How do the Satellite Galaxies Gift "Cool" Gas to Their Host?

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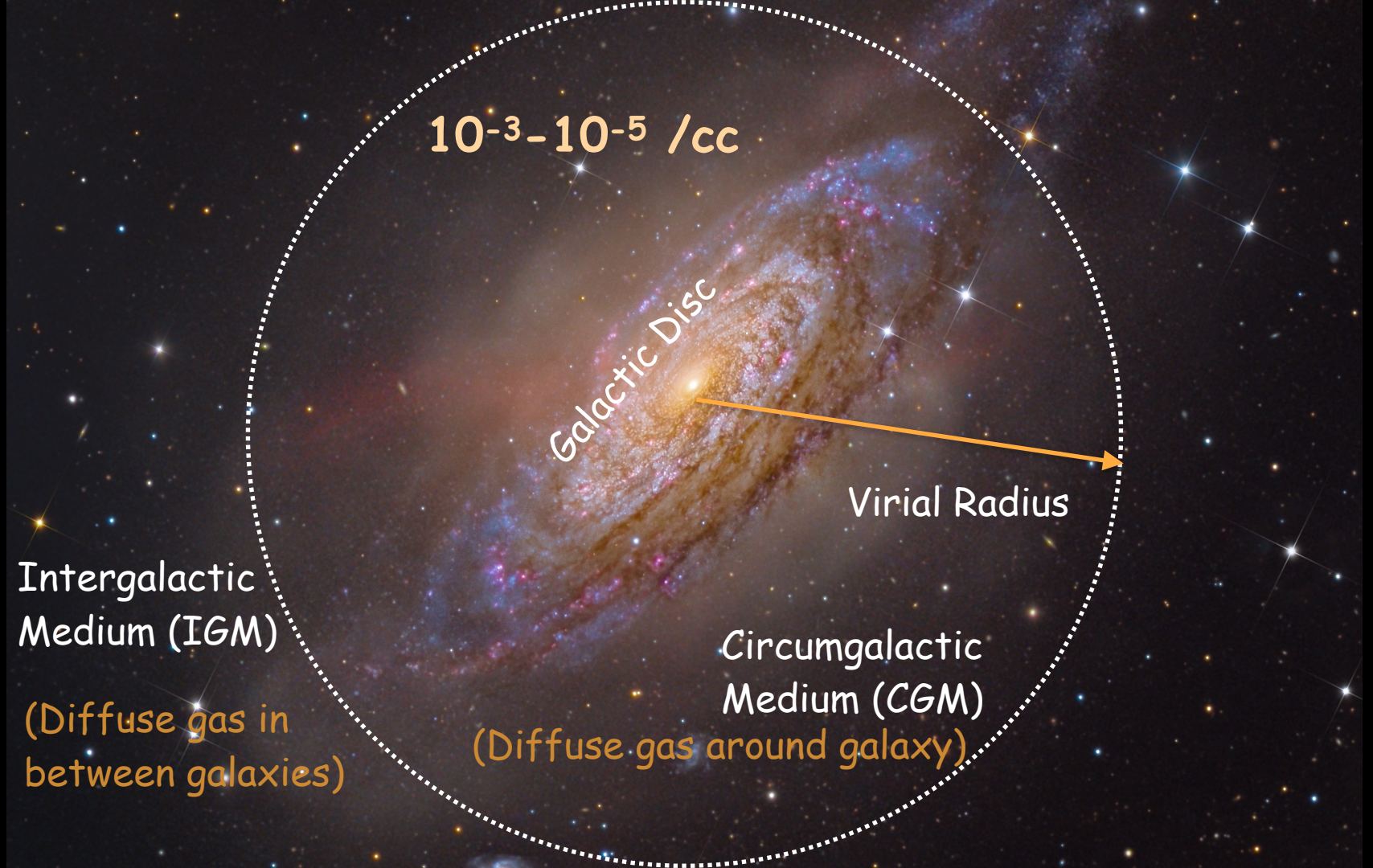
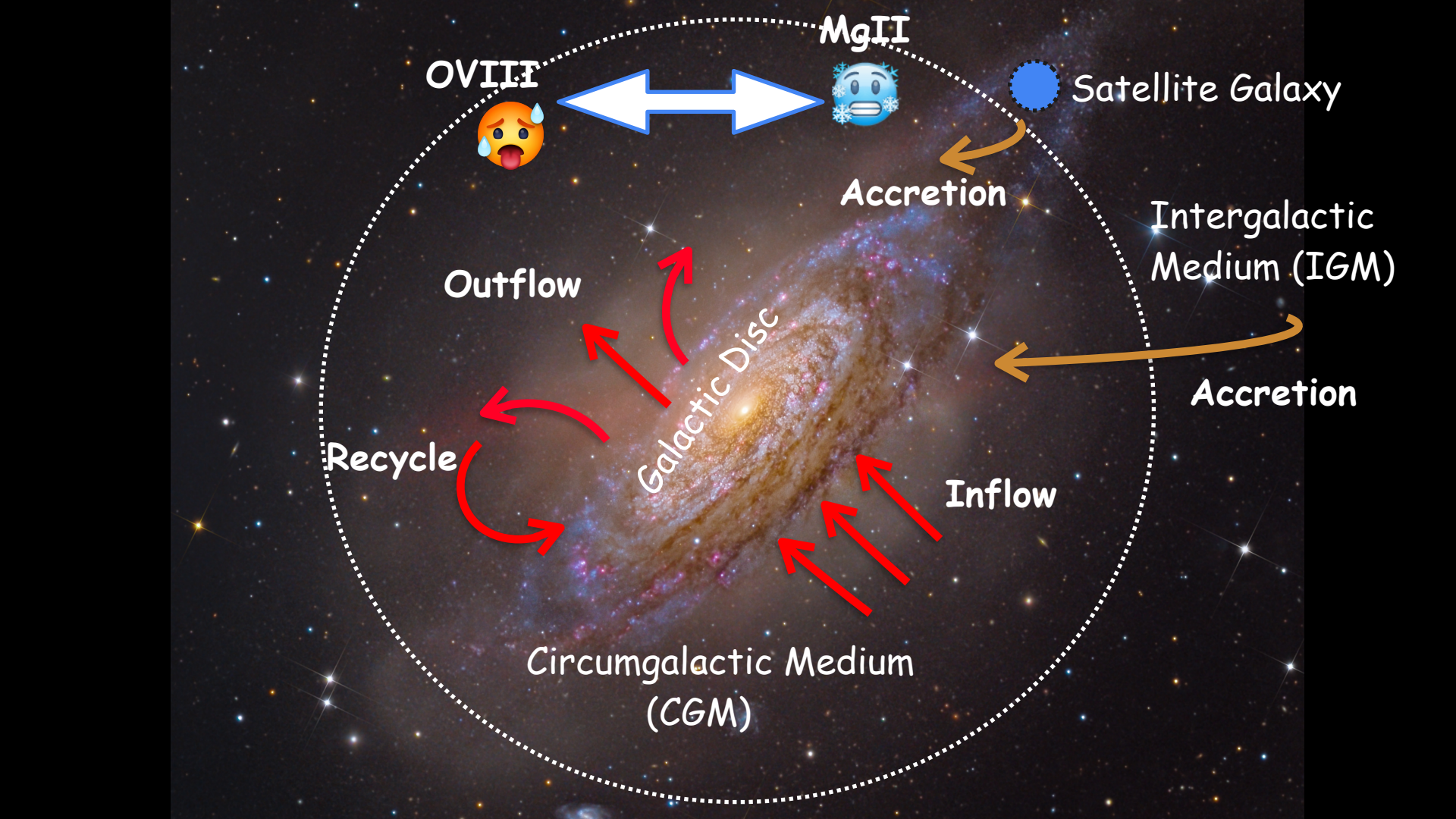
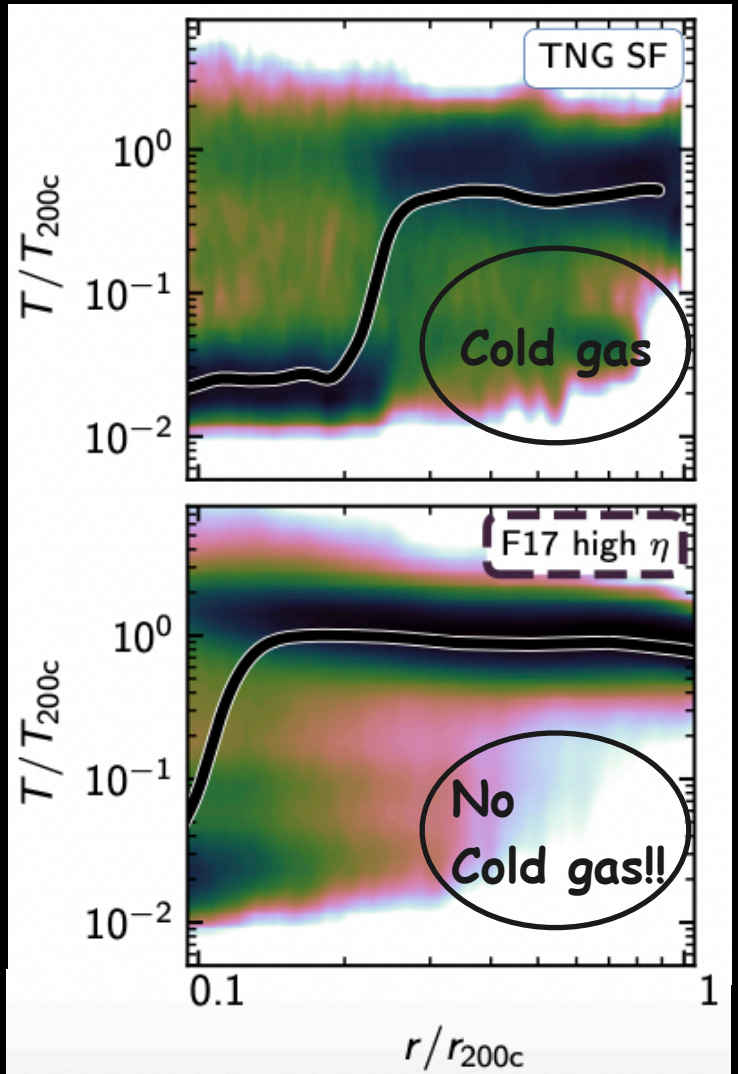

10^{-3}–10^{-5} /cc
Galactic Disc
Virial Radius
Intergalactic Medium (IGM)
(Diffuse gas in between galaxies)
Circumgalactic Medium (CGM)
(Diffuse gas around galaxy)

