The Origin and Distribution of Gas in the Halo of a Milky Way-sized Galaxy

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Work done with Mary Putman, M Ryan Joung and Josh Peek

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Goals of the Project

Study the halo gas of a Milky-Way sized galaxy using a cosmological simulation

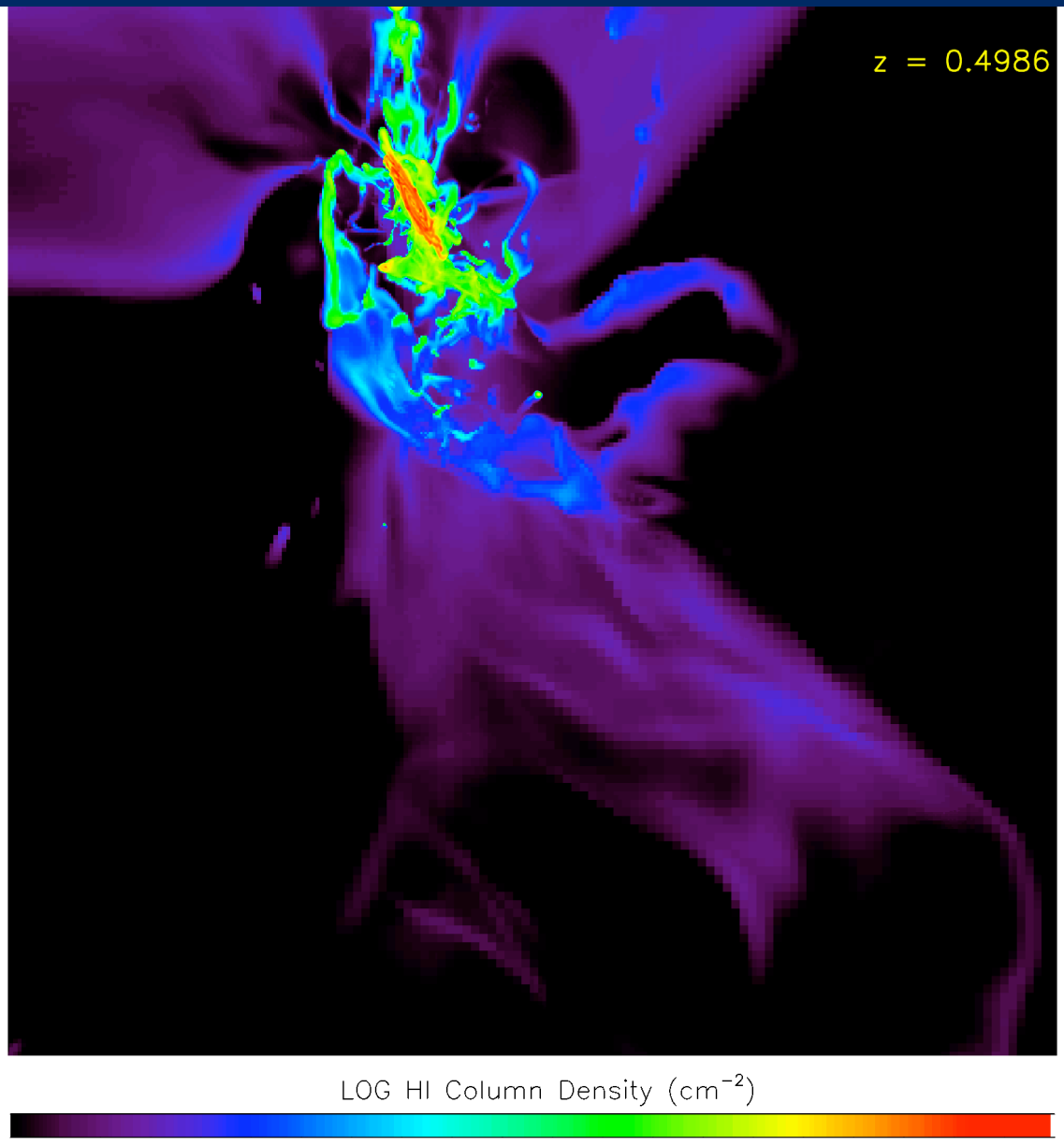
- Compare with observations
  - Distribution and amount of gas
- Explore the origin
  - Stripped gas from satellites (e.g., Grcevich & Putman 2009)
  - Material from cold flows (e.g., Keres & Hernquist 2009)

