How the CGM accretes onto galaxies

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- What are the morphological and physical properties of the IGM/CGM from parsec to Megaparsec scales?

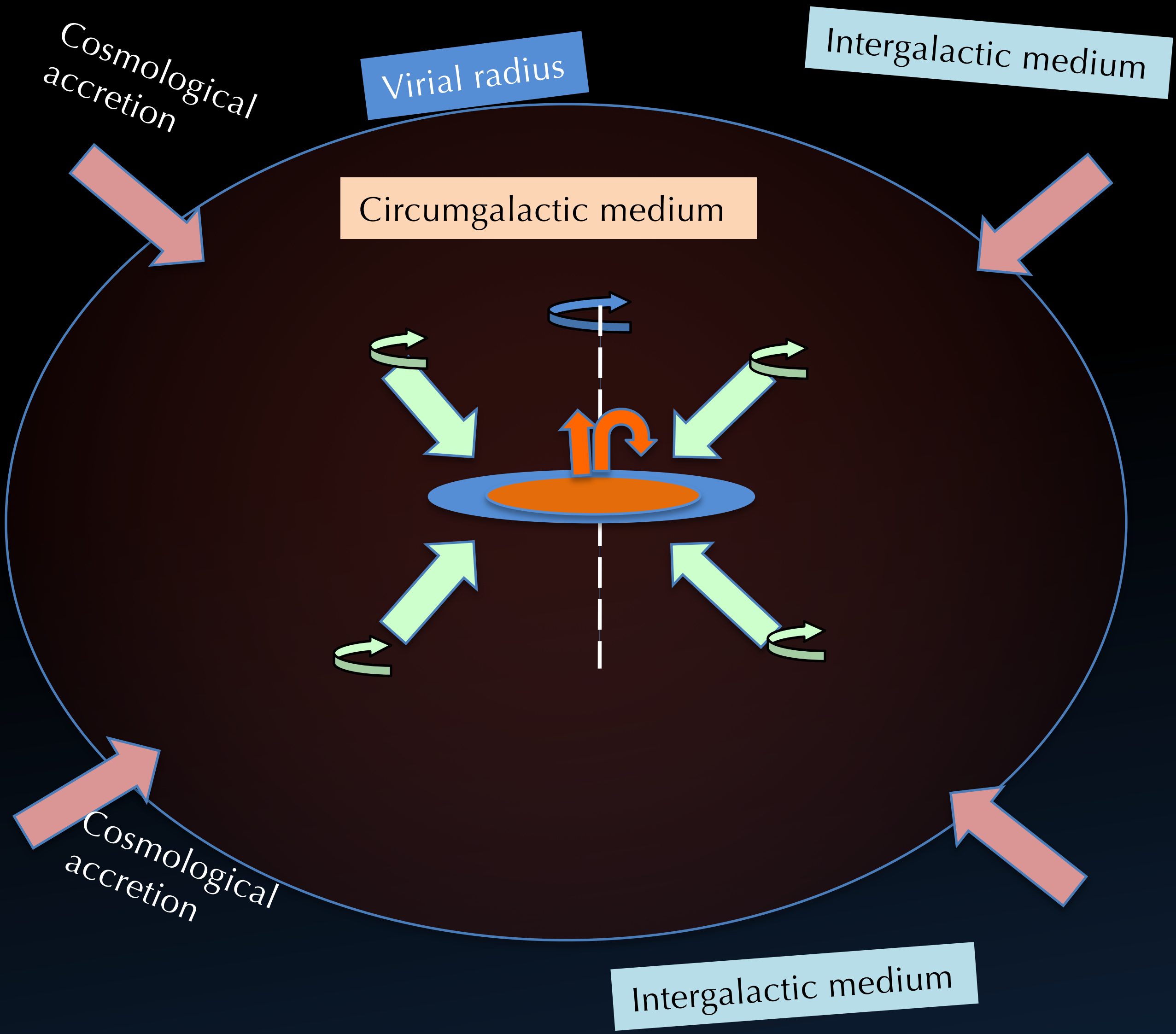
- What do metals tell us about intergalactic gas-galaxy interactions?

Part 1

How the CGM accretes onto disc galaxies (today)