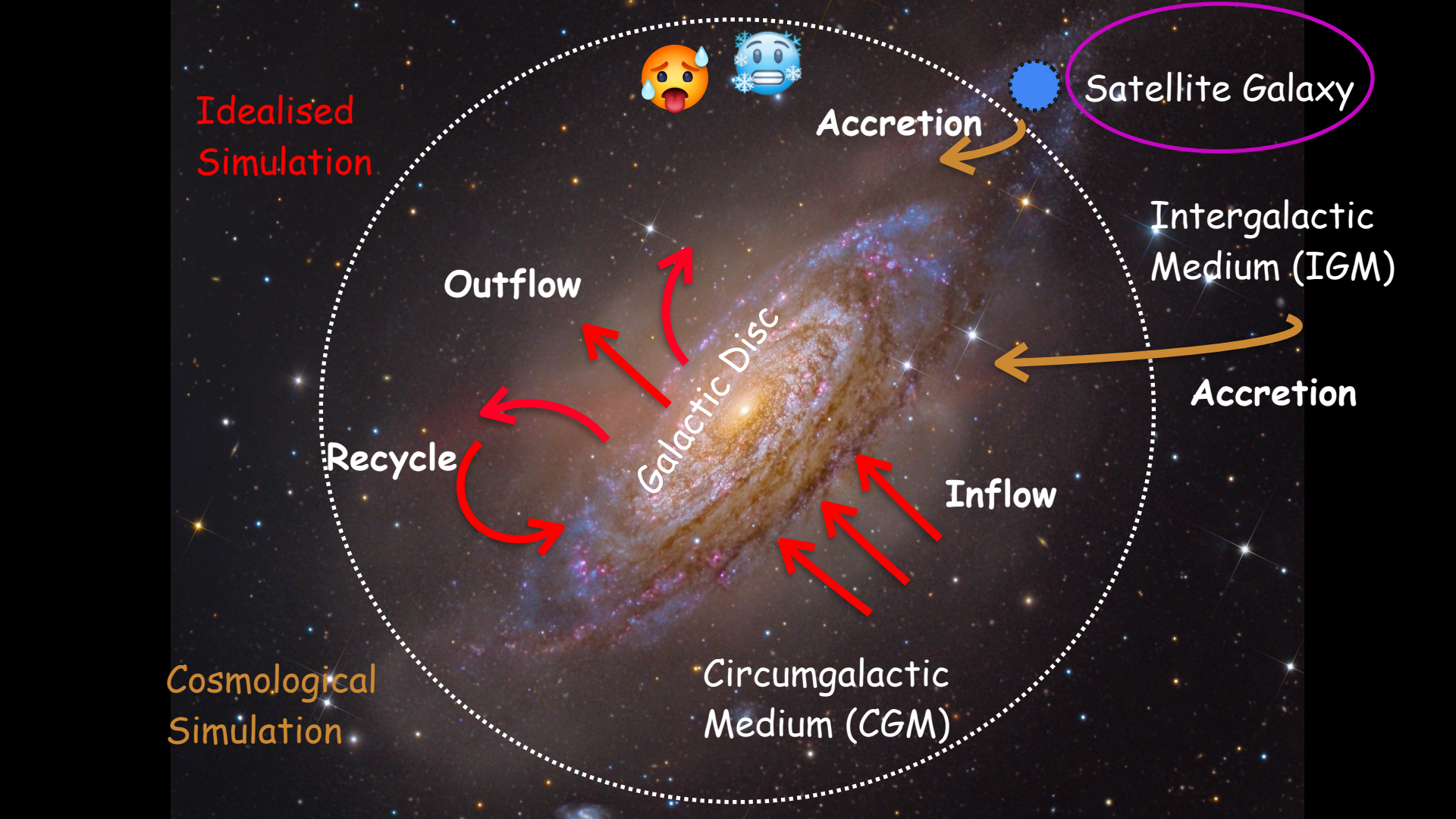

MgII
OVIII
Satellite Galaxy
Accretion
Intergalactic
Medium (IGM)
Outflow
Galactic Disc
Accretion
Recycle
Inflow
Circumgalactic Medium
(CGM)



Cosmological Simulation

Idealised Simulation

Ref: Fielding+ 2020


Idealised Simulation
Satellite Galaxy
Accretion
Intergalactic Medium (IGM)
Outflow
Galactic Disc
Accretion
Recycle
Inflow
Cosmological Simulation
Circumgalactic Medium (CGM)

Initial Conditions

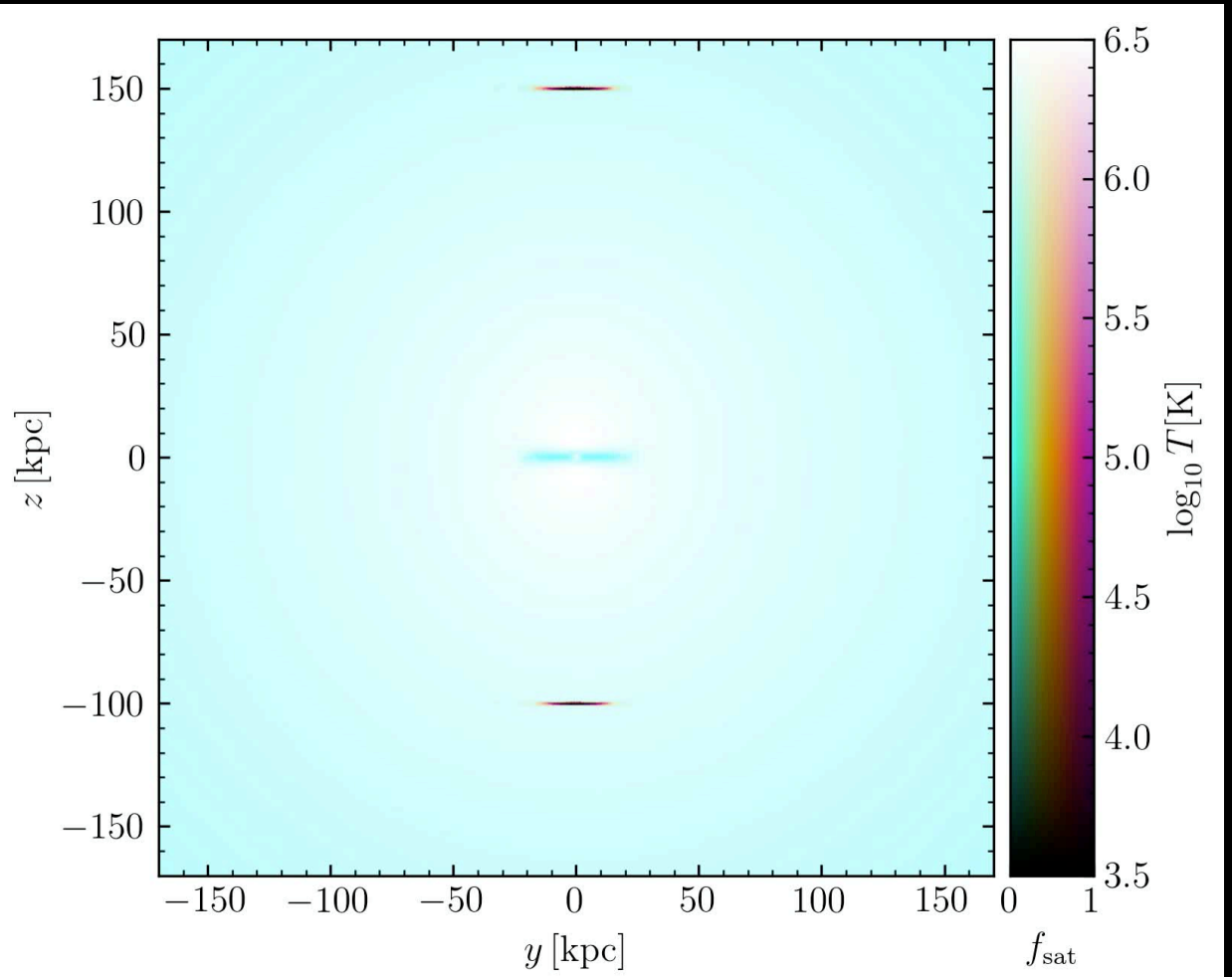
Simulation Code : GIZMO
Isolate Galaxy Simulation
FIRE-2 Physics

Mass of Dark Matter halo of the host -----> 1.8×10^{12} M_{solar}

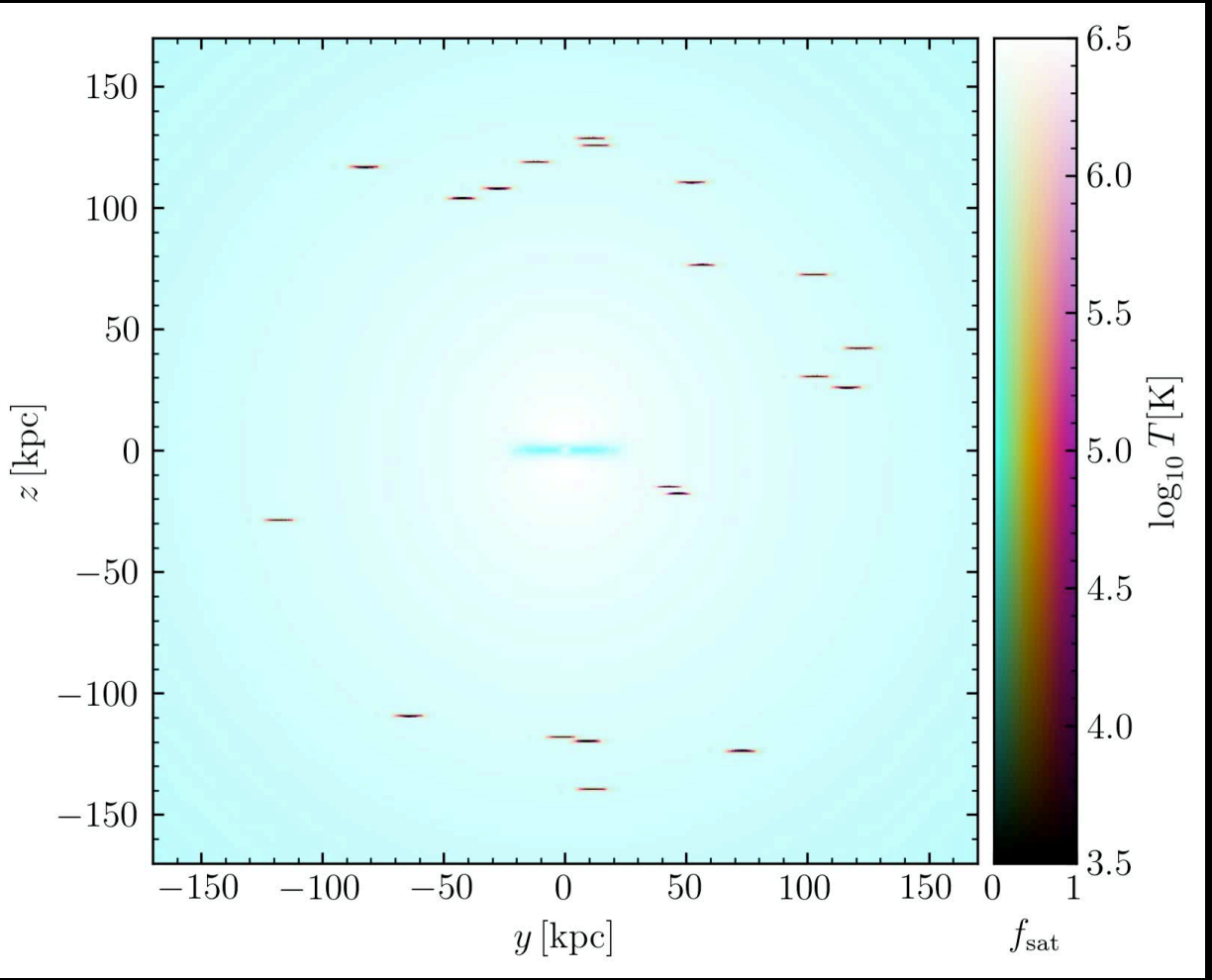
Black Hole + Stellar Bulge + Stellar Disk + Gas Disk + DM halo + Gas halo (CGM)

