Gas flows at the interface between galaxies and IGM

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3 points

0. Gas accretion is very important

1. There is a lot of cold extraplanar gas around spirals

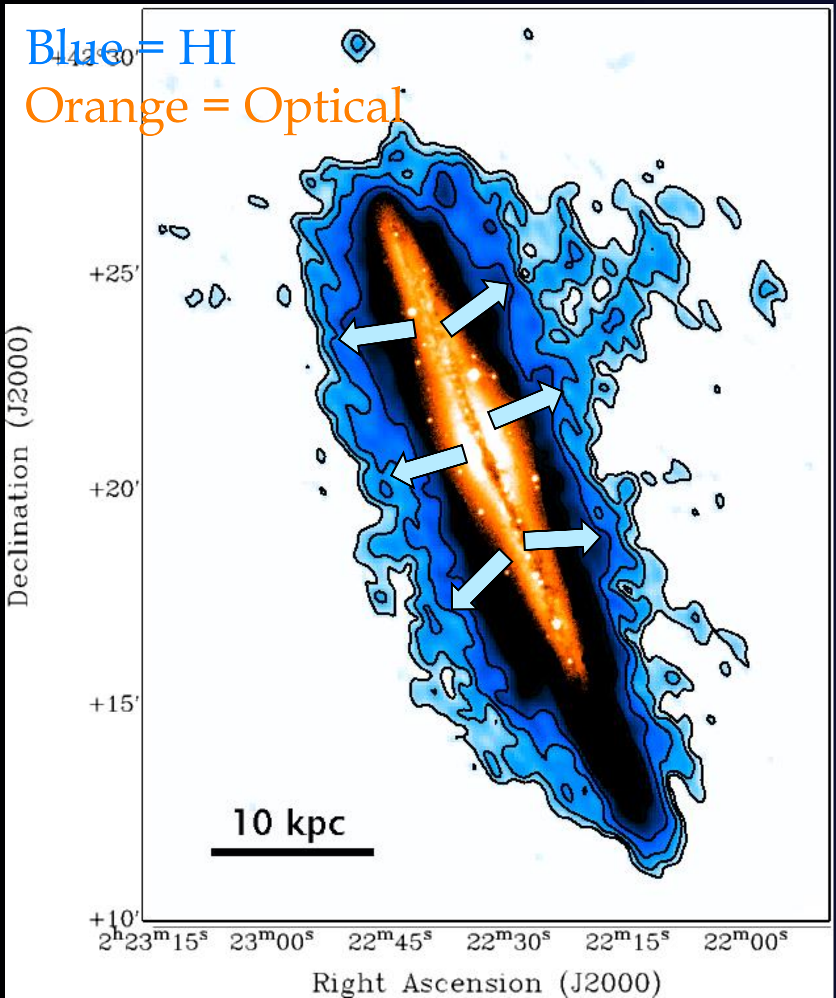
2. Galactic fountain cools the corona: Feedback <u>is not</u> only *negative*