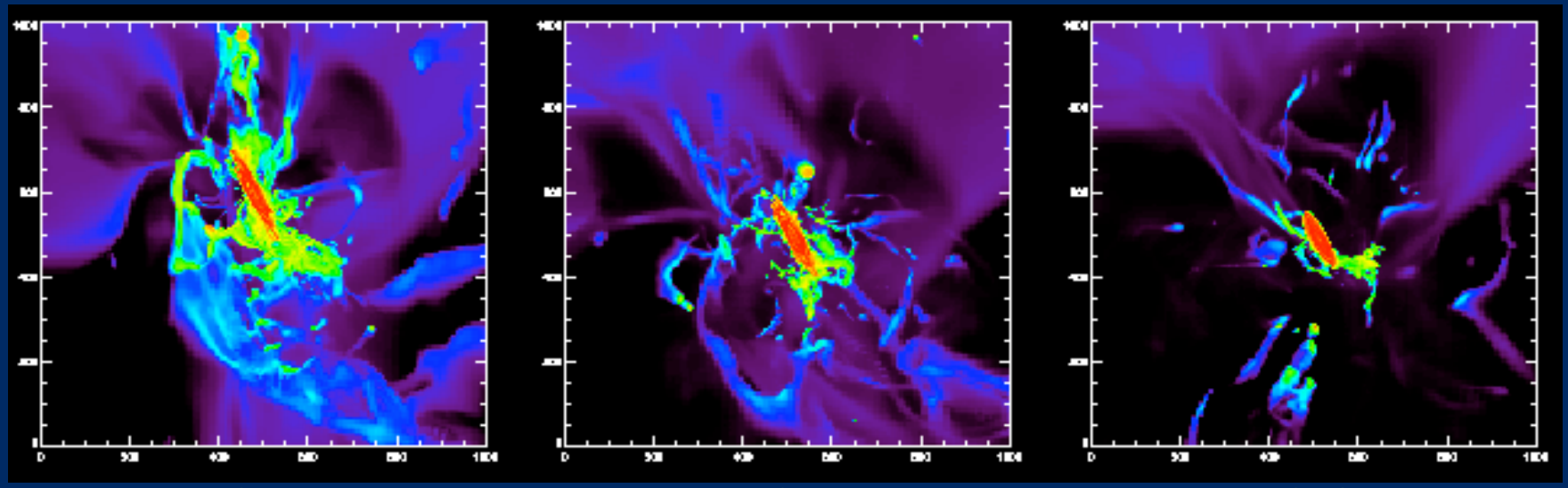
How do galaxies get their gas?

Enzo Simulation

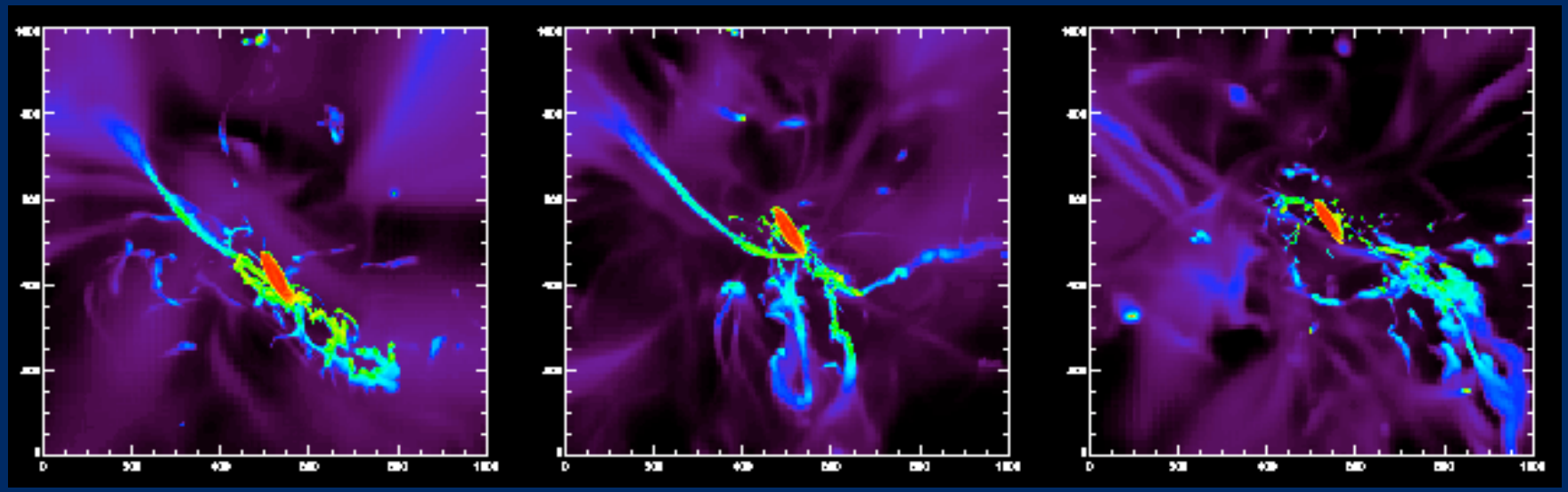
- Cosmological simulation done with Enzo (AMR code)
- M_{DM}= 1.4 x 10^{12} $M_{\odot}$ at z=0
  - 8.2 million DM particles within the virial radius
- Maximum spatial resolution of 136-272 pc
- Radiative cooling
- Includes star formation and supernova feedback

(M Ryan Joung)