Mass of Dark Matter halo of the satellites -----> 200×10^{8} , 20×10^{9} and 2×10^{10} M_{solar}

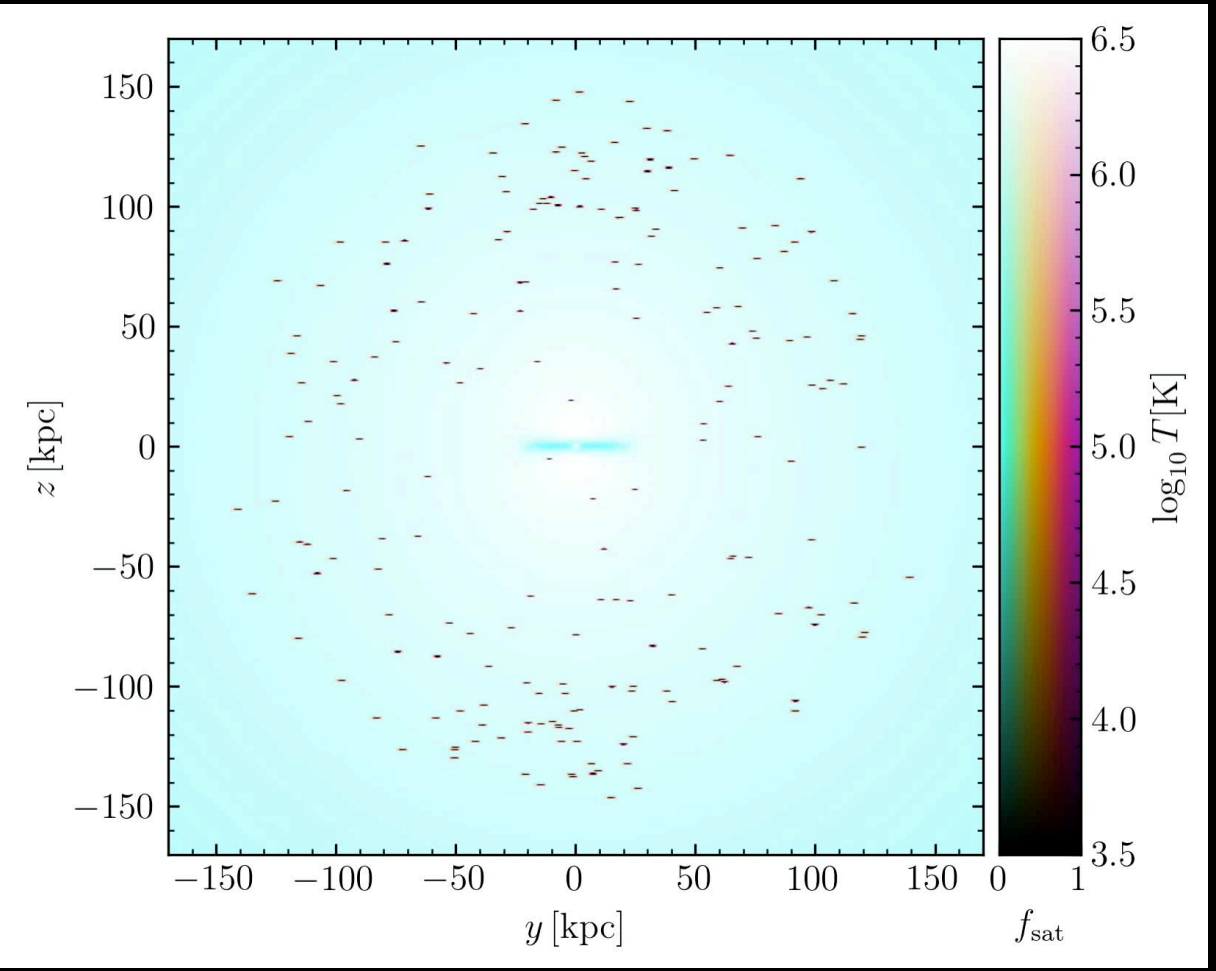
Black Hole + Stellar Bulge + Stellar Disk + Gas Disk + DM halo + ~~Gas halo (CGM)~~



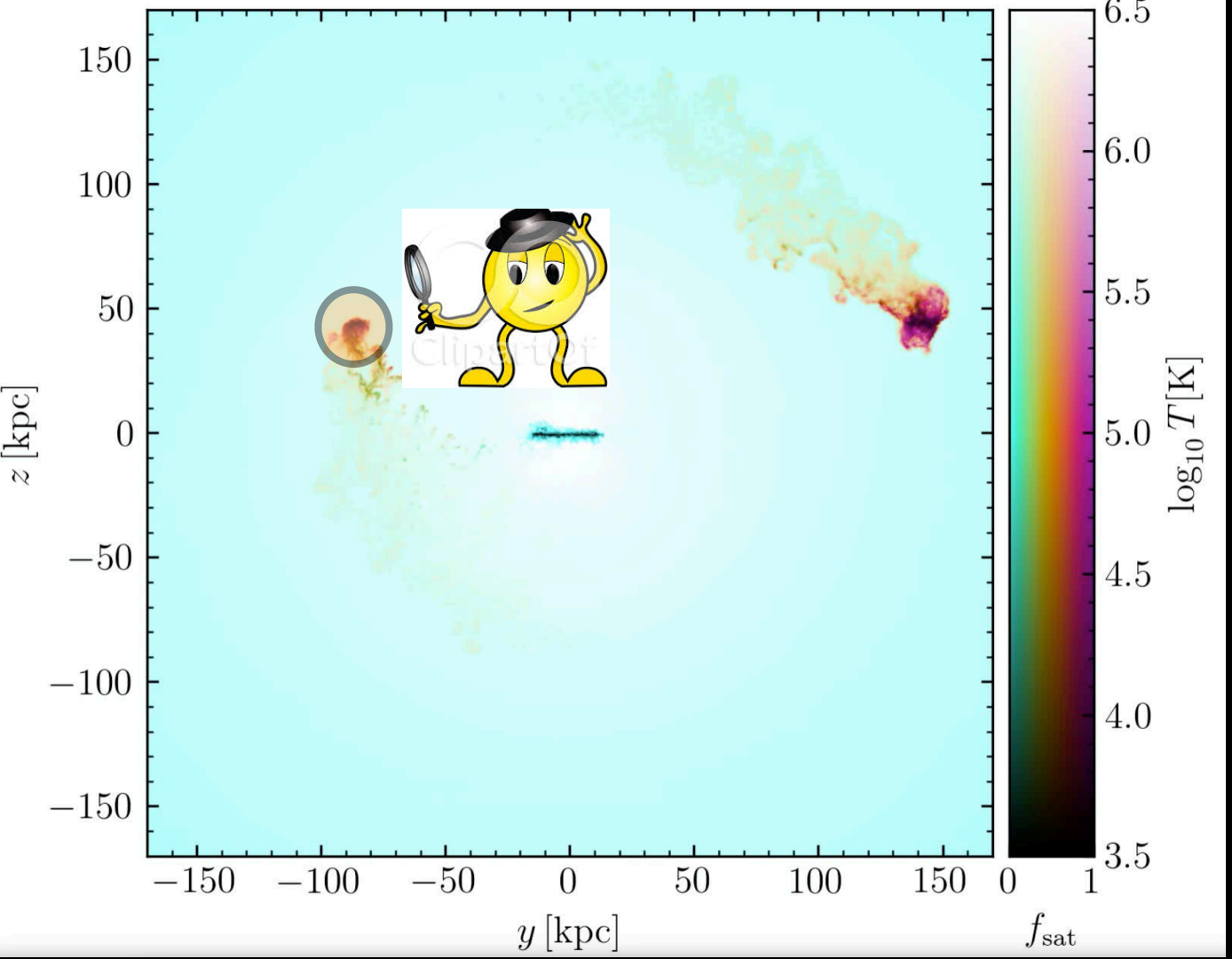
2×10^{10} M_{solar} satellites



20×10^9 M_{solar} satellites



200 x 10^8 M_{solar} satellites

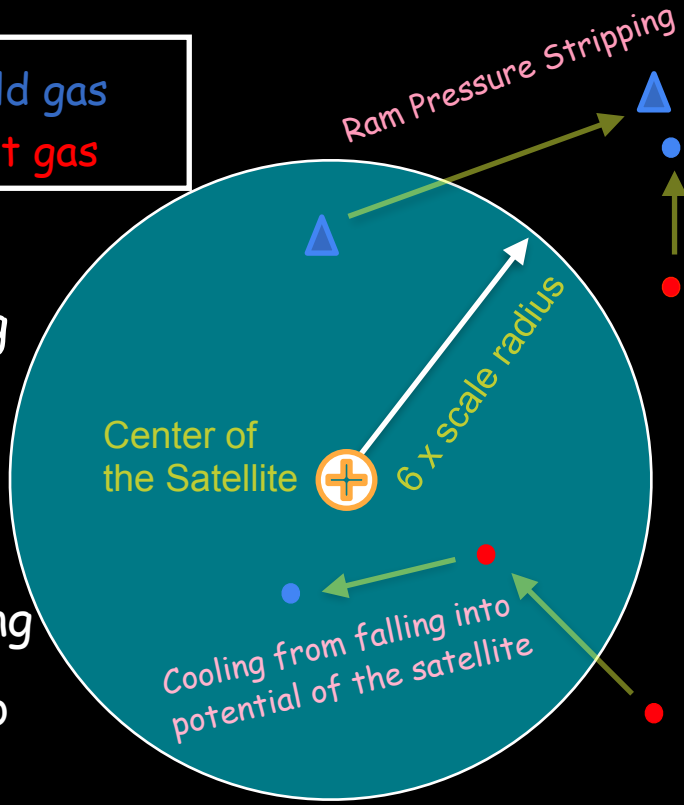


What is Happening Around Satellites?

