Sipping baryons through the cosmic straw:

the filament-galaxy connection past the virial shock in massive halos

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City University of New York
NYC College of Technology

Cosmicweb23 conference
KITP
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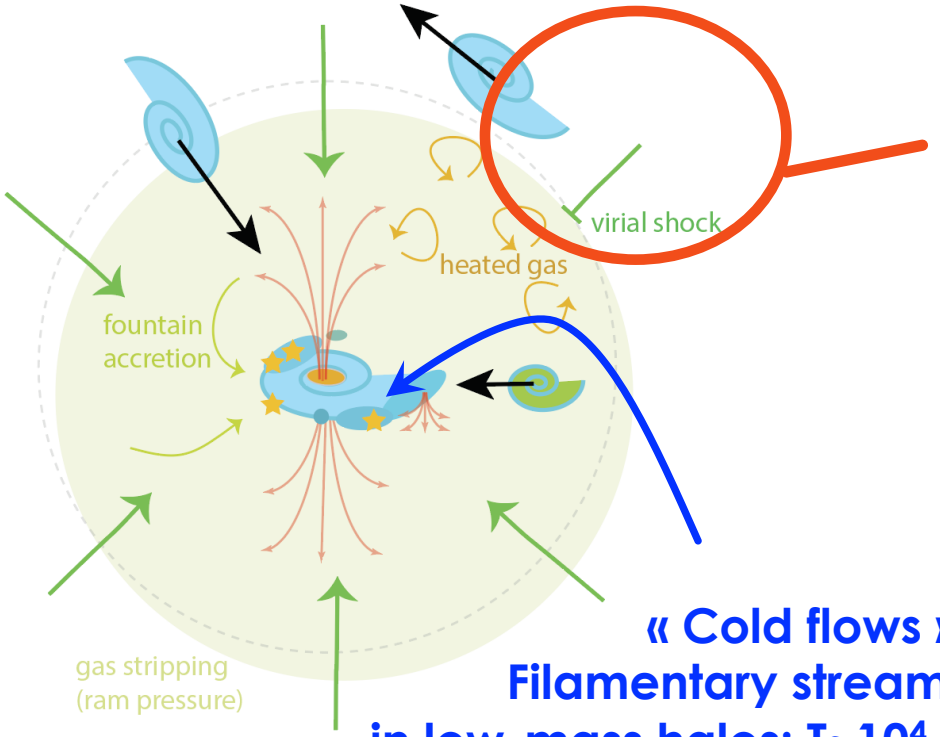
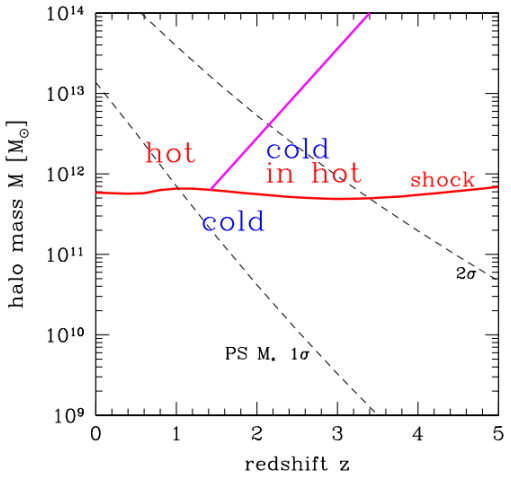
A standard view of cold gas accretion into galaxies?

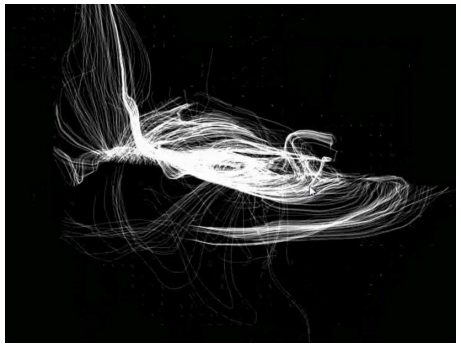


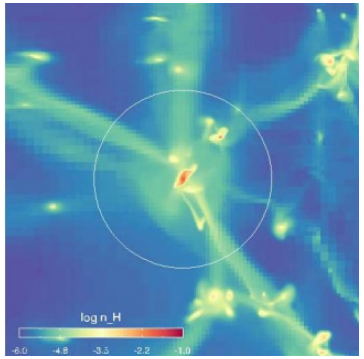
$$M_{\rm halo} > 10^{12} M_{\rm sun}$$

At z<2 cold flows from filaments shock at the virial sphere before entering the halo (Birnboim+03, Dekel+06, Danovich+15)…



« Cold flows »: Filamentary streams in low-mass halos: T~10^4 K





Pichon+2011

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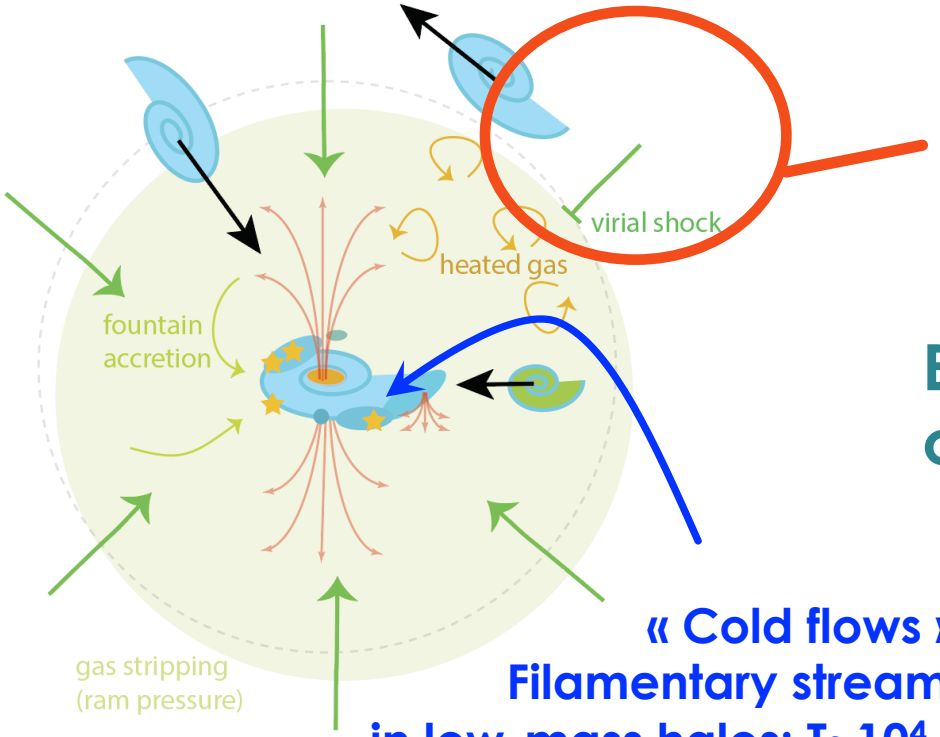

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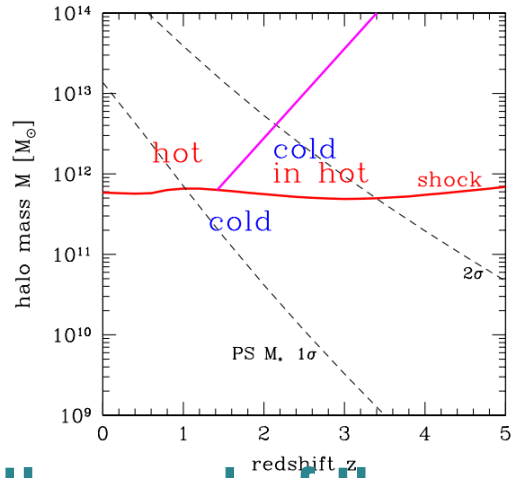
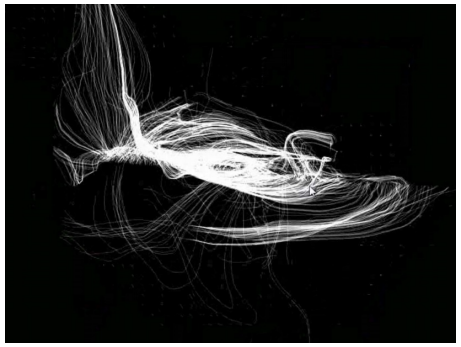
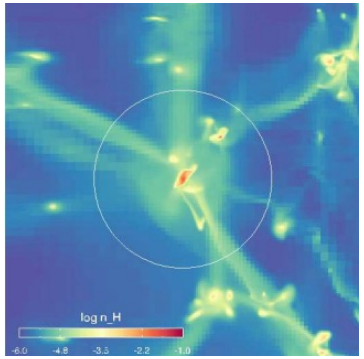


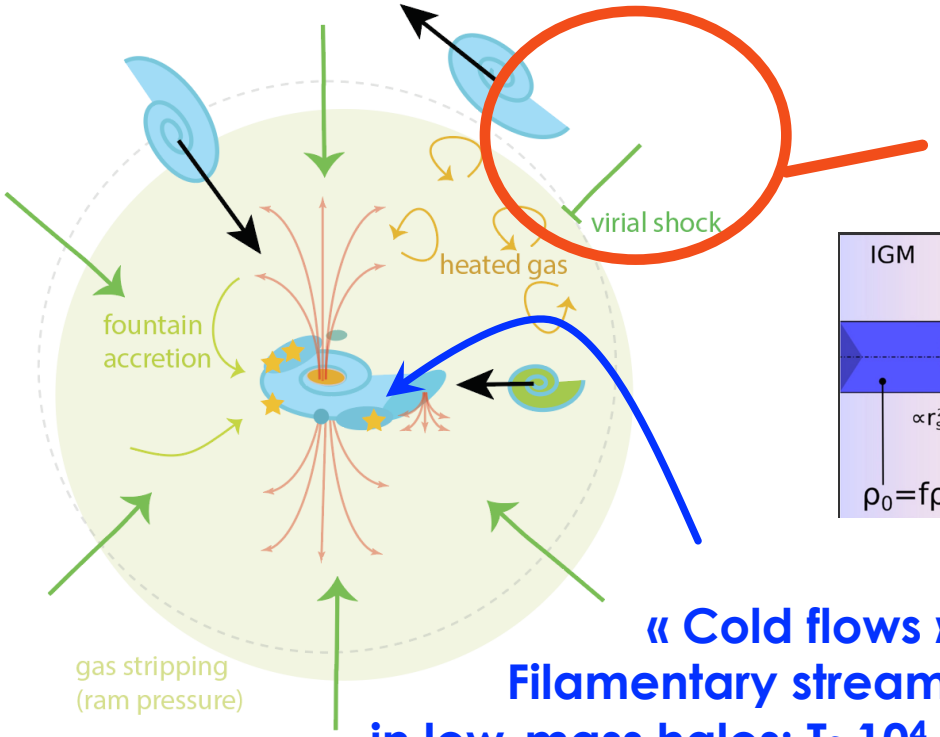
But is the end of cold flows really the end of the connection to the cosmic web?





Pichon+2011

Multiphase accretion might be more ubiquitous than initially thought



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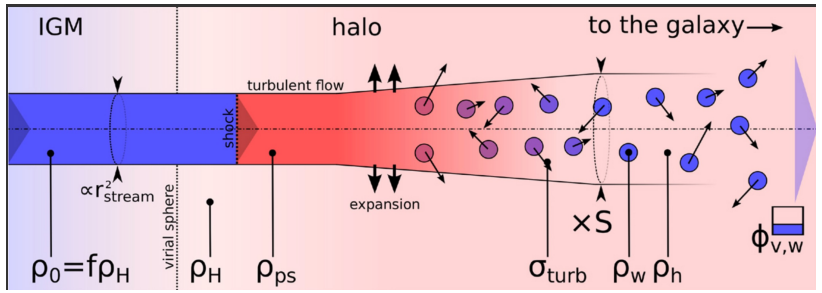
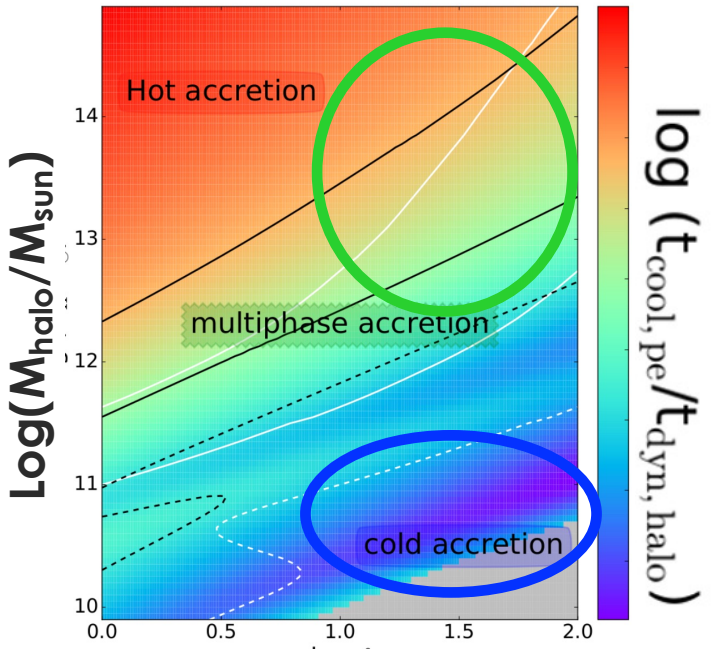


