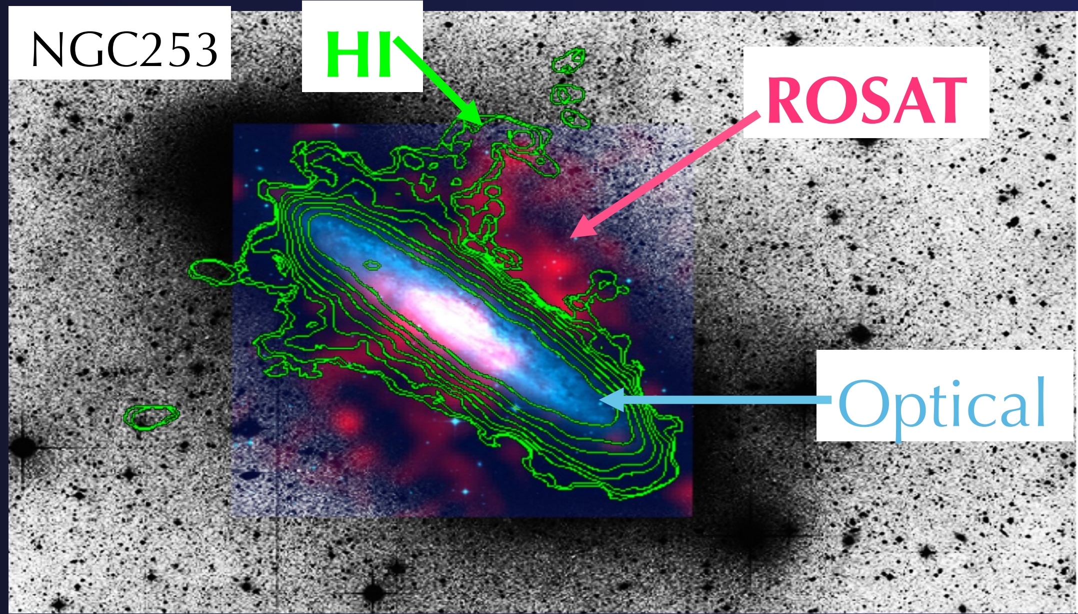
Not enough mergers to feed star formation

Di Teodoro & Fraternali, A&A, 2014

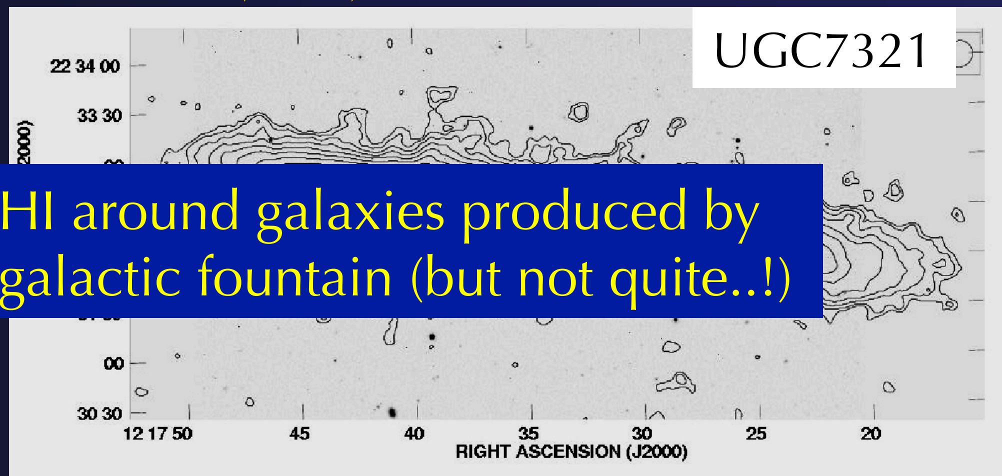
Extraplanar HI



Oosterloo, Fraternali, Sancisi 2007, AJ



Boomsma et al., 2005, A&A



HI around galaxies produced by galactic fountain (but not quite..!)

Matthews and Wood, 2003, ApJ

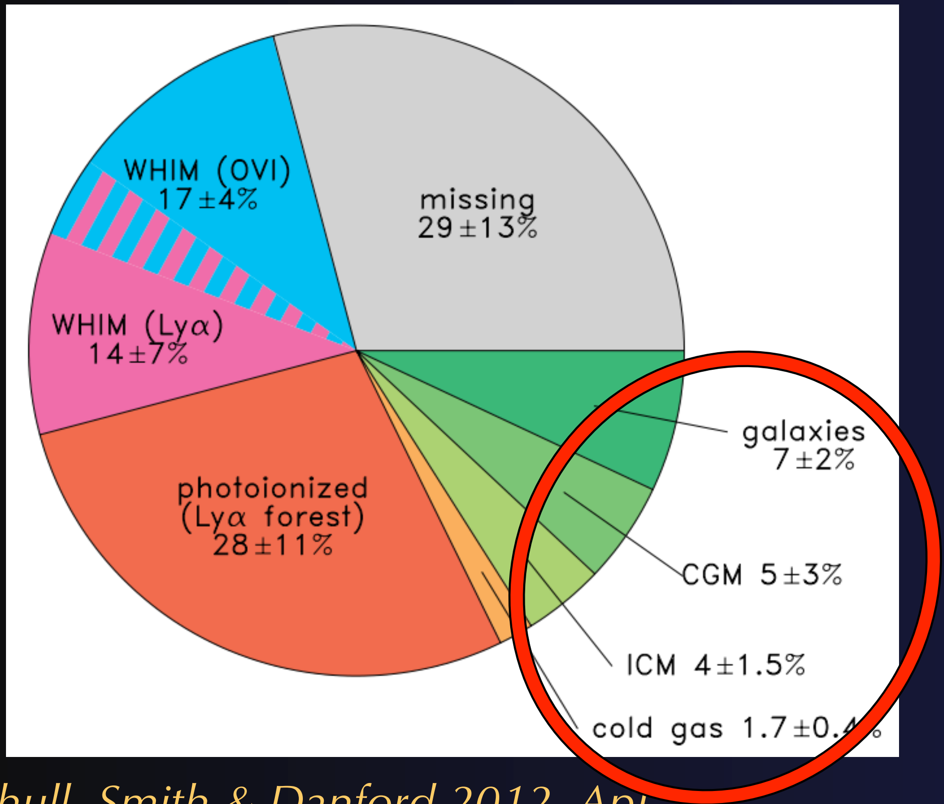
Mass_{HI} = 5-20 % disk mass

Galactic fountain kinematics (lagging halo)

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

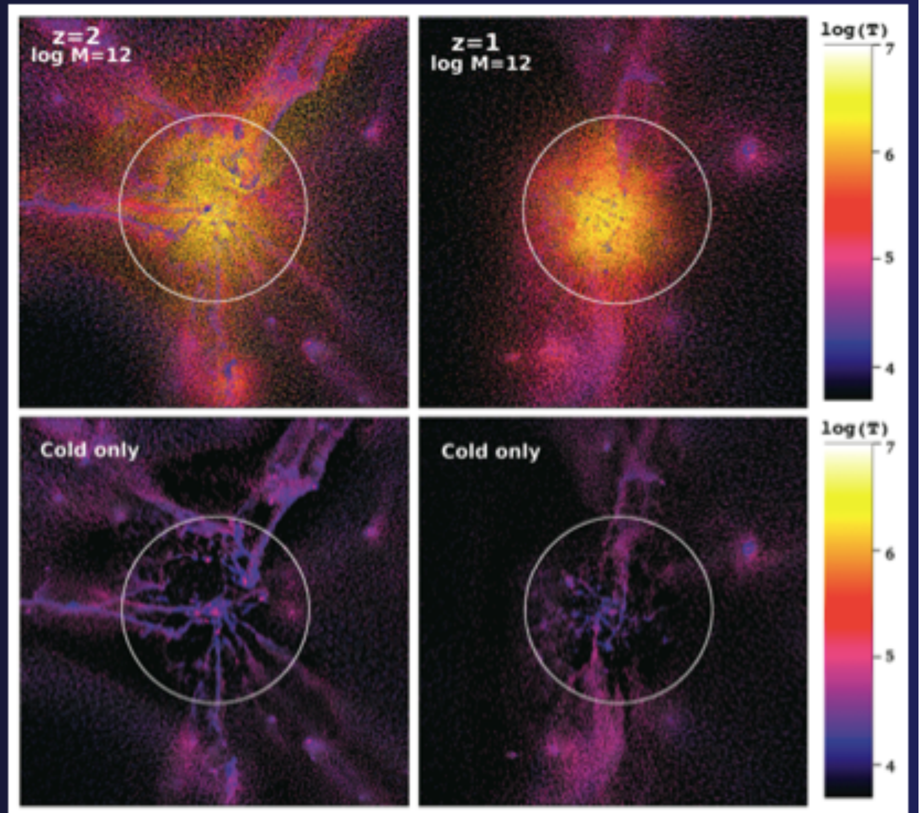
Where is the gas?