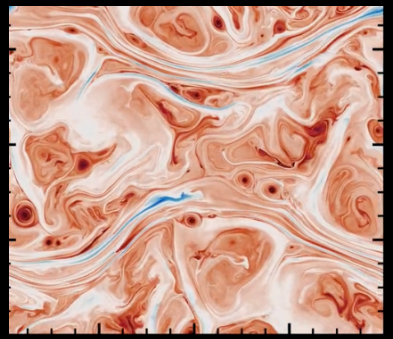
The origin of cool gas by Satellite

▲ Satellite gas	Cold gas
● Host gas	Hot gas

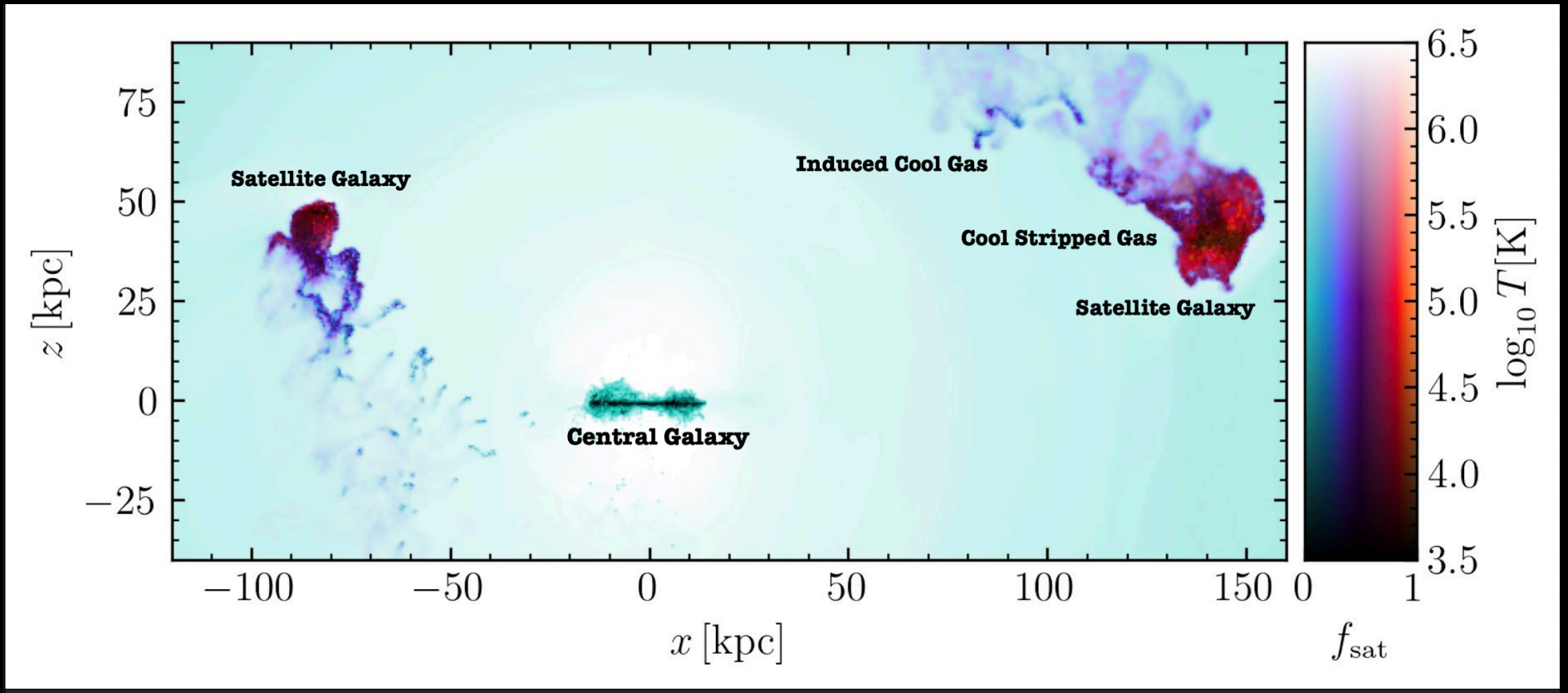
1. Ram Pressure Stripping
2. Induced cooling
   a. Mixing Layer cooling
   b. Turbulence driven cooling
   c. Cooling from falling into potential of satellite



Turbulence Driven Cooling

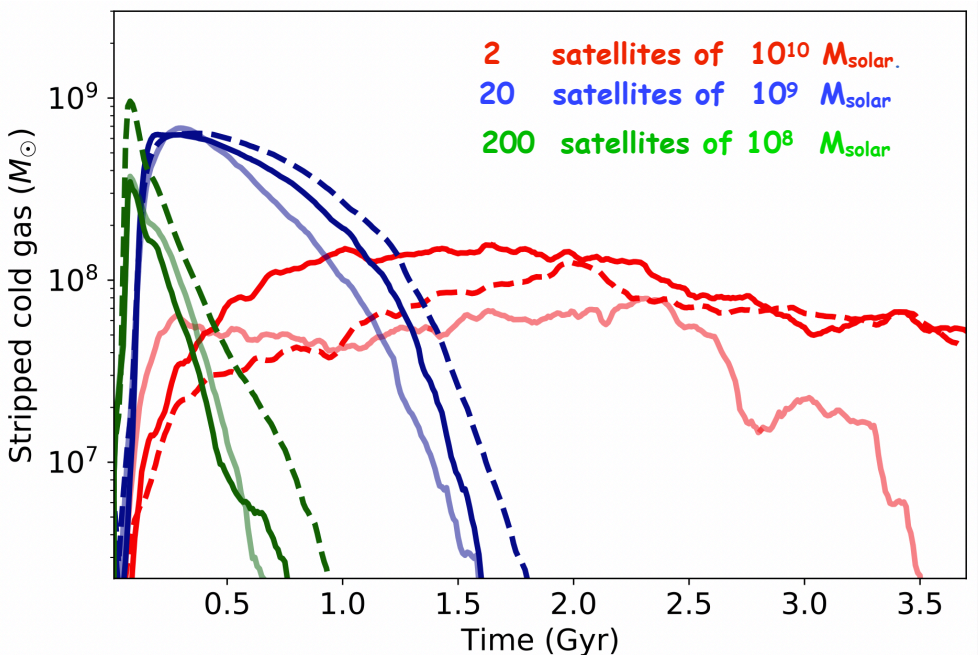


Courtesy : Drummond Fielding


Satellite Galaxy
Induced Cool Gas
Cool Stripped Gas
Satellite Galaxy
Central Galaxy
75
50
25
0
−25
z [kpc]
−100
−50
0
50
100
150
x [kpc]
0
1
$f_{\rm sat}$
6.5
6.0
5.5
5.0
4.5
4.0
3.5
$\log_{10} T$[K]

Time Evolution of cold gas mass

R > 40 kpc exclude the host ISM



Similarities

Stripped gas increase over time
—> reach a peak
—> then decrease

Dissimilarities

Massive ones continues to feed cool gas (~ 4 Gyr)

Less massive ones are getting stripped faster (1-1.5 Gyr)