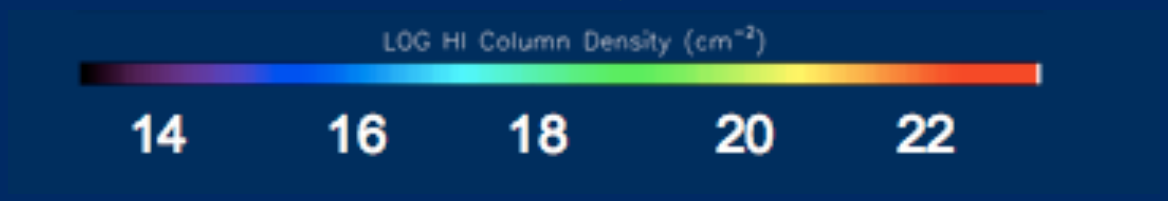

z = 0.4986
LOG HI Column Density (cm^{-2})
14
16
18
20
22



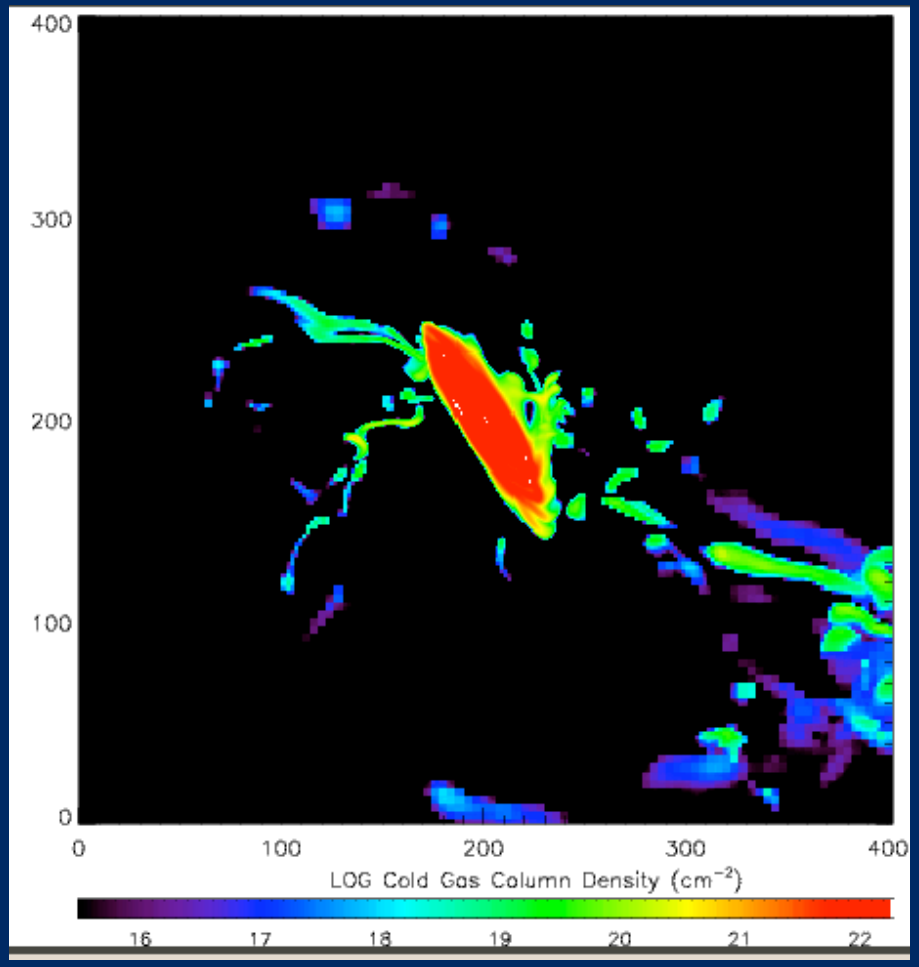
z=0.5 z=0.4 z=0.3

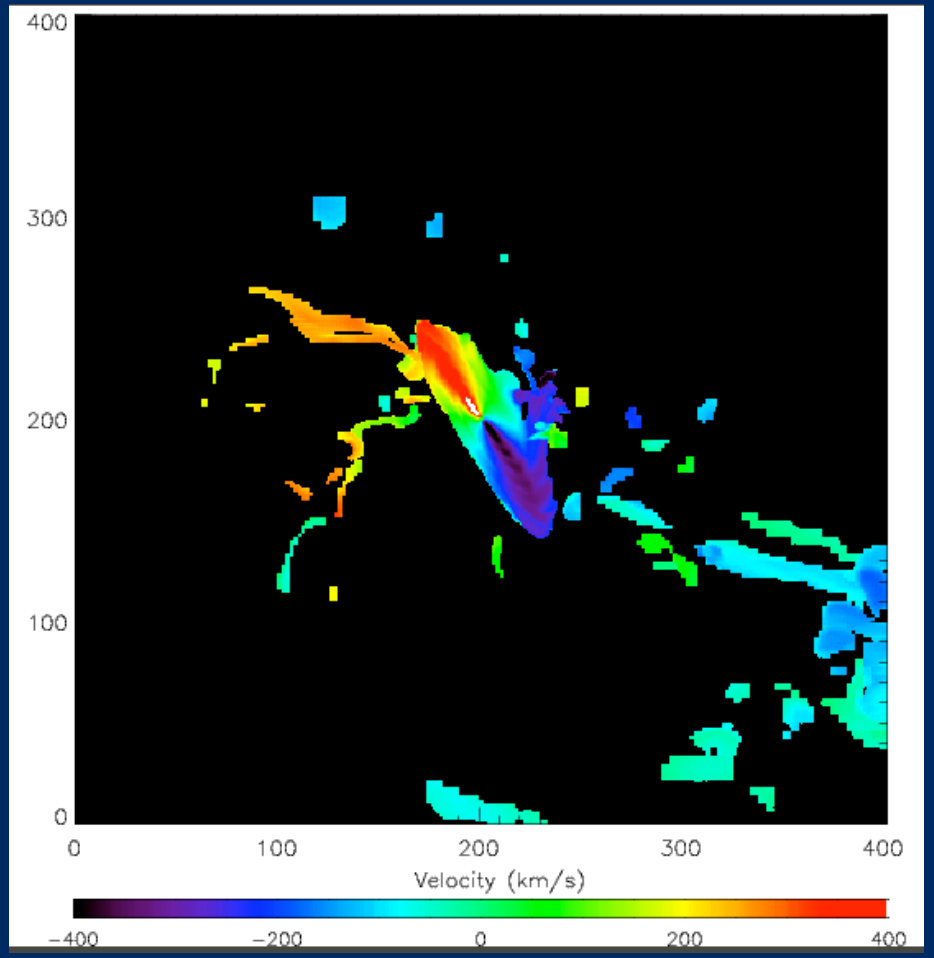


z=0.2 z=0.1 z=0

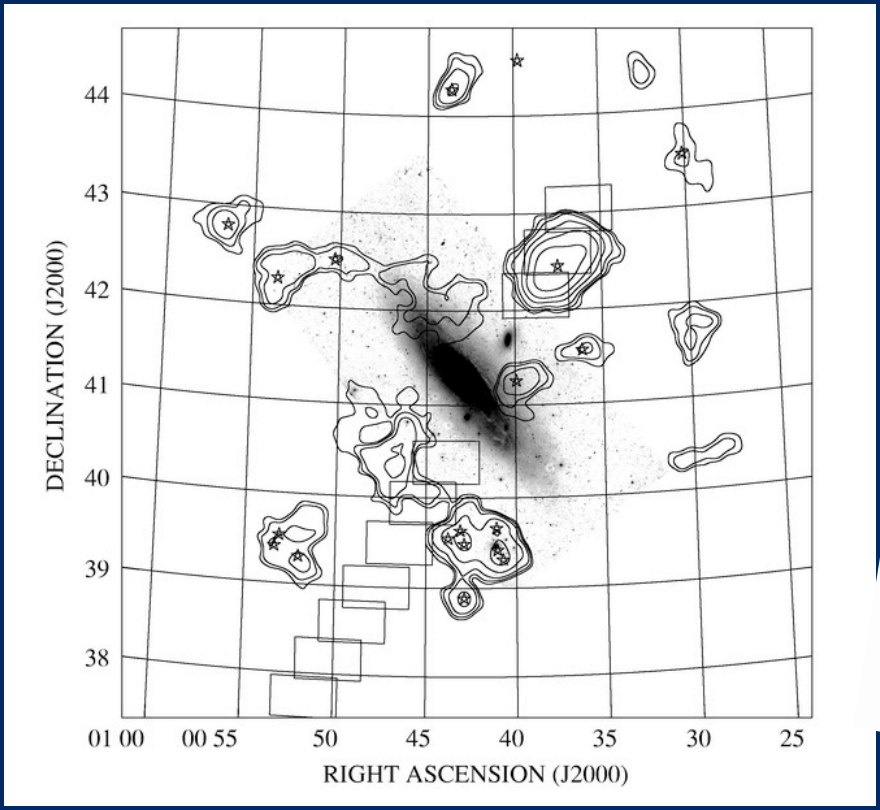


‘Observing’ the Simulation





Comparison with M31's Halo Gas

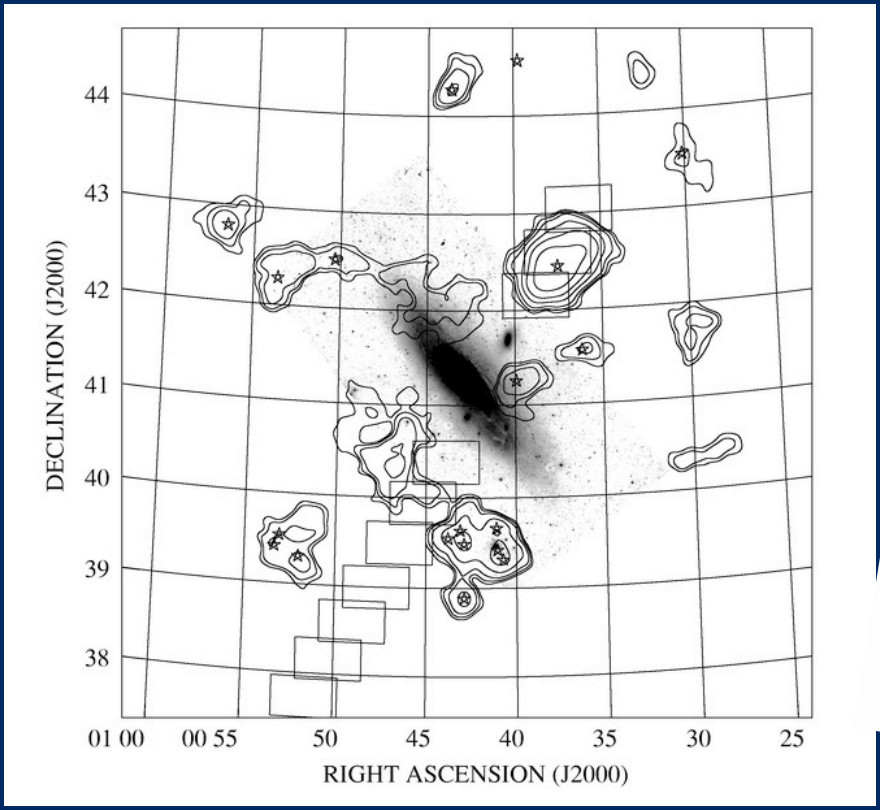


M31 (Thilker et al. 2004)

Simulated galaxy

Contour levels: 0.5, 1, 2, 10, 20 x 10^{18} cm^{-2}

Comparison with M31's Halo Gas



M31 (Thilker et al. 2004)

$M_{HI} = 3 \times 10^7 M_\odot$

Simulated galaxy

$M_{HI} = 6 \times 10^7 M_\odot$

Origin of the Gas

- Analyzed simulation starting at z=0.5 to track satellites and cold flows at different redshifts

Satellite identification

- Identified 19 satellites with HI
  - 14 lose their gas or leave the simulation box
  - 5 still have gas at z=0