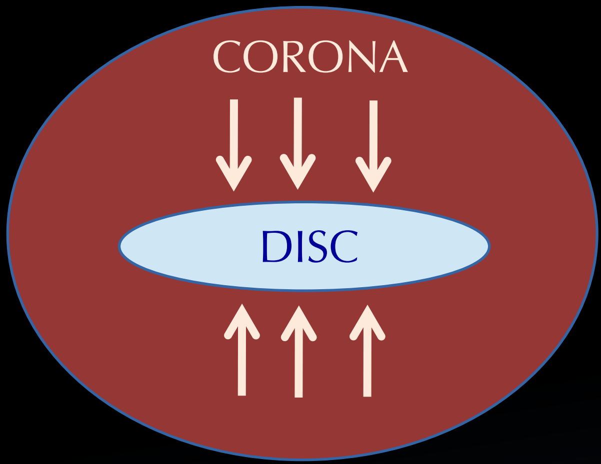
F. Fraternali & Gabriele Pezzulli

Galaxy growth



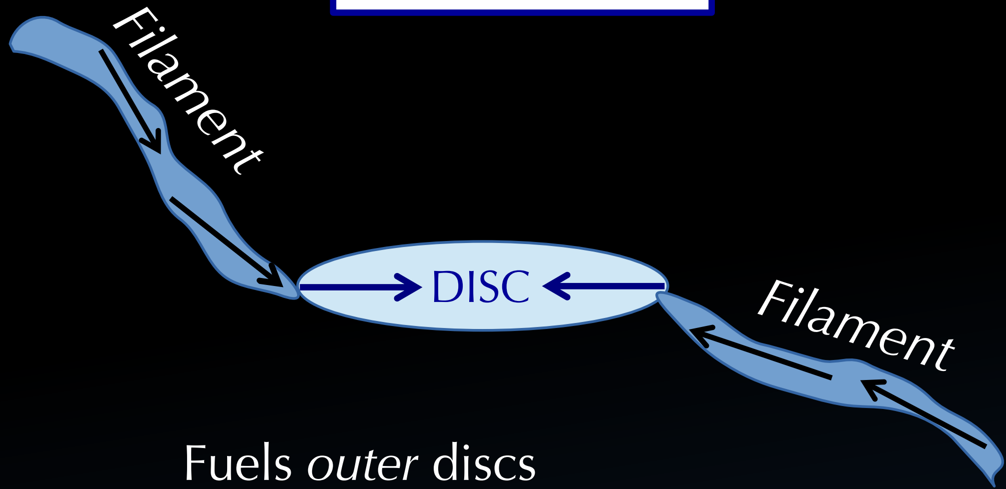
Modes of gas accretion

Vertical inflow
HOT MODE



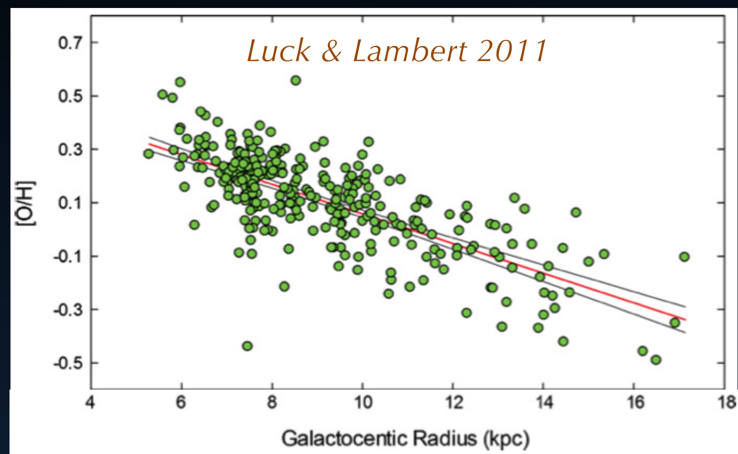
Condensation above the disc -> SF

Radial inflow
COLD MODE



Fuels *outer* discs
+ radial flows *within* the disc

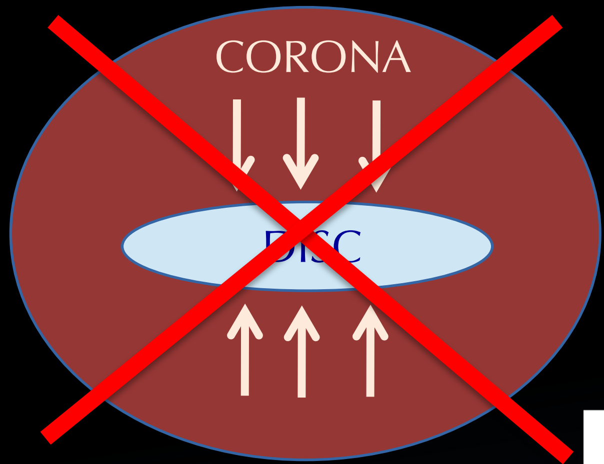
Influence on metallicity gradients: measurable!



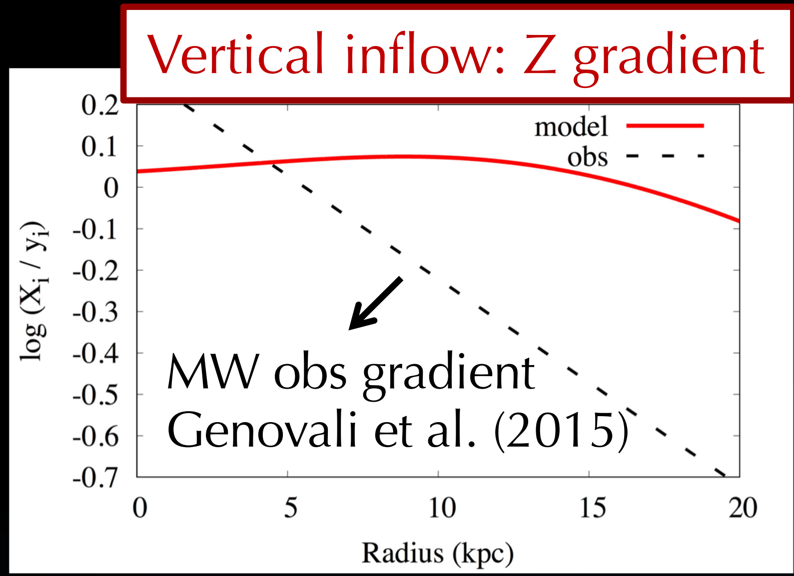
Metallicity gradients: models vs data

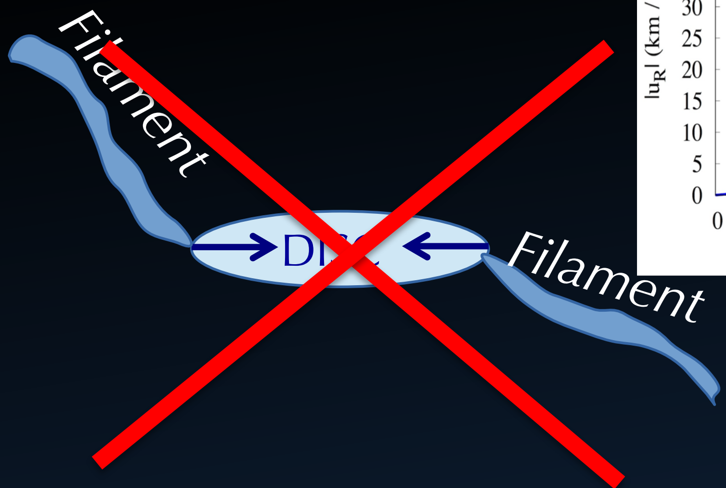
1) Fixed structural evolution
2) Gas-phase α-elements