3. Build artificial data

Cold extraplanar gas

Large amount of extraplanar HI

NGC 891



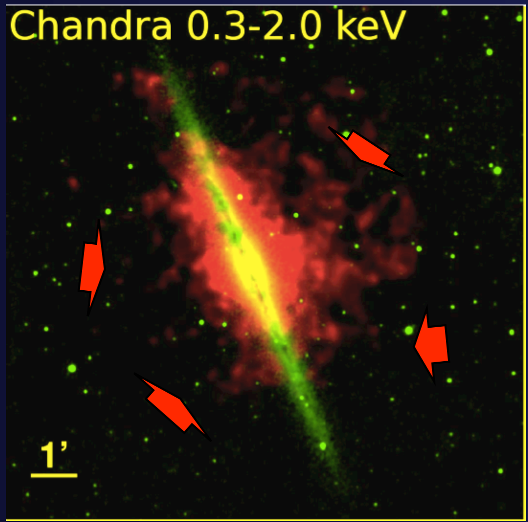
Oosterloo, Fraternali, Sancisi 2007, AJ

$Mass_{HI}$ = 1.2 x 10^9 $M_\odot$

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

Galactic fountain kinematics

Hot halo gas

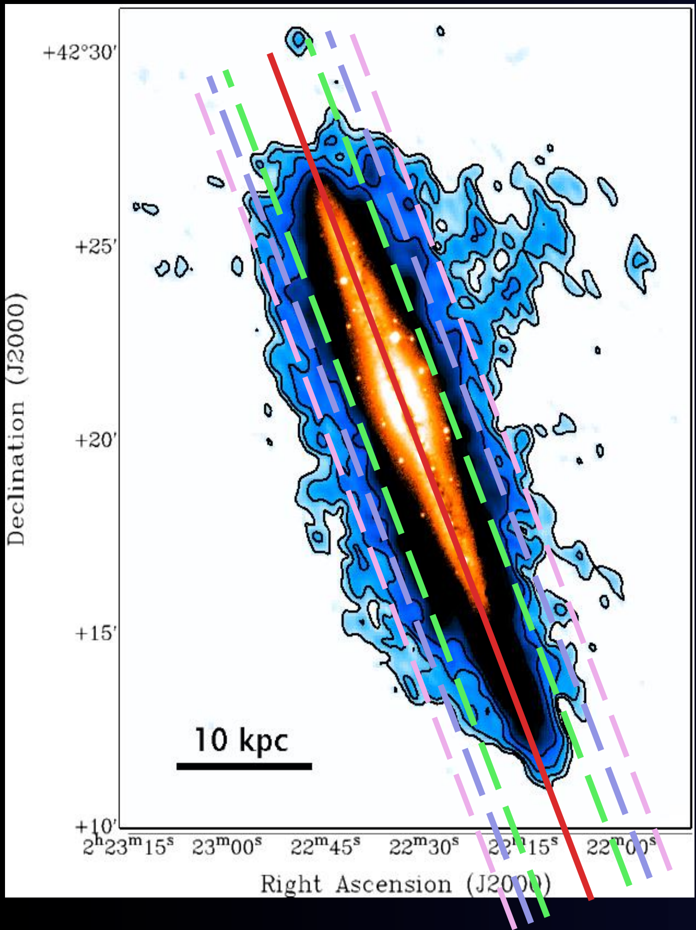


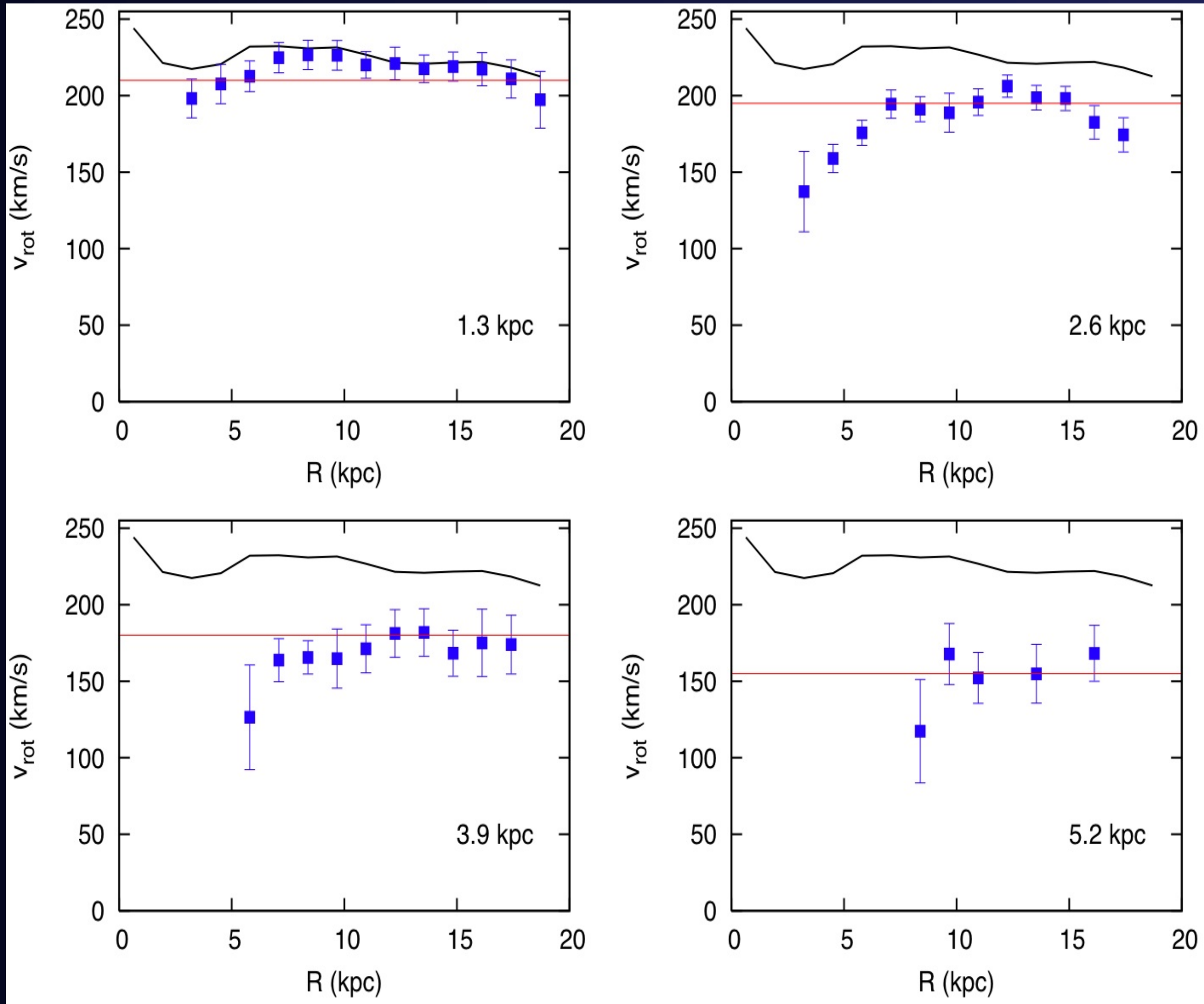
Hodges-Kluck & Bregman 2013, ApJ

$Mass_{hot}$ = 1-3 x 10^8 $M_\odot$

Z (HI) ~ 0.1 $Z_\odot$

Extraplanar HI rotates slowly

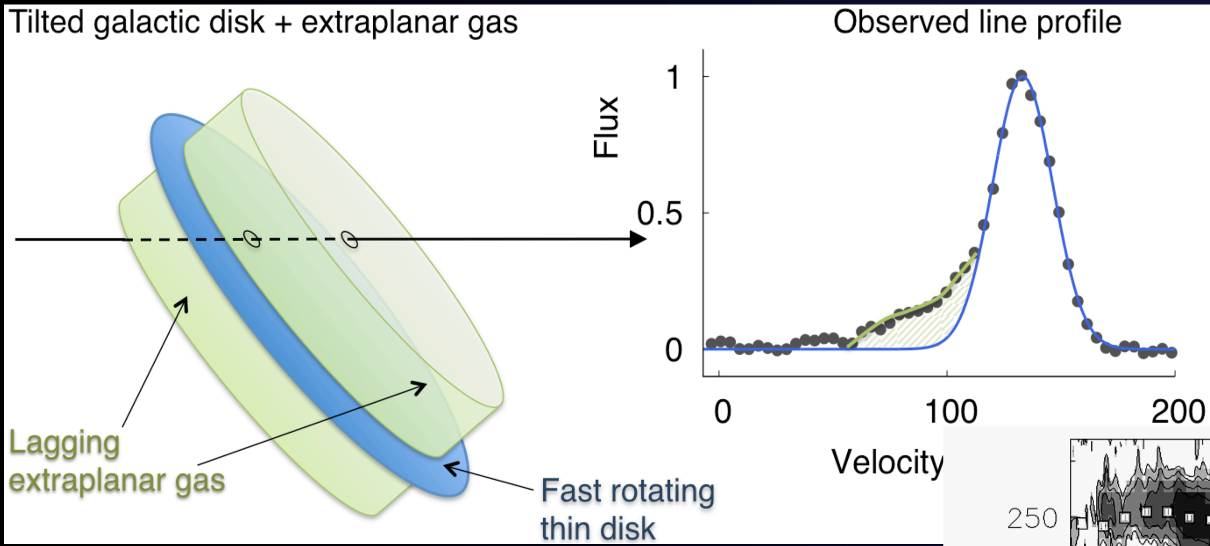




Strong (15 km/s/kpc) rotational gradient with z

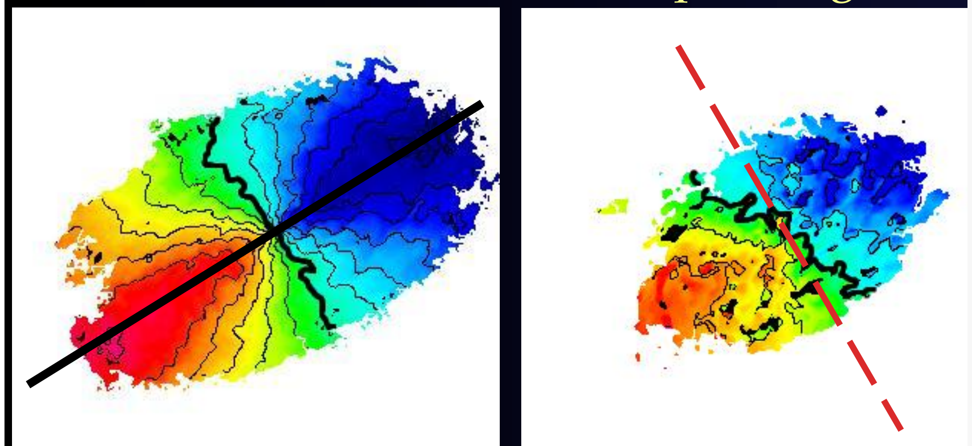
Fraternali et al. 2005

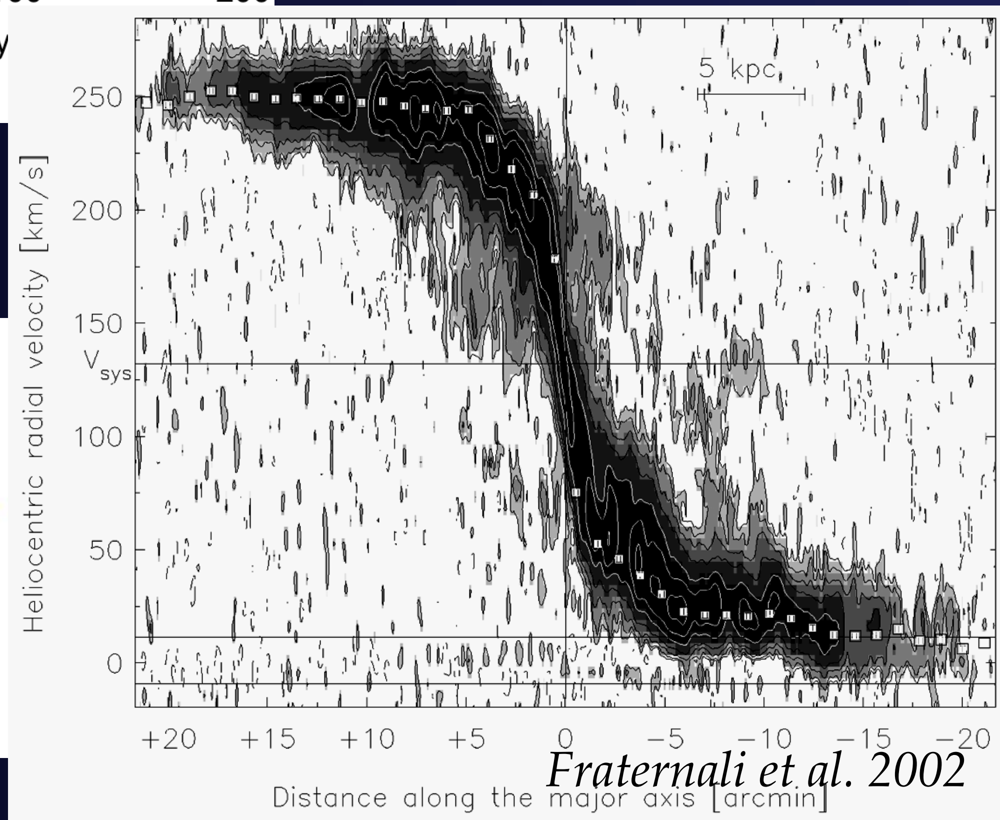
Extraplanar gas in non-edge-on galaxies