Satellite	HI mass loss
S10	55%
S12	80%
S13	97%
S15	44%
S19	85%

z=0.20

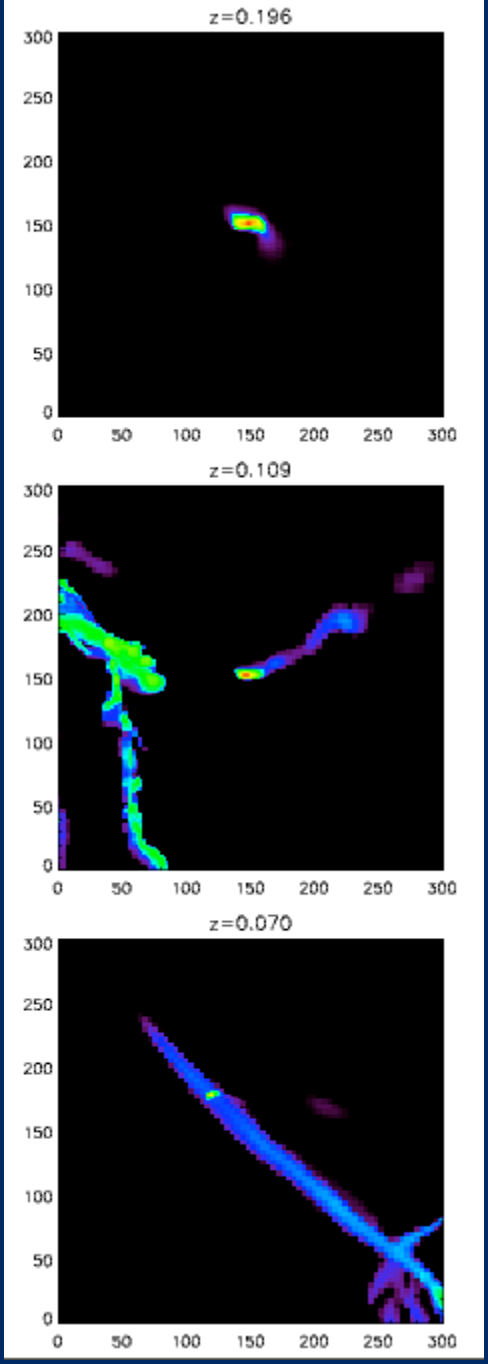
M_{HI}= 8 x 10^7 $M_\odot$

z=0.11

M_{HI}= 4 x 10^7 $M_\odot$

z=0.07

M_{HI}= 3 x 10^6 $M_\odot$



S13 (97%)