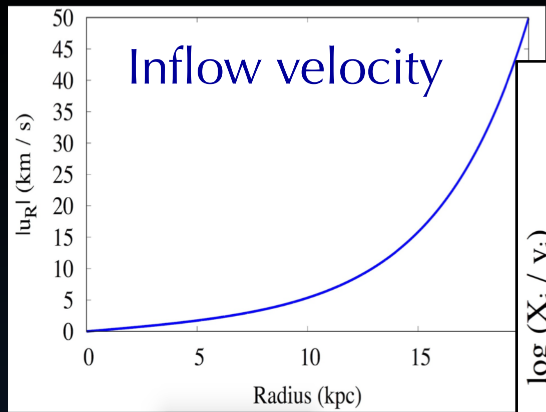
$$\frac{\partial \tilde{X}_i}{\partial t} = \frac{\dot{\Sigma}_\star}{\Sigma_g} - \tilde{X}_i \frac{\dot{\Sigma}_{acc}}{\Sigma_g}$$

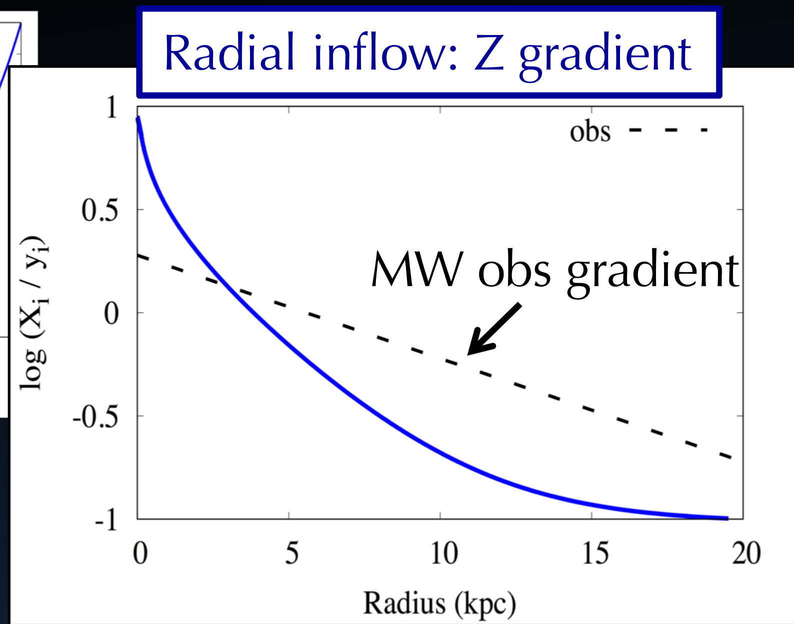


Low-Z infalling gas in the inner disc



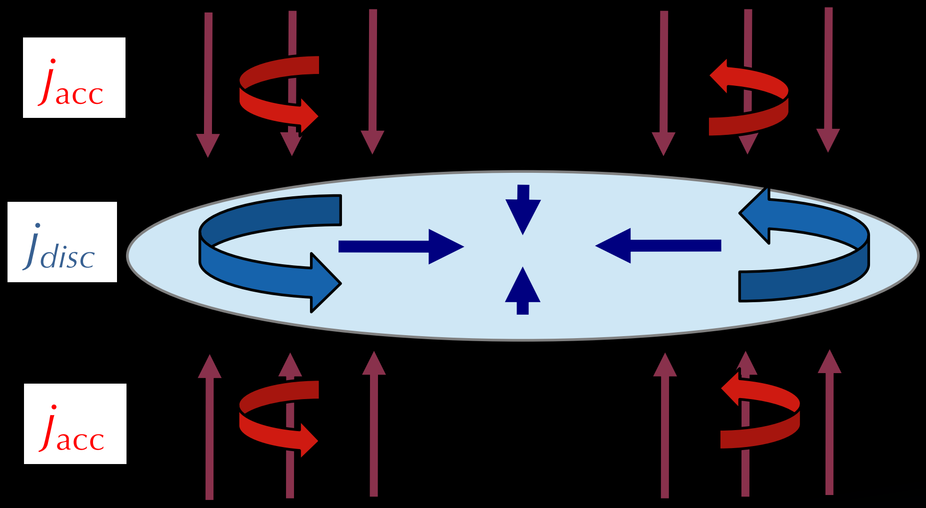






Infalling gas enriched on its way to the inner disc

Model with Coupled flow



$j_{acc} < j_{disc}$ → Radial inflow

Pitts & Tyler 1989

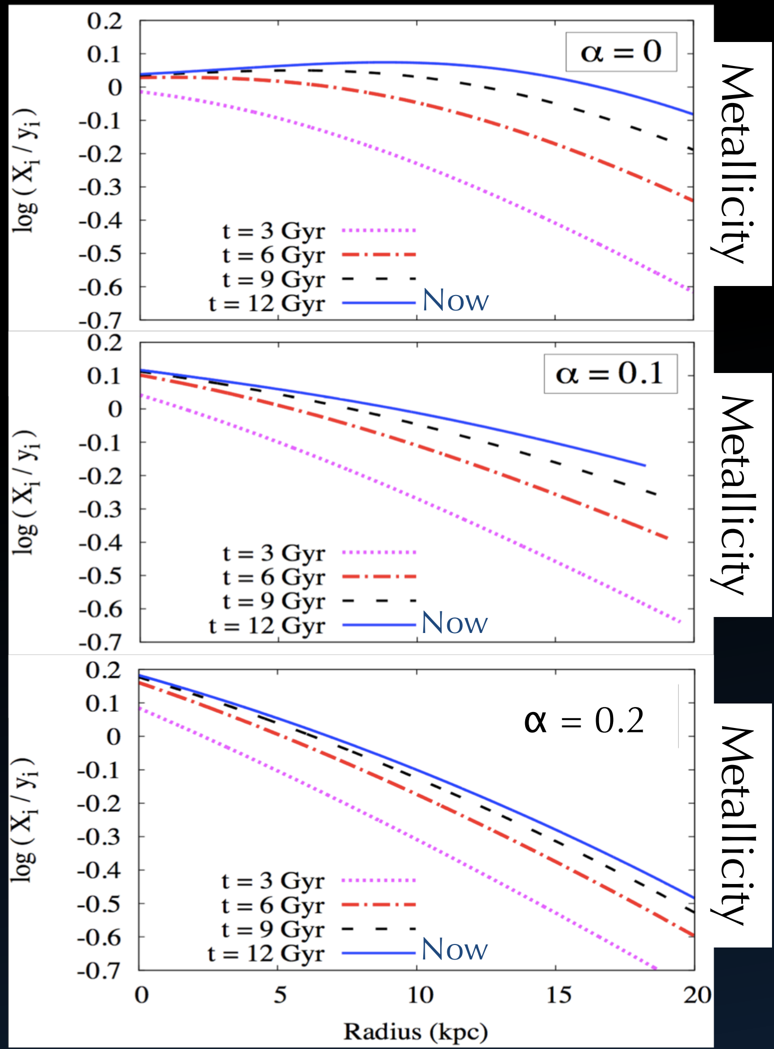
$$\dot{\Sigma}_{eff} = \dot{\Sigma}_{acc} - \frac{1}{2\pi R}\frac{\partial \mu}{\partial R}$$