Extraplanar gas is in the star forming region

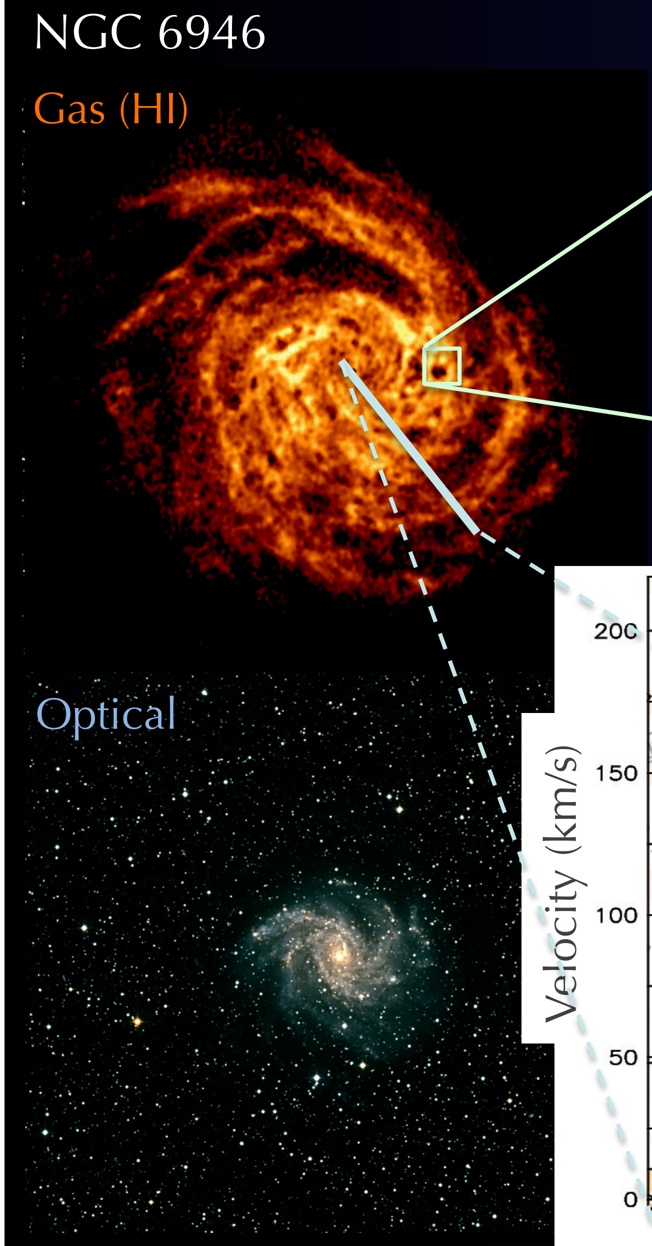
Extraplanar gas

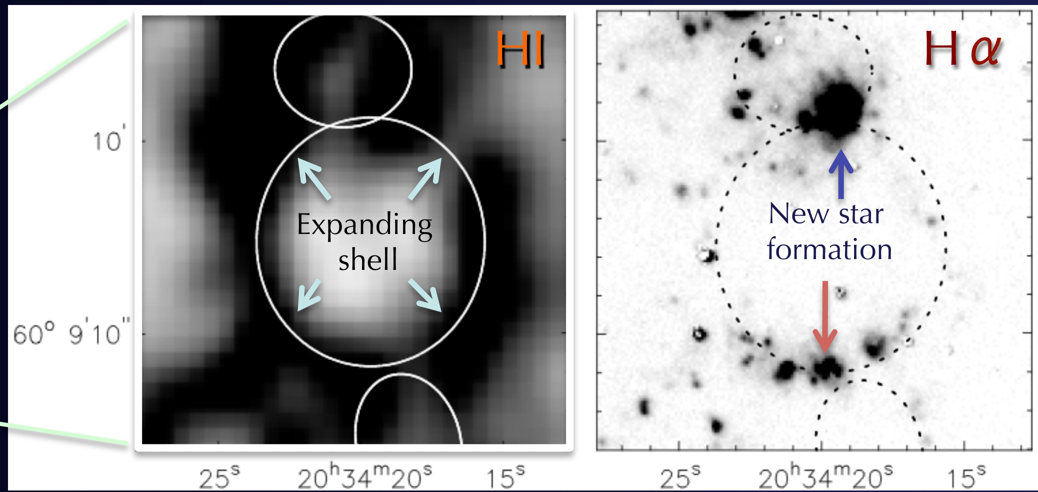


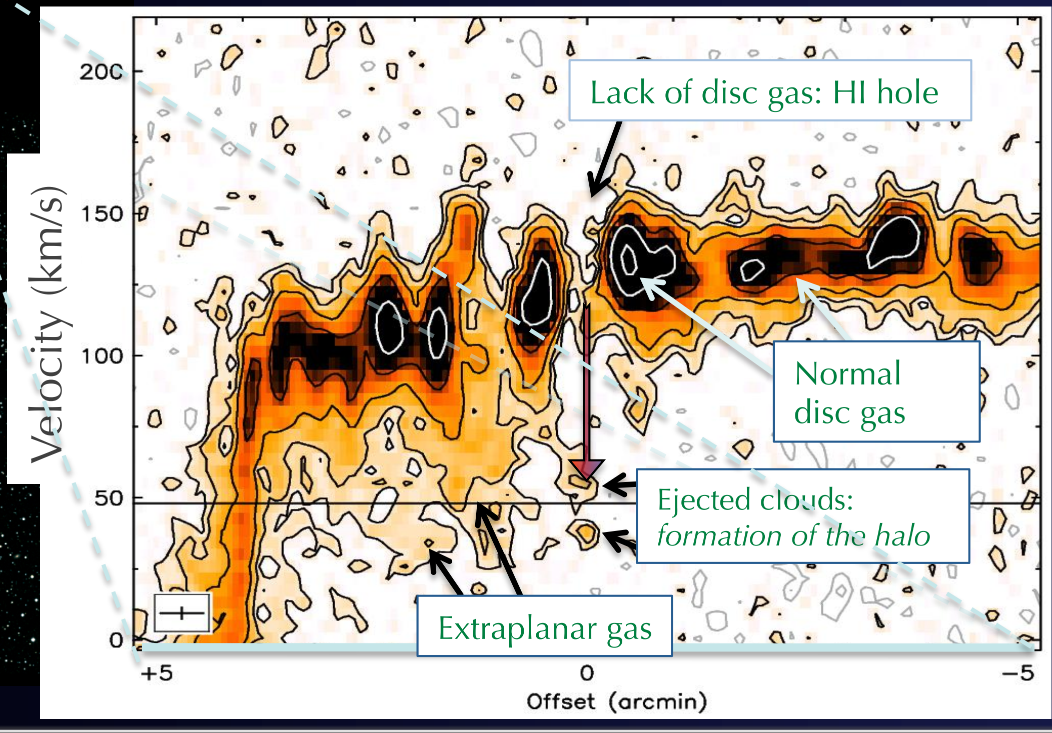


Fraternali et al. 2002

Superbubble outflows







Extraplanar gas
~ few10^8 $M_\odot$

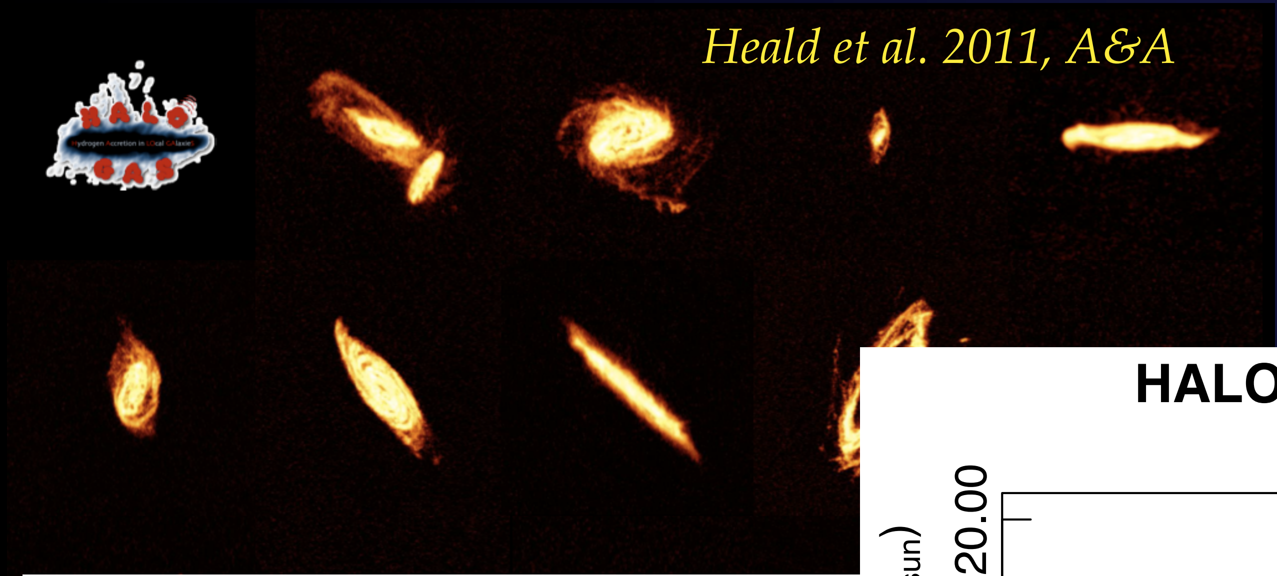
Cycle lifetime
~ few 10^7 yr

Fountain cycle:

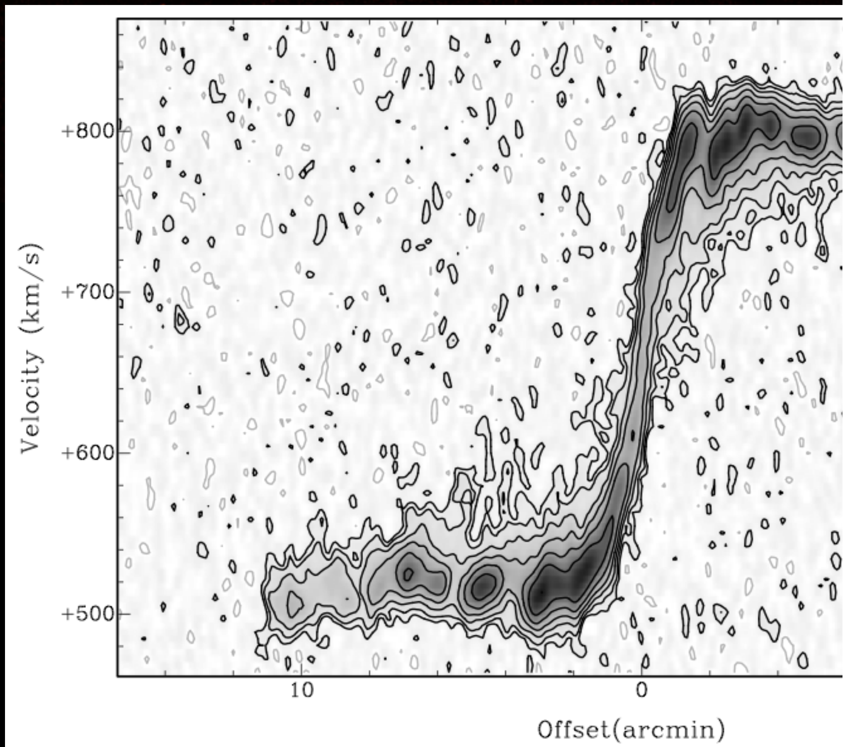
~10 $M_\odot$/yr!

HALOGAS

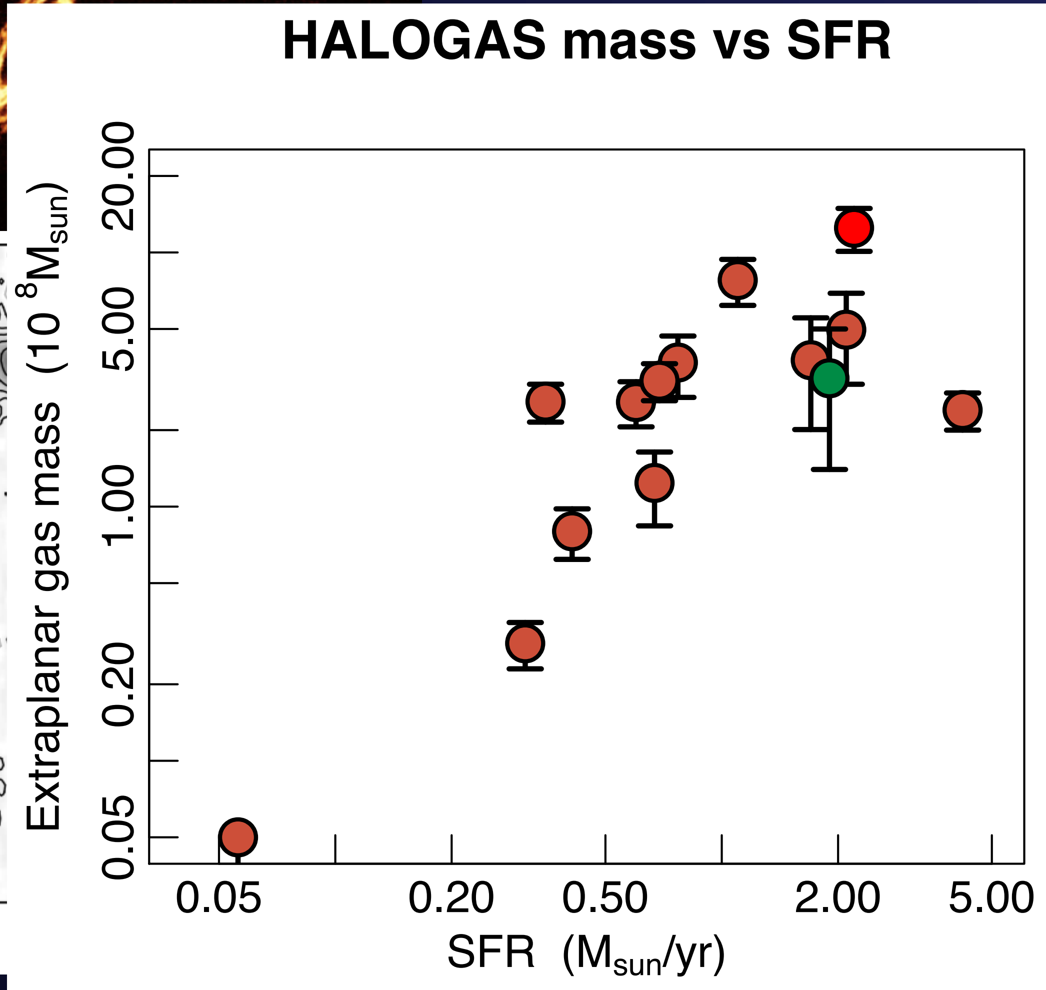
22 nearby galaxies at very high sensitivity with the WSRT



Heald et al. 2011, A&A



Gentile et al. 2013

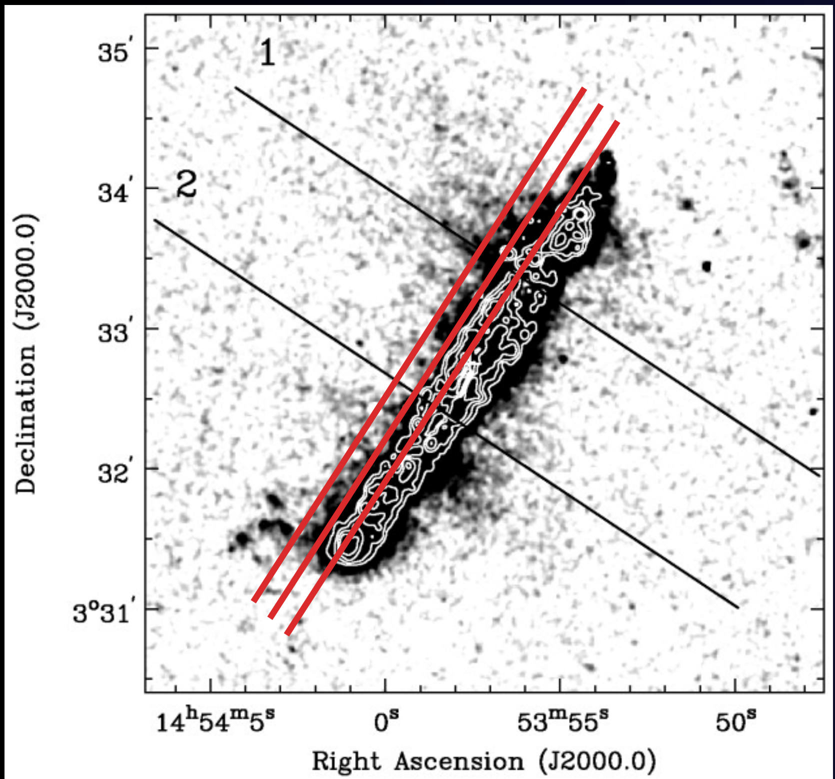


Fraternali, Heald et al., in prep.

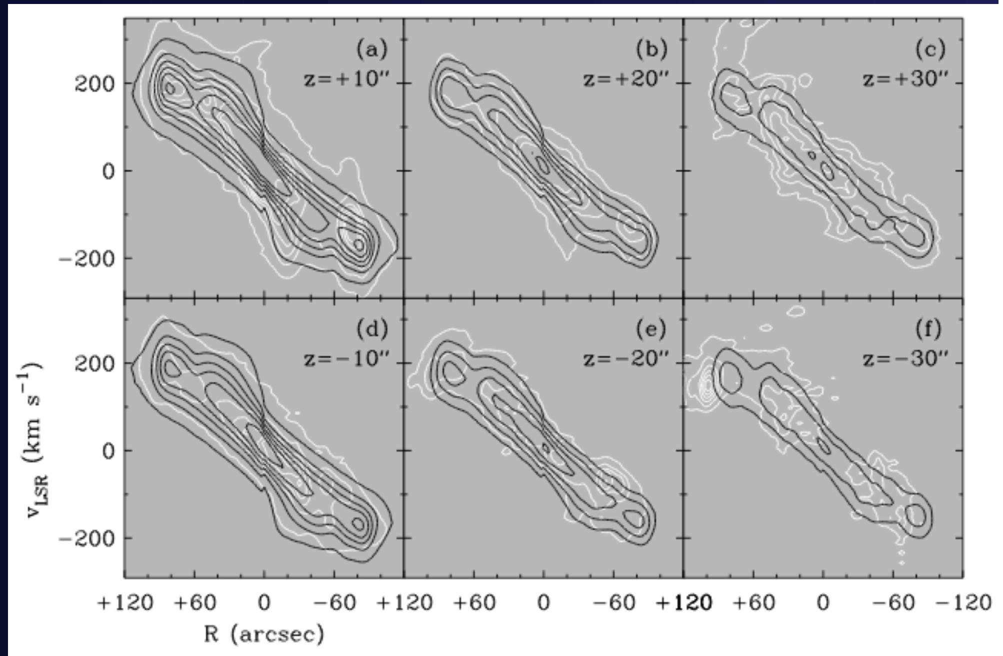
Photoionised gas

Diffuse ionized gas:

Hα image of NGC 5775



Rand 2000



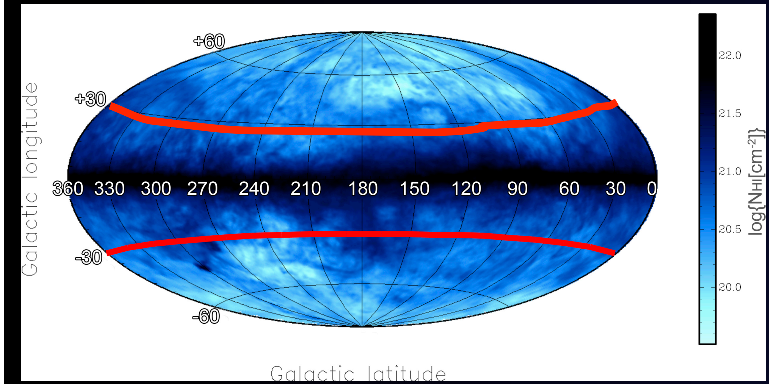
Star-forming galaxies have a lot of extraplanar *cold* gas

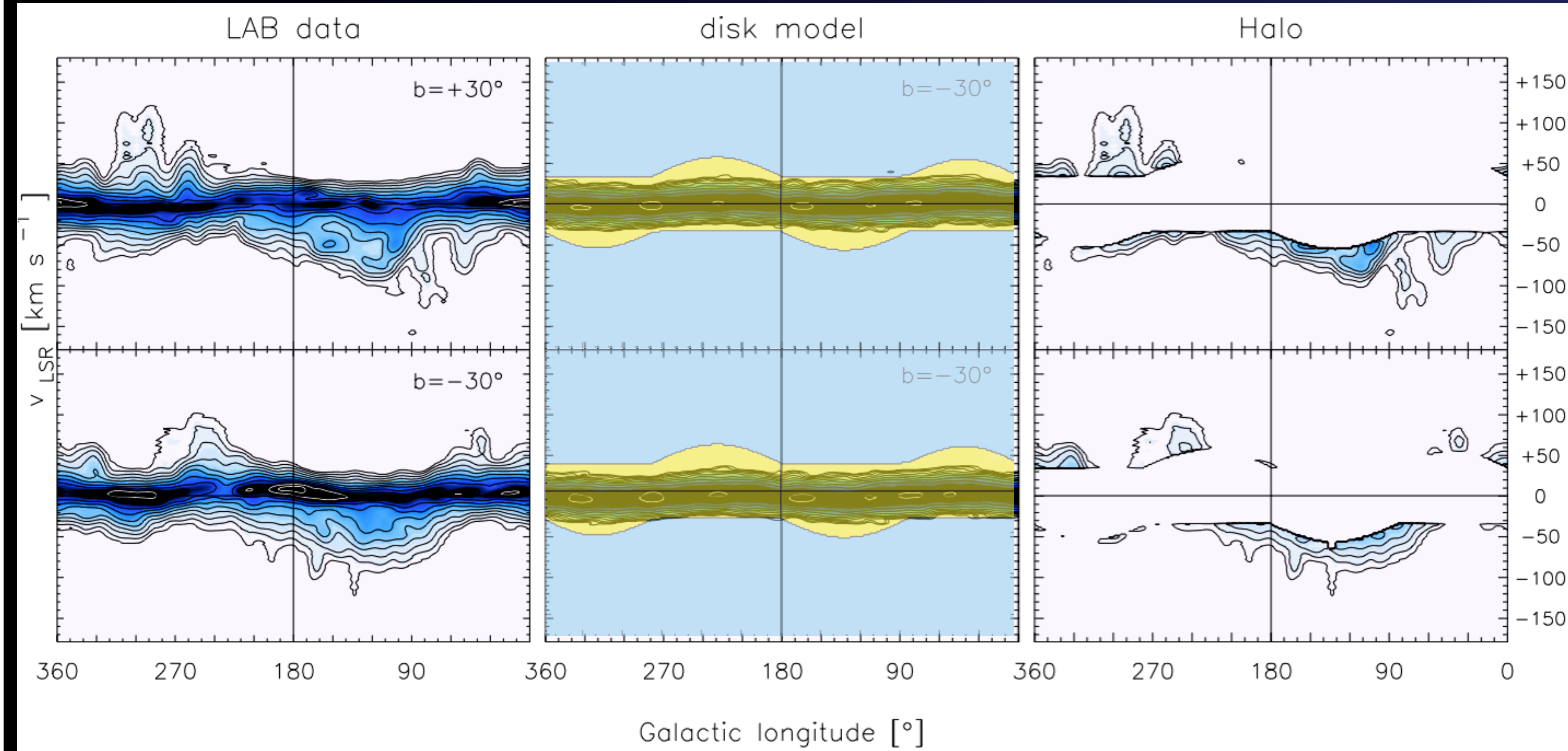
Fountain origin (most of it)

Mass cycle ~10 $M_\odot$/yr

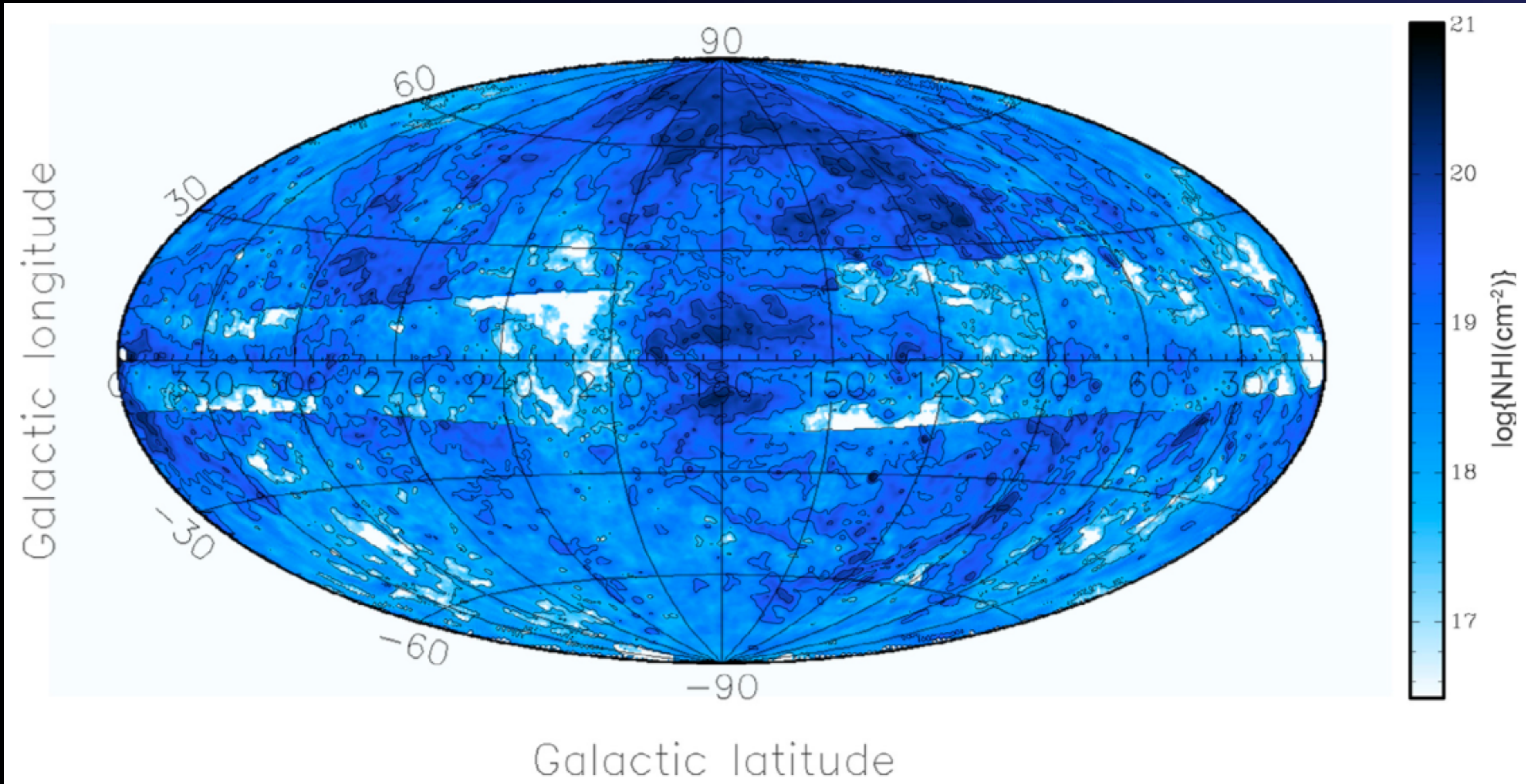
Extraplanar gas in the Milky Way

HI disk and halo in the Milky Way





Extraplanar HI – all-sky



Extraplanar HI mass = 3 - 4 x 10^8 $M_\odot$

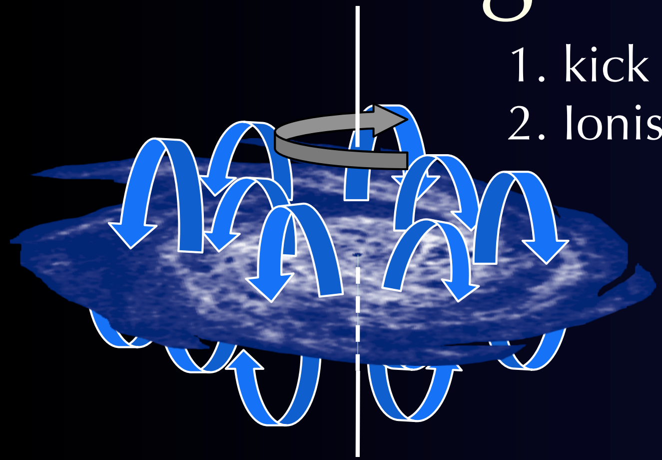
Rotational gradient: 15 km/s/kpc

Marasco & Fraternali 2011, A&A

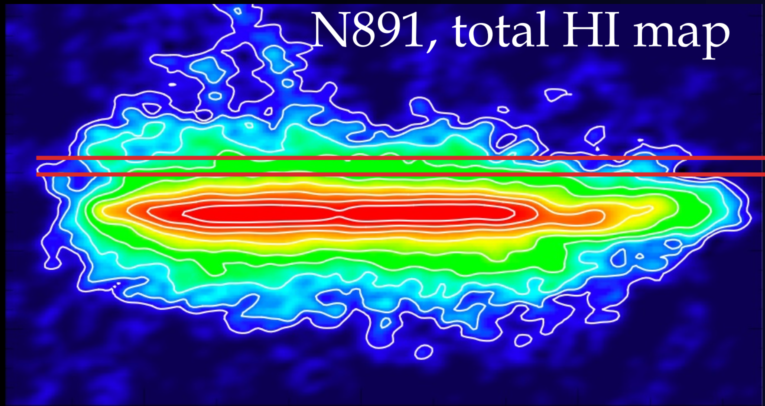
10% of the HI in the MW is out of hydrostatic equilibrium!