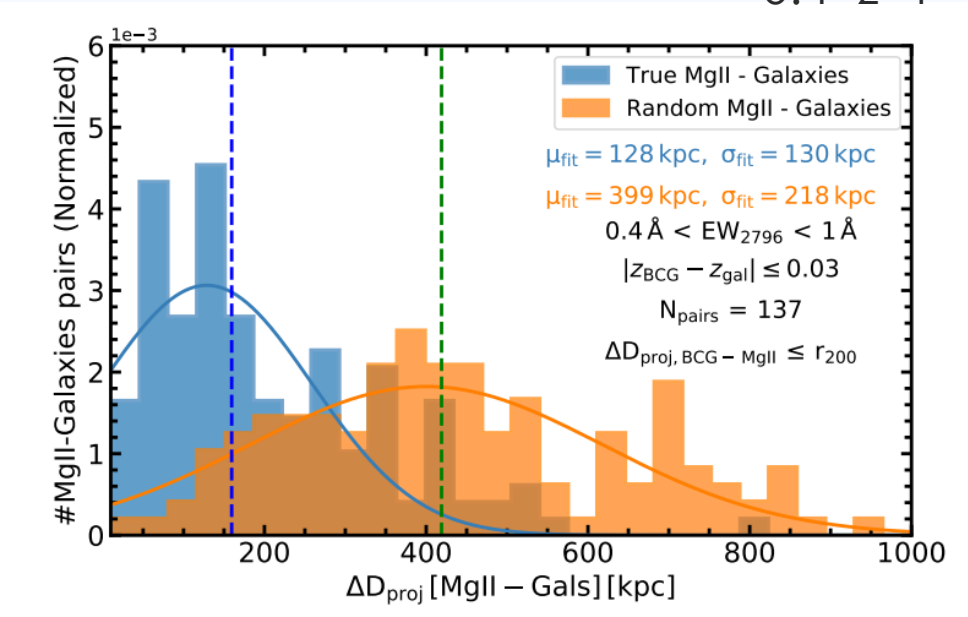
Cornuault+2018

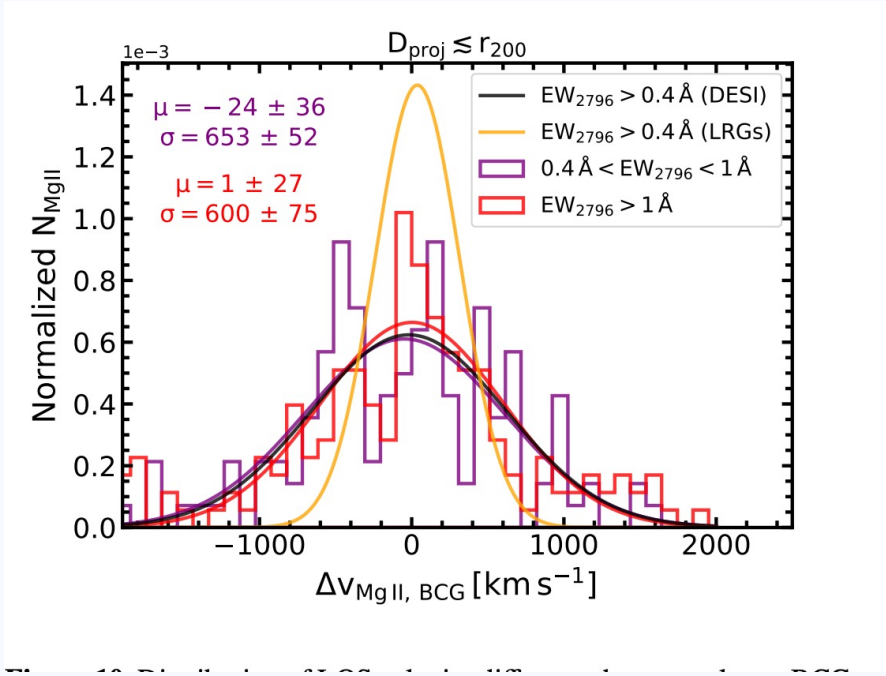


Cold clouds of MgII absorbers detected in DESI clusters

0.4<z<1

Anhand+2022





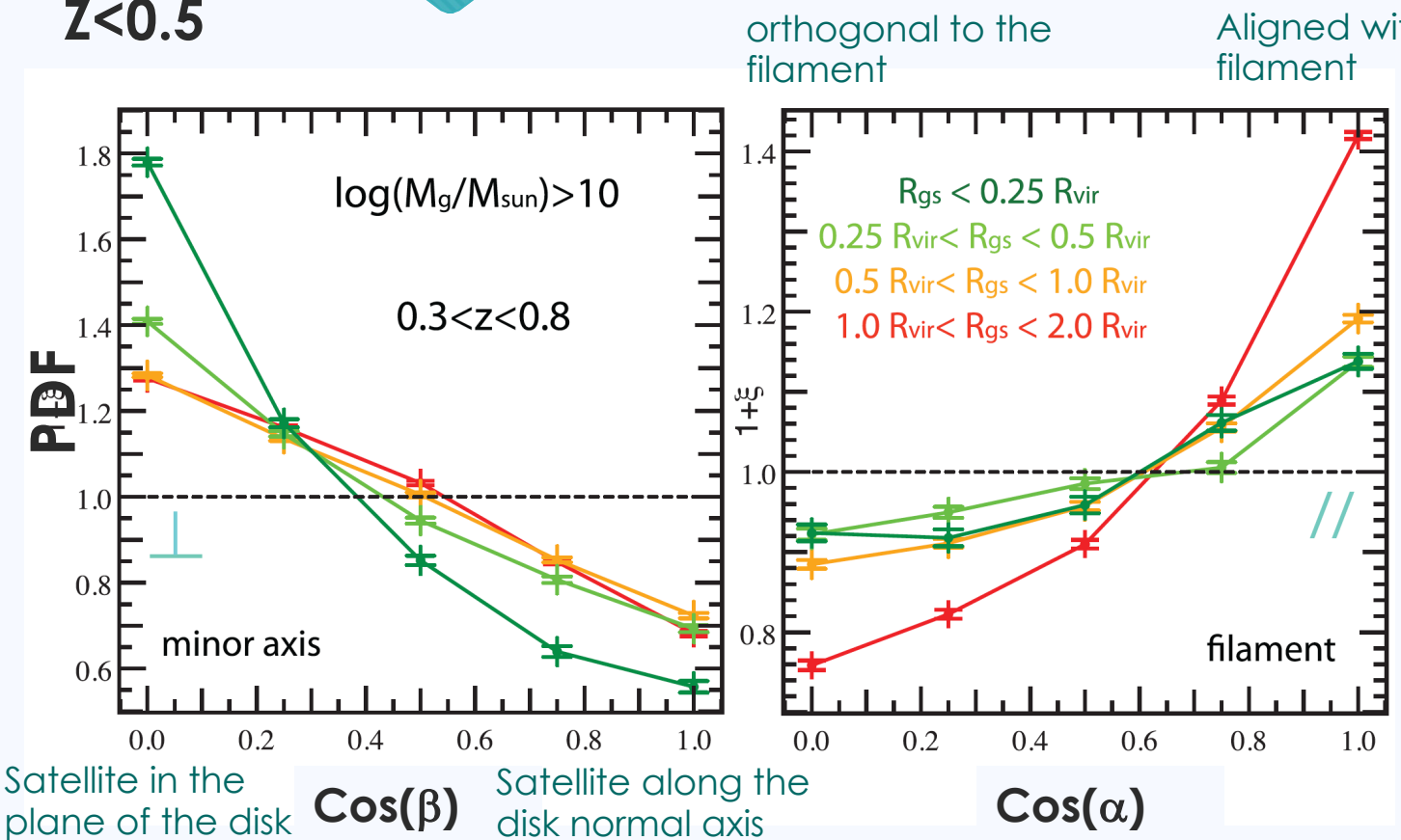
- **Large amounts of Mg II absorbers detected far away from the central galaxy (>200 kpc)**
- **Mg II cloud location correlated to the position of cluster satellites.**

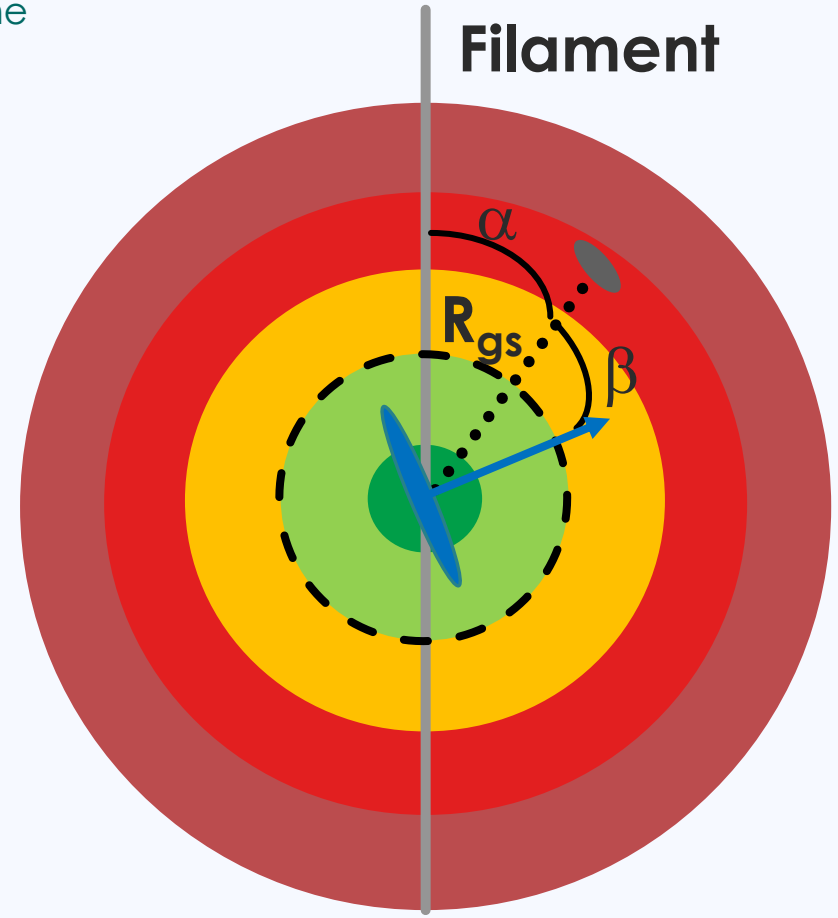
- **Weak evidence of a secondary peak with negative velocity (inflow?)**
- **Or stripped from infalling satellites?**

The distribution of satellites at z<0.5 recapitulates the helicoidal structure of cold flows

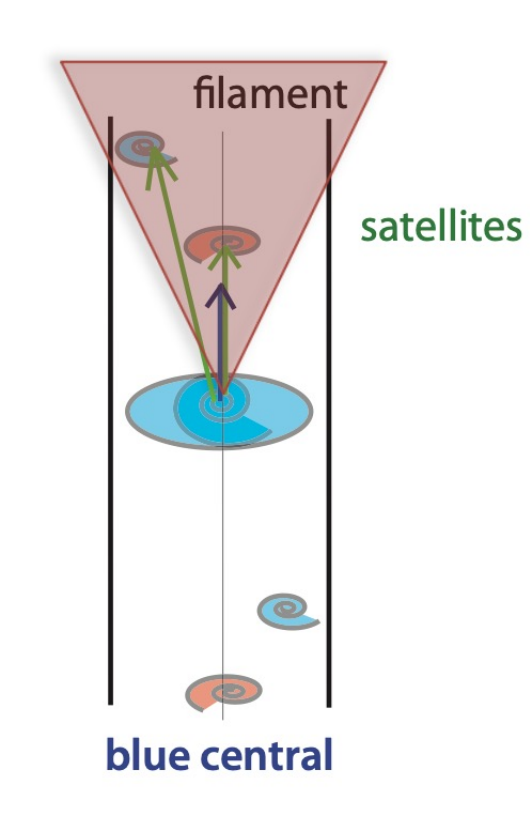
Helocoidal flows visible in the distribution of satellites