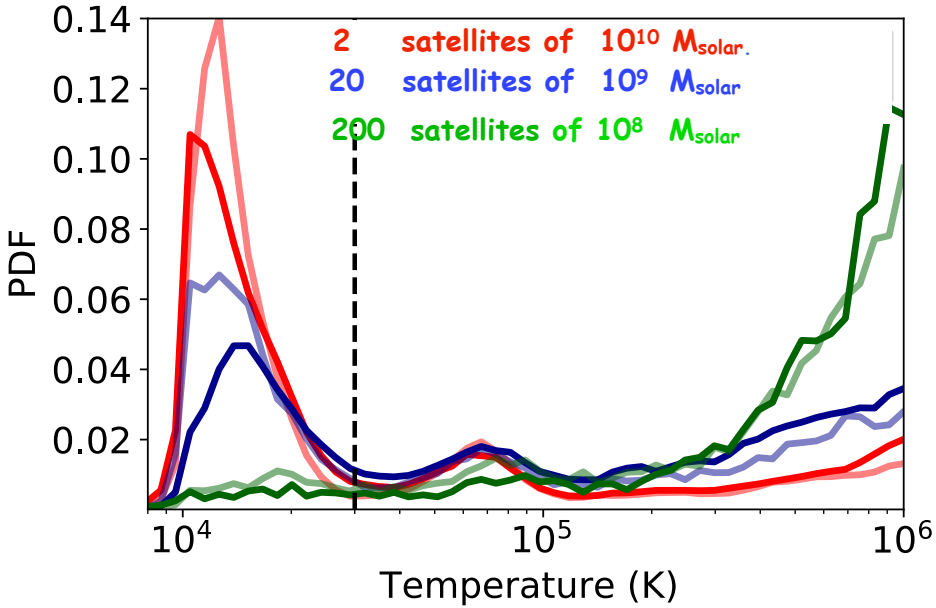
The Fate of cool stripped gas

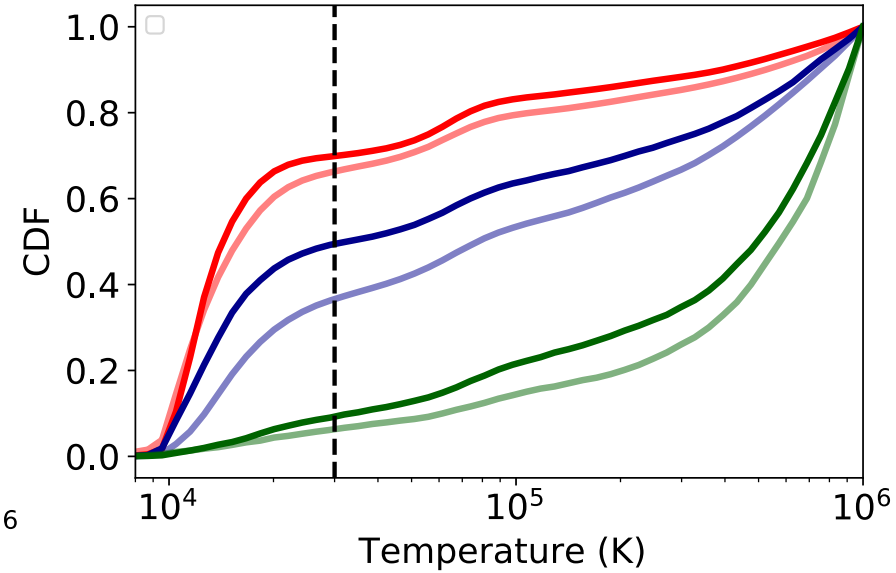
Falling into host ISM

or

Getting mixed with hot gas of host CGM

The Fate of cool stripped gas

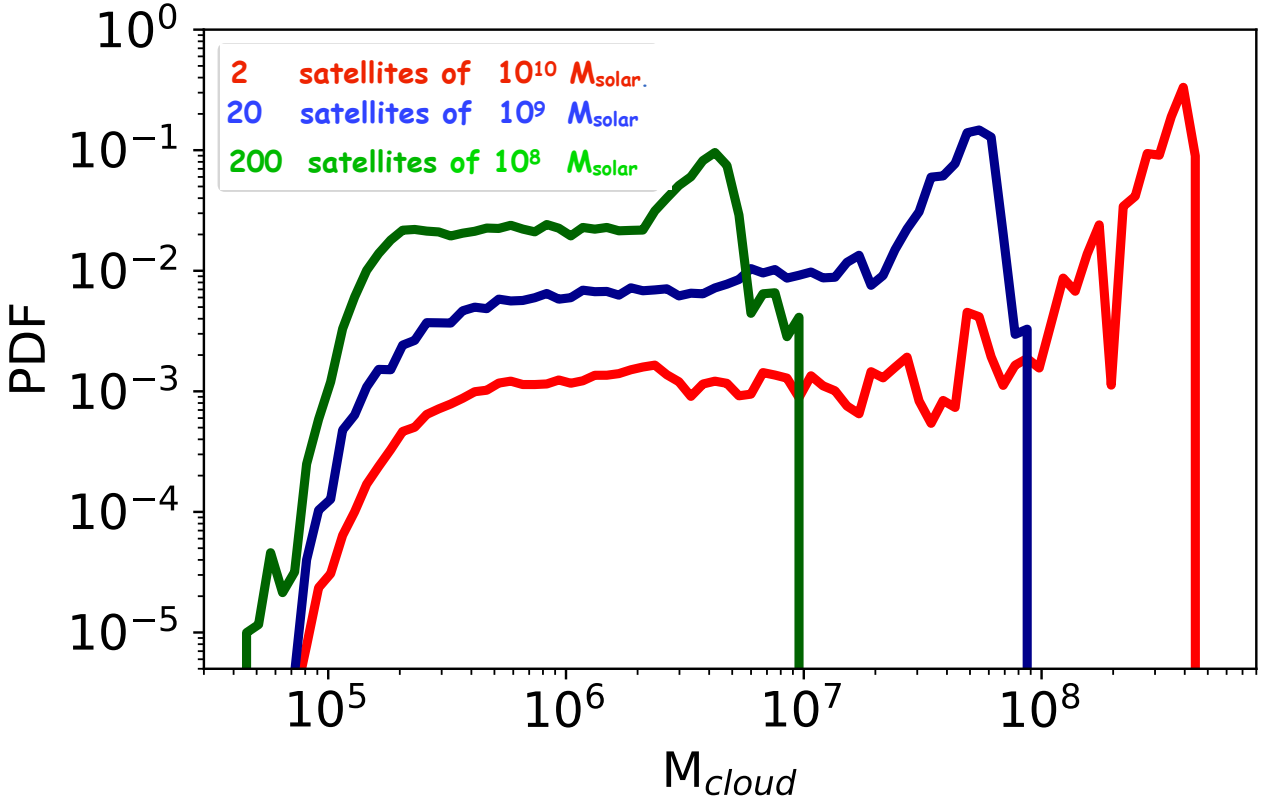




Large cloud remains cool

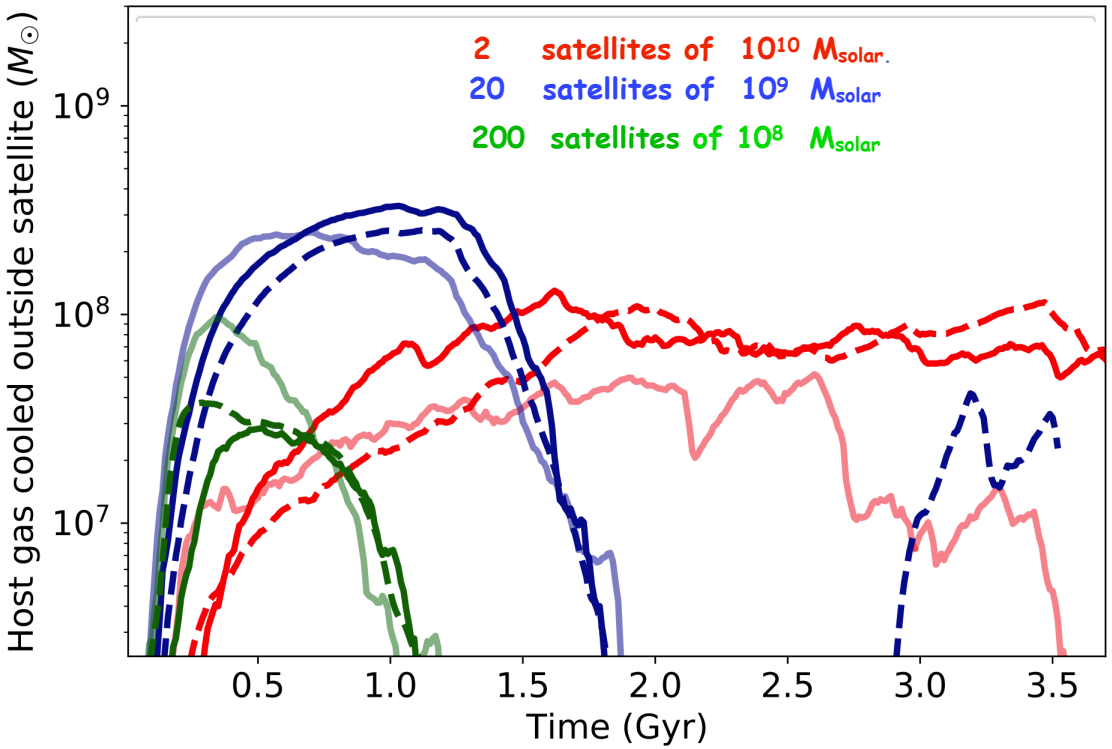
Small cloud gets mixed and heat up

Mass Distribution of cool stripped gas



Time Evolution of induced cold gas mass

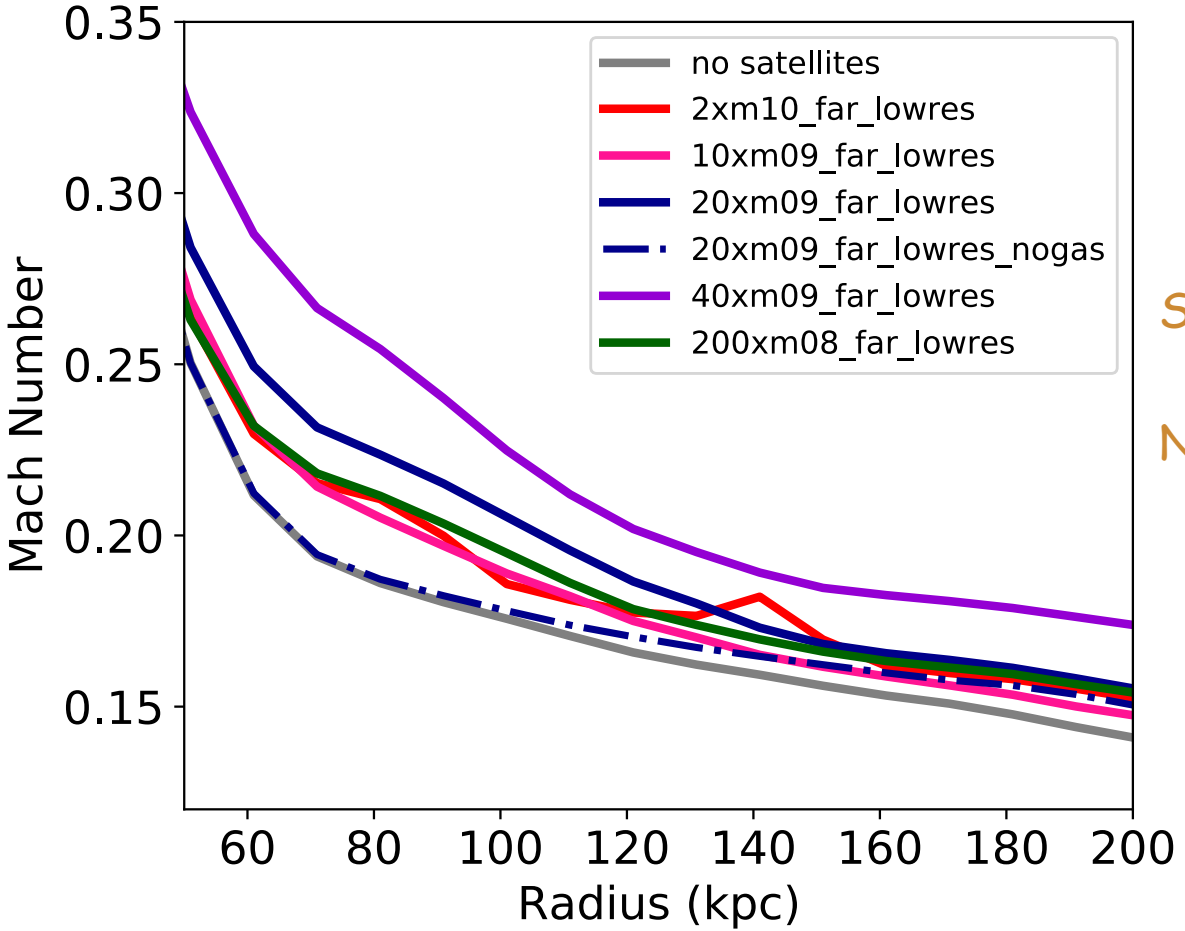
R > 40 kpc exclude the host ISM



Induced cooling = Stripping

Most of the induced cooling is contributed by Mixing layer cooling? 🤔

Turbulence?

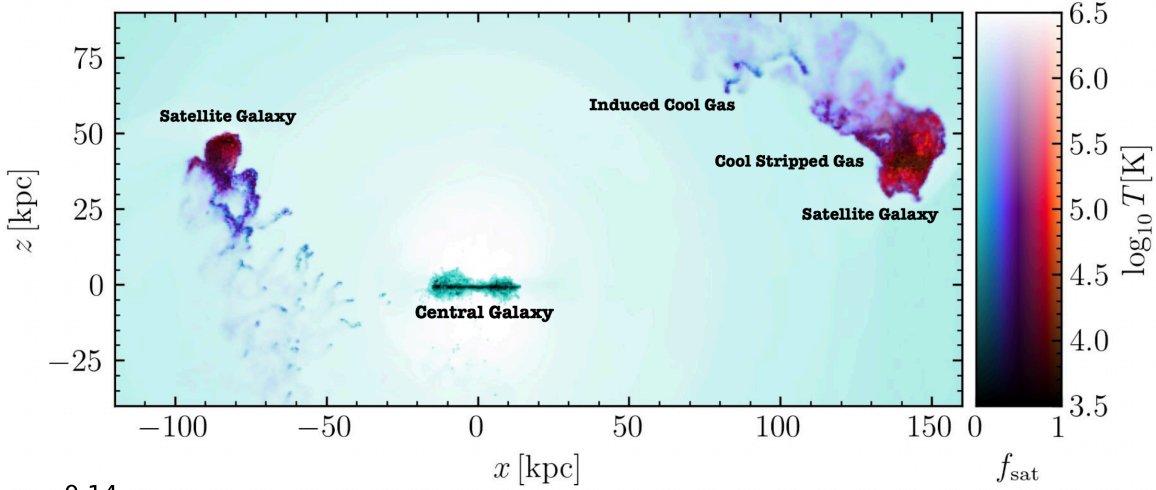


Subsonic Mach Number!!!