z=0.20

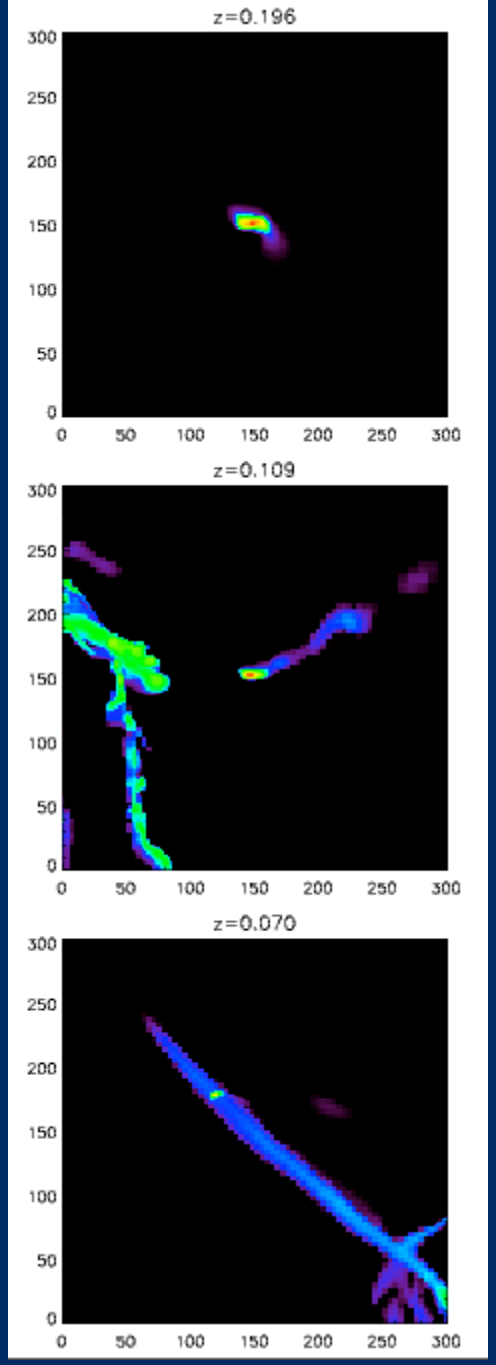
M_{HI}= 8 x 10^7 $M_\odot$

z=0.11

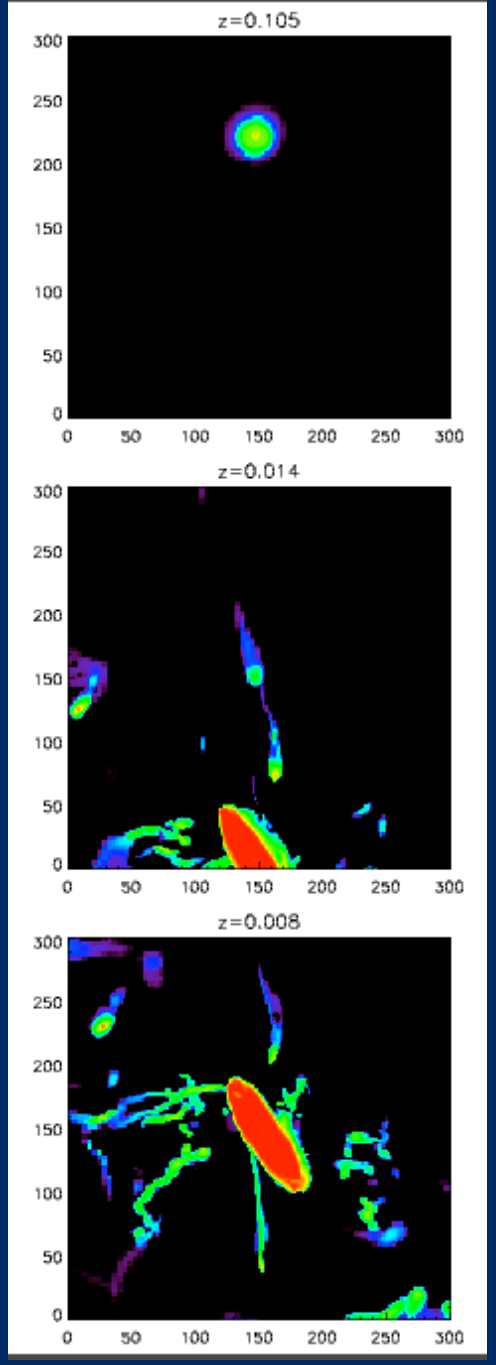
M_{HI}= 4 x 10^7 $M_\odot$

z=0.07

M_{HI}= 3 x 10^6 $M_\odot$



S13 (97%)



S19 (85%)