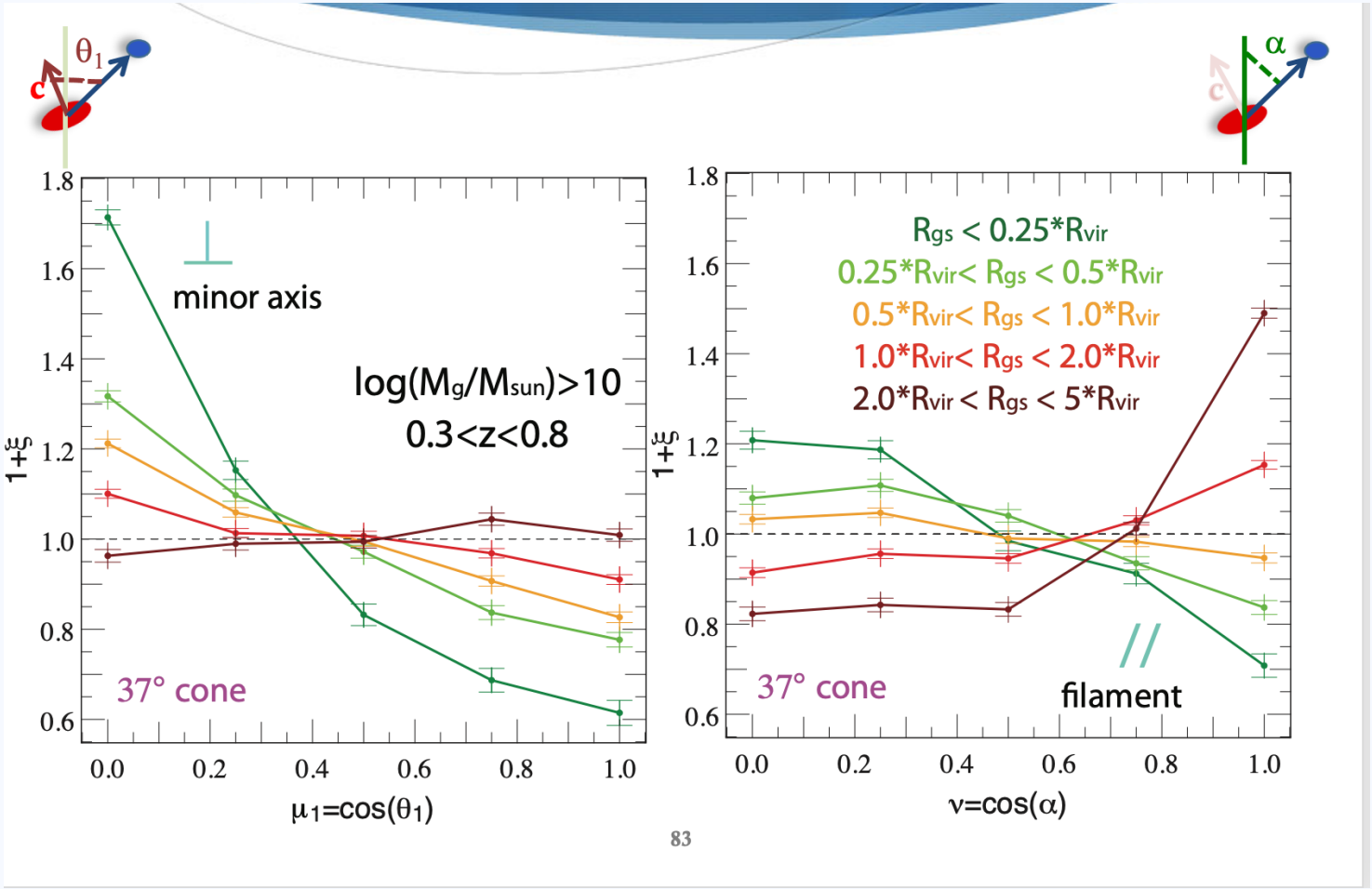
Welker+2018





The extreme case of massive galaxies with spin aligned to the filament



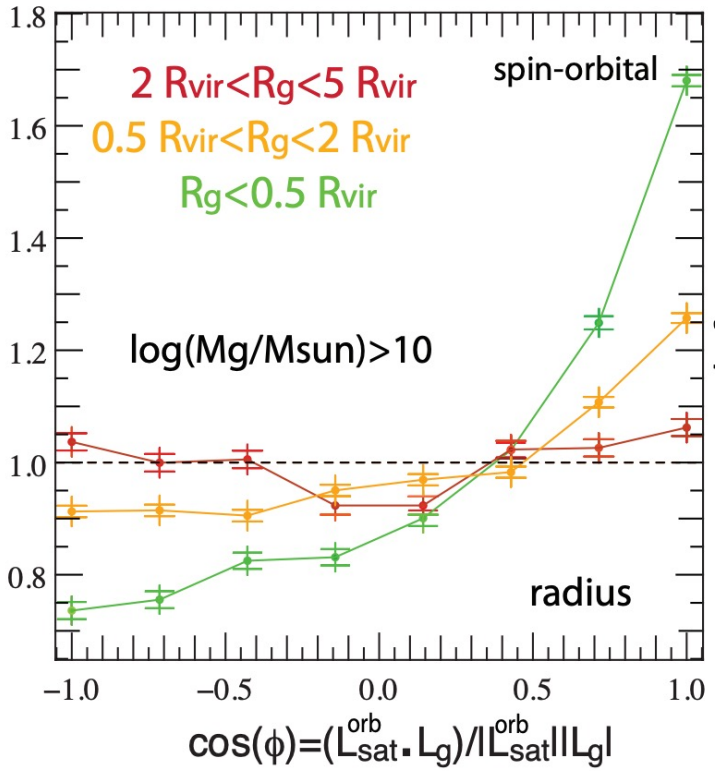


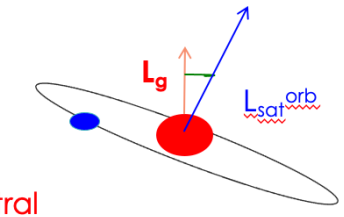
Inner satellites align their orbital momentum with the central galaxy's spin

Welker+2018

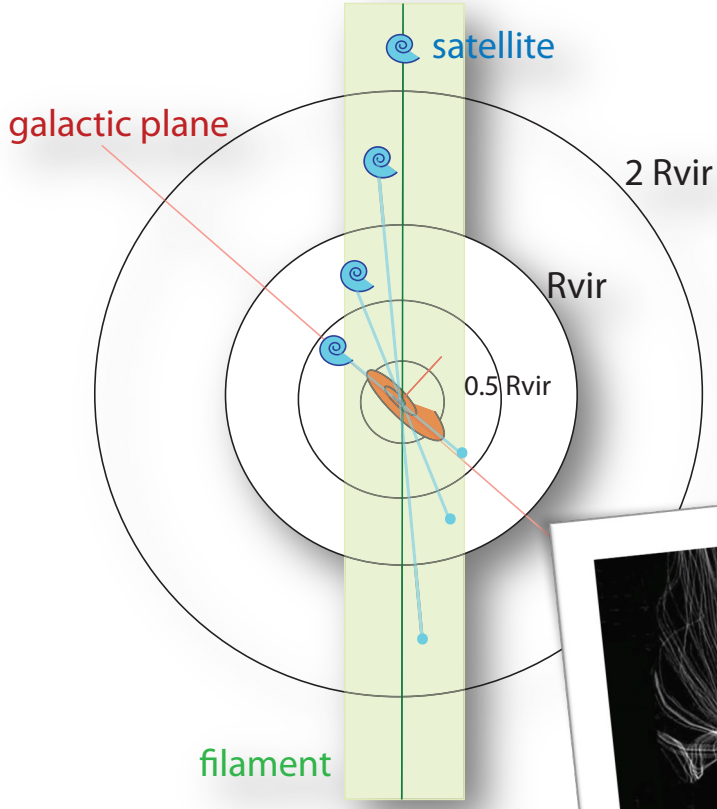
Orbital momentum orthogonal to central spin

Orbital momentum aligned with central spin

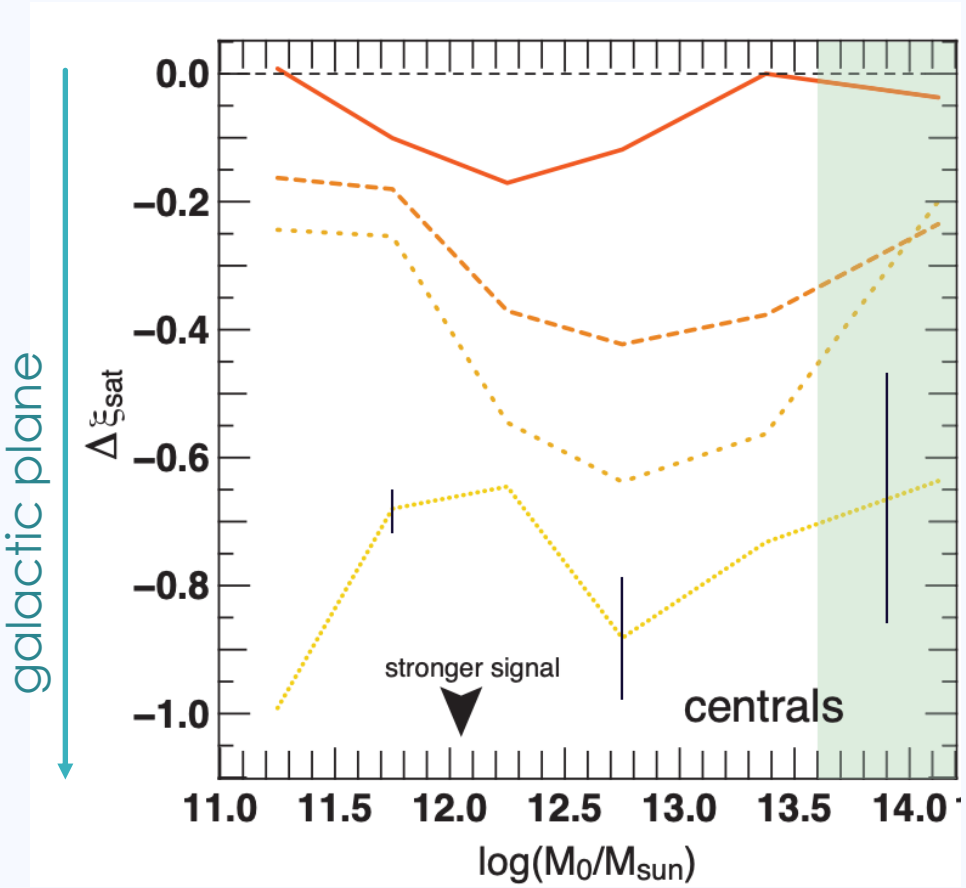




central satellite



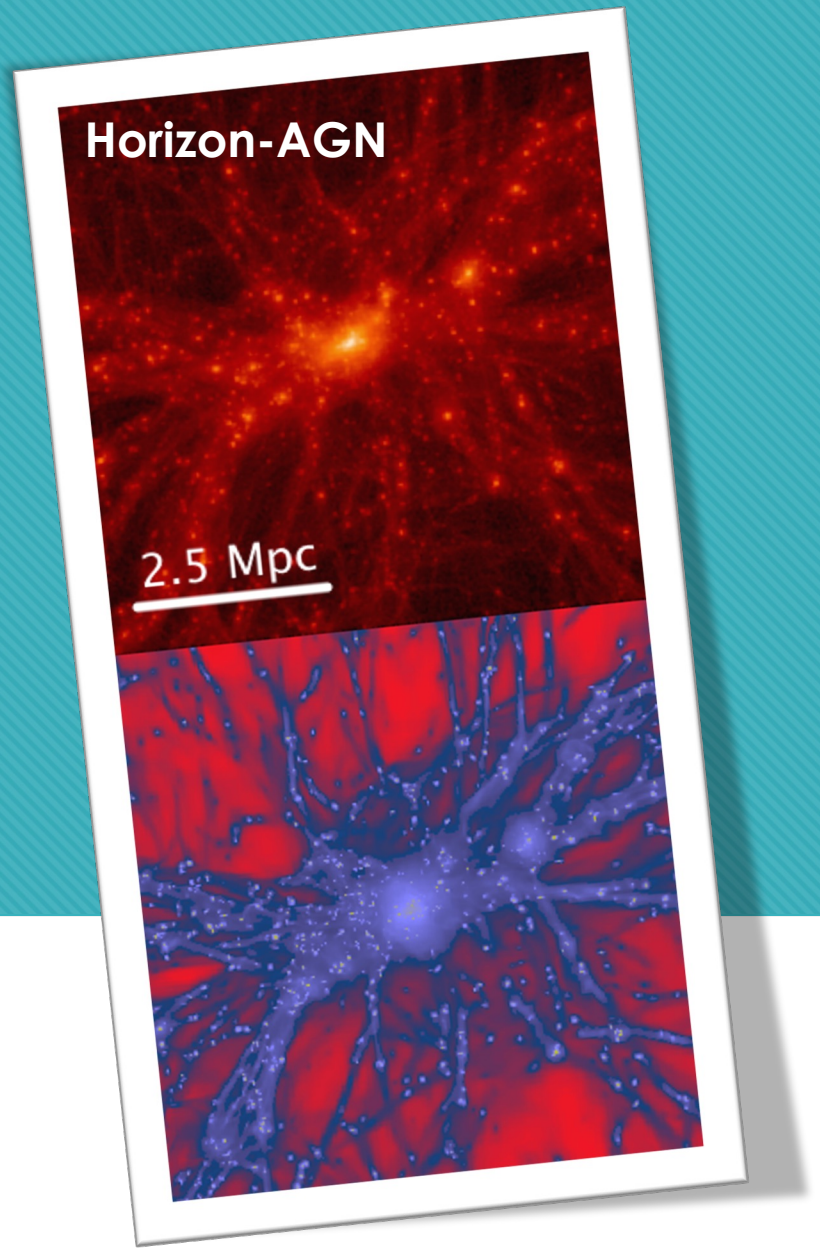
Inner satellite alignments particularly pronounced for central disks at all halo masses