Radial mass flux

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

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

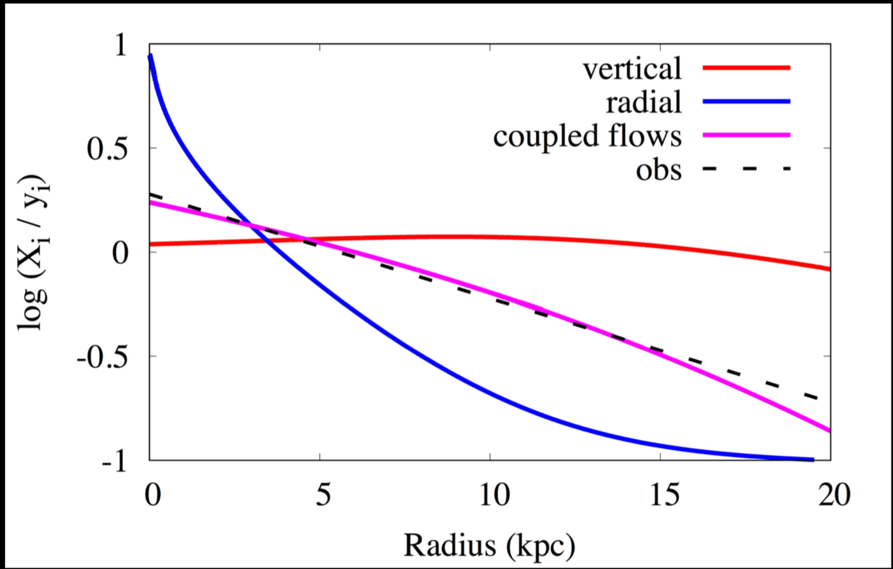
Angular momentum mismatch



Pezzulli & Fraternali 2016, MNRAS

Mayor & Vigroux (1981); Lacey & Fall (1985); Bilitewski & Schoenrich 2012

Angular momentum of the accreting gas



Fraternali & Pezzulli 2018, IAU
Pezzulli & Fraternali 2016, MNRAS

Best fit for α=0.2-0.3

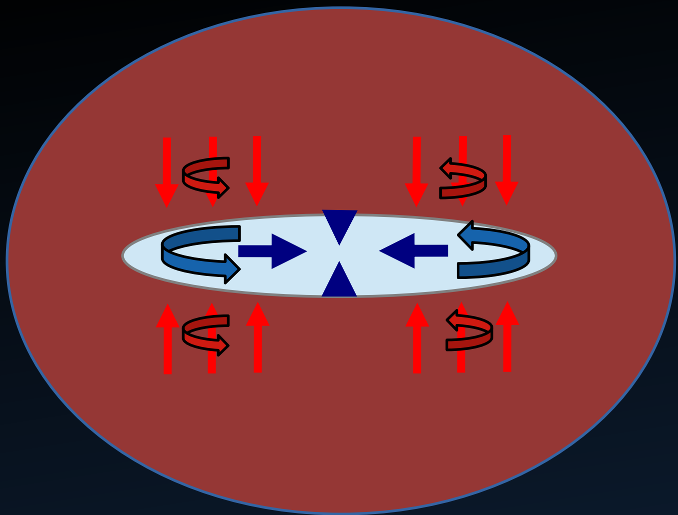
$$\alpha = 1 - \frac{V_{\rm acc}}{V_{\rm disc}}$$

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

$v_{\rm rot,\,acc}$ ~160-190 km/s in the MW

Few months later the rotation
of the corona was observed
$V_{\rm rot} = 183 \pm 41$

Hodges-Kluck et al. 2016, ApJ

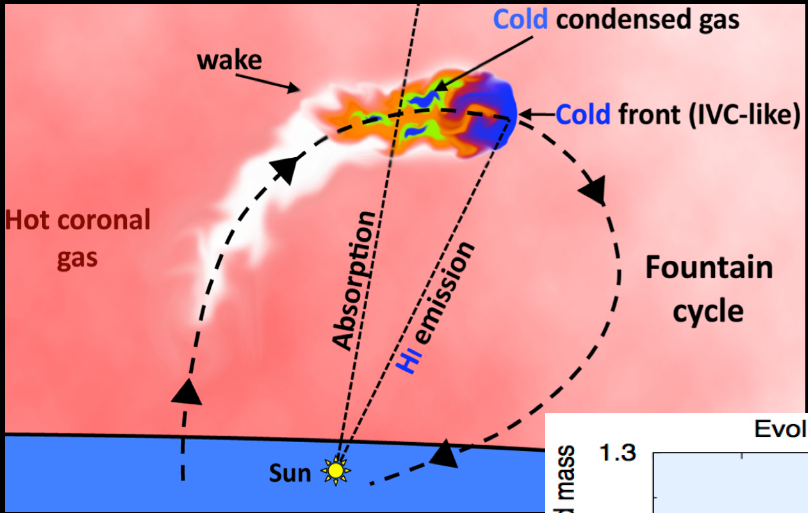


Implications:
1) CGM does not accrete at the edge of the discs
2) Instead it accretes above the disc
3) It has on average 0.7-0.8 $v_{\rm disc}$