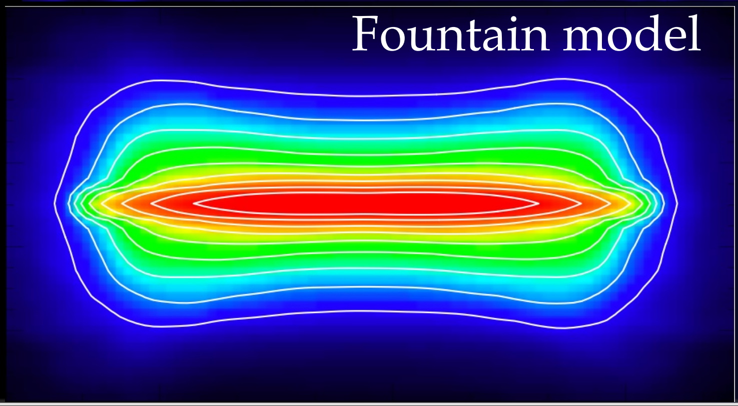
Galactic fountain models

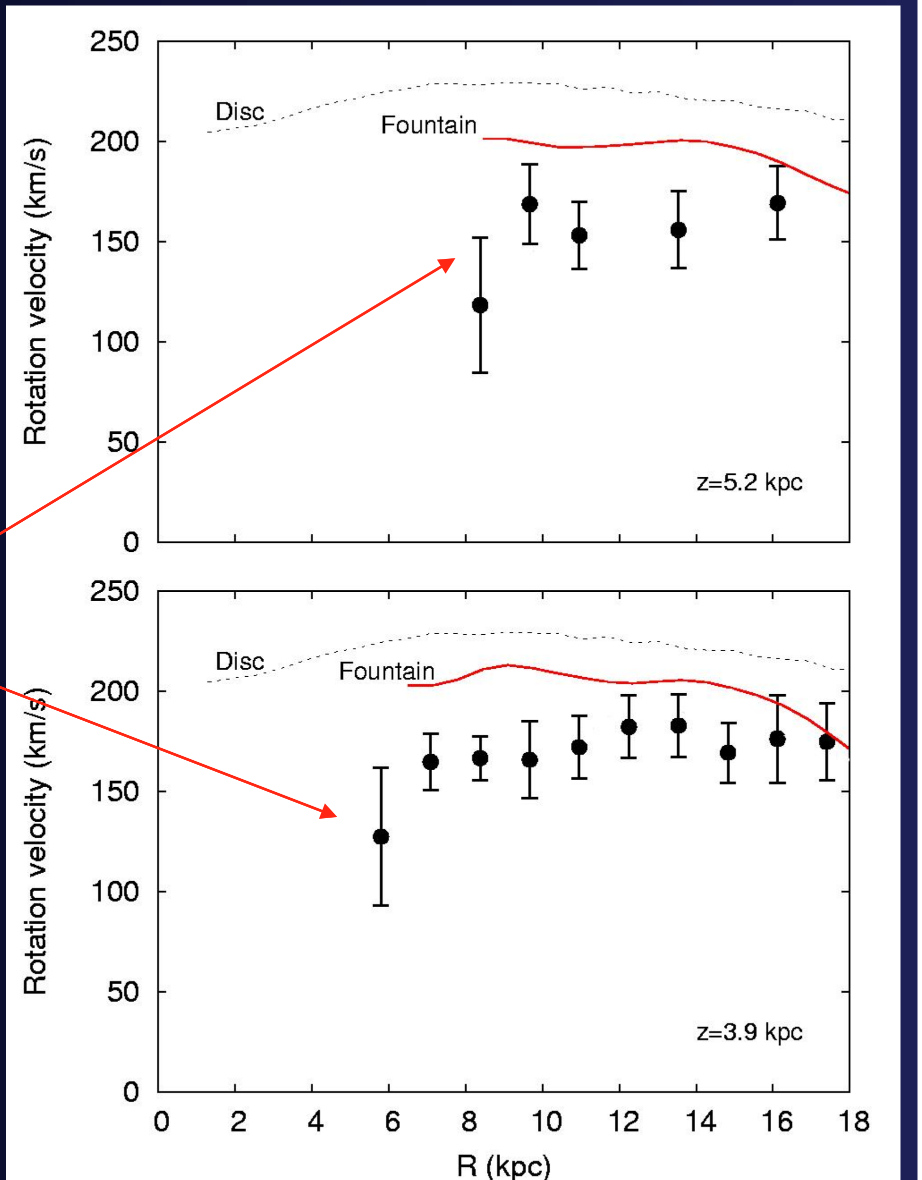
Pure galactic fountain model



1. kick velocities (v_k)
2. Ionised fraction (f_{ion})

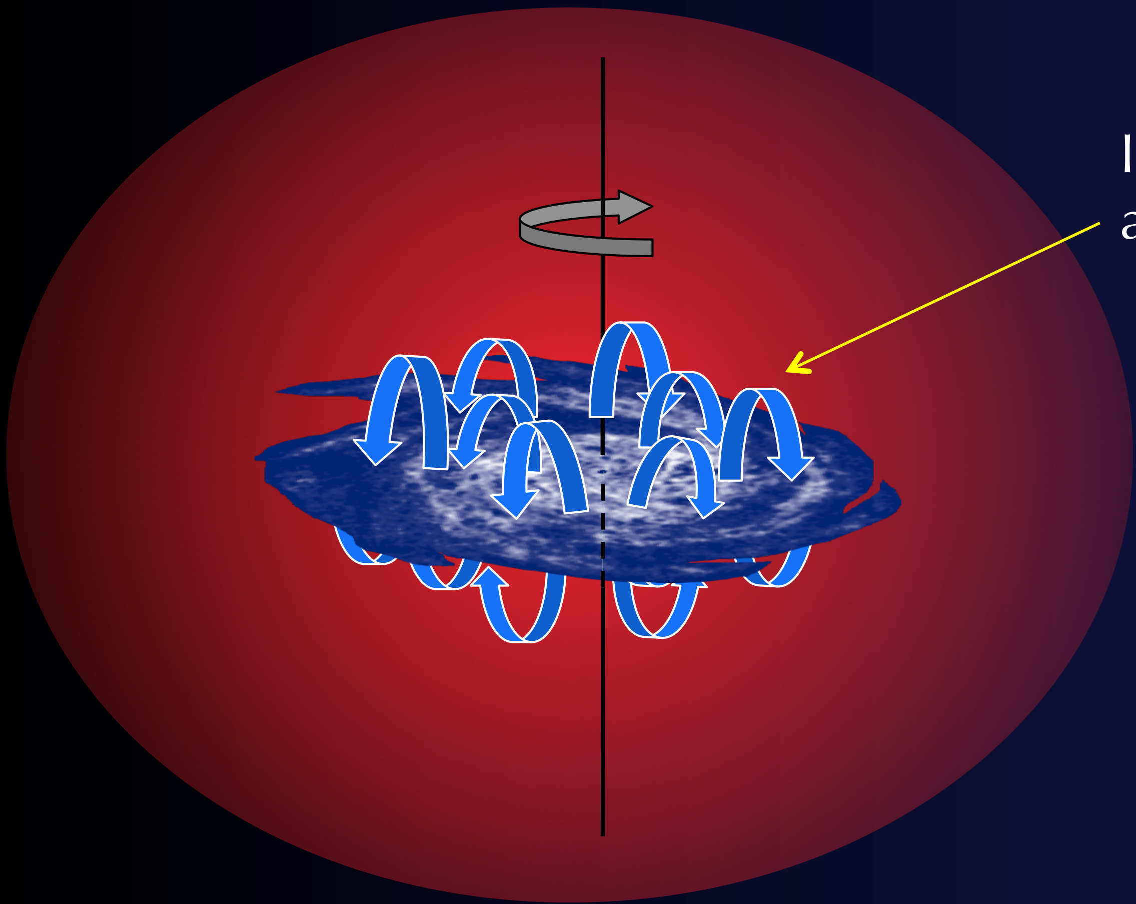






Fraternali & Binney, 2006

Disc-corona interplay



Interface layer where disc and coronal materials mix

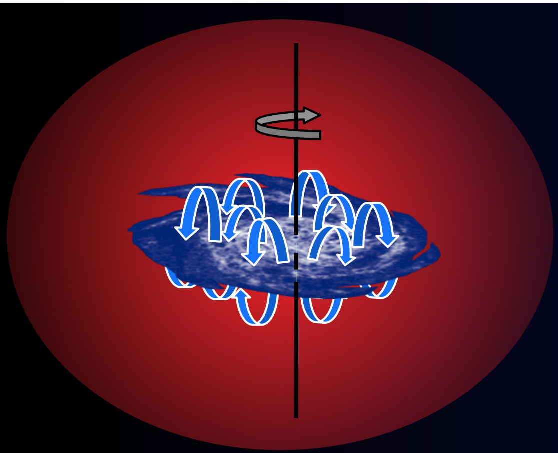
Requires high-resolution hydrodynamical simulations

Fraternali & Binney 2008, MNRAS

Marinacci, et al. 2010, 2011, MNRAS

Marasco, Fraternali & Binney 2012, MNRAS

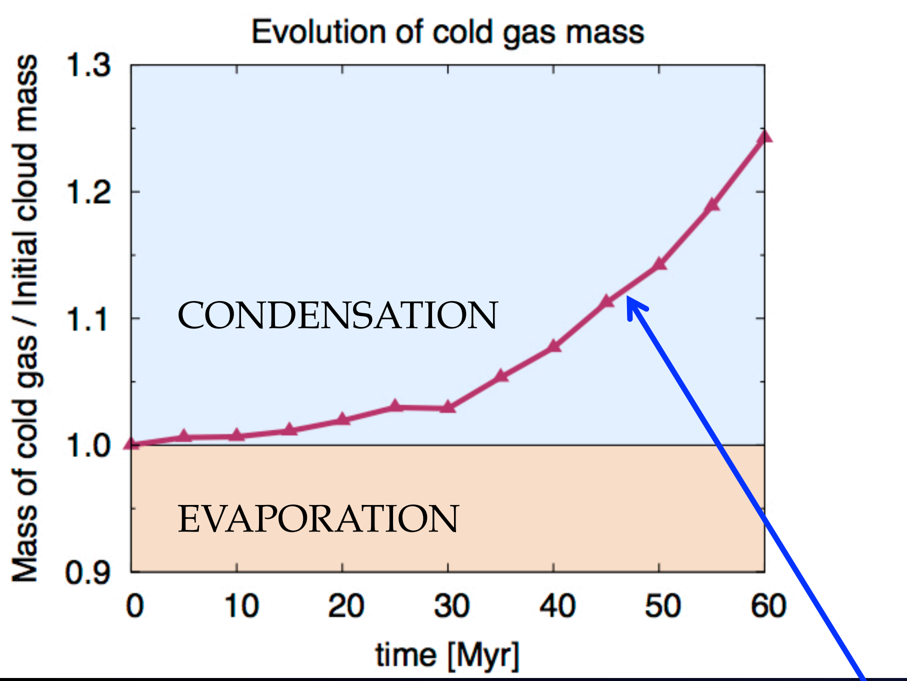
Disc-cloud corona interaction

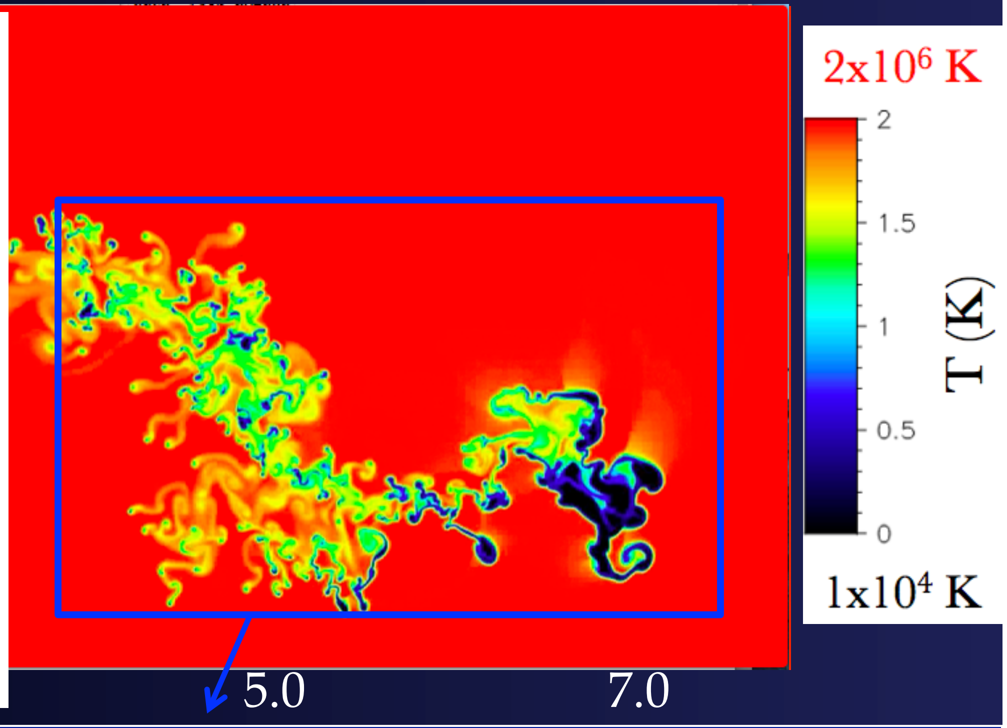


$T_{corona}=2x10^6$ K

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

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

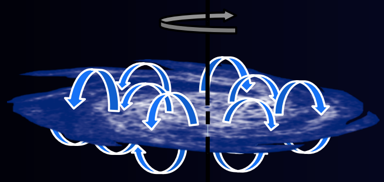




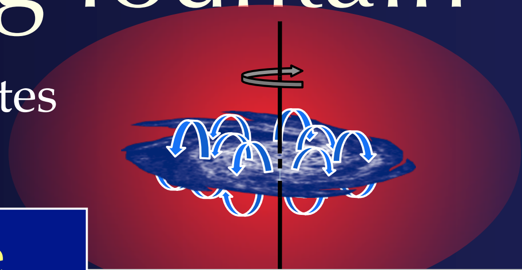
Mass of cold gas increased by ~20%!