Minor to major axis ratio of the central

- $c_g/a_g > 0.75$
- $0.60 < c_g/a_g < 0.75$
- $0.45 < c_g/a_g < 0.6$
- $c_g/a_g < 0.45$

More prominent disc

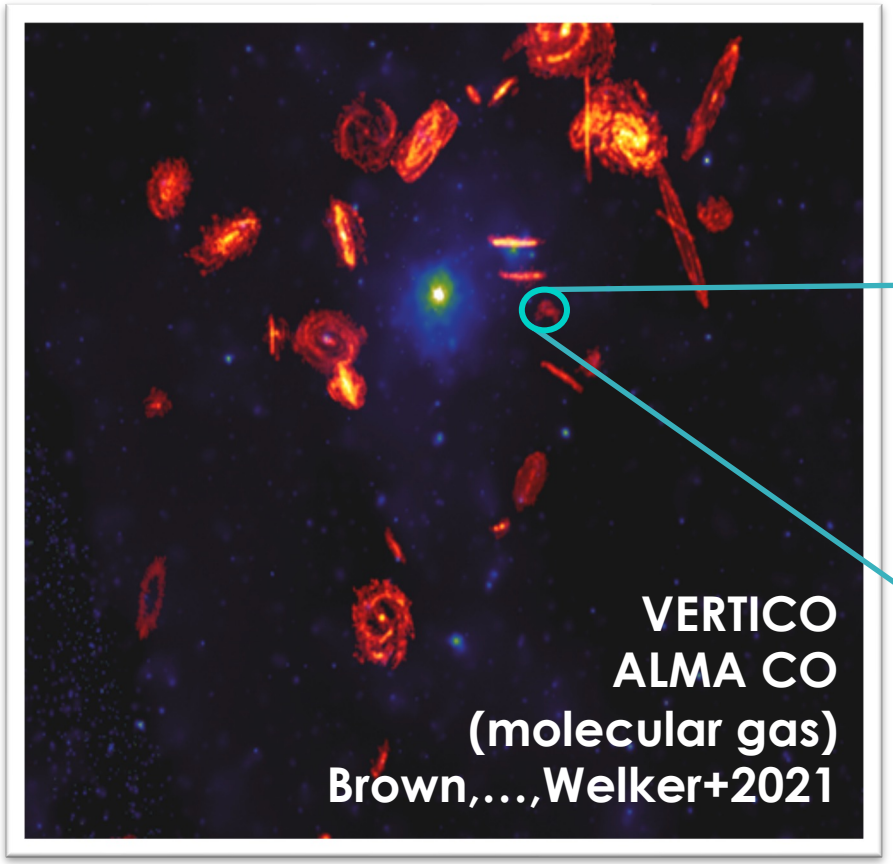


Life in inter/intra-cluster filaments

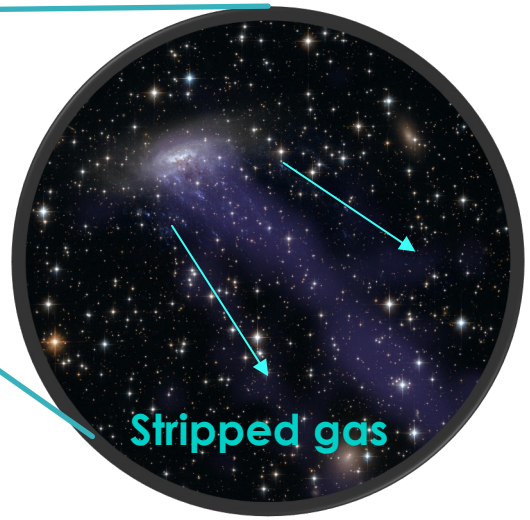
The most detectable of gas filaments!

The fate of galaxies in clusters

Virgo cluster



- Several 100s to 1000 galaxies
- M_{halo} ~ 10^{14} to 10^{15} M_{sun}



Starvation:
Hot, turbulent medium prevents cooling of gas into stars

Ram pressure stripping:
dynamic pressure from dense cluster strips galaxy of its gas as it is ploughing through

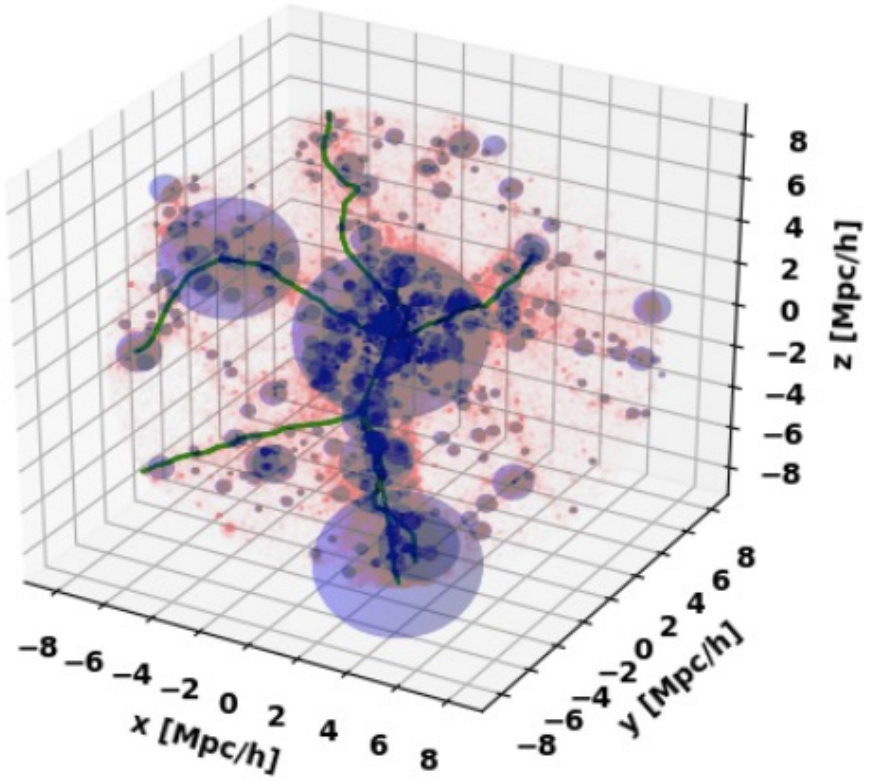
$$P_{\rm ram} \approx \rho_{\rm ICM}\, V_{\rm gal}^2 > 2\pi {\rm G} \Sigma_* \Sigma_{\rm ISM}$$

Gunn & Gott (1972)

Galaxies stop forming stars: they quench!

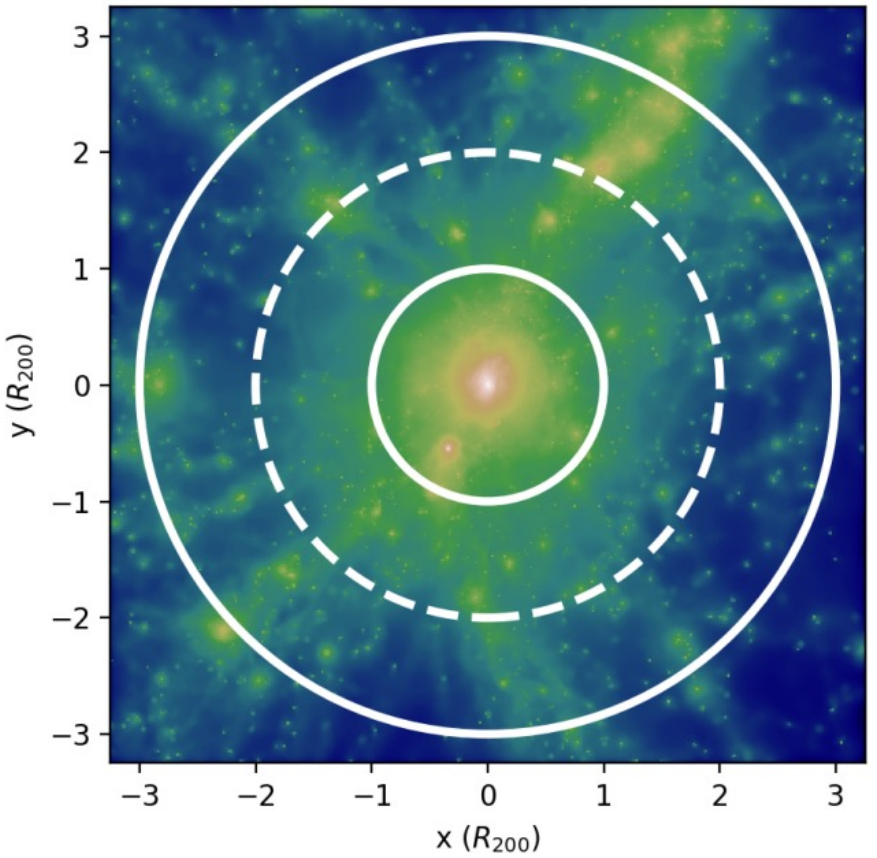
Identification of intra-cluster filaments in The Three Hundred simulated suite

TheThreeHundred :
324 simulated clusters at intermediate resolution (~ few kpc)
Cui,(…),Welker+2018