Missing baryons



Shull, Smith & Danford 2012, ApJ

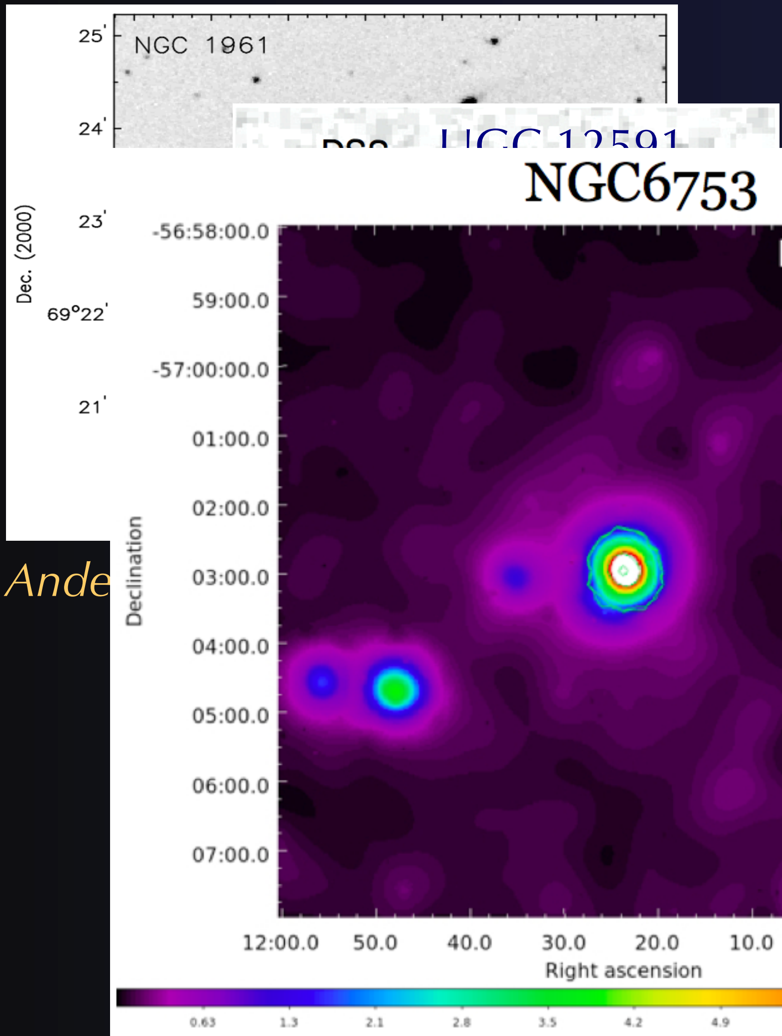
Most baryons are not in collapsed structures

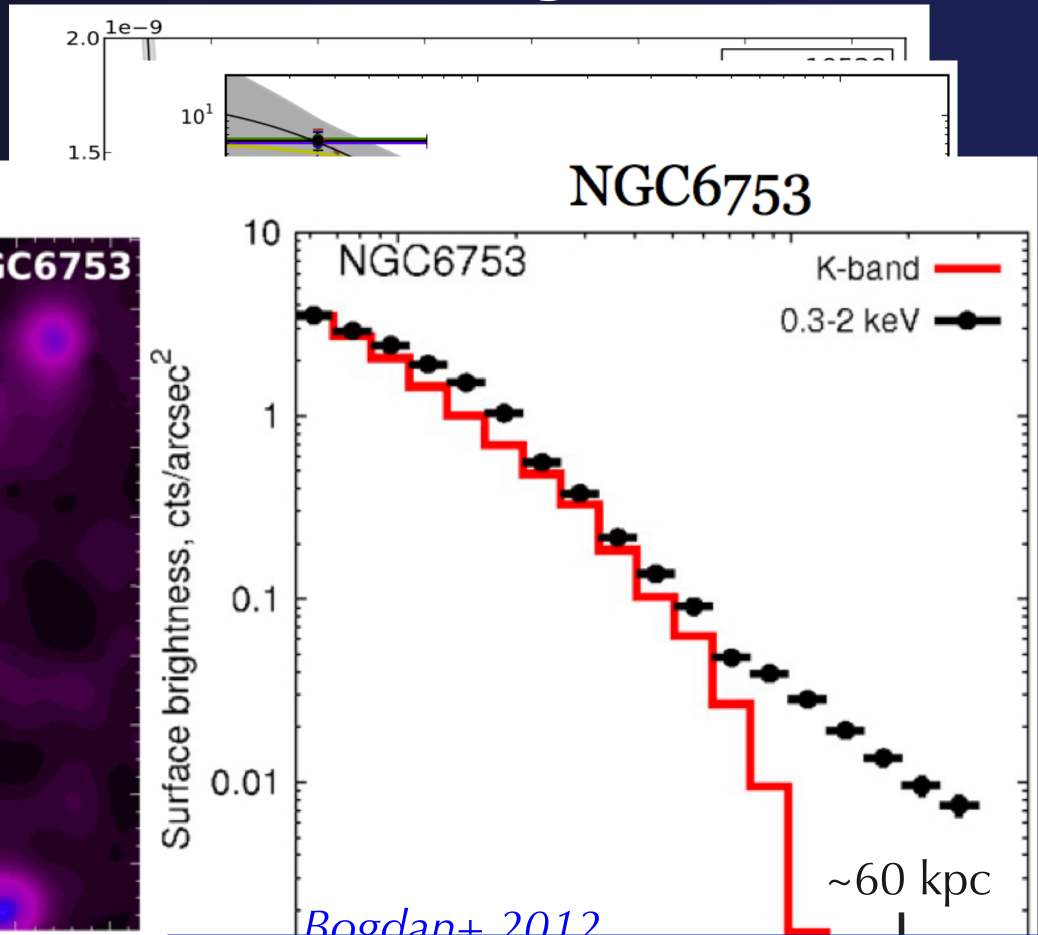


Keres+ 2009
Hot-mode dominates for z<1-2 for MW halos

Cosmological coronae as in the classical theory (e.g. *White & Rees 1978*)

Hot coronae around disc galaxies





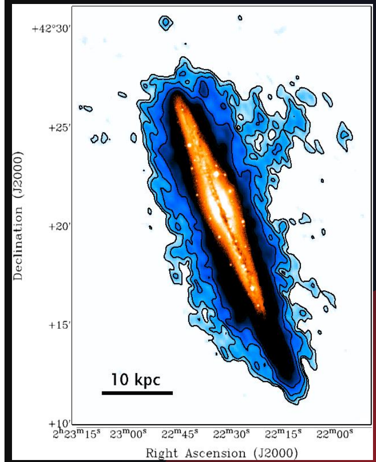
Corona is a large potential reservoir: needs to cool and accrete

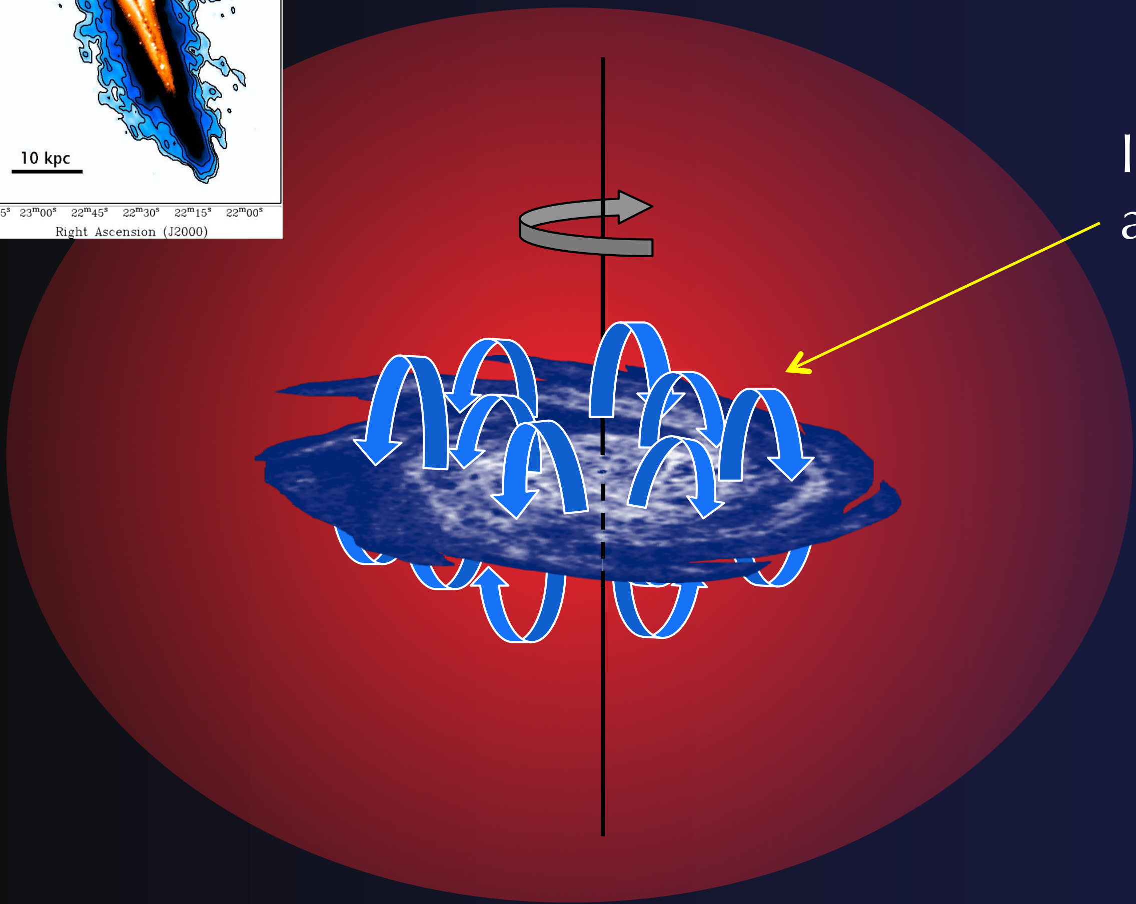
Stacking ROSAT *Anderson+ 2013*
Corona of the MW *Gatto+ 2013*

- Corona detected out to almost 100 kpc
- Mass ~ M_b of discs (~10-20% of missing gas)