Marinacci, et al. 2010, 2011, MNRAS *Lucia Armillotta*

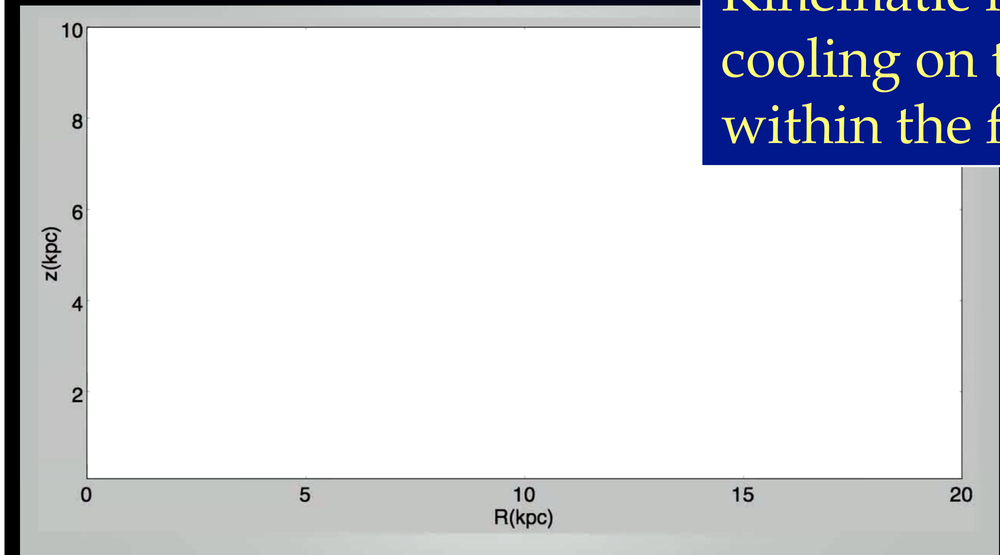
Pure fountain vs cooling fountain

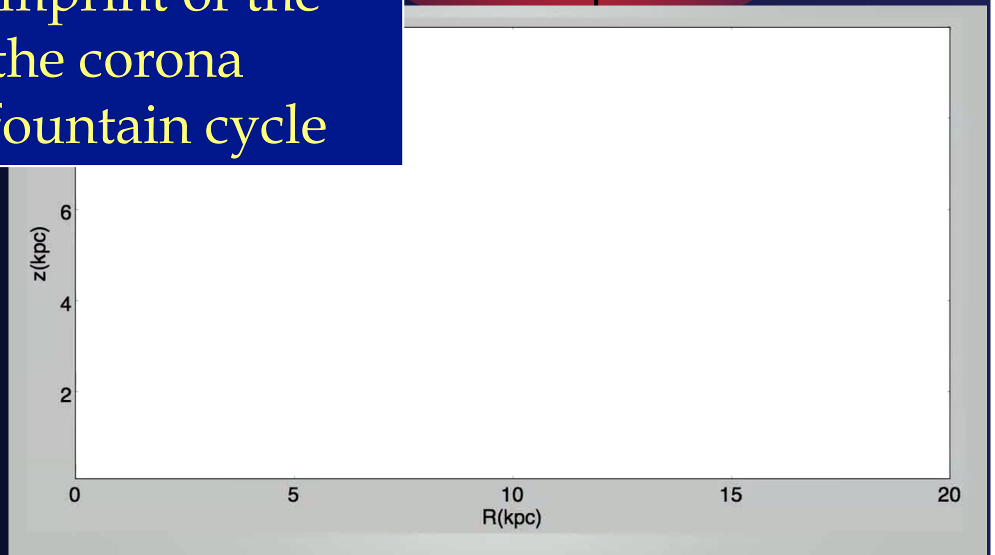


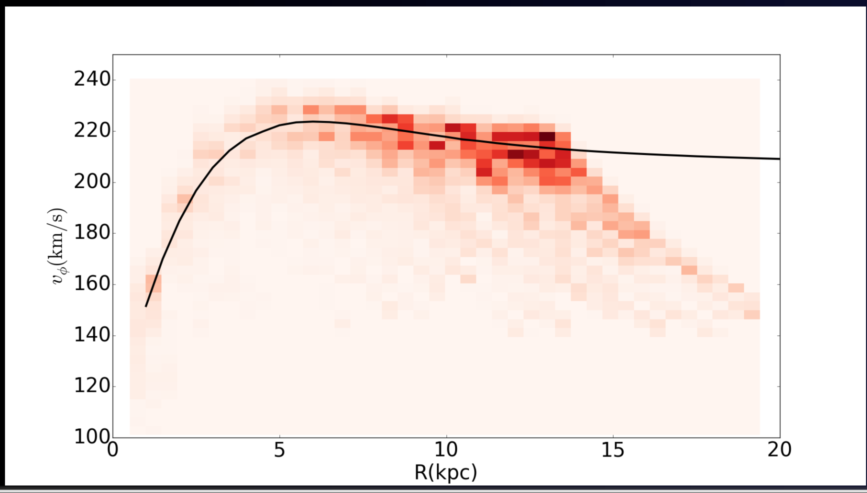
The corona rotates more slowly

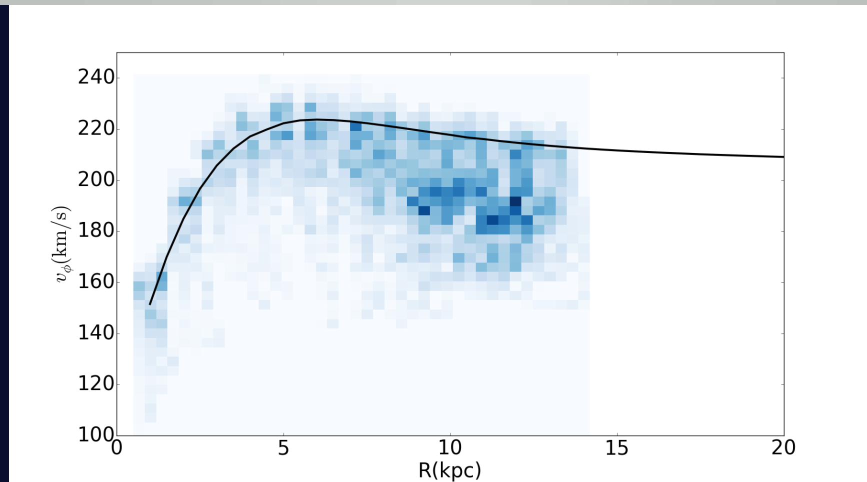


Kinematic imprint of the cooling on the corona within the fountain cycle



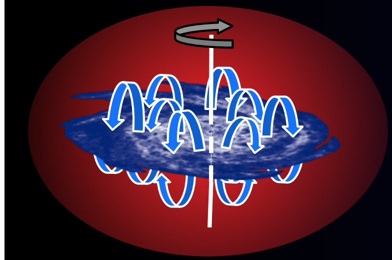




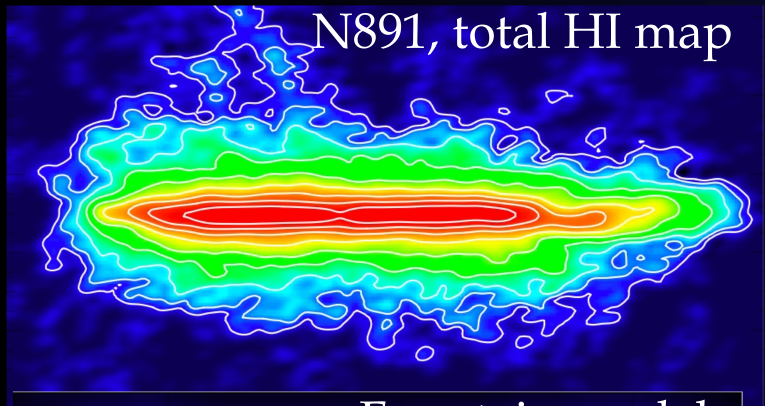


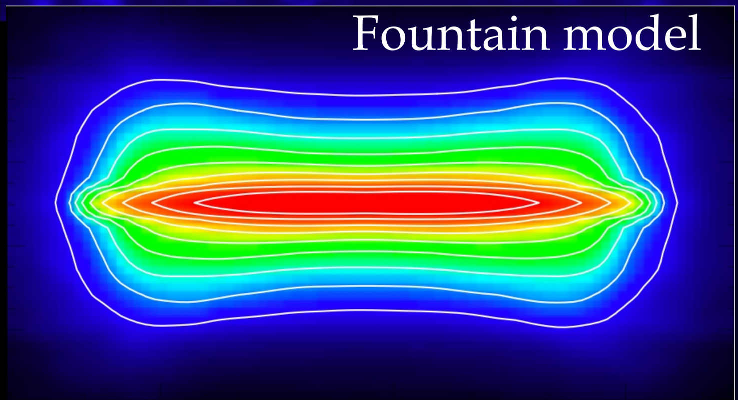
Fitting the extraplanar gas

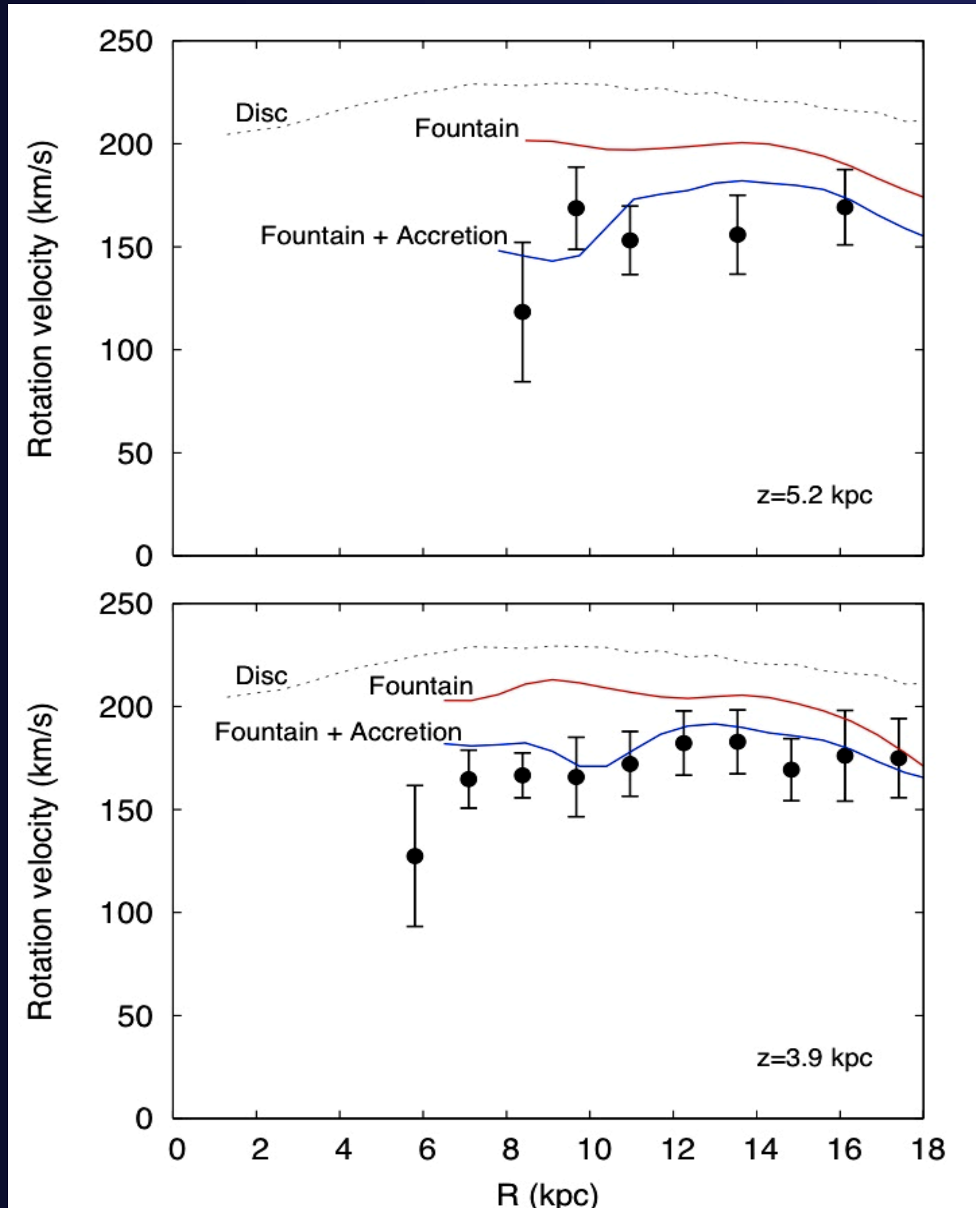
Fountain + accretion model



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