No turbulence driven cooling

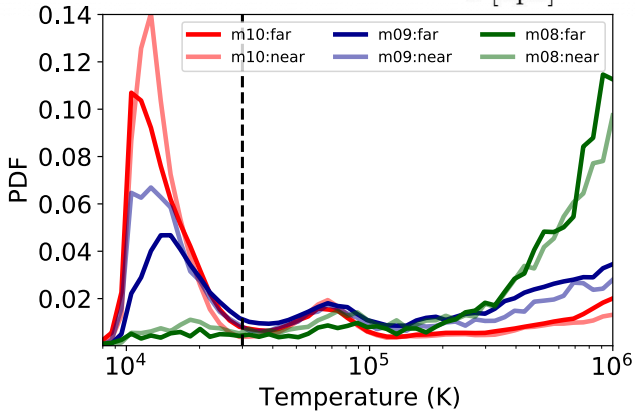
Most induced cooling happening outside satellite is by Mixing Layer Cooling!!!!

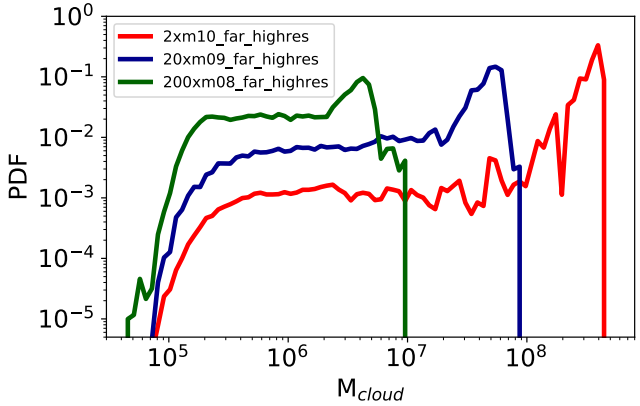
Take Home points:



→ Induced cooling = Stripping

Most of the induced cooling is contributed by Mixing layer cooling.





→ Cold stripped gas from less massive satellites heat up whereas most cold stripped gas from massive remain cold !!!

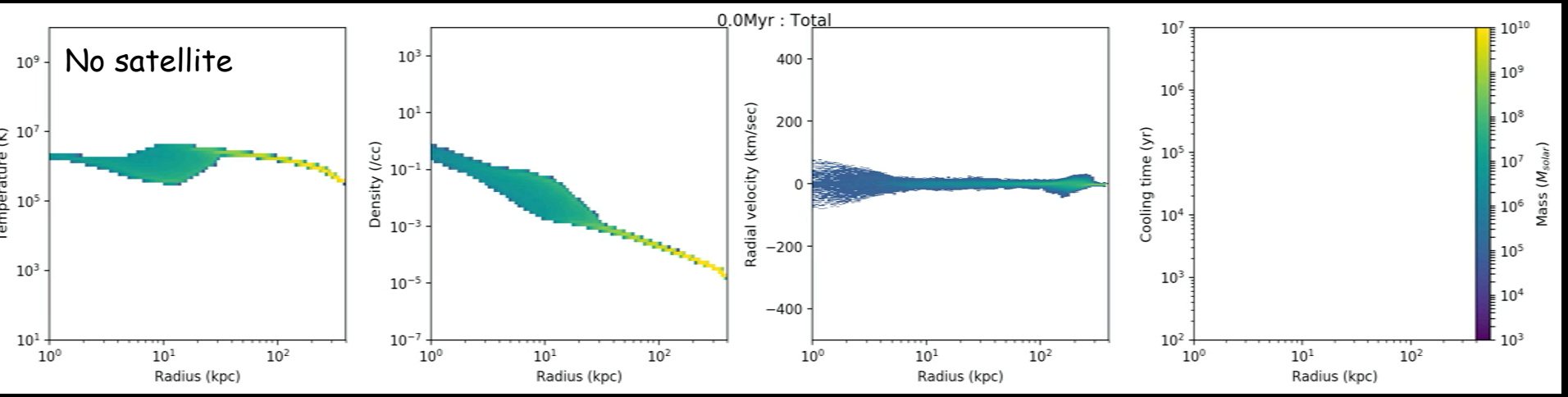
What about observations?

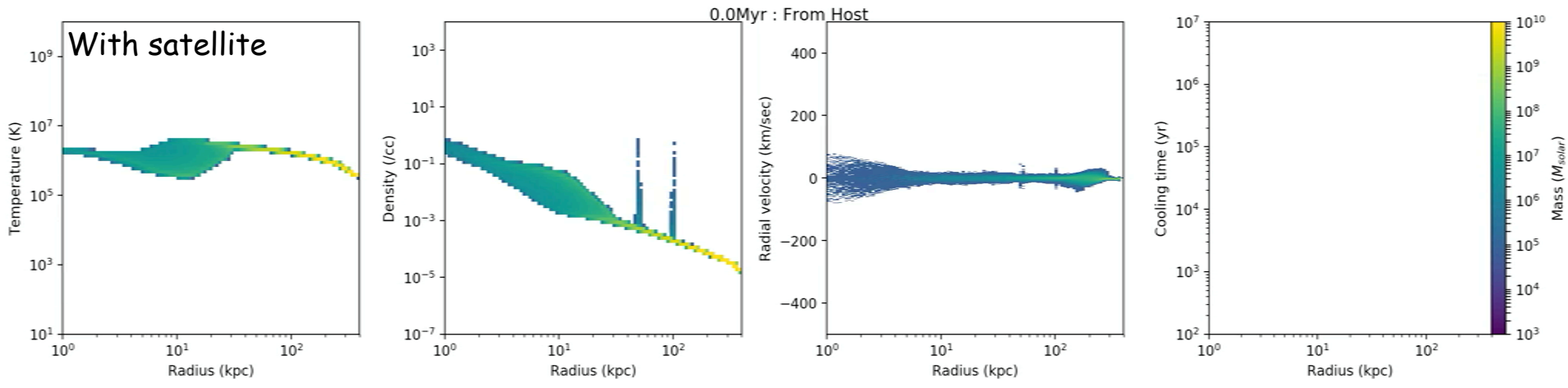
What about observations?

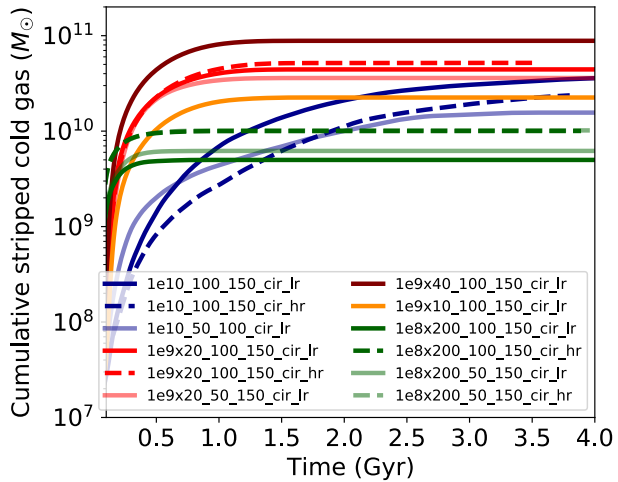
Observed cold gas mass of MW = $10^{8\text{-}9}$ M_{solar}

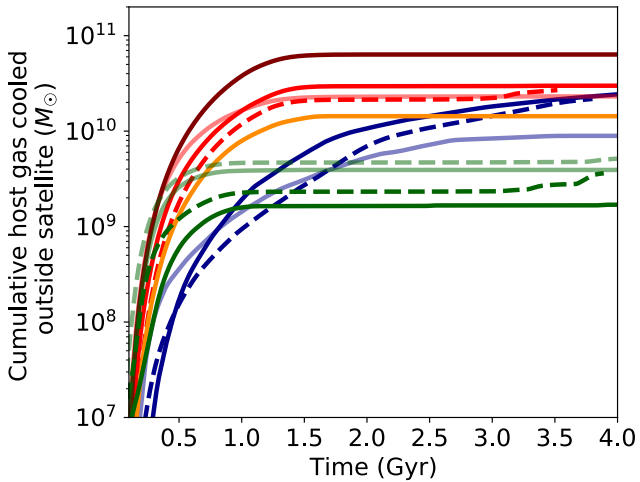
m10 satellite ~ 10^{8} M_{solar}
Infall time of LMC/SMC ~ 1.5 Gyr

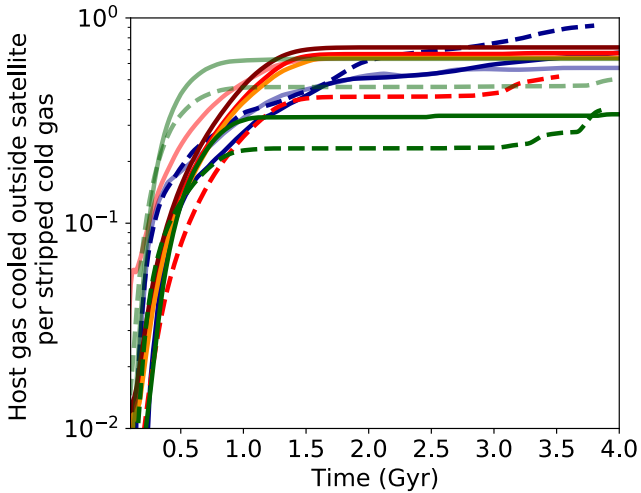
Back up Slides


No satellite
0.0Myr : Total
Temperature (K)
Density (/cc)
Radial velocity (km/sec)
Cooling time (yr)
Mass (M_{solar})
Radius (kpc)


With satellite
0.0Myr : From Host
Temperature (K)
Density (/cc)
Radial velocity (km/sec)
Cooling time (yr)
Mass (M_{solar})
Radius (kpc)


Cumulative stripped cold gas ($M_\odot$)
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Time (Gyr)
1e10_100_150_cir_lr
1e10_100_150_cir_hr
1e10_50_100_cir_lr
1e9x20_100_150_cir_lr
1e9x20_100_150_cir_hr
1e9x20_50_150_cir_lr
1e9x40_100_150_cir_lr
1e9x10_100_150_cir_lr
1e8x200_100_150_cir_lr
1e8x200_100_150_cir_hr
1e8x200_50_150_cir_lr
1e8x200_50_150_cir_hr


Cumulative host gas cooled outside satellite ($M_\odot$)
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Time (Gyr)


Host gas cooled outside satellite per stripped cold gas
10^{0}
10^{-1}
10^{-2}
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Time (Gyr)