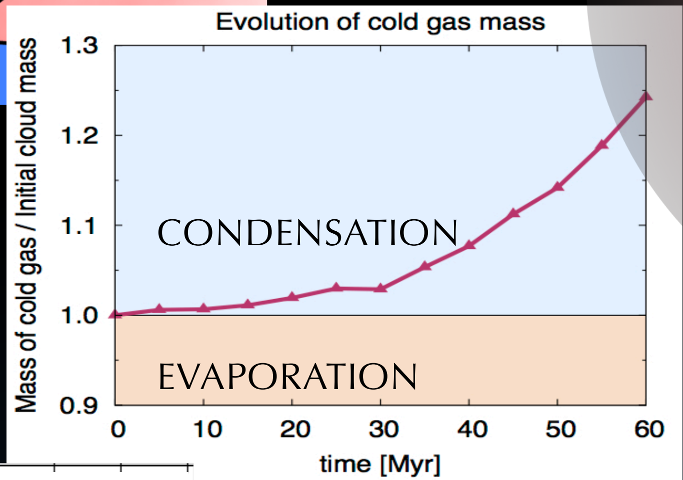
Compatible with accretion from a cosmologically motivated
corona (with cosmological angular momentum distribution)

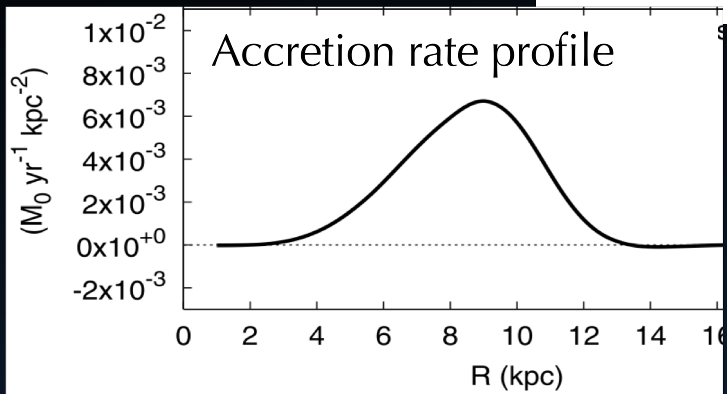
Pezzulli, Fraternali & Binney 2017, MNRAS

Fountain accretion does it

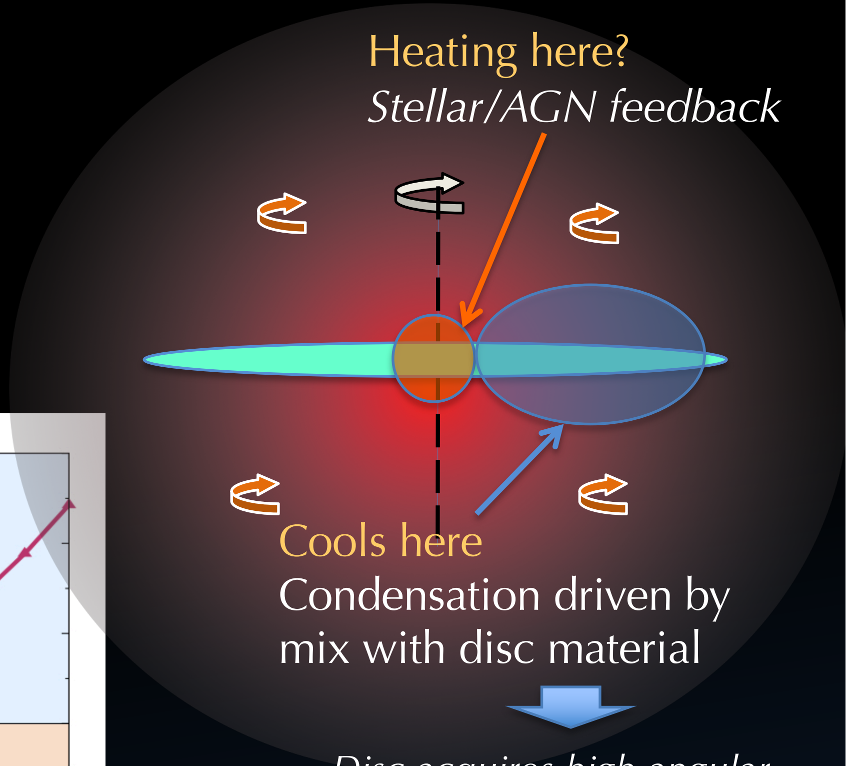


Fraternali et al. 2013, ApJL
Armillotta+ 2016, MNRAS





Marasco, Fraternali & Binney 2012, MNRAS



Disc acquires high angular momentum gas $j = R\, v_{\varphi}$

1) Cooling over the disc
2) Corona must rotate at ~70% disc velocity
3) Produces accretion of ~1 Mo/yr
Sevaral observational confirmations

Fraternali 2017, ASSL - Springer, 430, 323

Part 2

How the CGM does not accrete onto galaxies

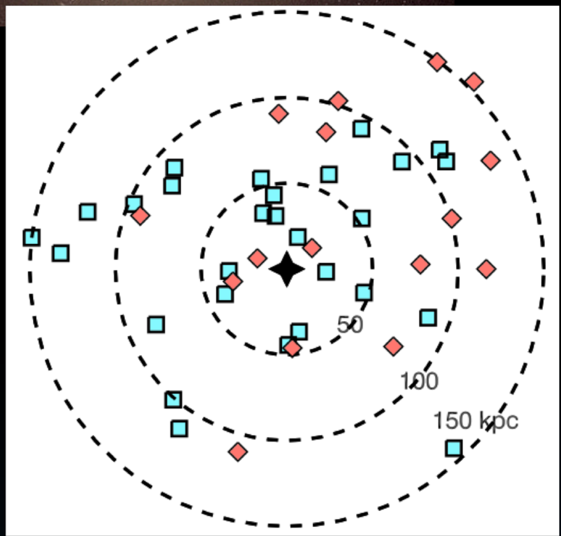
Afruni, Fraternali & Pezzulli, A&A, 2019