Fountain-driven accretion

Disc-corona interplay





Interface layer where disc and coronal materials mix

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

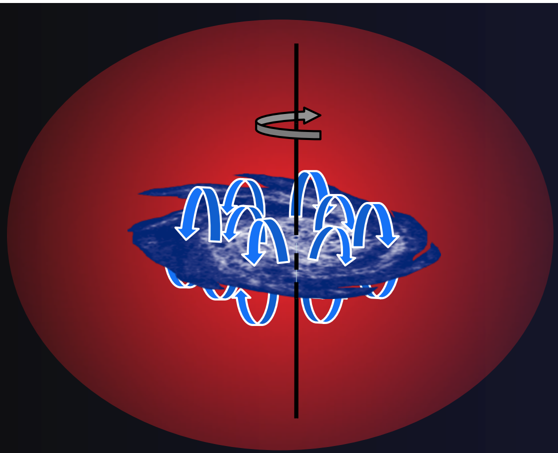
1. *cold* gas
2. High Z gas

Fraternali & Binney 2008, MNRAS

Marinacci, et al. 2010, 2011, MNRAS

Marasco, Fraternali & Binney 2012, MNRAS

Disc-cloud corona interaction

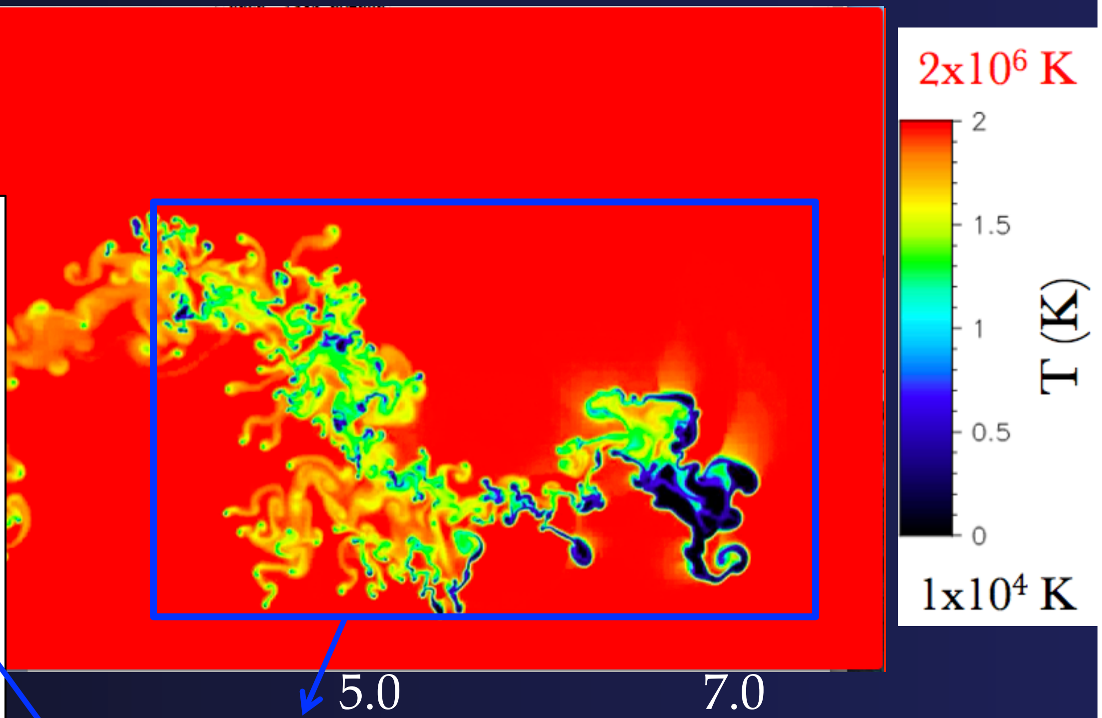


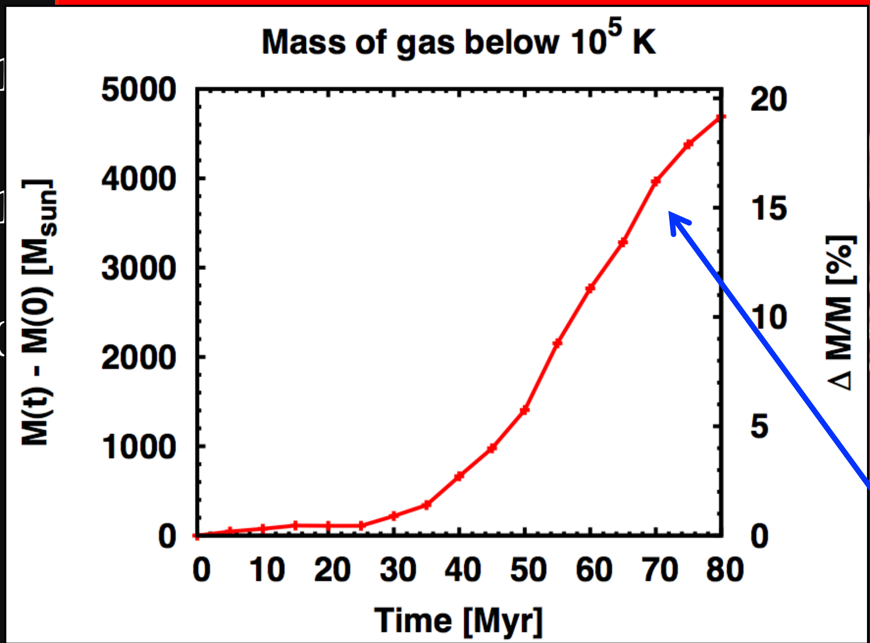
T_{corona}=2x10^6 K

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

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

1 pc x 1 pc Grid!



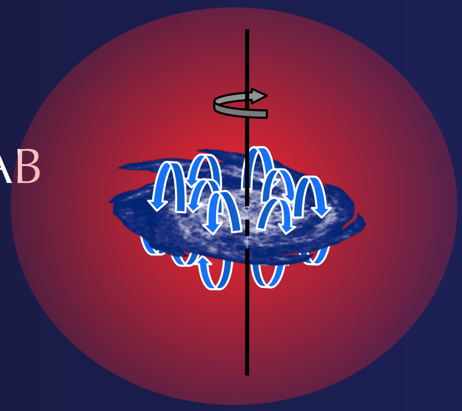


Mass of cold gas increased by ~10-20%!

Marinacci, et al. 2010, 2011, MNRAS

Armillotta et al., in prep.

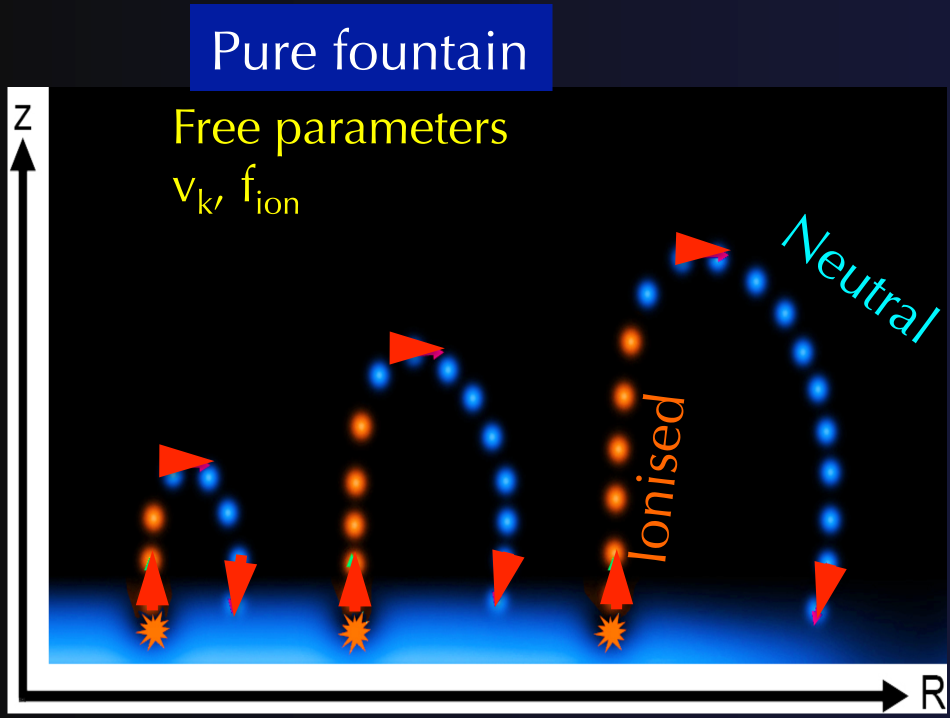
Galactic fountain model

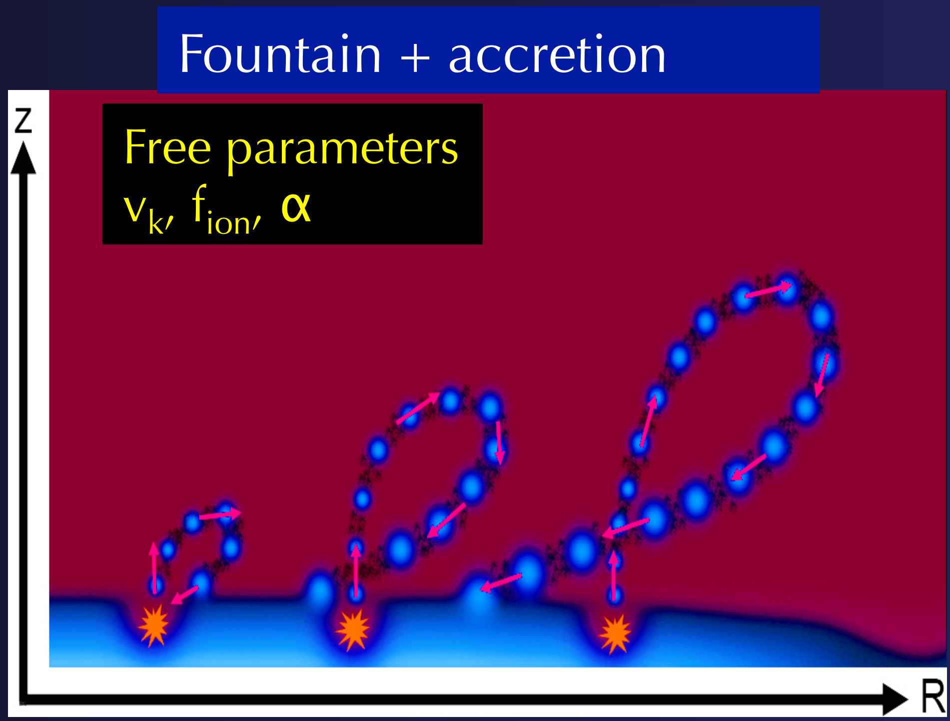


Building of several model cubes -> minimization residuals with LAB

We fit:

1. kick velocities (v_k) → scaleheight
2. Ionised fraction (f_{ion}) → vertical motions
3. Accretion coefficient (α) → Loss of angular momentum $\dot{m} = \alpha m$

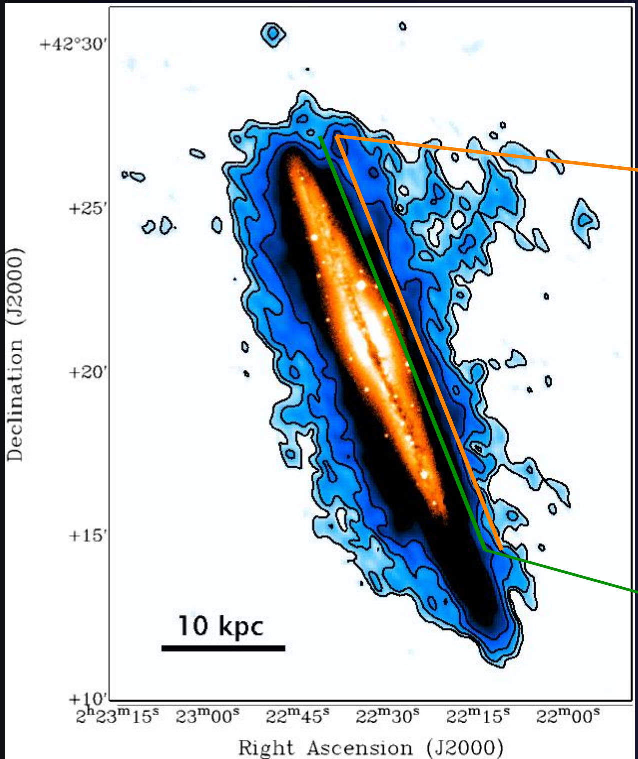


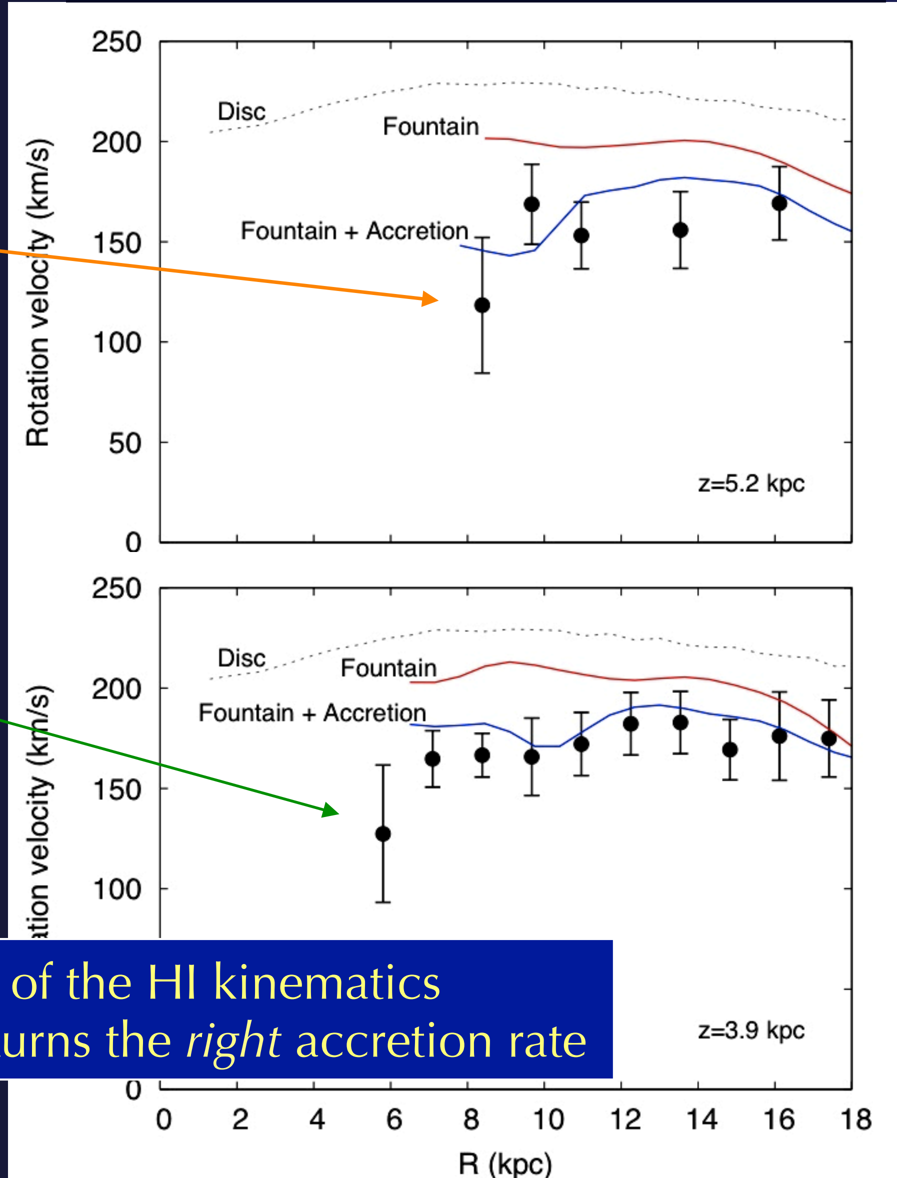


Galactic fountain and gas accretion

Fraternali & Binney 2006, 2008, MNRAS

NGC 891, total HI map





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

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

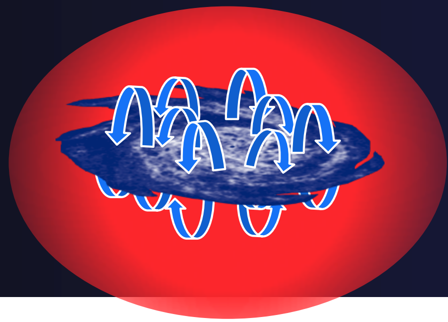
Fit of the HI kinematics returns the *right* accretion rate