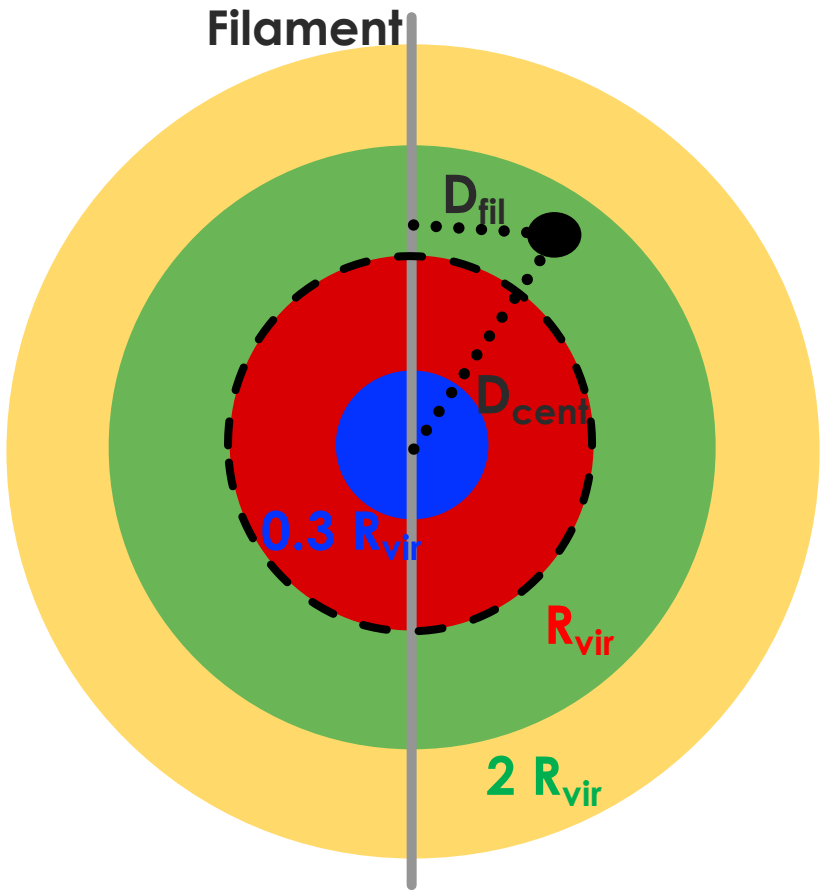
>1 million galaxies above 10^9 Msun

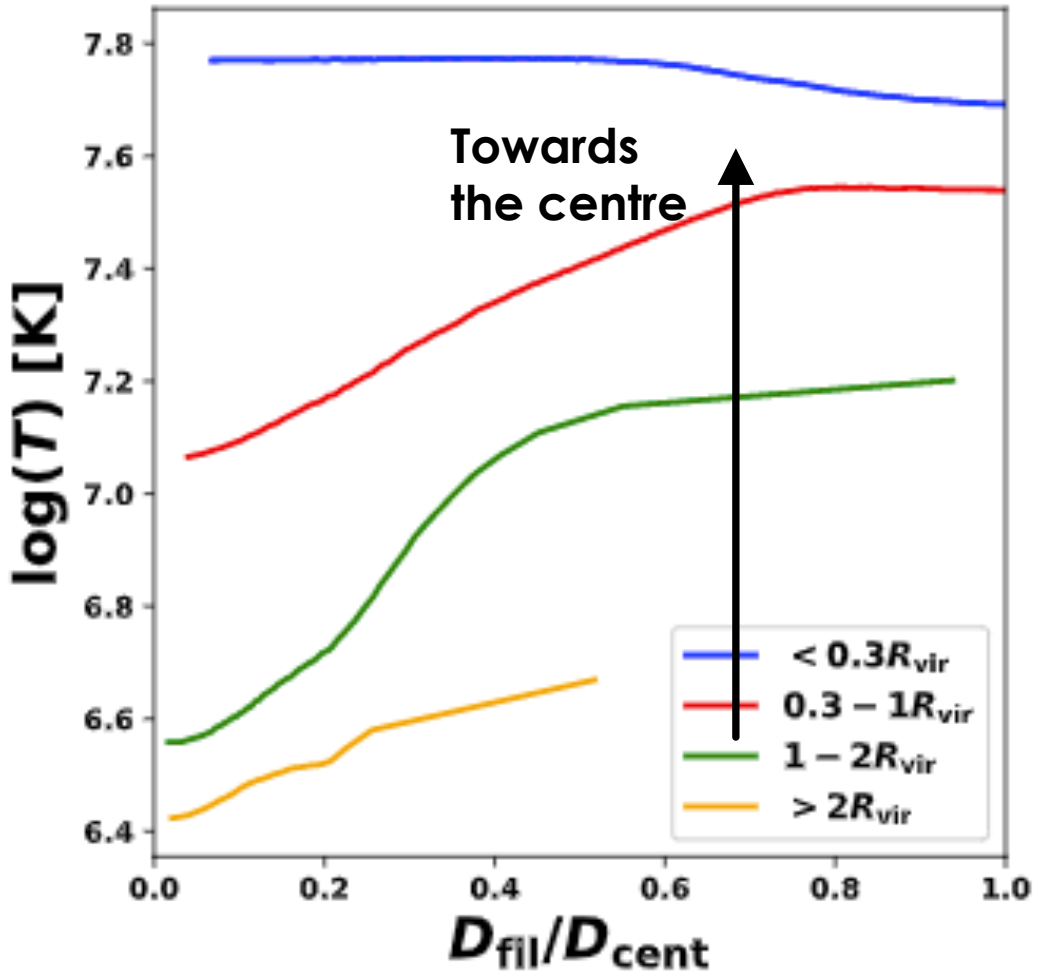
At z=0



Intra-cluster filaments are regions of reduced gas temperature

Kotecha&Welker+2022



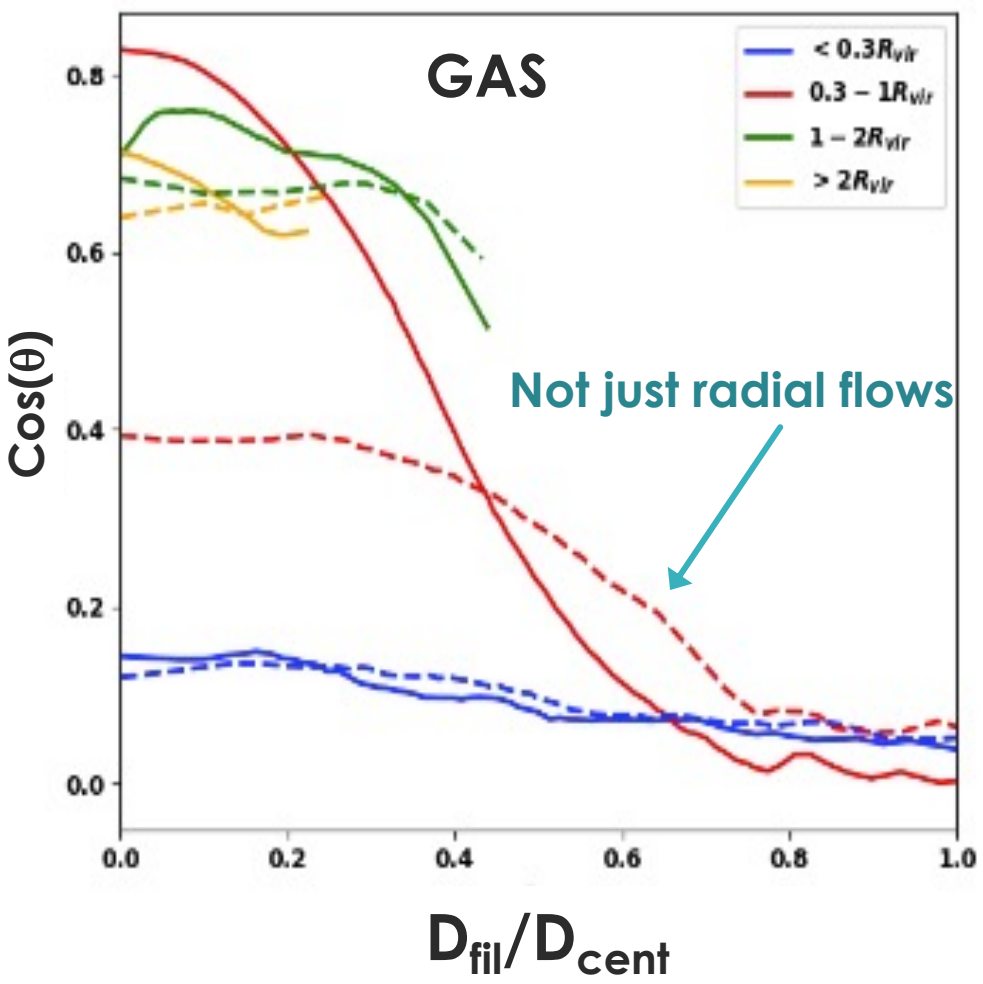


Sachin Kotecha

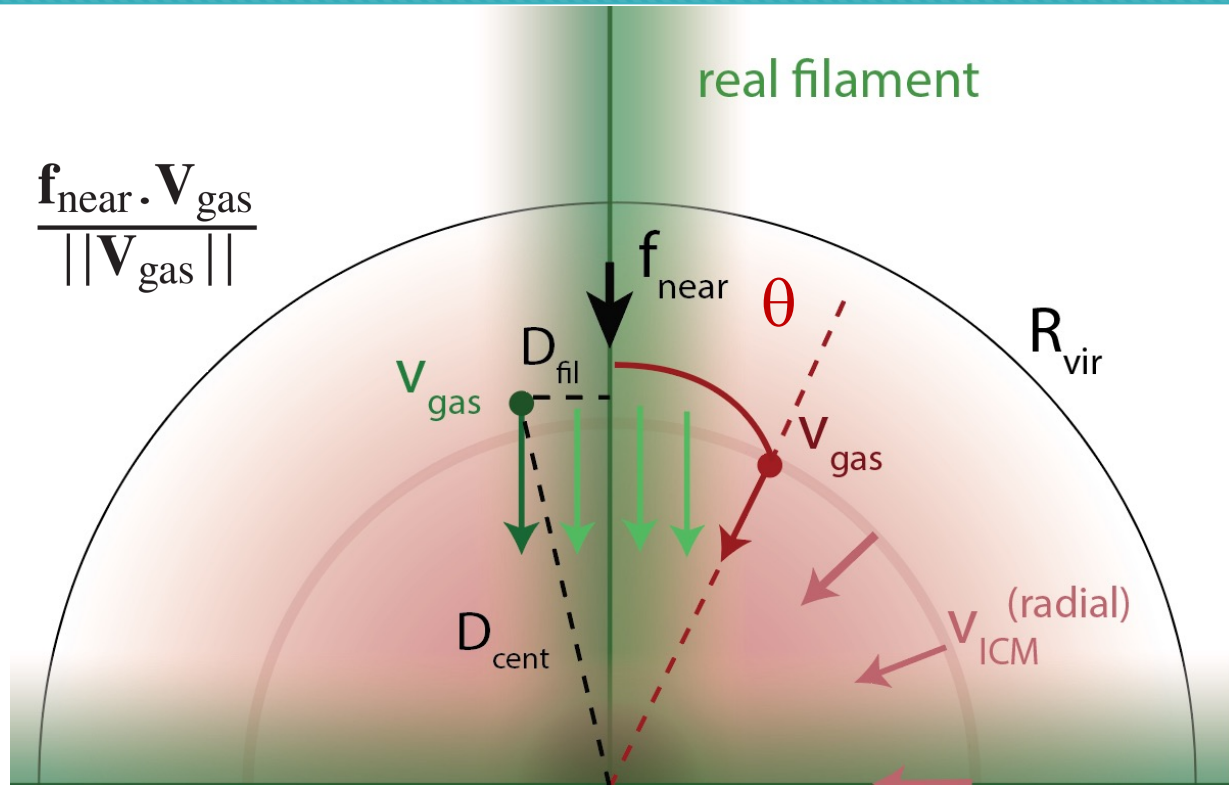
Zihan Zhou

Intra-cluster filaments are regions of coherent streams

Kotecha&Welker+2022



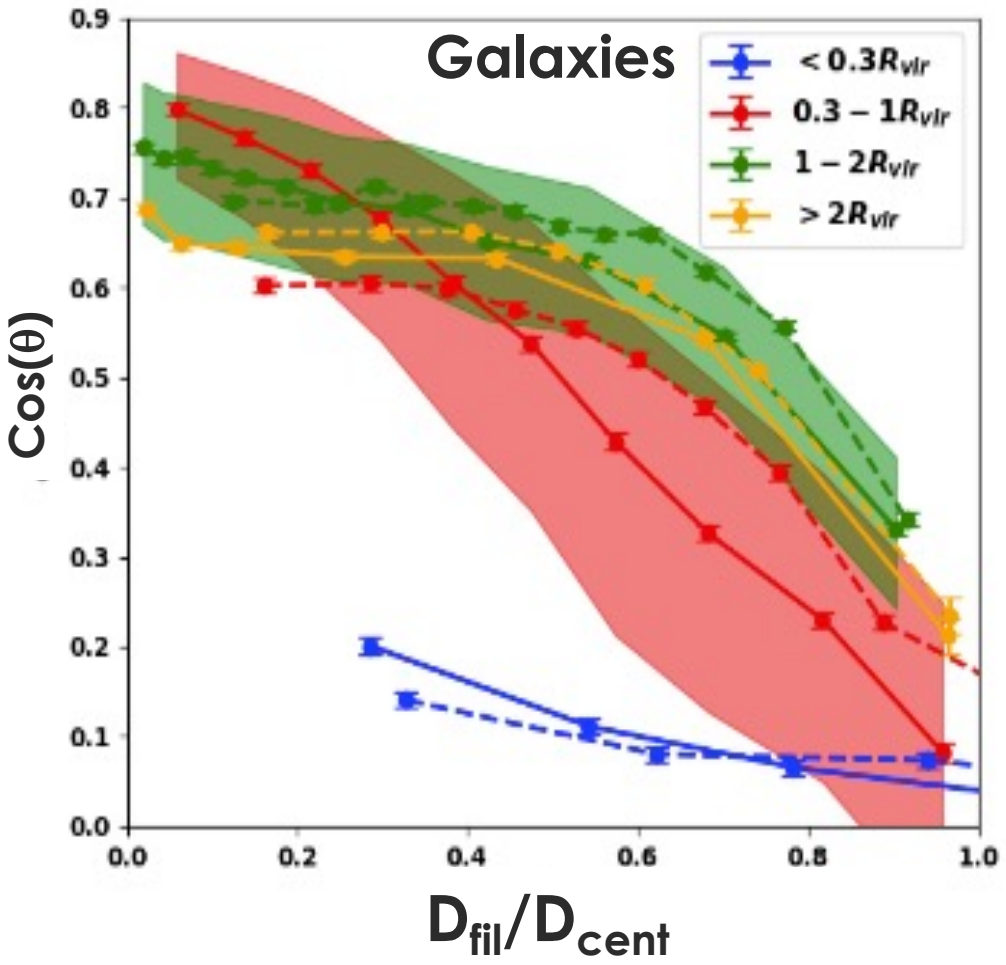
$$\cos\theta = \frac{\mathbf{f}_{near} \cdot \mathbf{V}_{gas}}{||\mathbf{V}_{gas}||}$$



Diffuse gas markedly flows along the filaments, inwards!