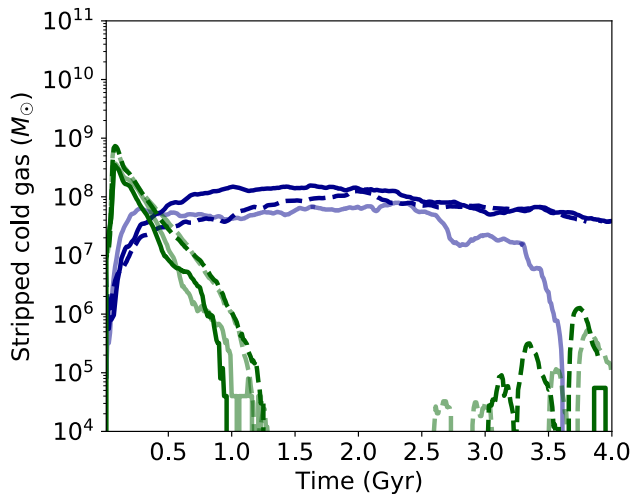
Take Home points:

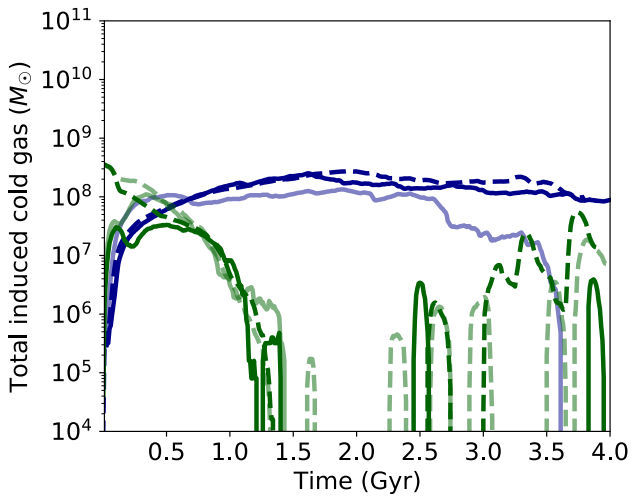
1) There are different mechanisms by which the satellite galaxies could contribute cold gas to host CGM — Ram pressure stripping, Similar amount of Induced cooling such as — Mixing layer cooling around stripped cold gas Turbulence driven cooling….

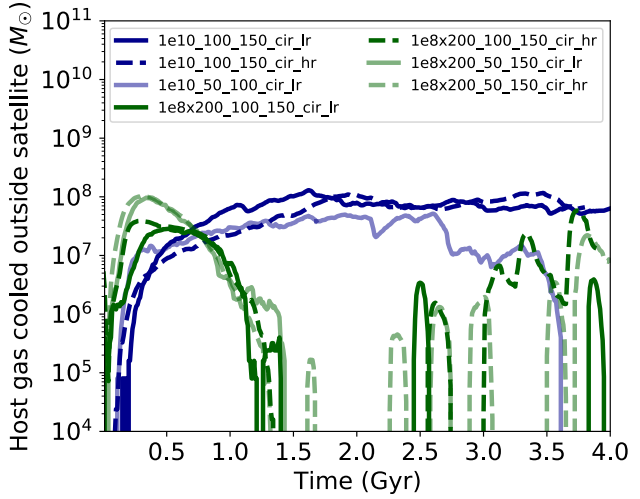
2) Most of the induced cooling is contributed by Mixing layer cooling.

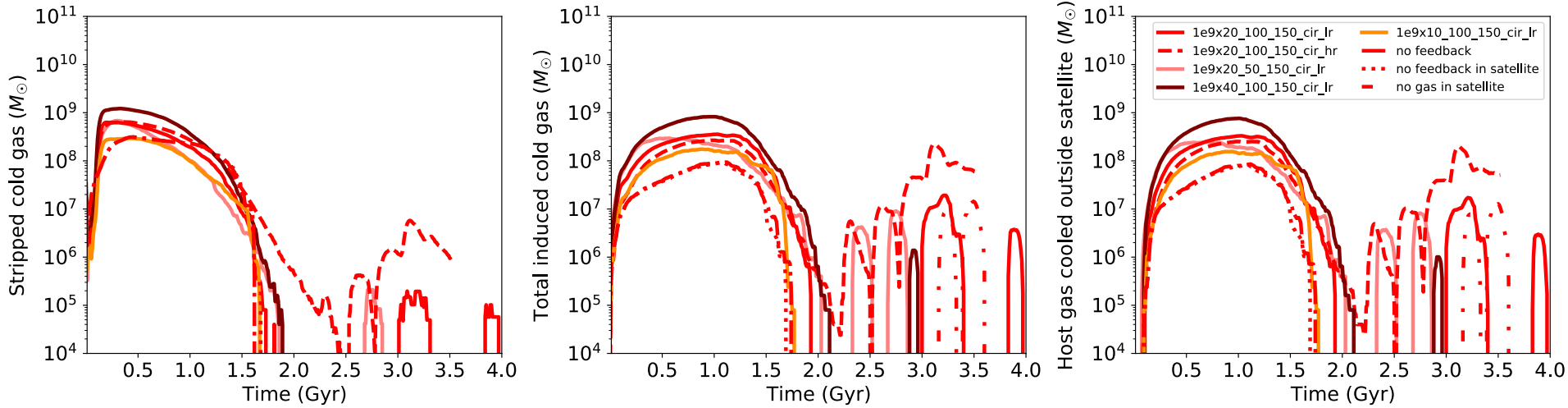
3) Different mass distribution of satellite has different time scales for ram pressure stripping, hence for the induced cooling in mixing layer

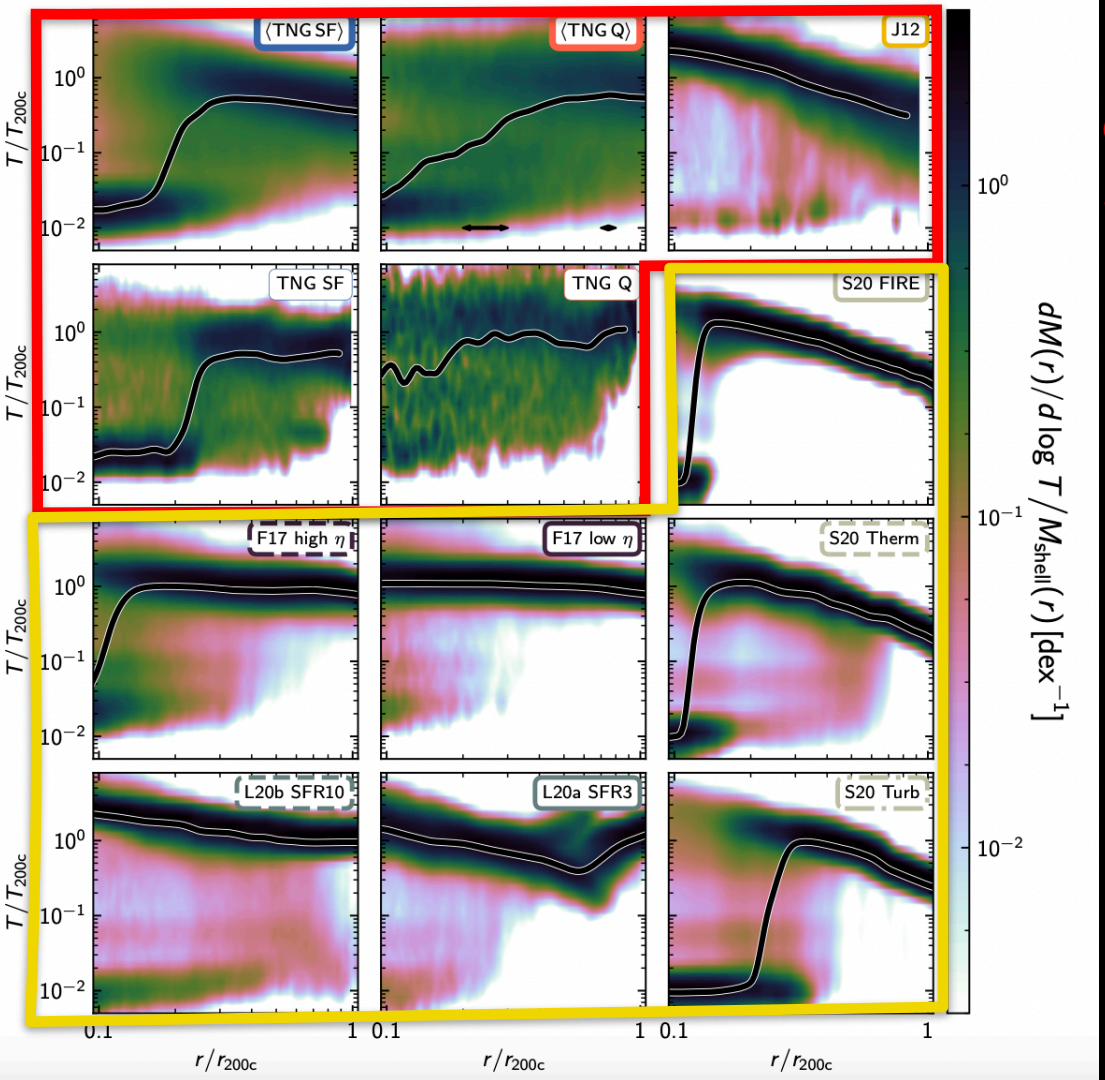
4) Cold stripped gas from less massive satellites are likely to heat up whereas most cold stripped gas from massive ones retain temperature.


Stripped cold gas ($M_\odot$)
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Time (Gyr)


Total induced cold gas ($M_\odot$)
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Time (Gyr)


Host gas cooled outside satellite ($M_\odot$)
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Time (Gyr)
1e10_100_150_cir_lr
1e10_100_150_cir_hr
1e10_50_100_cir_lr
1e8x200_100_150_cir_lr
1e8x200_100_150_cir_hr
1e8x200_50_150_cir_lr
1e8x200_50_150_cir_hr

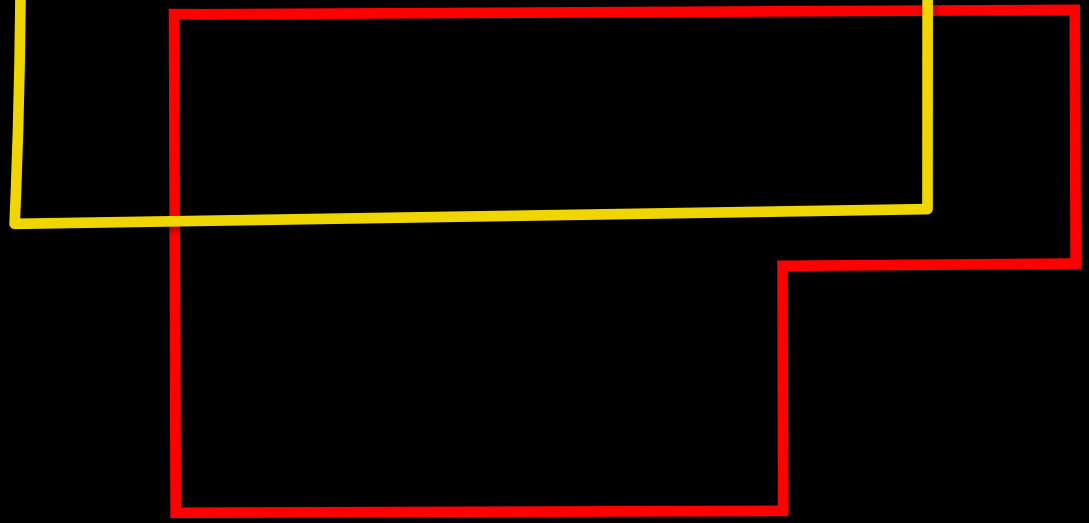

Stripped cold gas ($M_\odot$)
Total induced cold gas ($M_\odot$)
Host gas cooled outside satellite ($M_\odot$)
Time (Gyr)
1e9x20_100_150_cir_lr
1e9x20_100_150_cir_hr
1e9x20_50_150_cir_lr
1e9x40_100_150_cir_lr
1e9x10_100_150_cir_lr
no feedback
no feedback in satellite
no gas in satellite