Fountain accretion in the Milky Way

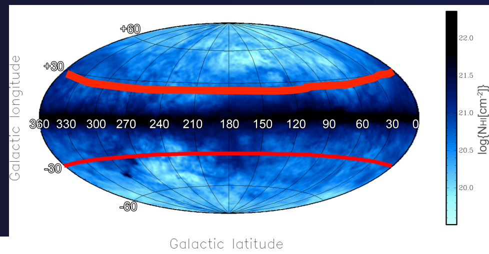
1) Extraplanar HI

Pure fountain

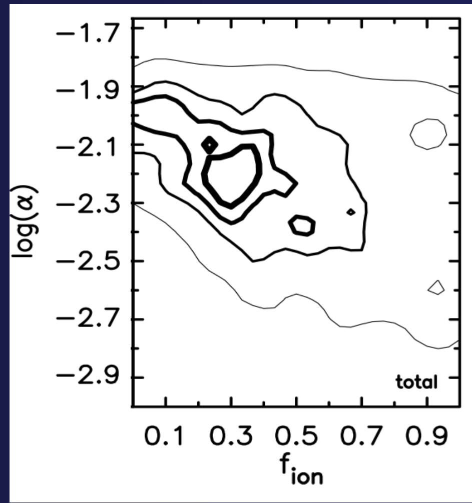
Fountain + accretion

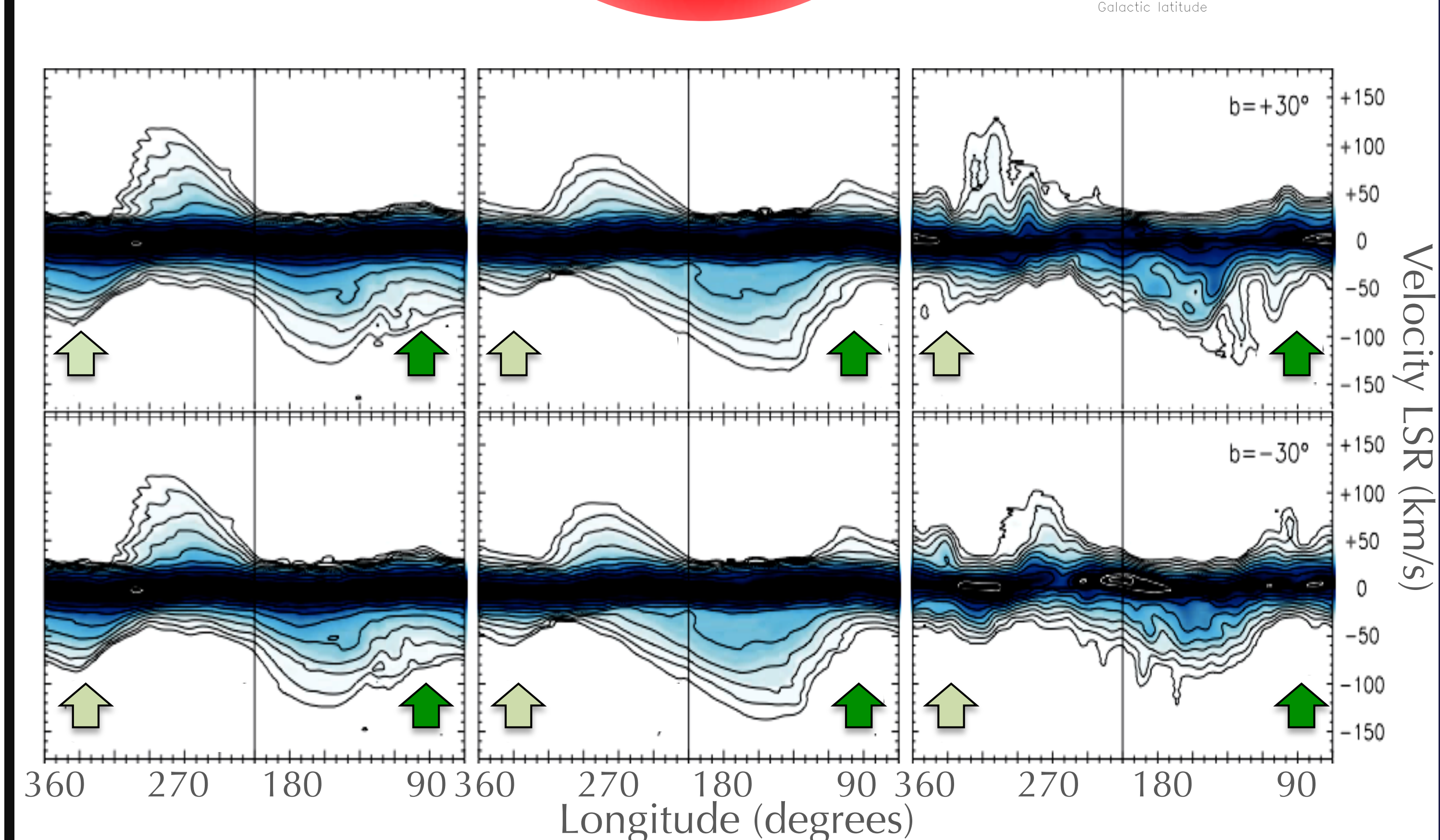


HI data



Best fit





Marasco, Fraternali & Binney 2012

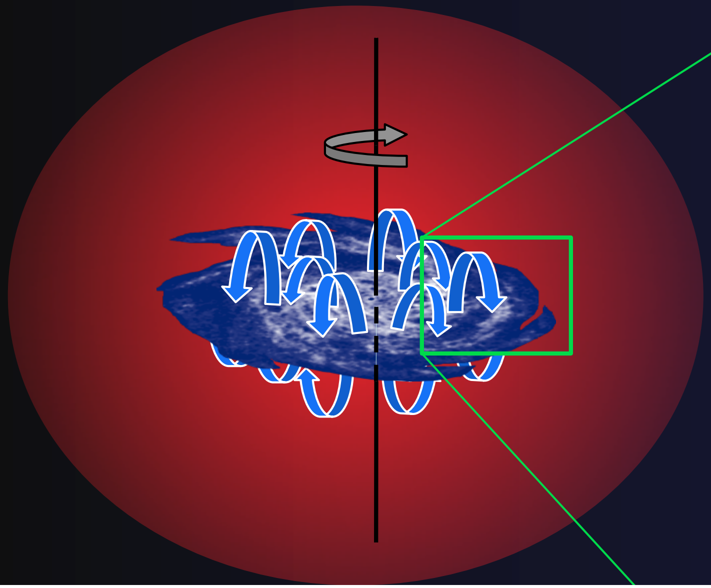
$v_k = 75$ km/s

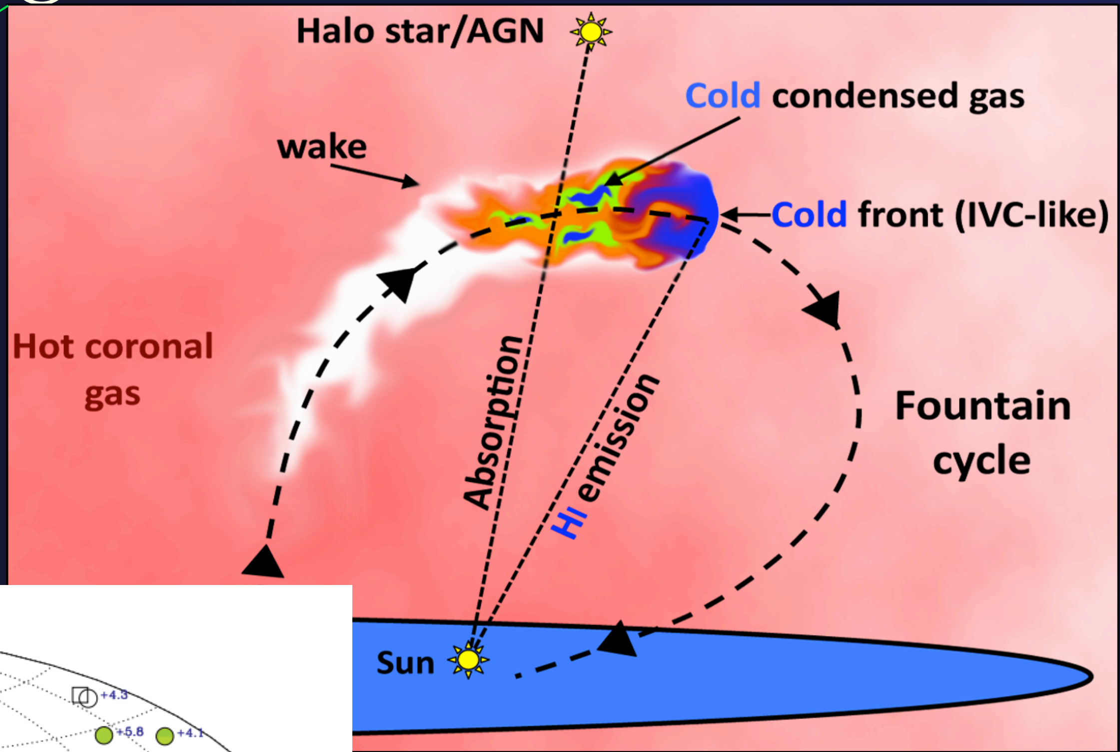
$f_{ion} = 0.3$

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

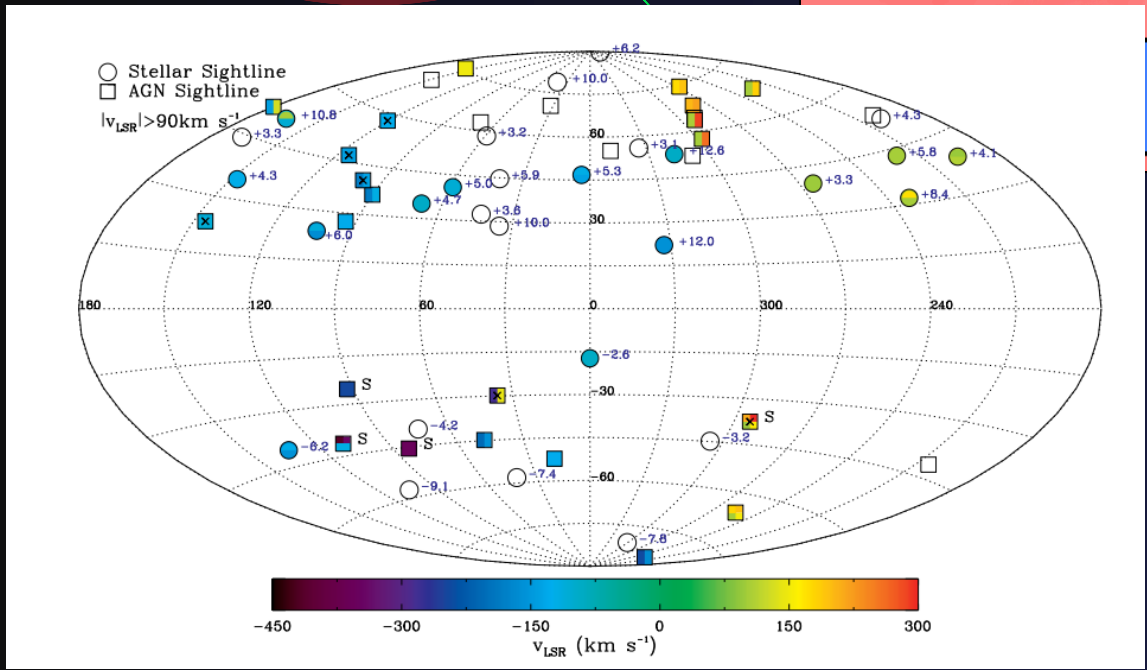
Halo gas:
~80% from fountain
~20% from corona