Cool CGM of early type galaxies

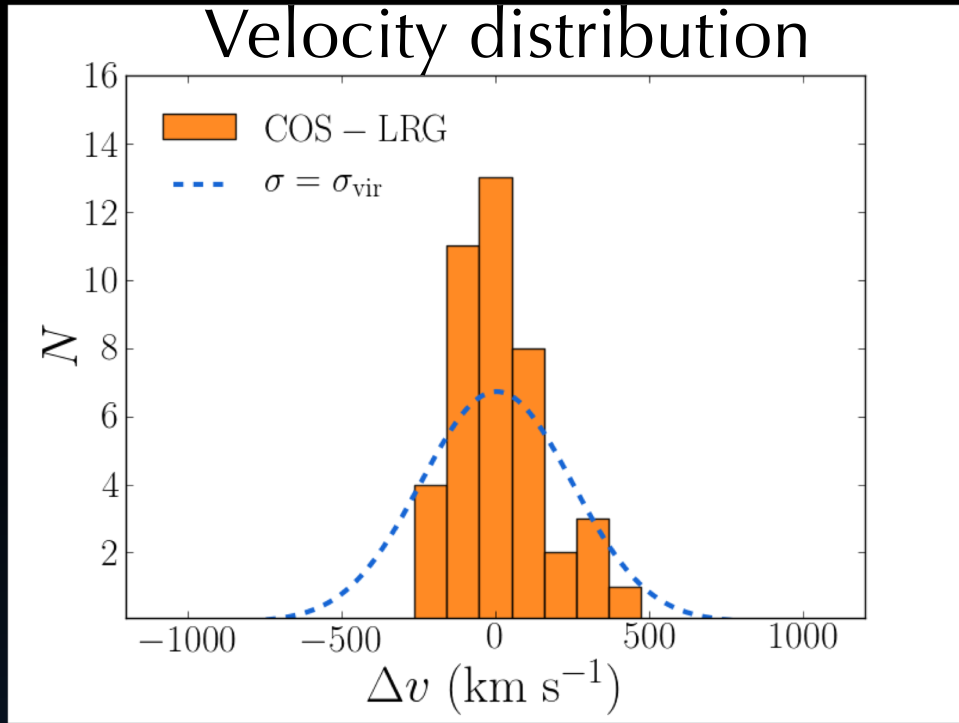
Sample of 16 massive early-type galaxies

COS-LRG *(Chen et al. 2018; Zahedy et al. 2019)*

$\langle M_{\rm vir} \rangle \sim 10^{13.3}\ {\rm M}_\odot$ $\langle r_{\rm vir} \rangle \sim 530$ kpc



Thom et al. 2012; Tumlinson et al. 2013



ETGs have lots of cool CGM!

Why?

- No cool ISM, no outflow
- Inflow? But why quenched?

$$\sigma_{\rm obs} = 150 \pm 20\ {\rm km\ s}^{-1}$$

But $\sigma_{\rm vir} \sim 250\ {\rm km\ s}^{-1}$!

CGM modelling: infalling IGM clouds

Continuous inflow of cool "clouds"
Clouds in pressure equilibrium with the virial-temperature halo gas