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

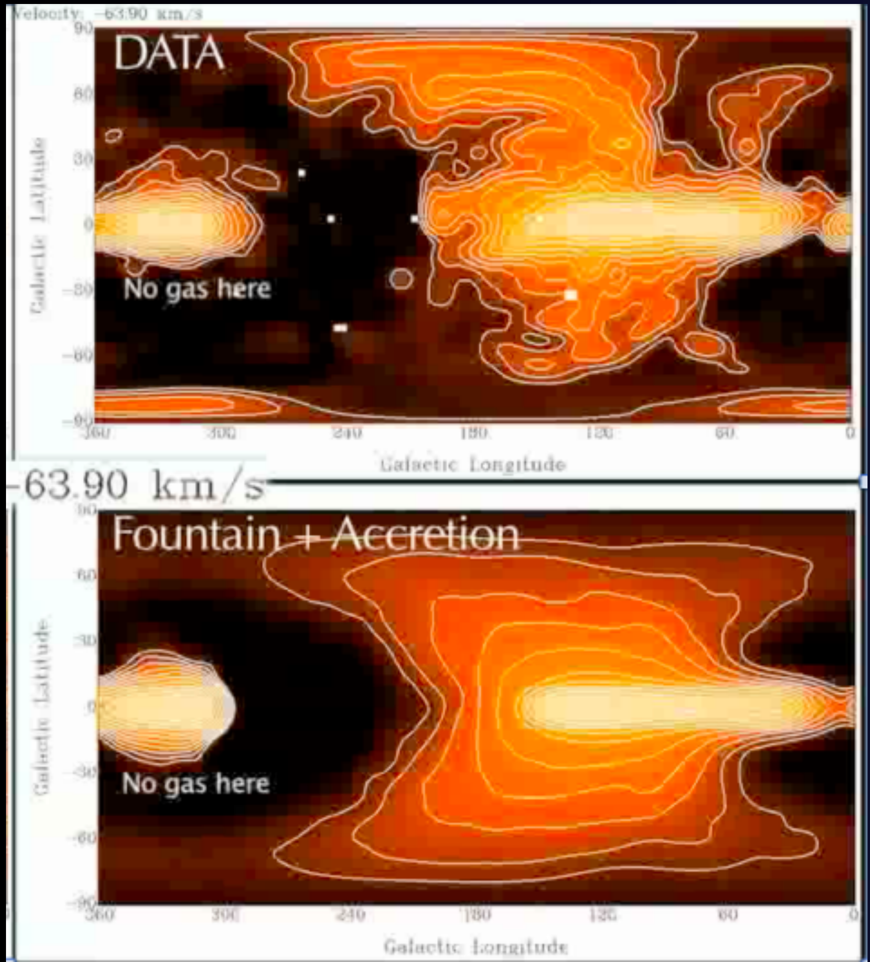
Compare to SFR ~ 4 $M_\odot yr^{-1}$

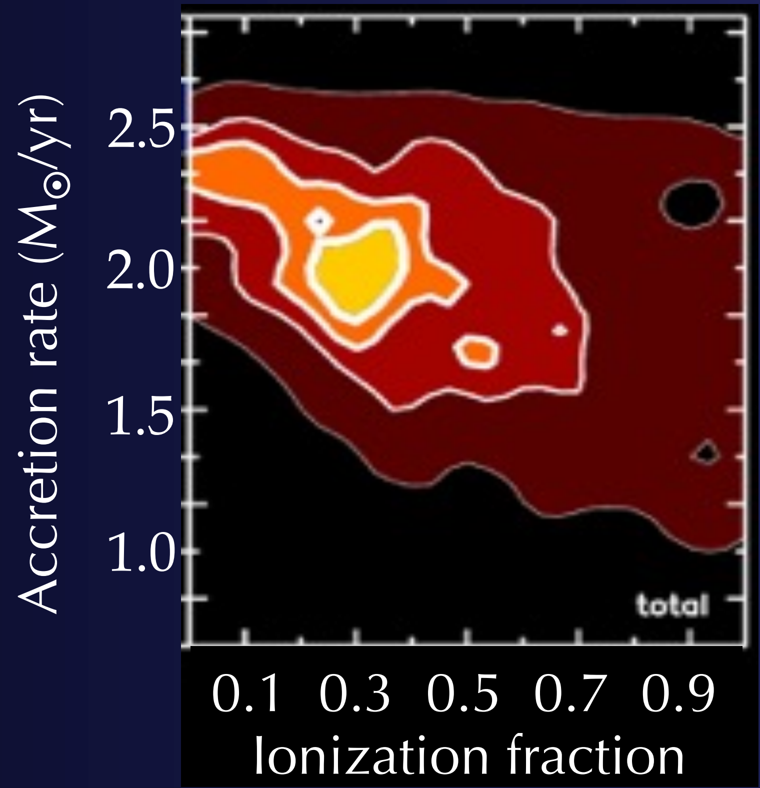
Fraternali & Binney, 2008

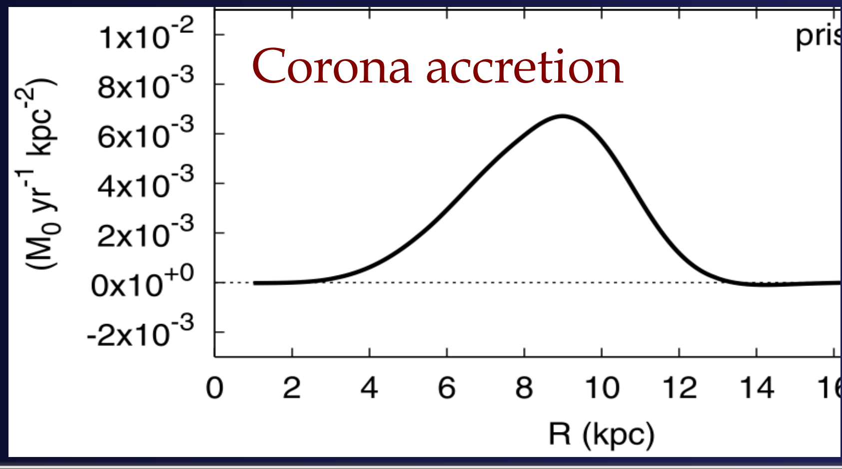
Extraplanar HI in the Milky Way

Marasco, Fraternali & Binney, 2012

Extraplanar HI in the Milky Way





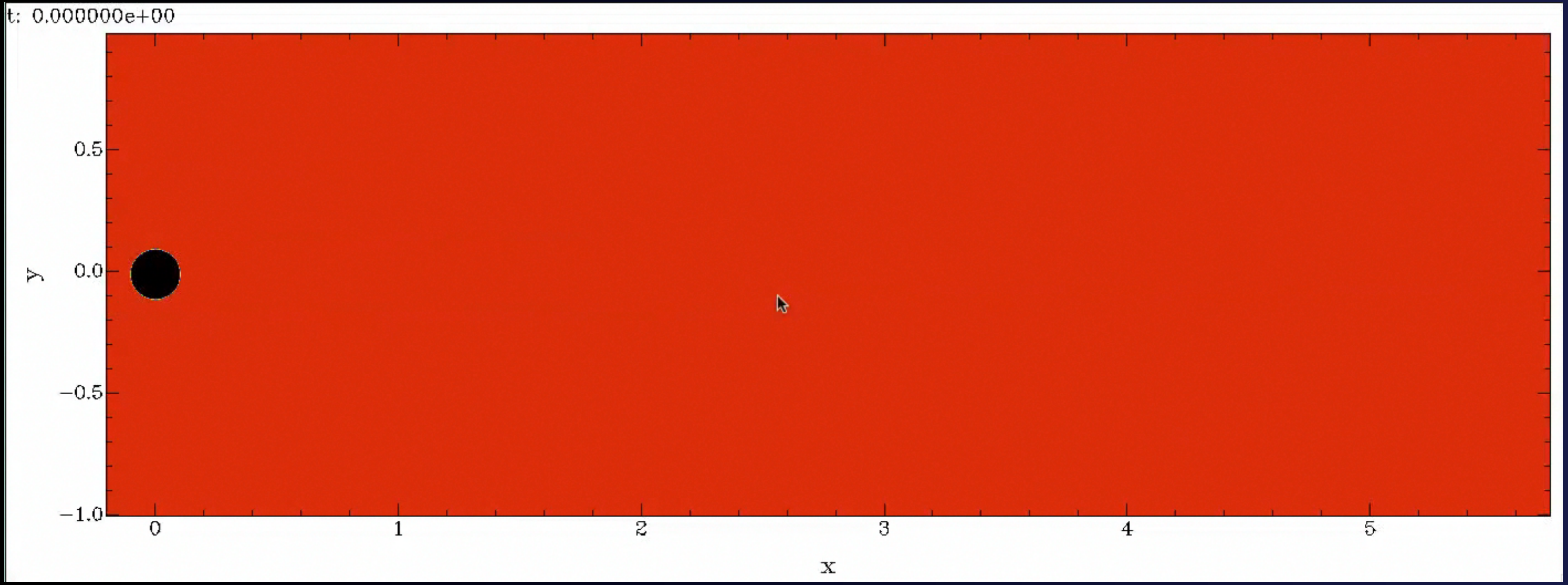


Best-fit Accretion Rate ~ 2 $M_\odot yr^{-1}$

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

New high resolution simulations

The effect of thermal conduction



Only cooling

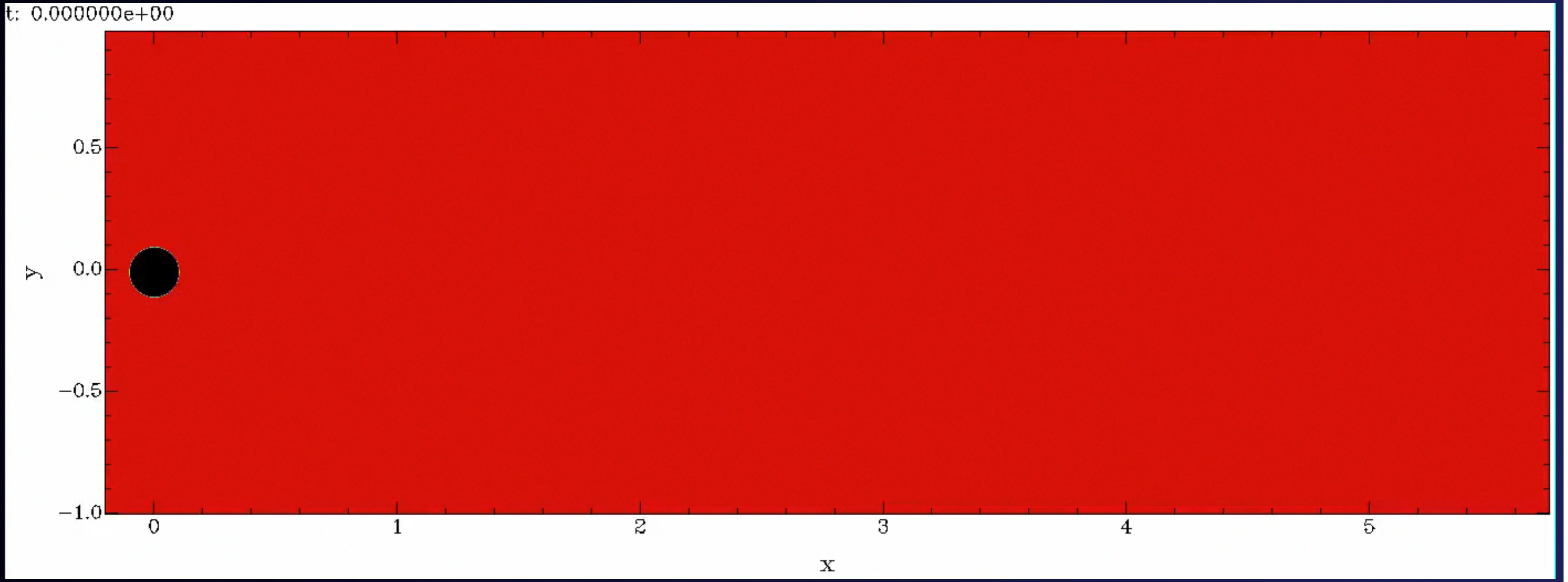
T_{corona}=2x10^6 K

Z_{corona}=0.1 $Z_\odot$

Z_{cloud}=1 $Z_\odot$