Cooling in the wake





Fraternali et al. 2013, ApJL

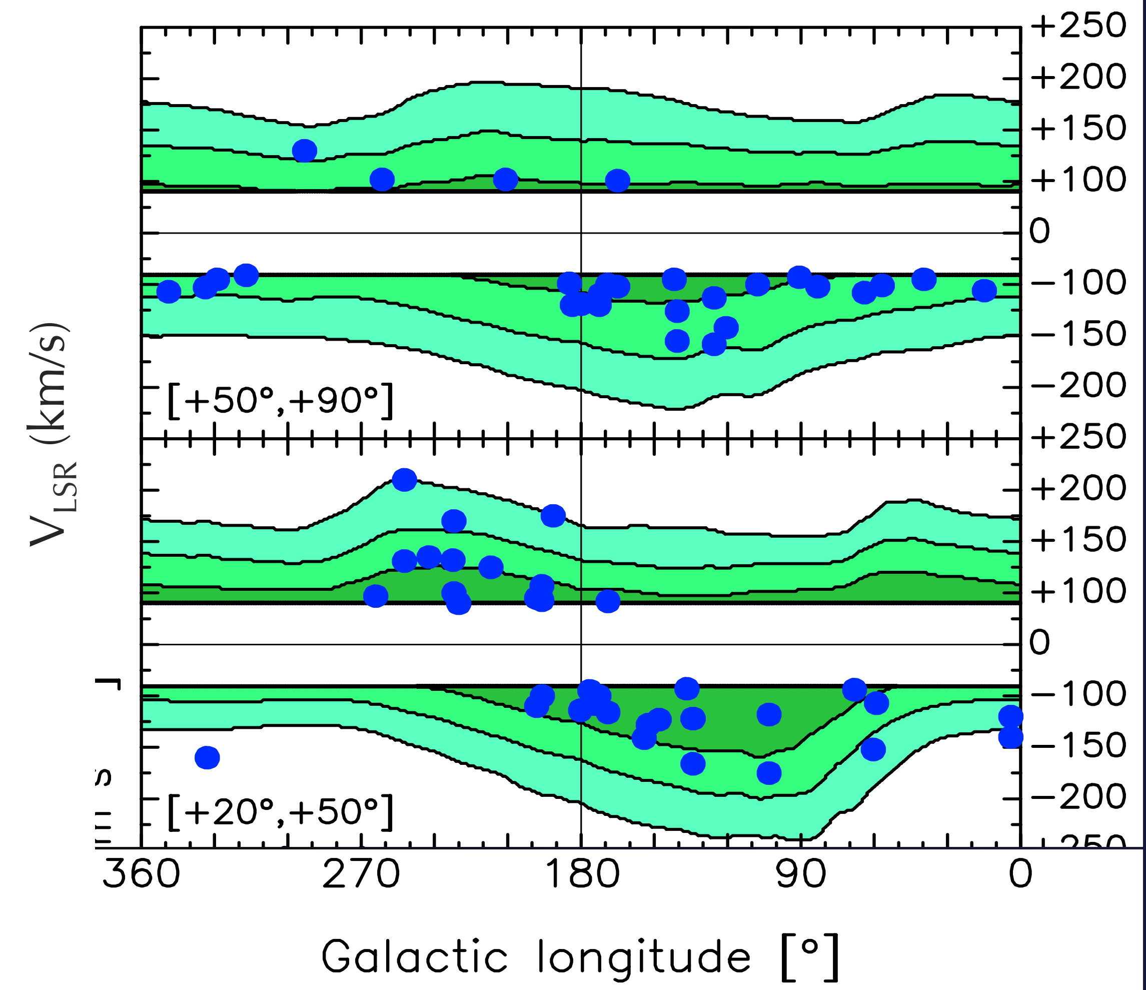


Shull+ 2009, ApJ
Lehner & Howk 2011, Science
Lehner et al. 2012, MNRAS

C II, Si II, Si III, … 4.3<logT<5.3 K

2) Ionized gas in the MW

Marasco, Marinacci & Fraternali 2013, MNRAS



• *Data from Lehner et al. 2012, MNRAS*

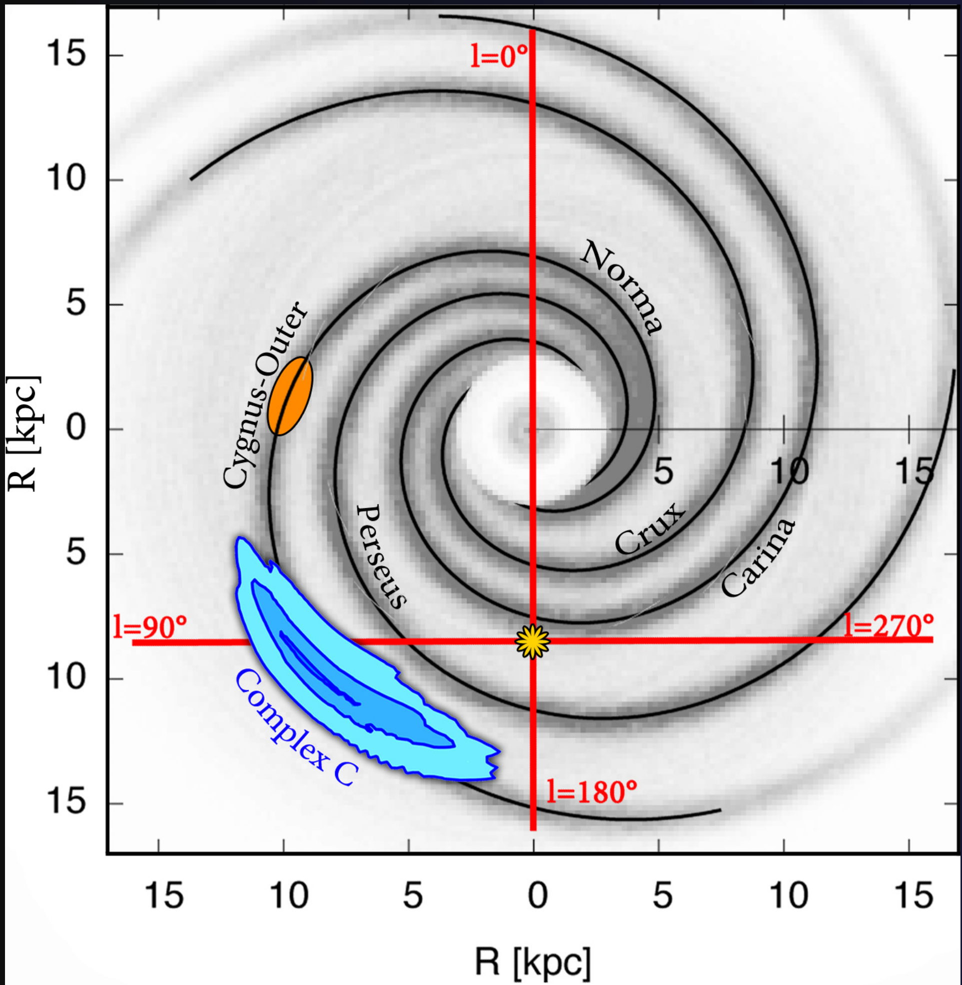
This model reproduces:

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

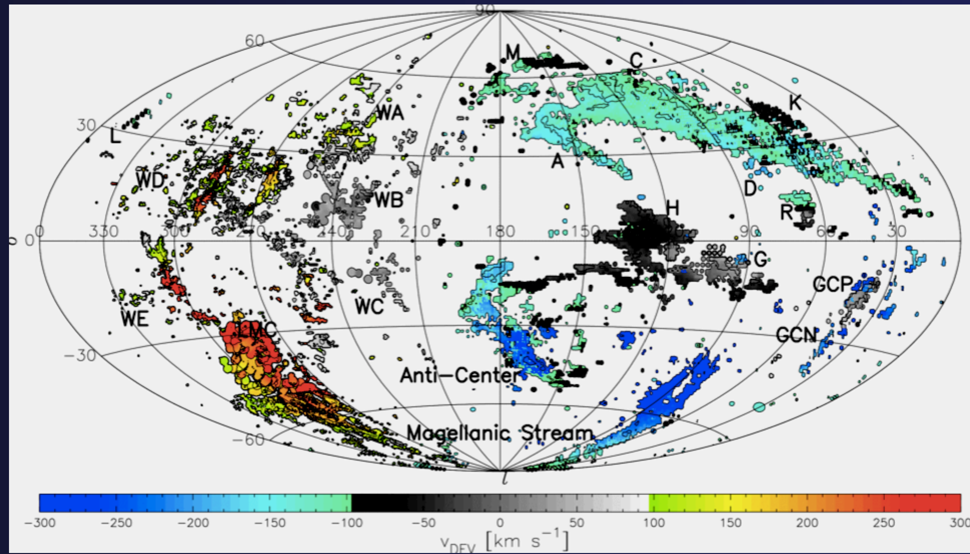
'Warm' accretion: ~1 $M_{\odot}$/yr

Similar to interaction between Mag Stream and corona
Bland-Hawthorn et al. 2007, ApJ

3) High velociy clouds



Fraternali, Marasco, Armillotta, & Marinacci, MNRAS, submitted

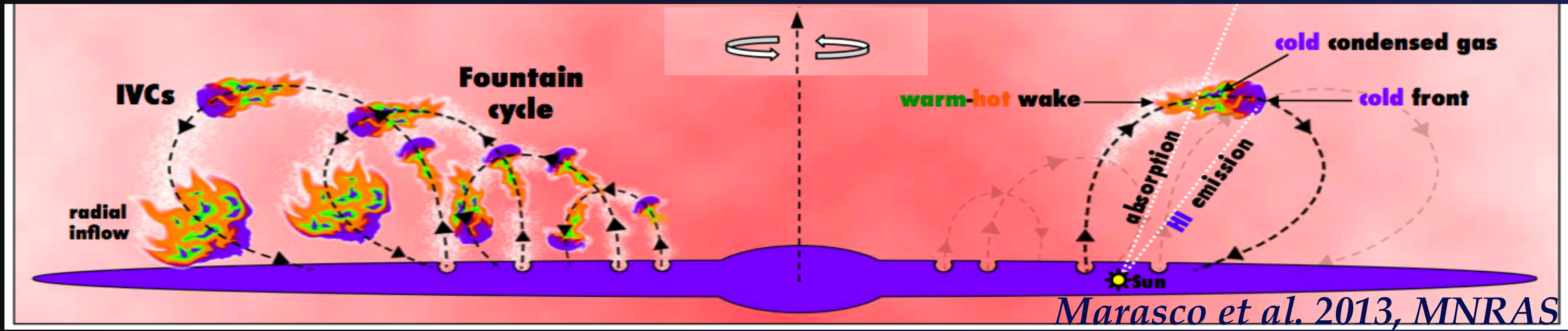


Origin of Complex C

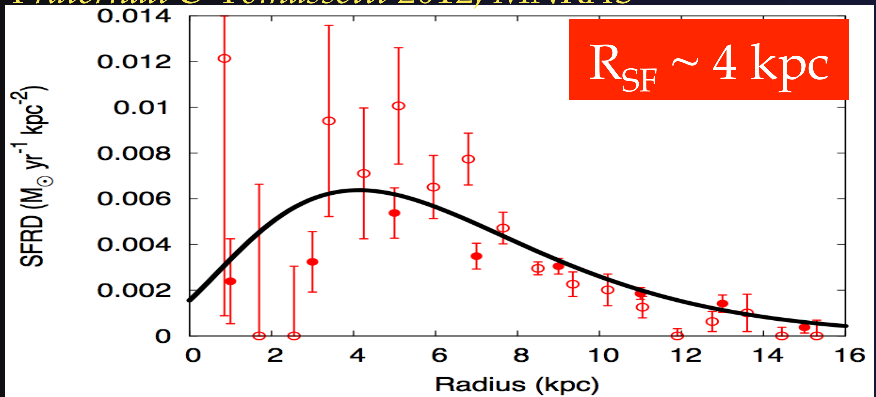
Superbubble blowout in the Cygnus-Outer arm triggering the cooling of a large portion of the corona