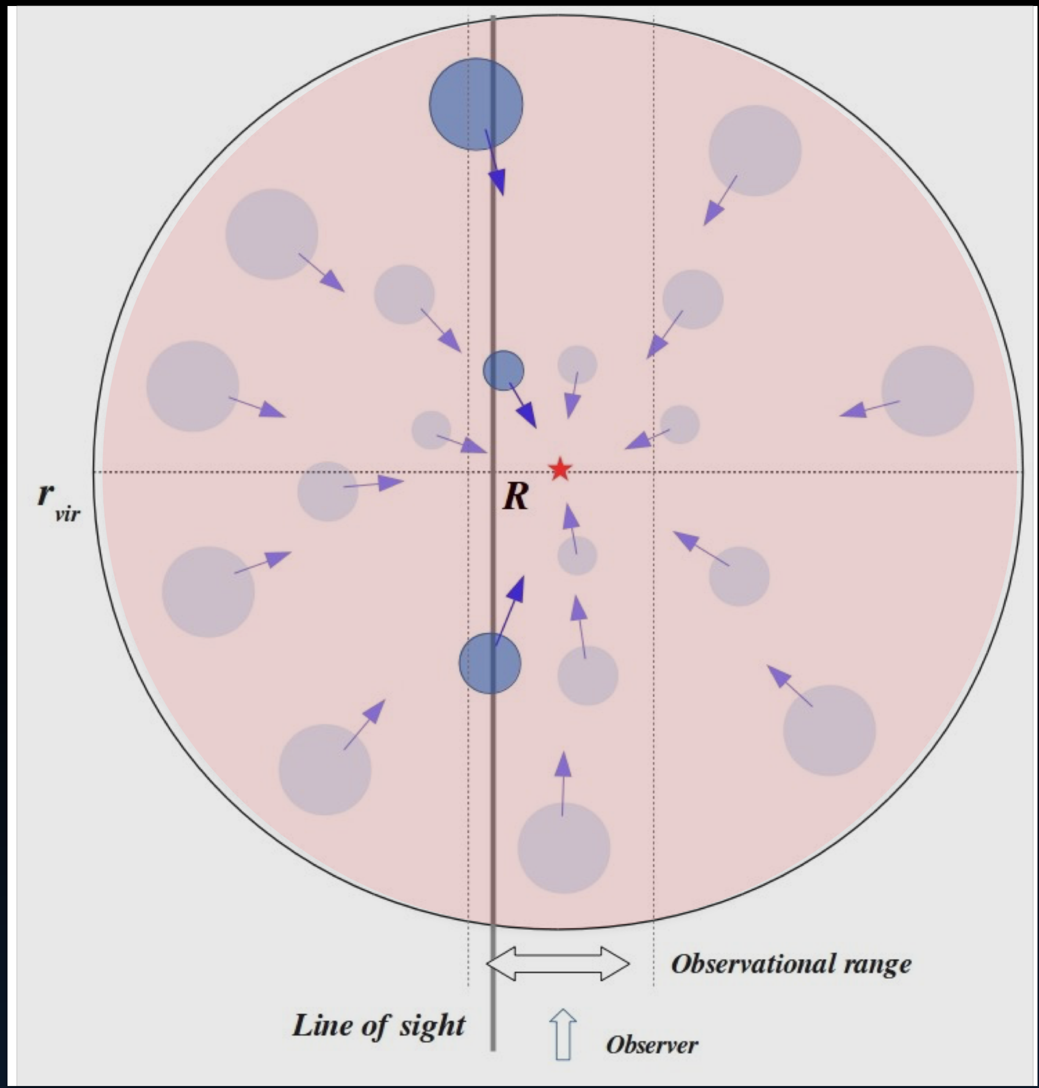
Free parameters

$$f_{\rm accr} = \frac{\dot{M}}{\dot{M}_{\rm cosm}}$$ Global Infall rate

$$v_{\rm start}$$ Initial velocity

$$\dot{v}_{\rm drag} = \frac{\pi R_{\rm cl}^2 \rho_{\rm hot} v^2}{m_{\rm cl}}$$ Drag efficiency: cloud mass

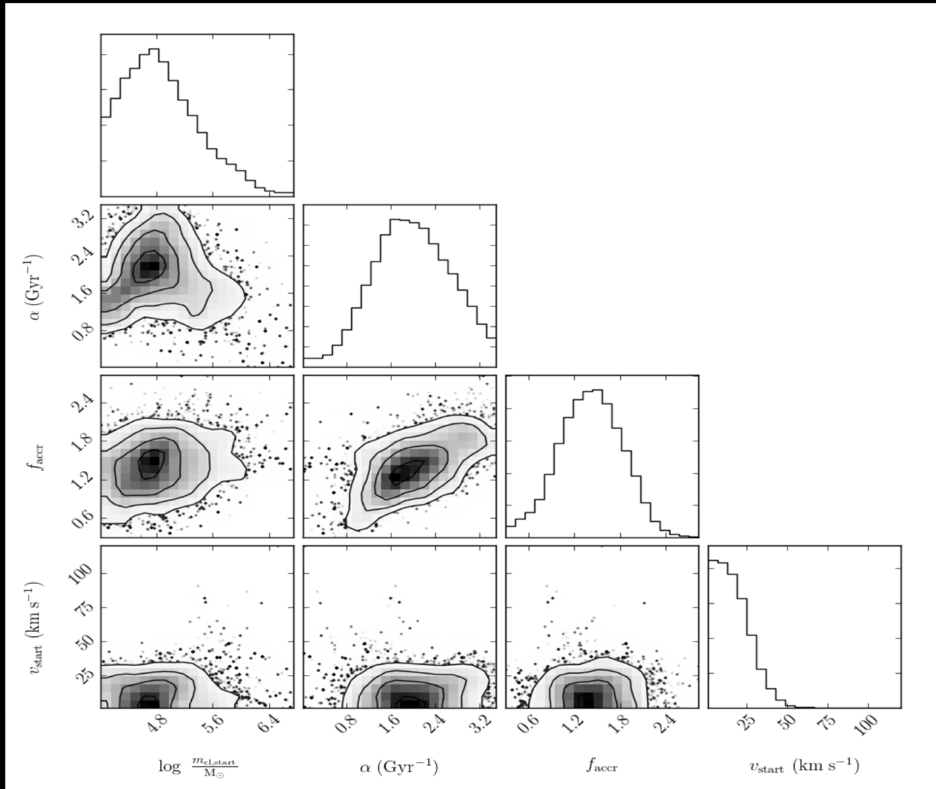
$$\frac{dm_{\rm cl}}{dt} = -\alpha m_{\rm cl}$$ Evaporation rate



Observables

- Velocity distribution
- Number of clouds along the l.o.s.

Infall of IGM/CGM clouds in ETGs: results

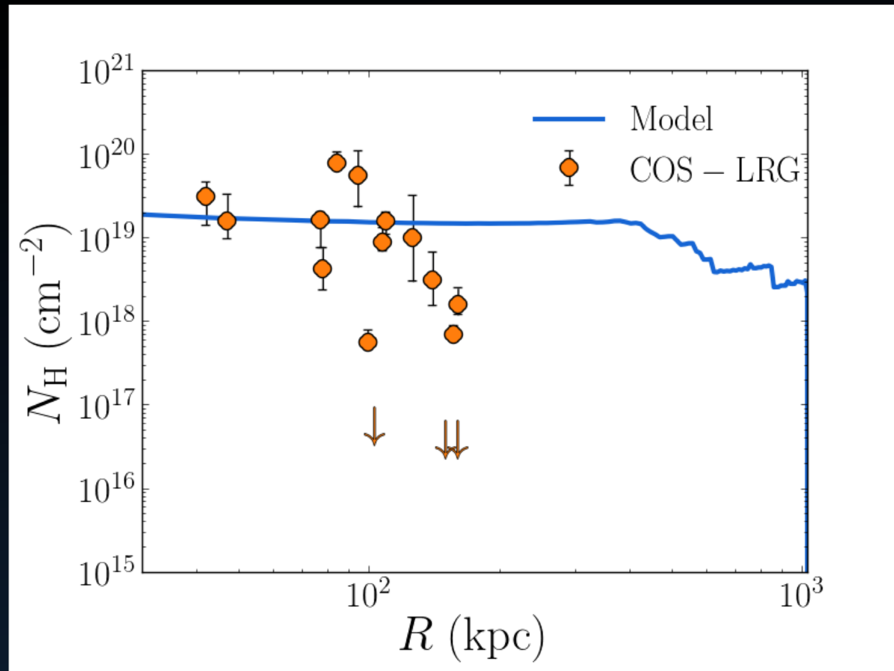


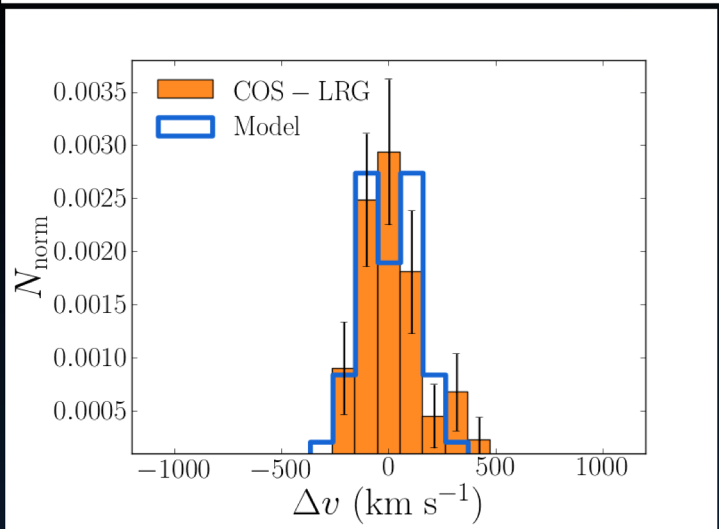
Infall rate ~ cosmological value
Initial velocity ~ 0 km/s

Evaporation time < 1 Gyr

(Initial) cloud mass ~ 10^5 Mo

Column densities – not fitted!