Cosmological Simulation

Idealized Simulation

Ref: Fielding+ 2020



Cosmological Simulation

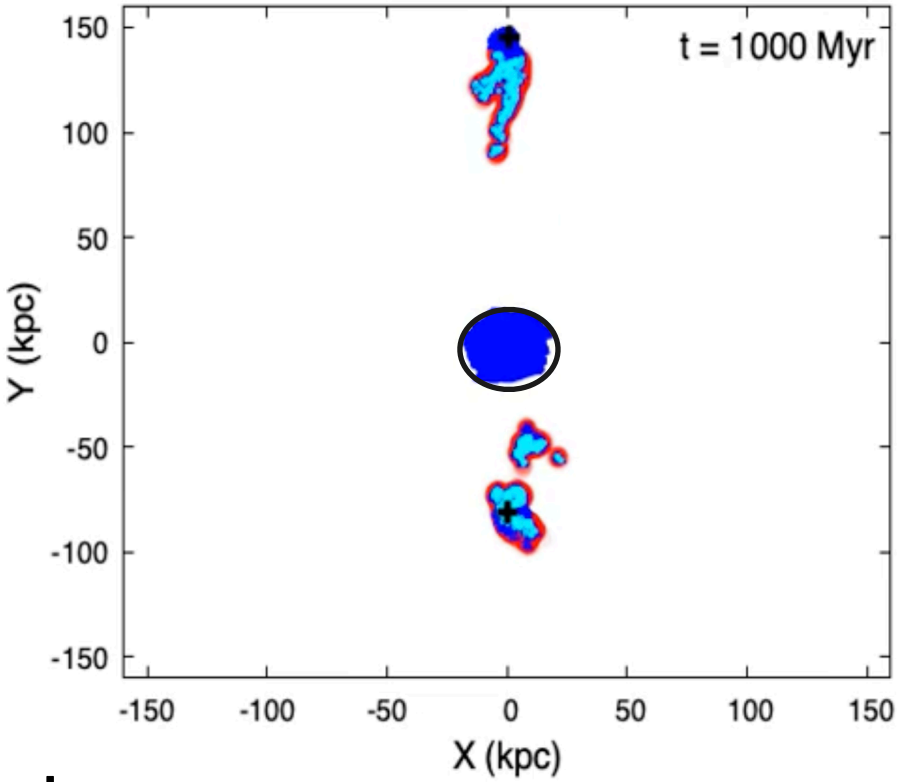
Idealized Simulation

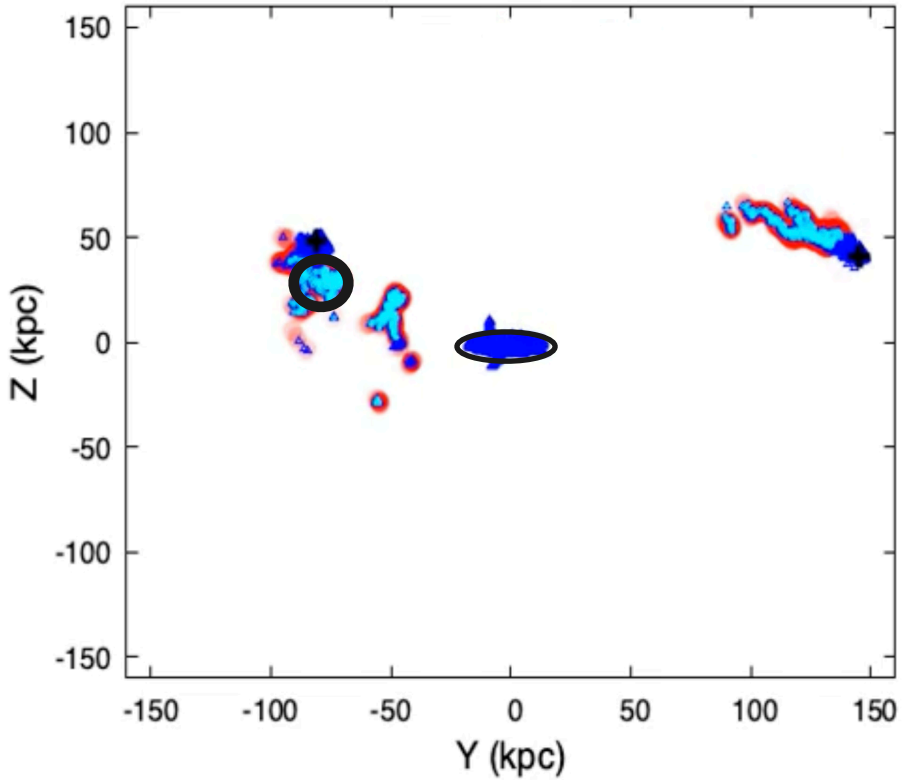
Ref: Fielding+ 2020

The origin of cool gas → < 3×10^4 K

1) Ram pressure stripping

2) Induced cooling —>
   a. Mixing Layer Cooling around Stripped cool gas
   b. Turbulence driven thermal instability
   c. Cooling from falling into potential of the satellite





+ Black hole of the satellite

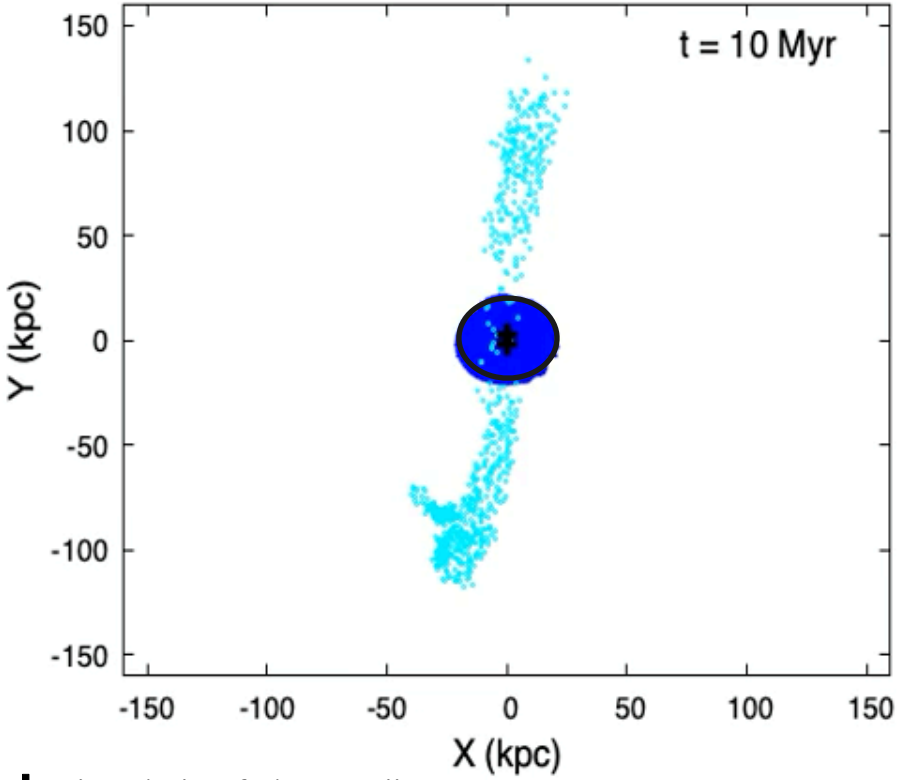
Stripped satellite cold gas

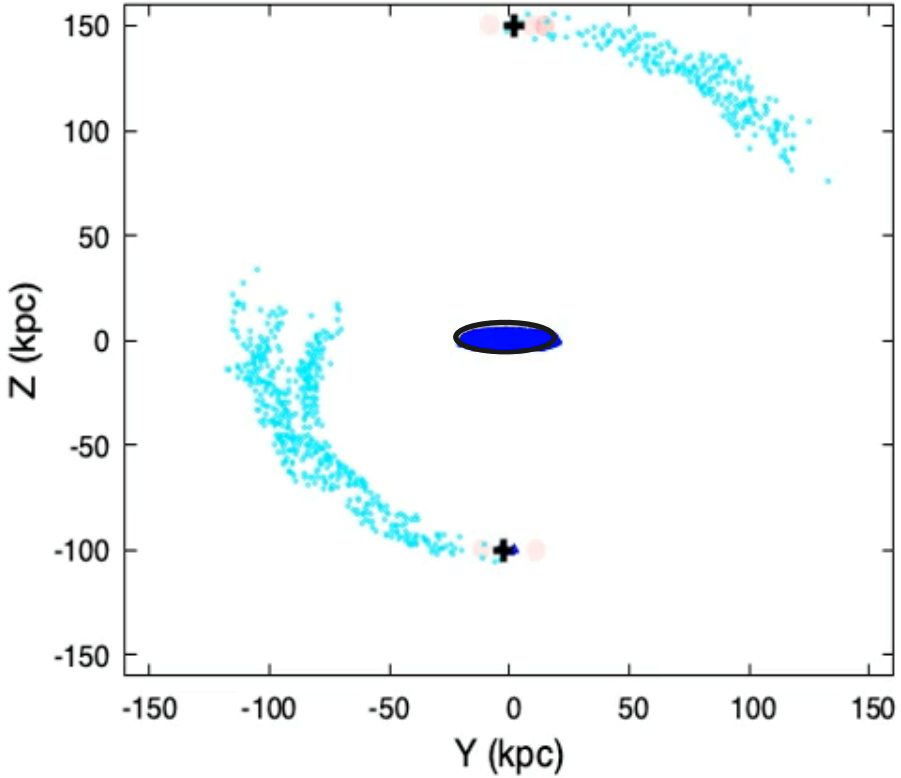
Host gas which gets cooled

Host gas cooled outside of the satellite

Time evolution of the coordinates of the host gas cooled outside of the satellite at 1 Gyr

Time evolution of the coordinates of the host gas cooled outside of the satellite at 1 Gyr





✚ Black hole of the satellite

Stripped satellite cold gas

Host gas which gets cooled

Host gas cooled outside of the satellite