Fountain-driven accretion reproduces extraplanar HI, ionised absorbers & HVCs
And predicts the *right* accretion rate

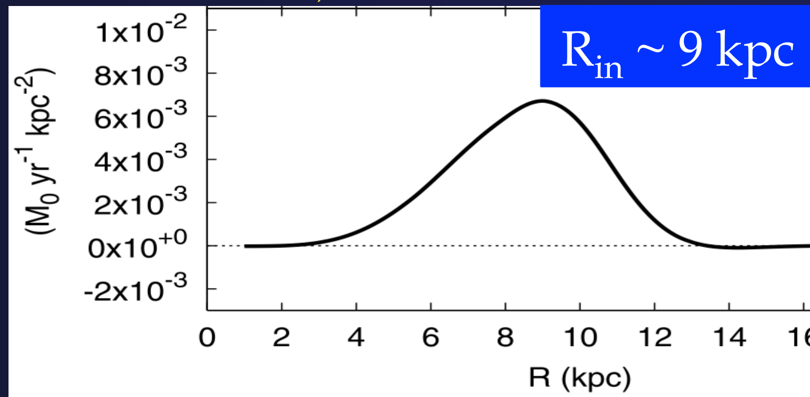
Inside-out evolution

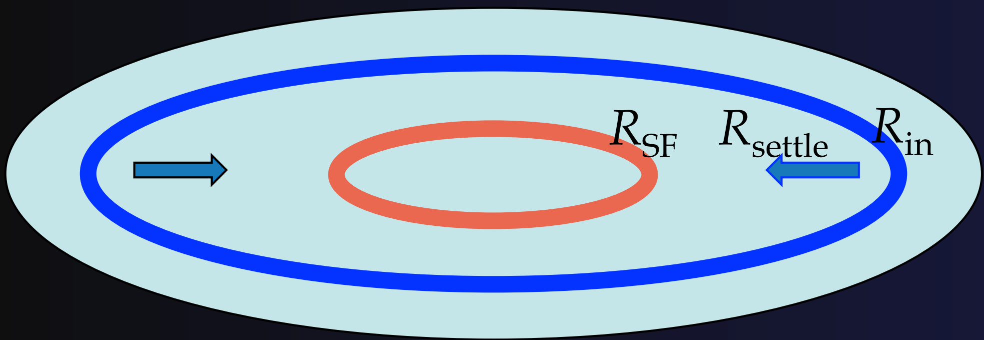


Fraternali & Tomassetti 2012, MNRAS



Marasco et al. 2012, MNRAS





If accreted gas conserves j

$j_{in} \sim R_{in}\, v_{cor} = R_{settle}\, v_{disk}$

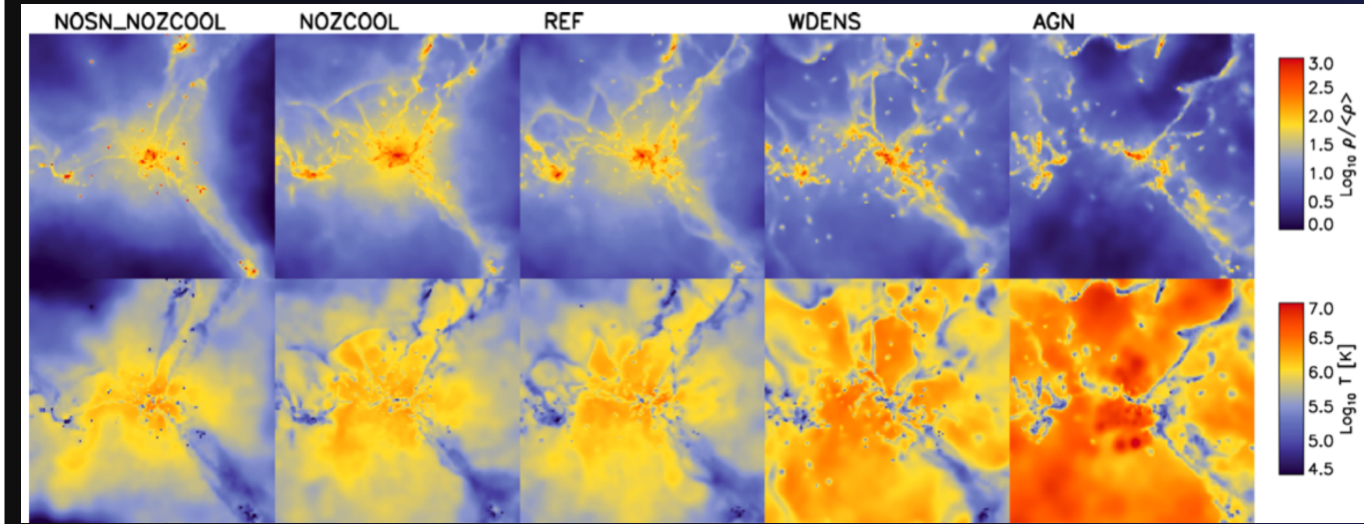
$v_{cor} \sim v_{disk}$-75 and $R_{settle} > R_{SF}$