z=0.11

M_{HI}= 2 x 10^7 $M_\odot$

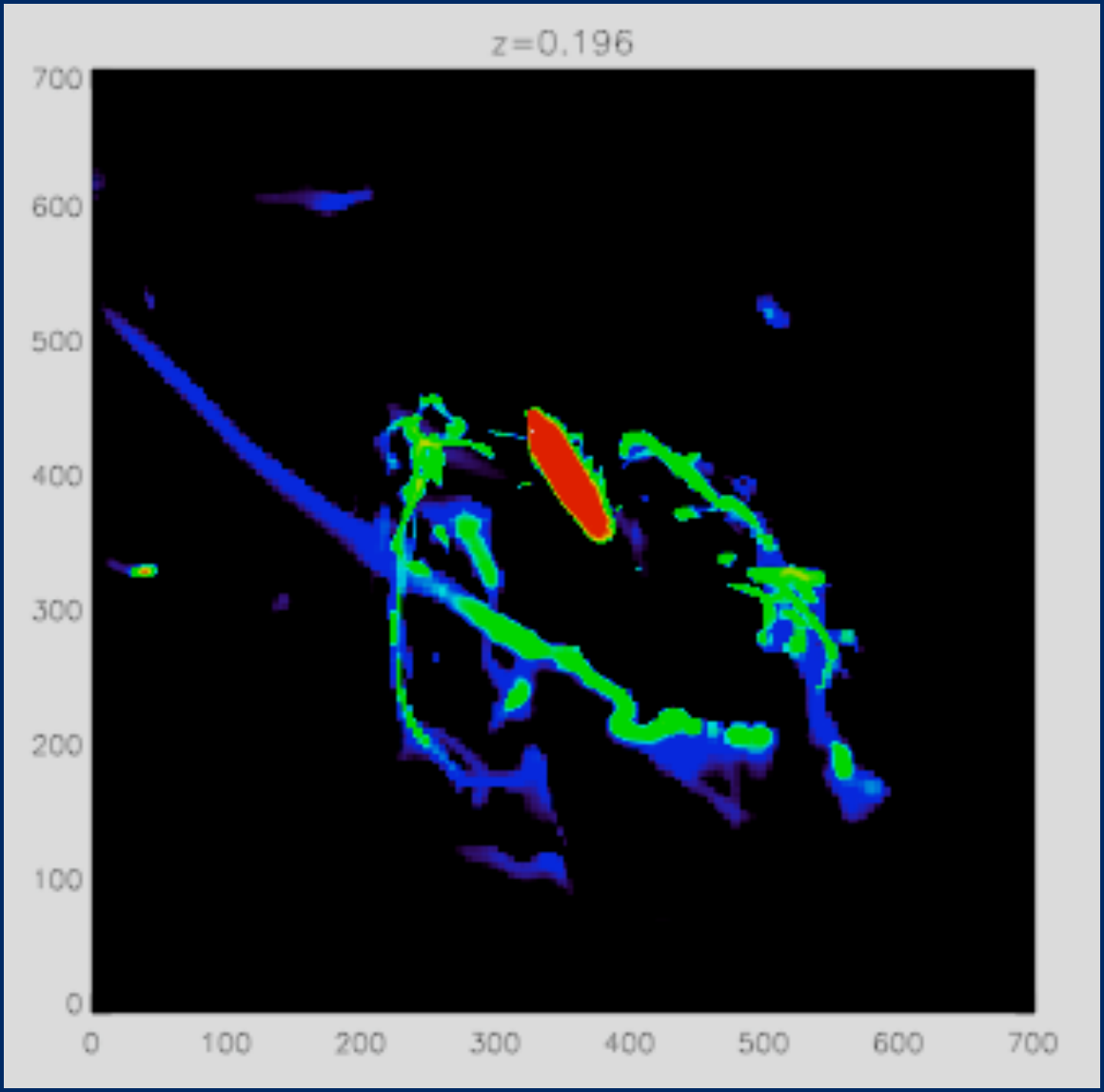
z=0.02

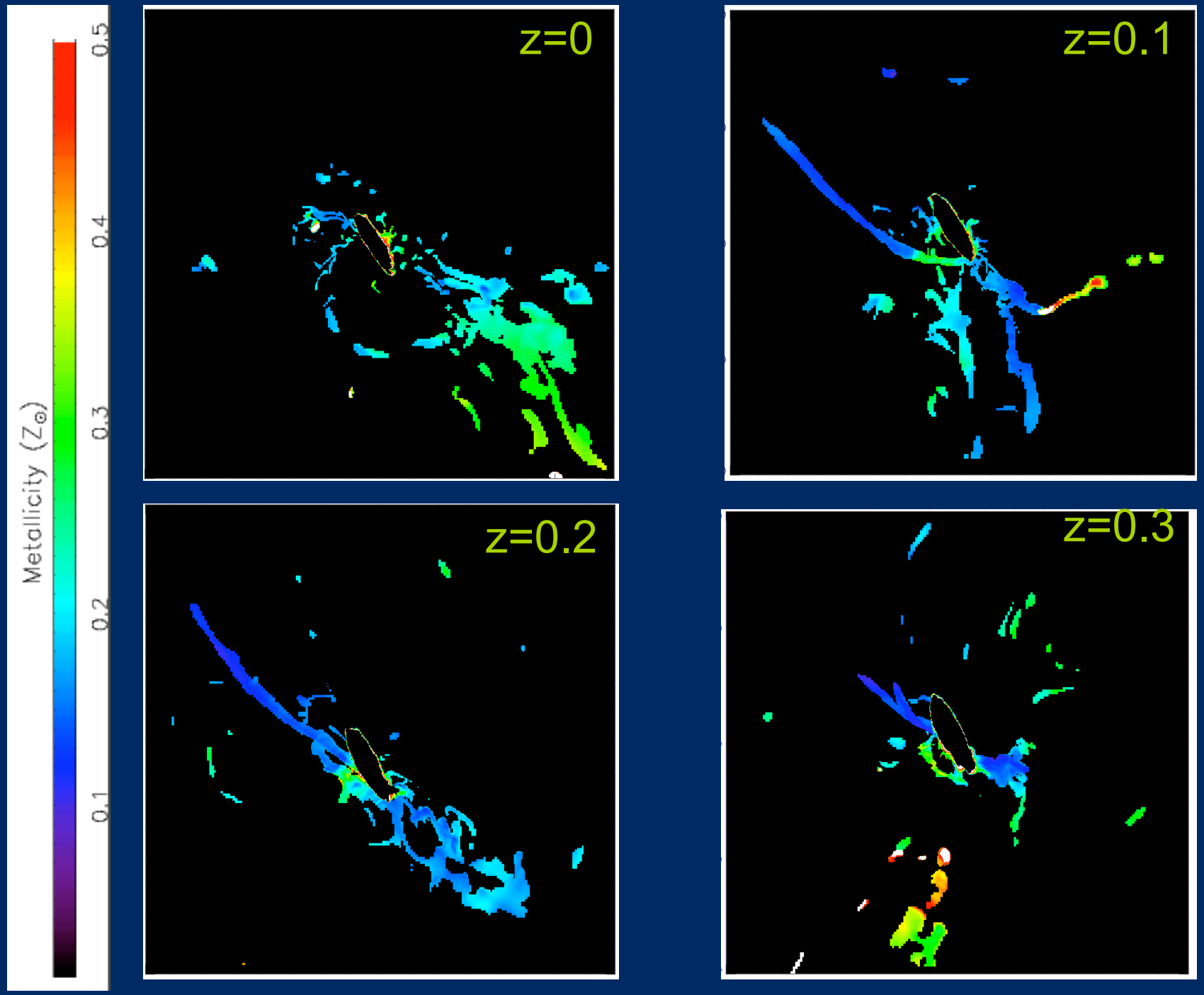
M_{HI}= 9 x 10^6 $M_\odot$