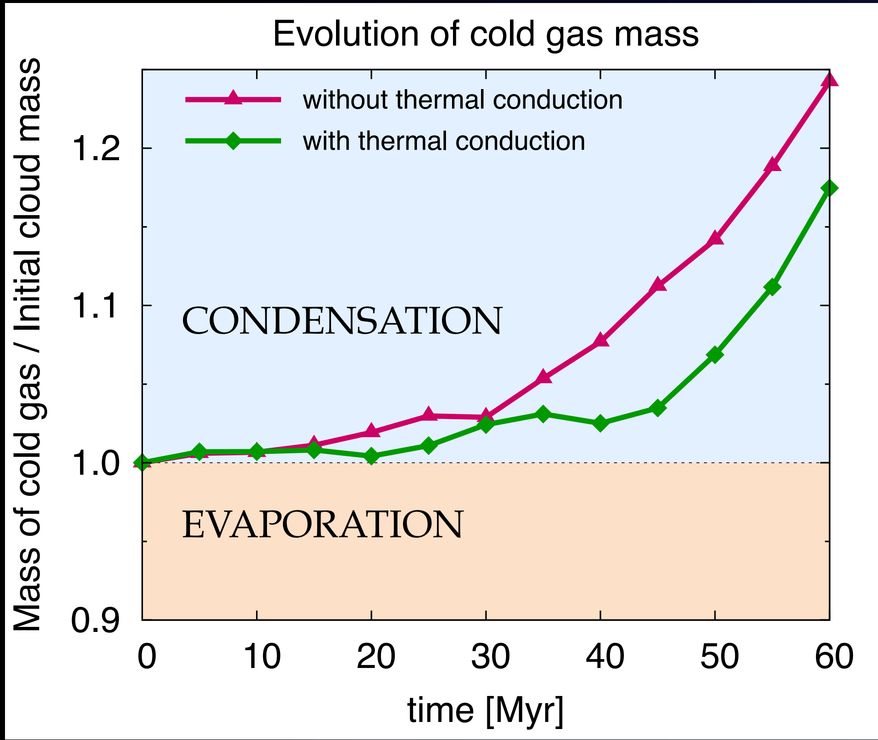
Cooling & thermal conduction

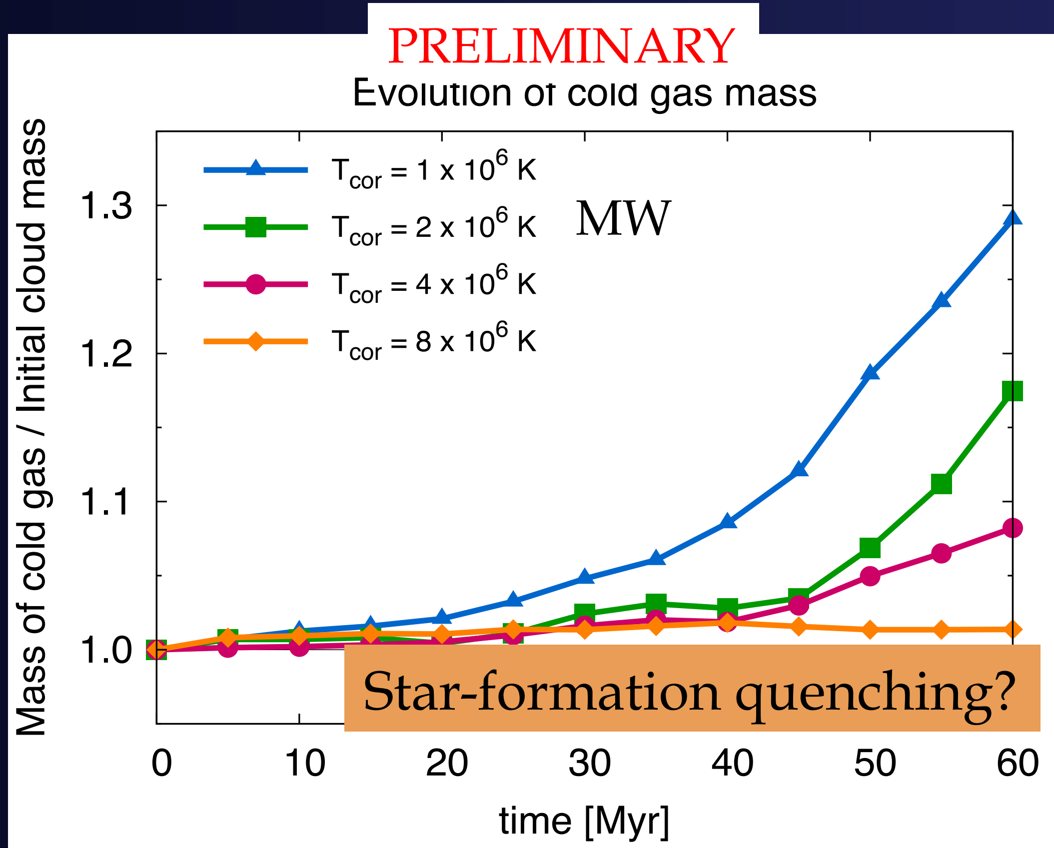
$$\mathbf{F}_{\rm cond} = f \times \kappa_{\rm Sp} T^{5/2} \nabla T$$



Lucia Armillotta

Efficiency of fountain-driven cooling

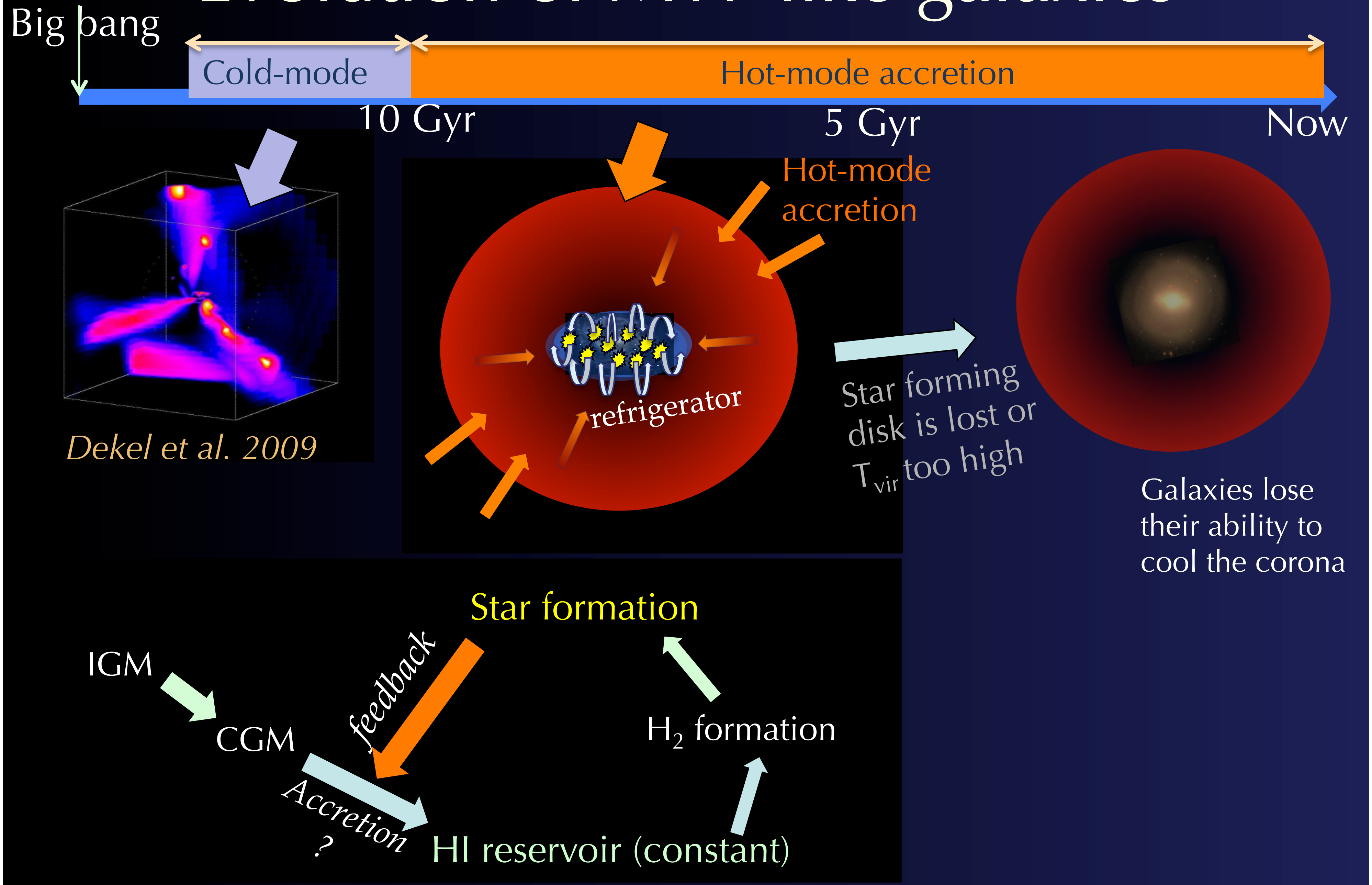




Condensation efficiency as a function of T_{vir} ⬌ M_{vir}

Armillotta+, in prep.

Evolution of MW-like galaxies



Conclusions

• There is a lot of extraplanar cold gas

• The fountain circulates ~10 $M_\odot$/yr and cools ~1 $M_\odot$/yr of low-metallicity gas *in the inner disk*

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

• *At z<1 galactic fountain drives star formation*