Intra-cluster filaments are regions of coherent streams… of galaxies

Kotecha&Welker+2022



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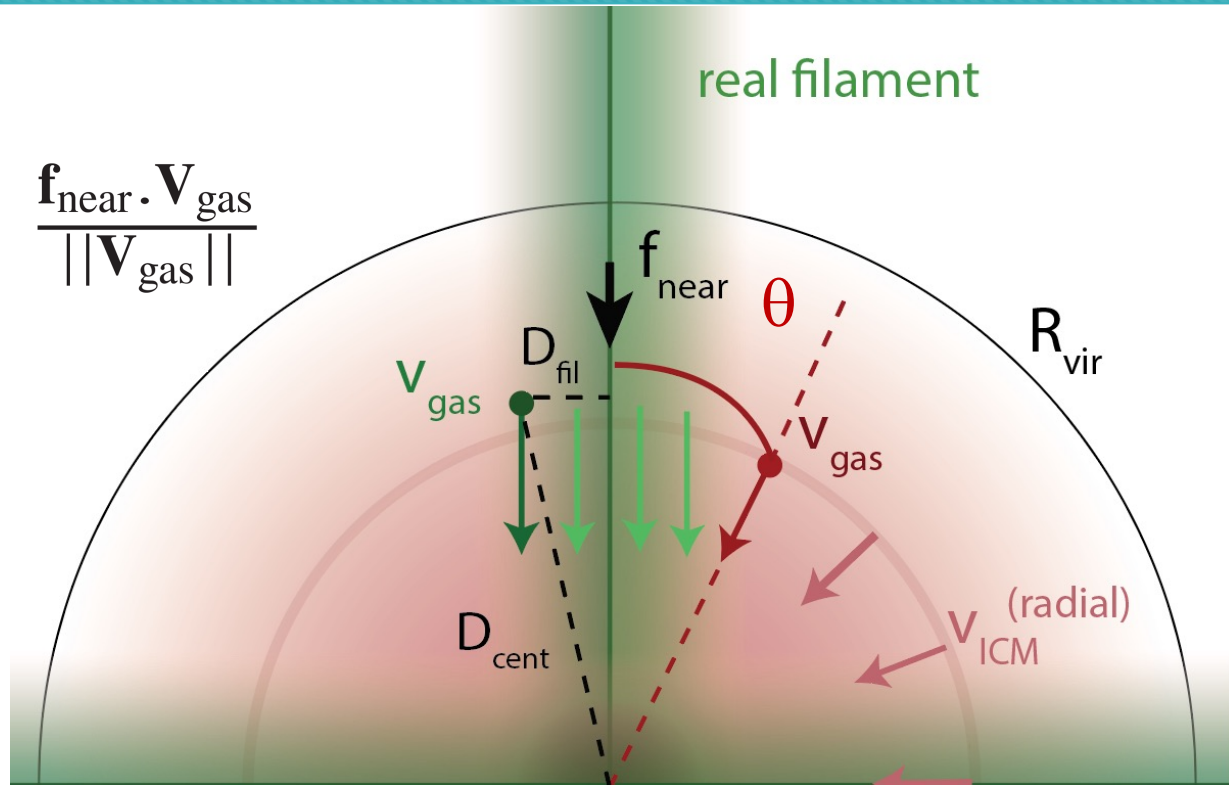


Galaxies markedly flow along the filaments, inwards!

Could they impact quenching?

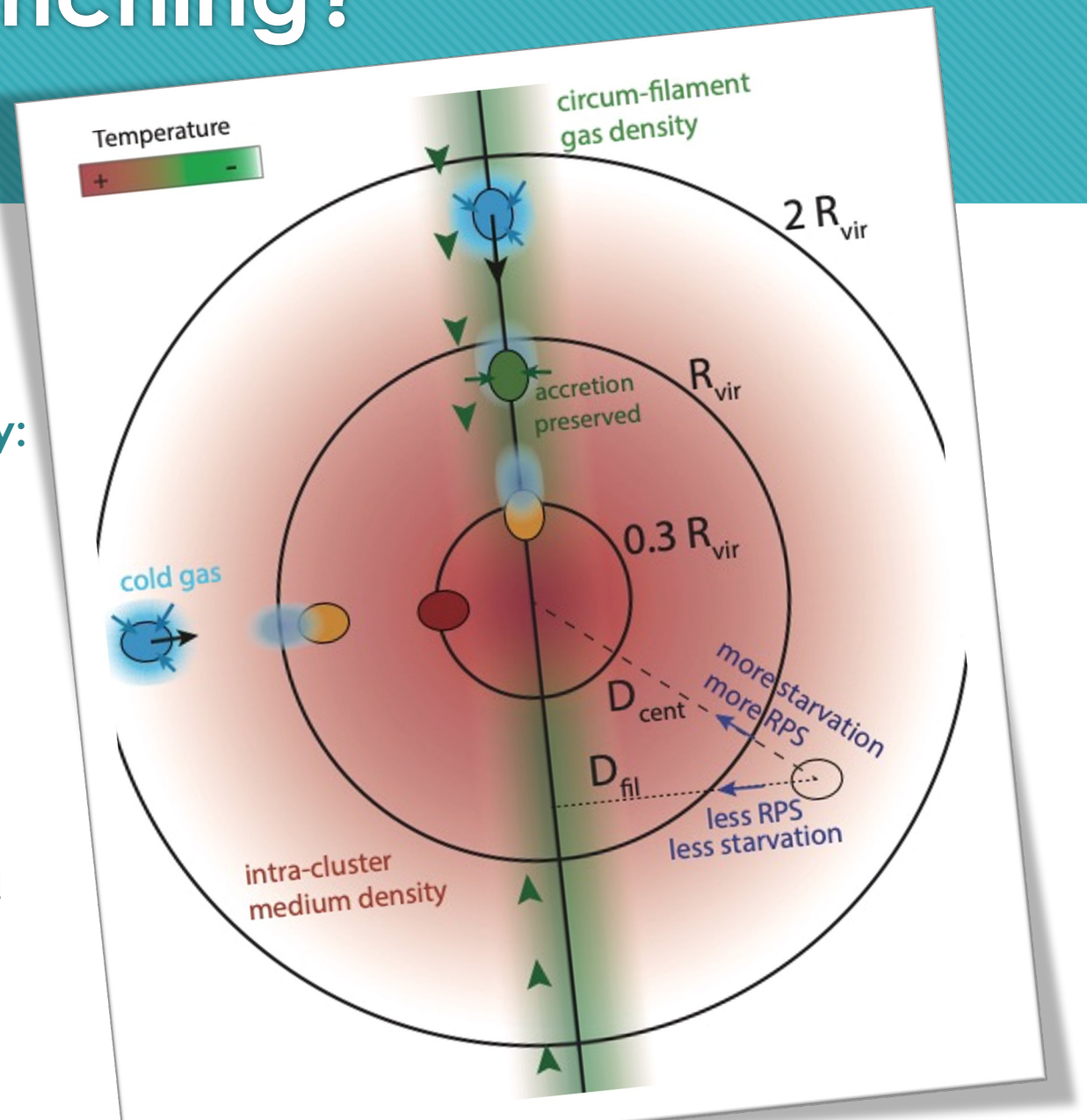
Coherent flows of cool gas and haloes could locally:

a. help preserve cold gas accretion

b. reduce ram-pressure stripping

c. Preserve gas fraction and star formation

That would be in stark contrast with filaments *outside clusters* where we expect *pre-processing*!

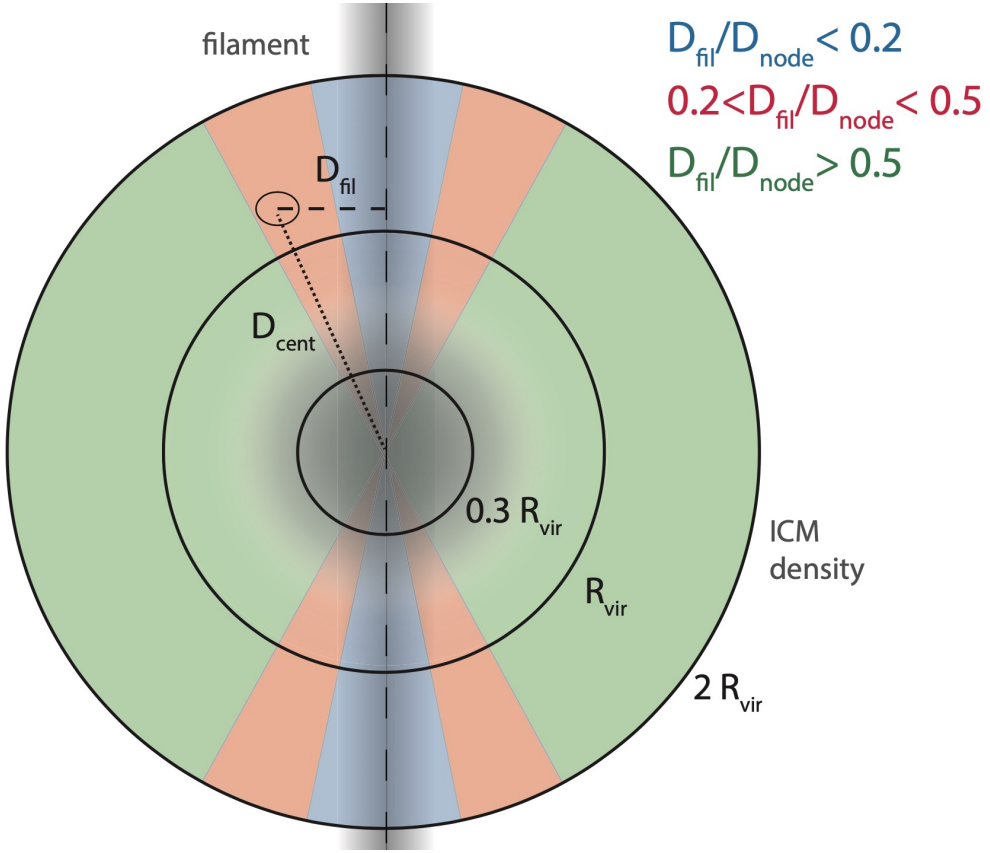


Let's check!

Cold gas fraction preserved near intra-cluster filaments

Kotecha&Welker+2022
Welker+2022

$$f_{\rm gas}^{\rm cold} = \frac{M_{\rm gas}(\mathrm{T} \leq 10^5\ \mathrm{K})}{M_{\rm gas}(\mathrm{T} \leq 10^5\ \mathrm{K}) + M_{\rm star}}$$



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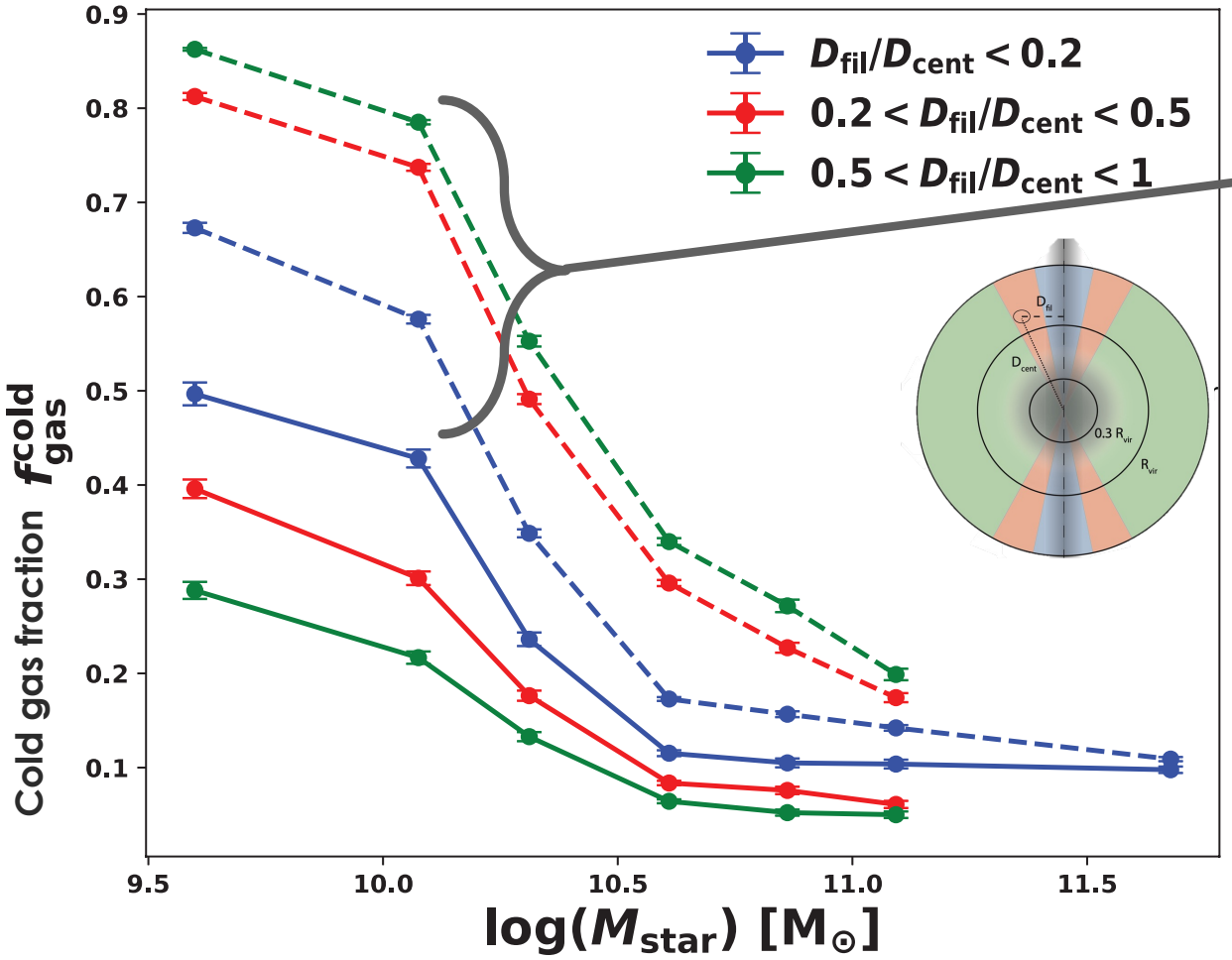