Mayor & Vigroux 1981; Gabriele Pezzulli, in progress

Inside-out growth
Metallicity gradient

Relation to other simulations

Feedback enhancing cooling

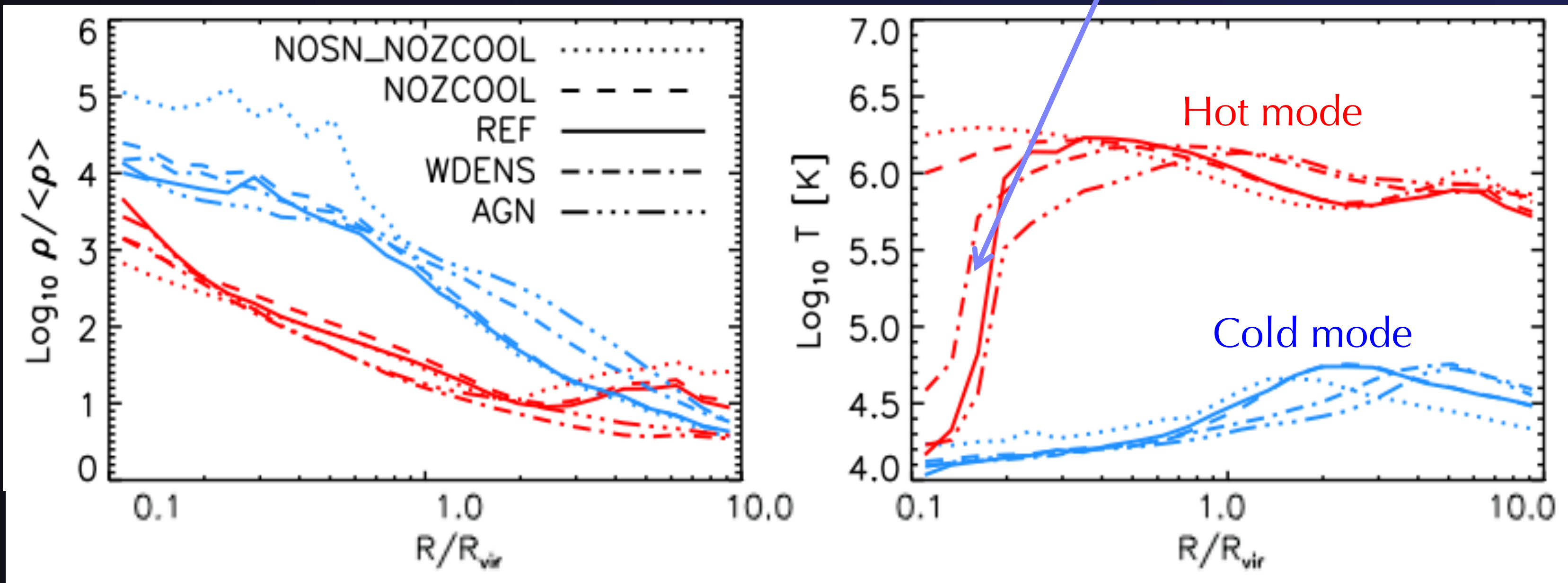


z=2

Cooling induced close to galaxies by metals ejected by feedback

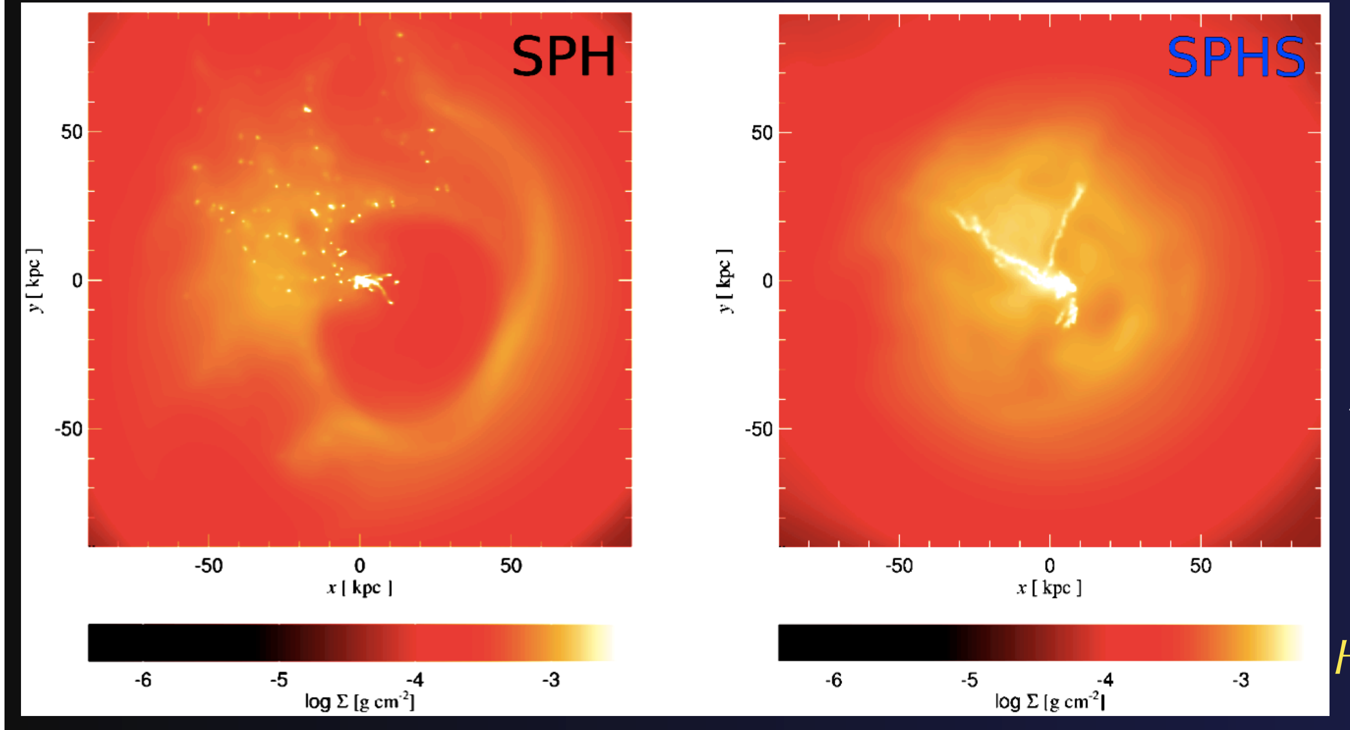
OWLS

GADGET-3



van de Voort & Schaye 2012

Feedback and accretion



Modified SPH

No formation of clumps

"Cold gas condenses from the halo at the intersection of supernovae-driven bubbles. This positive feedback feeds cold gas to the galactic disc directly, fuelling SF."

Hobbs et al. 2013, MNRAS

MaGICC - GASOLINE

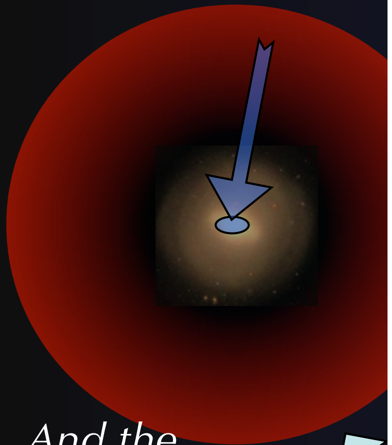
Importance of galactic fountain in the gas cycle

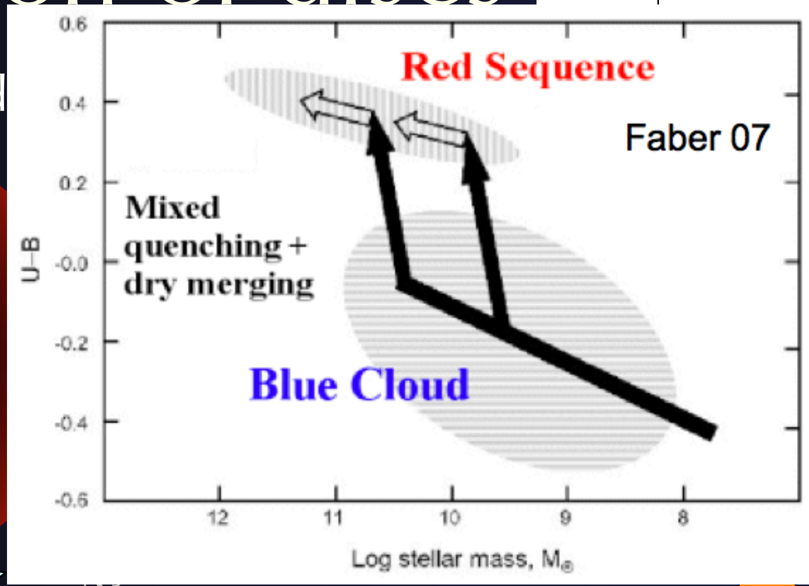
Gas in the fountain cycle comes back to the disk more metal poor!

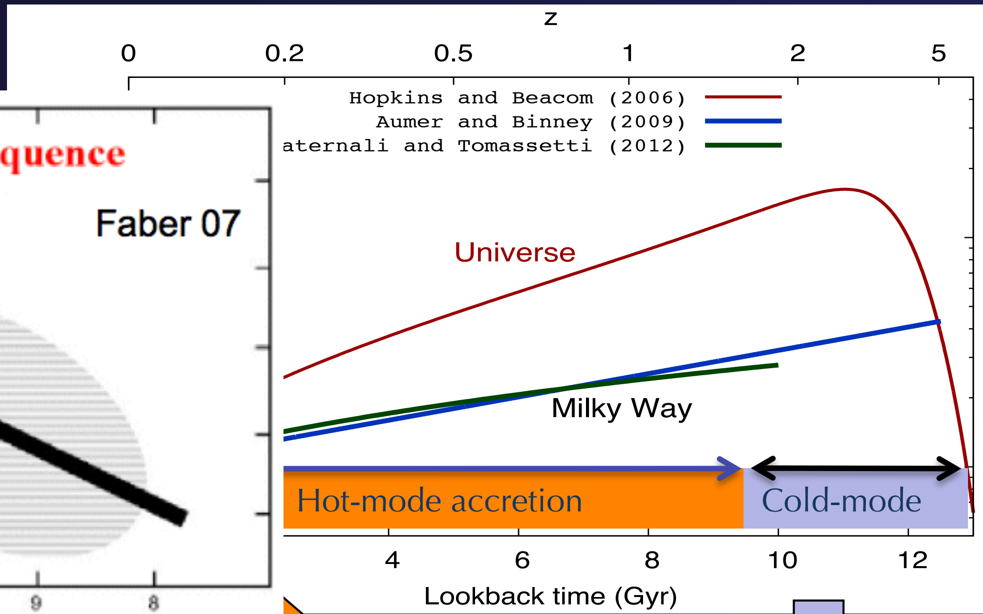
Brook+14

Evolution of discs

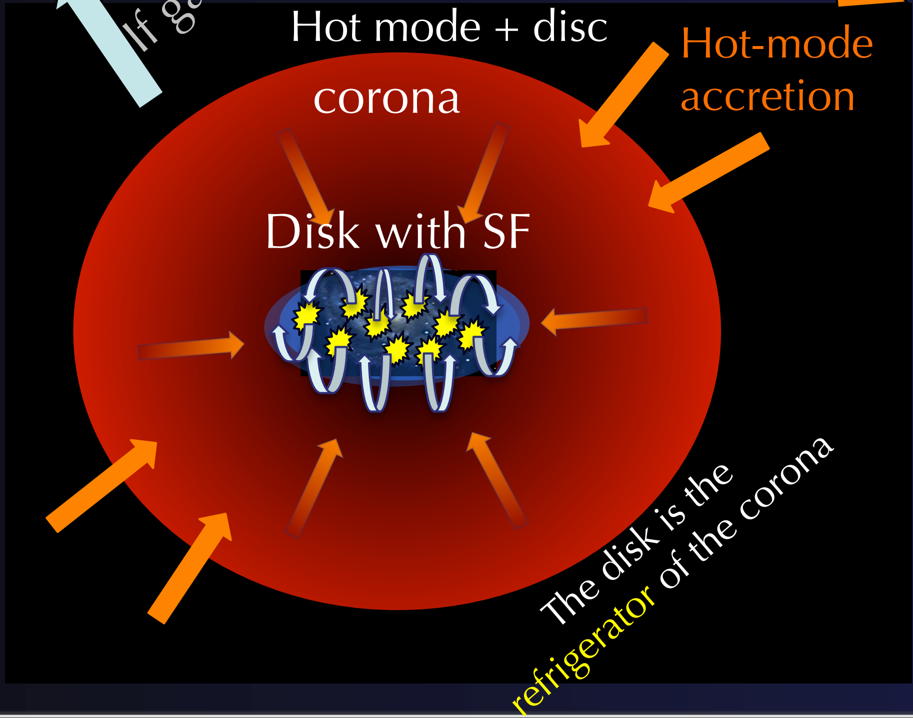
Red and dead



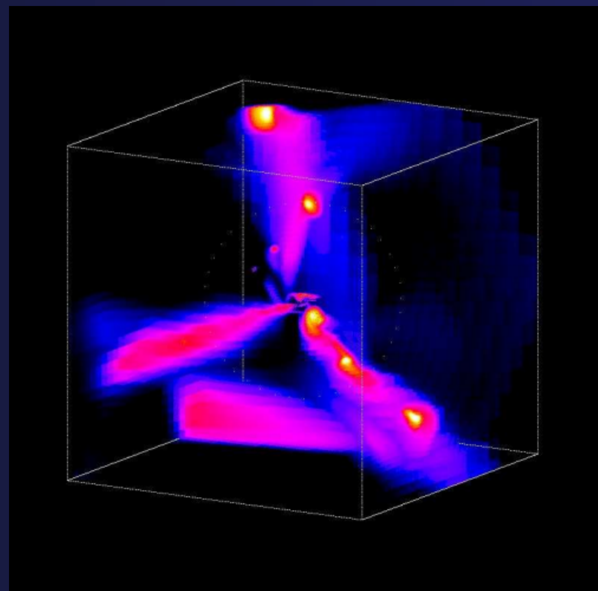




And the corona does not cool further



Cold mode



Dekel et al. 2009

Conclusions

- Accretion does not come from clouds but from cooling of the CGM

- Fountain-driven accretion explains:

    Extraplanar HI in the MW and external galaxies
    Ionized absorbers in the MW
    How galaxies accrete at rate ~ their SFR

- Hot mode feeds the corona & fountain mode feeds the disk: only late-types keep accreting