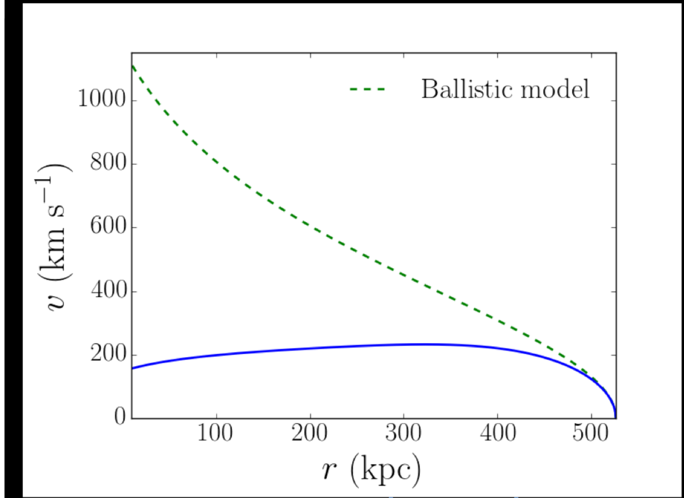




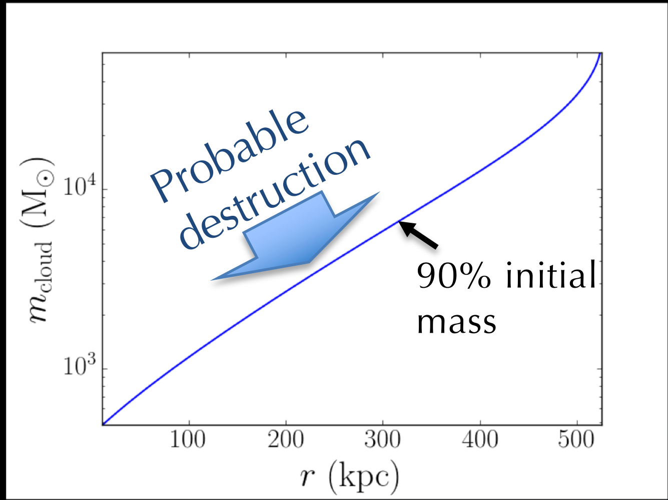
Afruni, Fraternali & Pezzulli, 2019

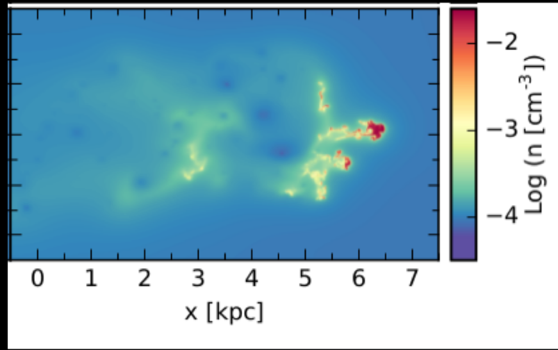
How CGM clouds do not accrete on ETGs

Average cloud speed

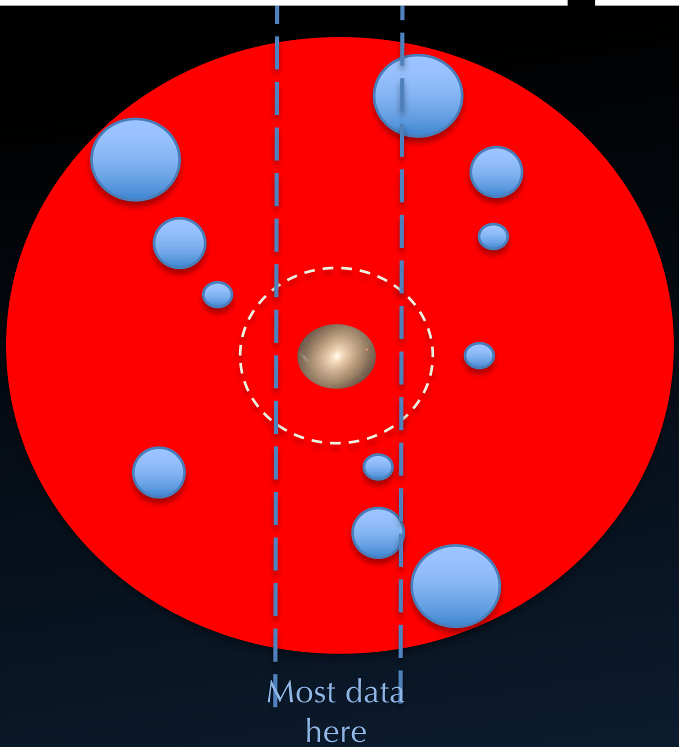


Average cloud mass





See Lucia Armillotta's talk



1) Accrete at cosmological rate
2) Interaction with hot gas -> ablation
3) Most cold gas in the outer parts (only 1% at intrinsic R<160 kpc)

➡ No accretion on ETGs (remain quenched)

Conclusions

1) Metallicity gradients powerful to determine the properties of the accreting gas

2) Star-forming galaxies accrete ~high-*j* material over the disc (not at the edge)
   -> regulated by fountain accretion?

3) Early-type galaxies cannot accrete as cold gas does not reach halo centre
   -> remain quenched