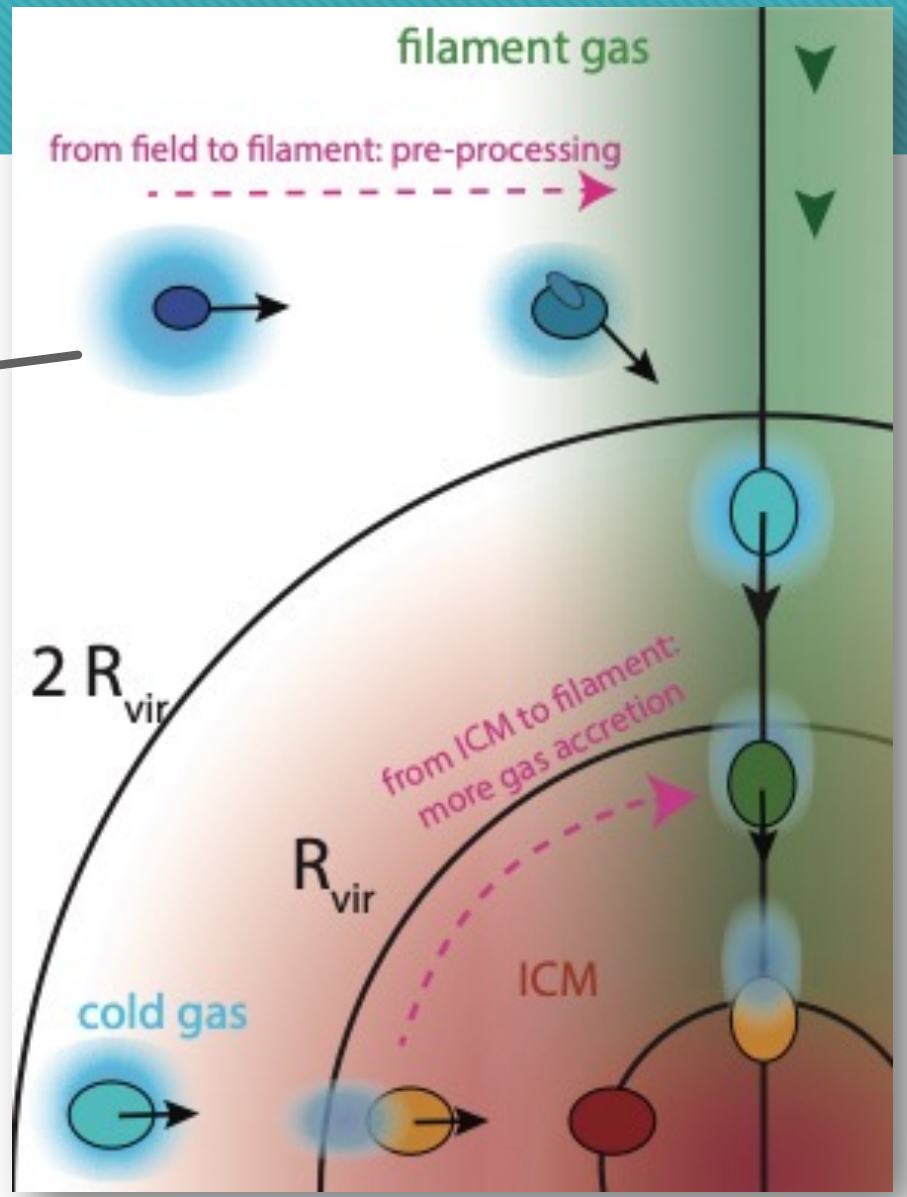

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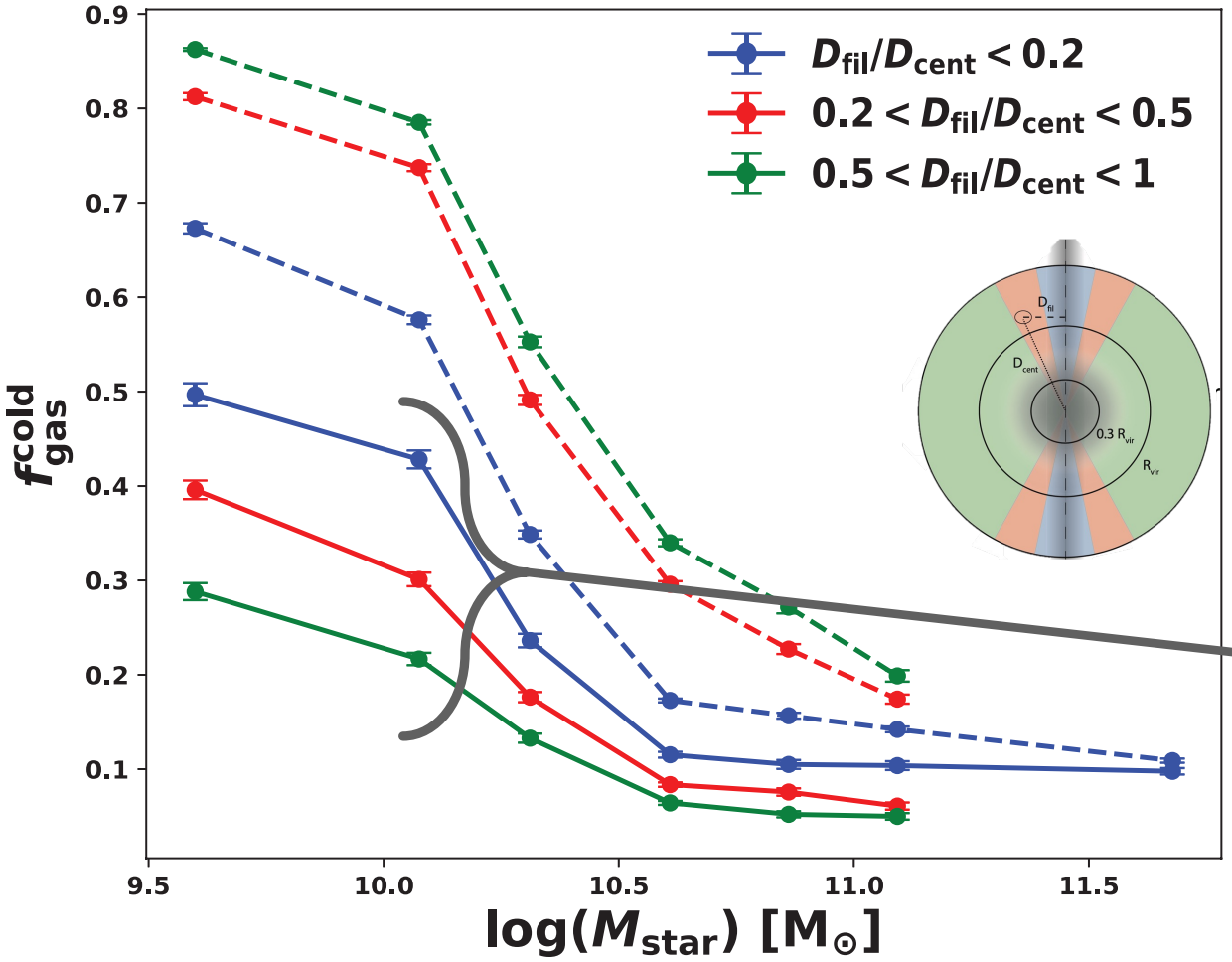
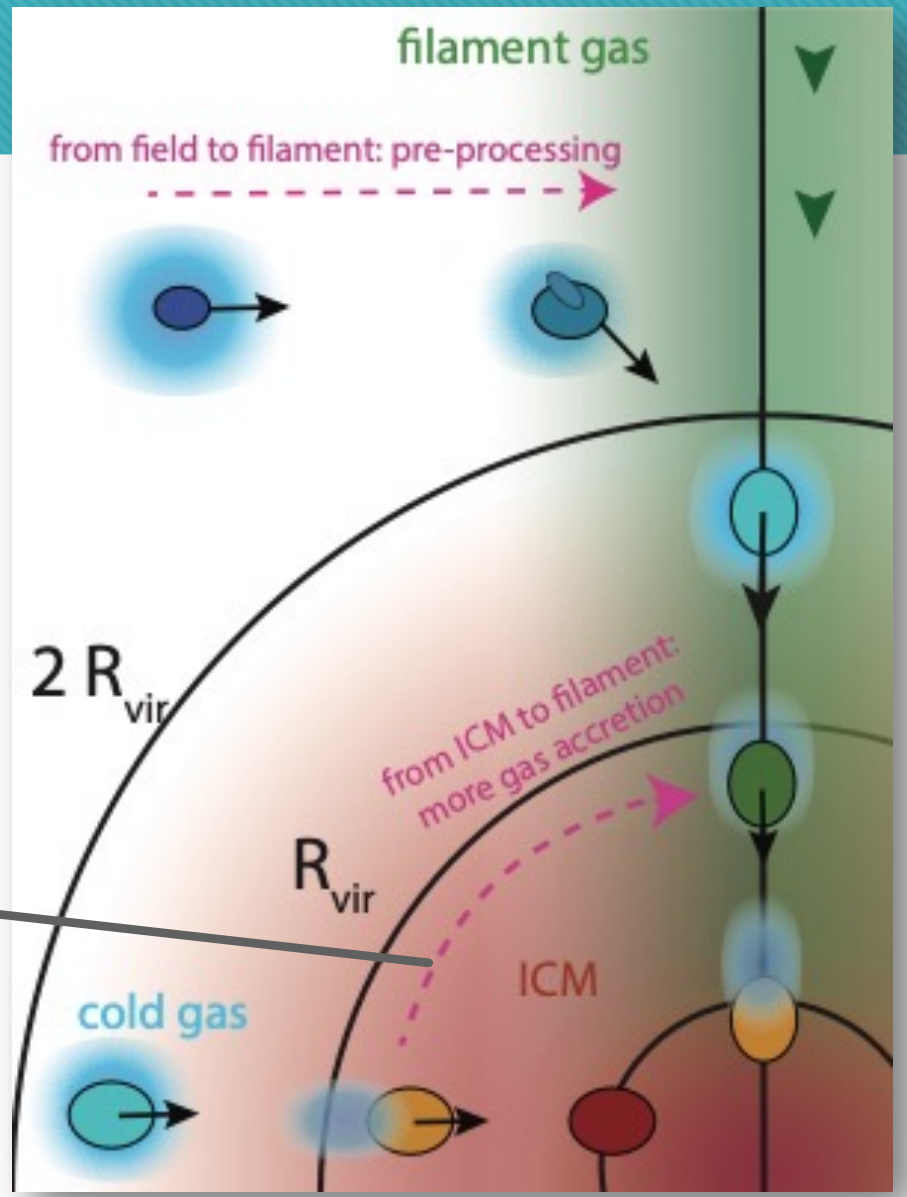
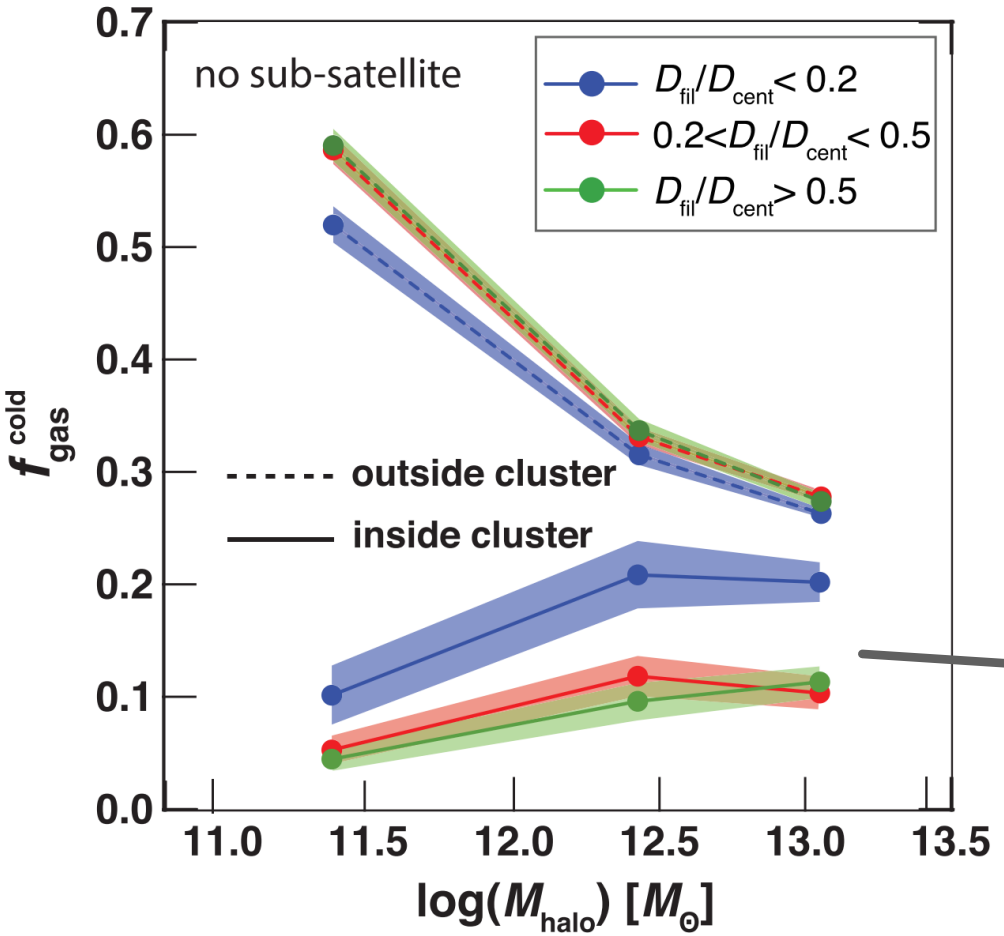
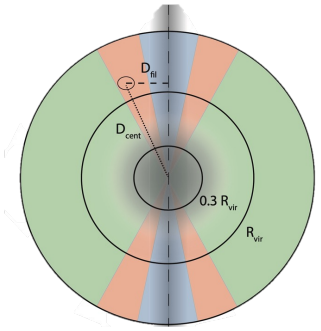
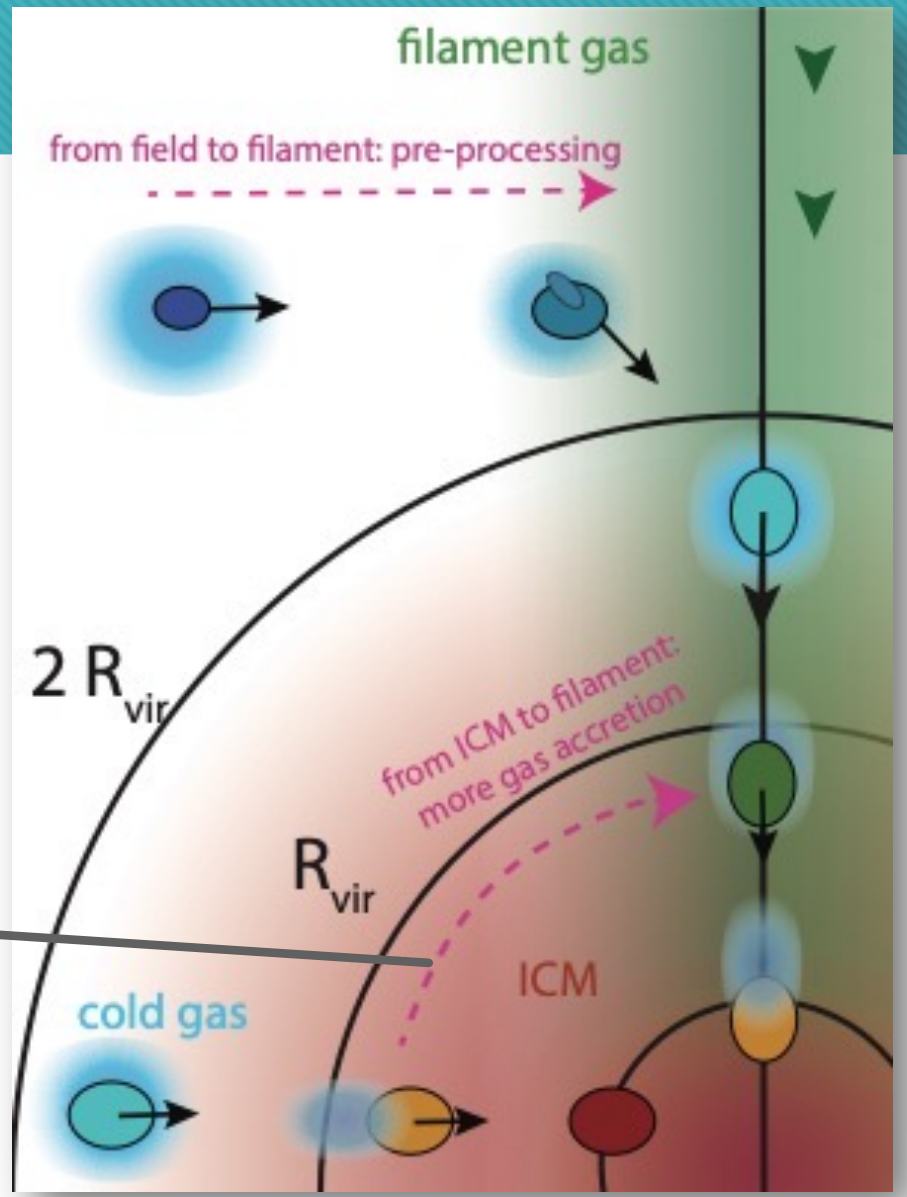




This effect is seen at all stellar and halo masses

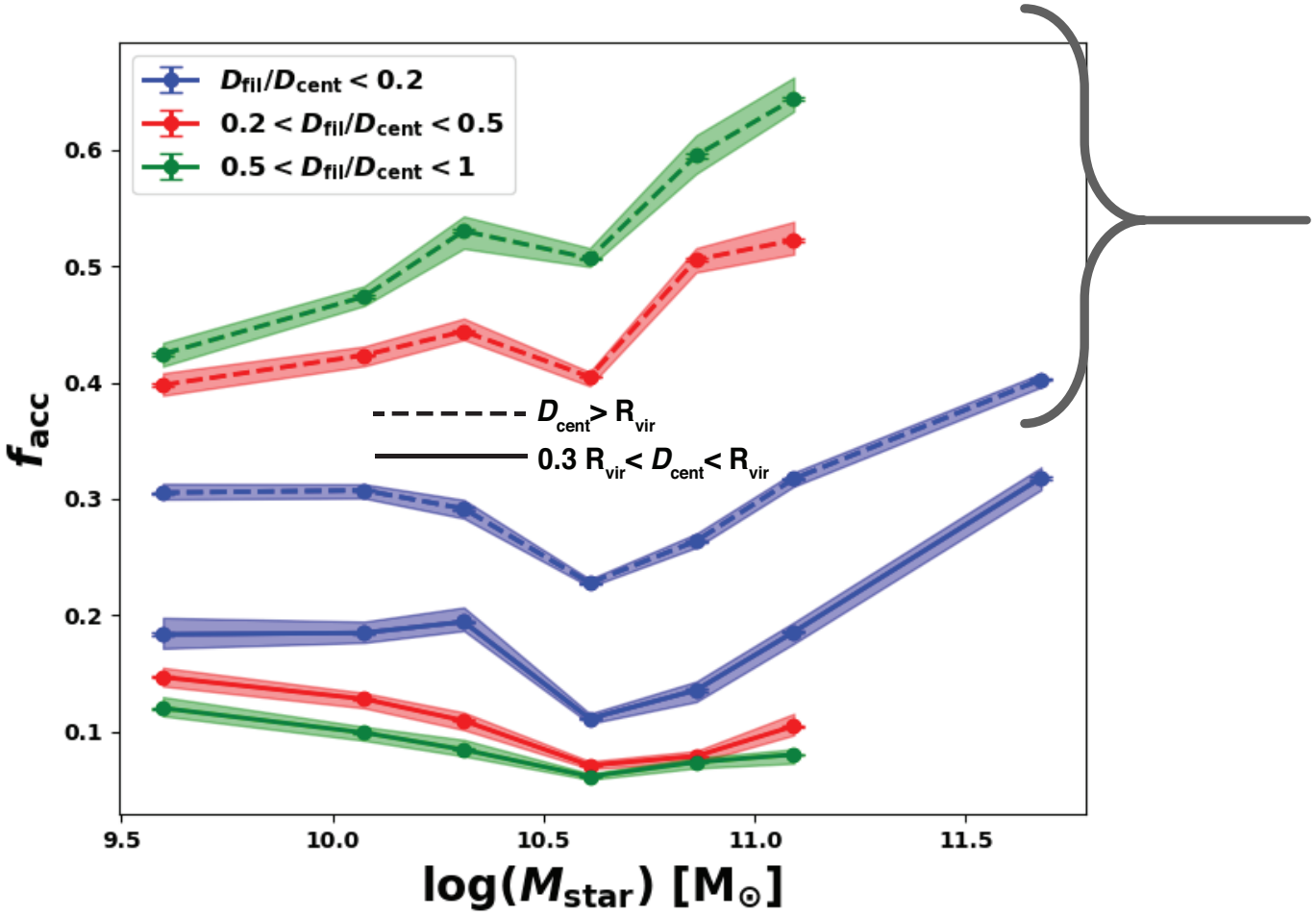






Cold accretion preserved in intra-cluster filaments!

Kotecha&Welker+2022



- **Outside Clusters:**

Less cold accretion near filaments

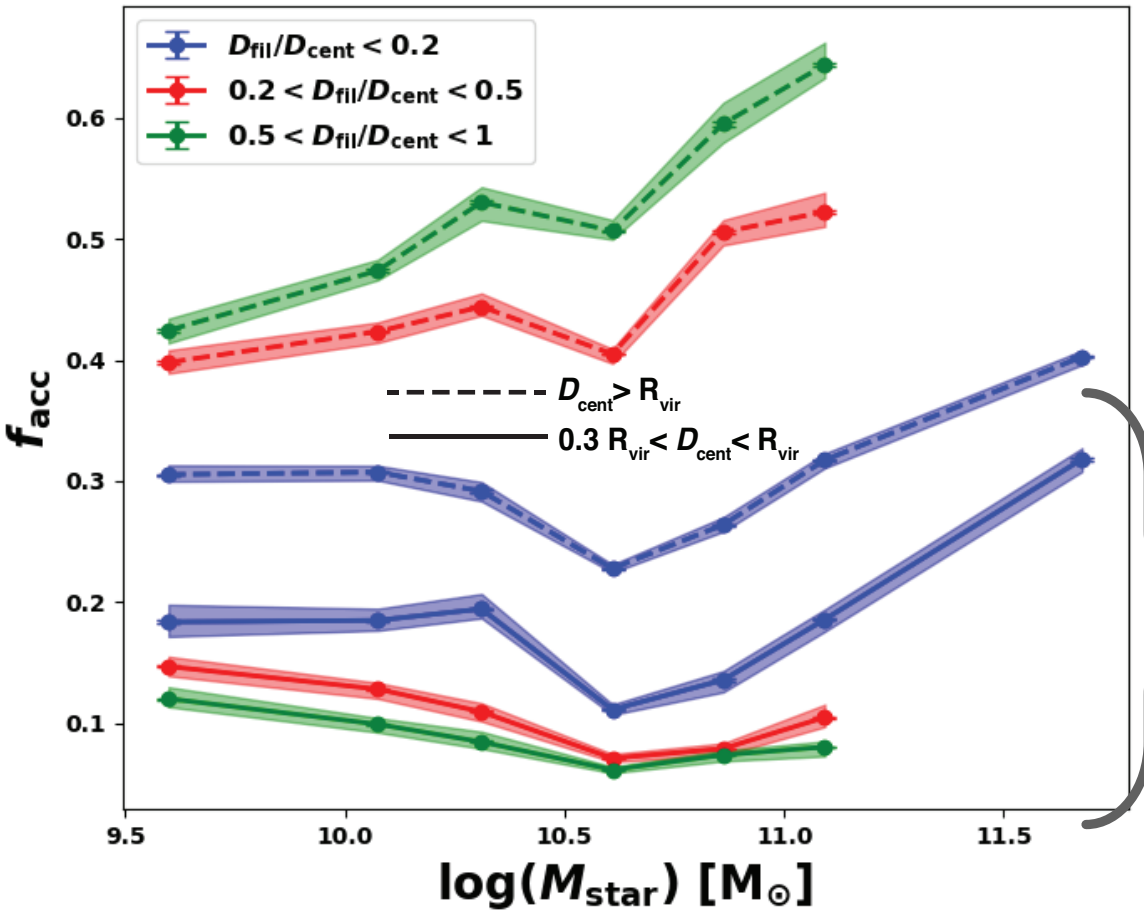
- **Inside Clusters:**

More cold accretion near filaments!

Fraction of accreting galaxies:

$$f_{acc} = \frac{n(\dot{M}_{gas}^{cold} < 0)}{N}$$

Cold accretion preserved in intra-cluster filaments!



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