z=0.01

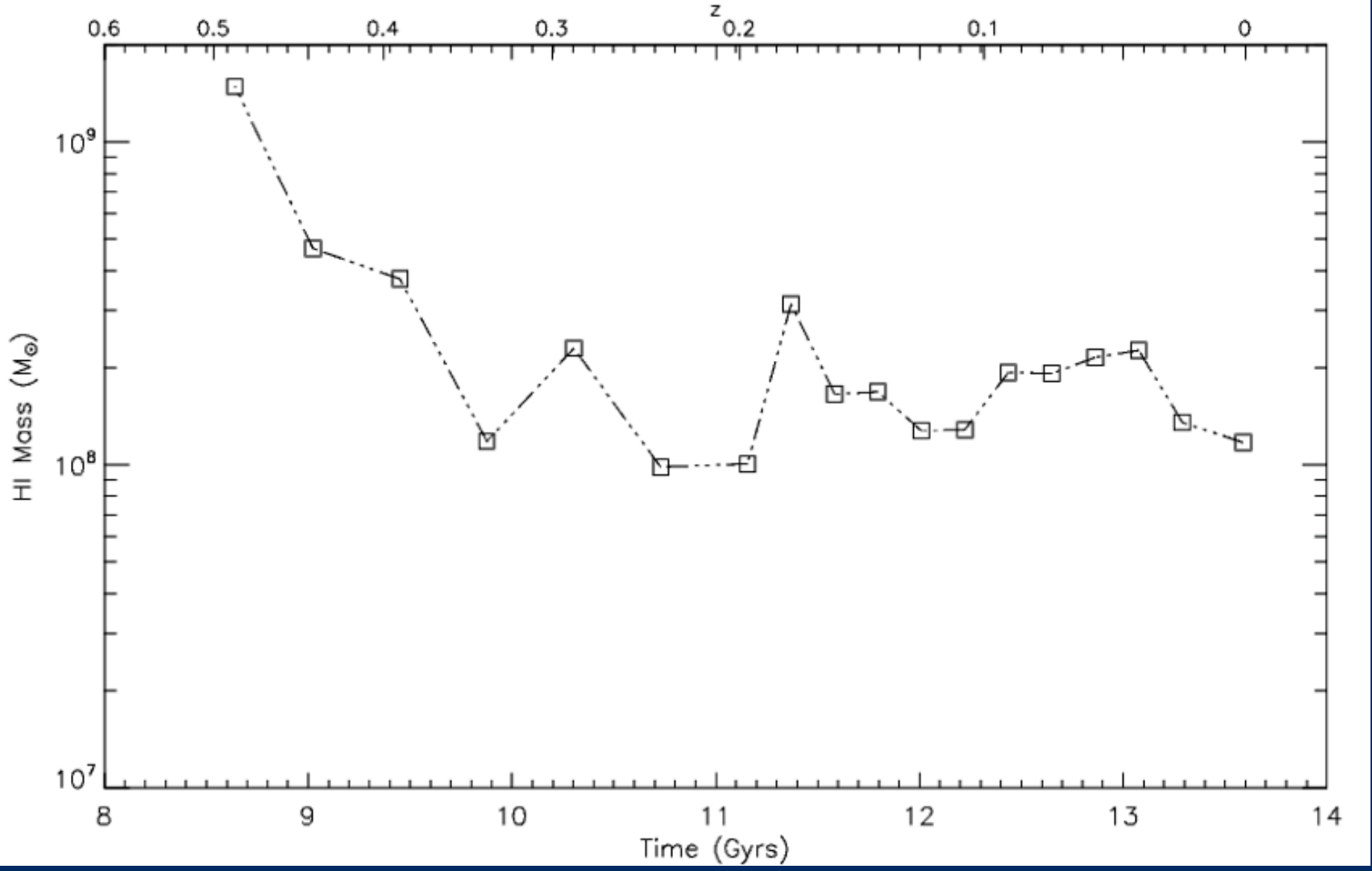
M_{HI}= 6 x 10^6 $M_\odot$

Tracking flows?

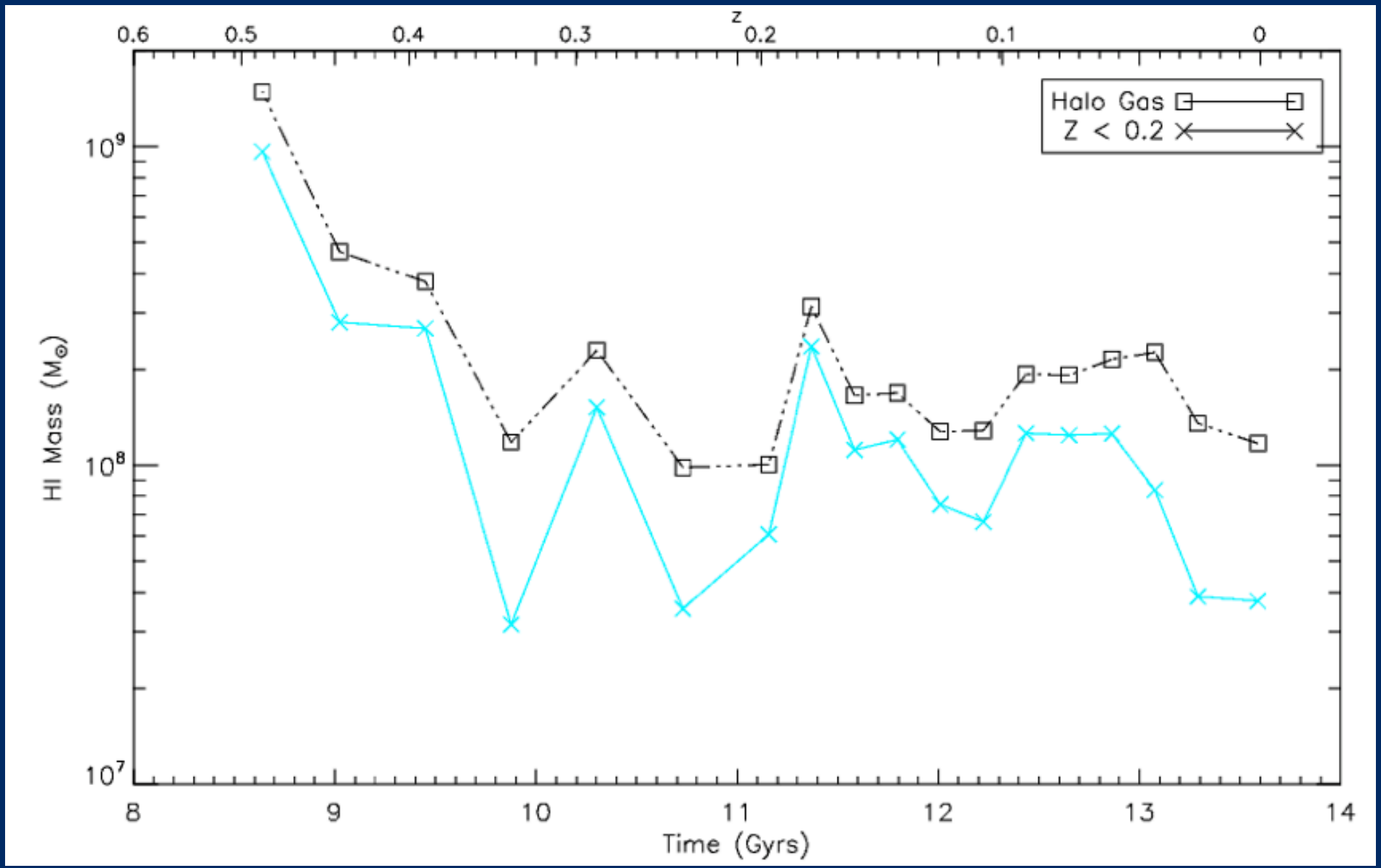


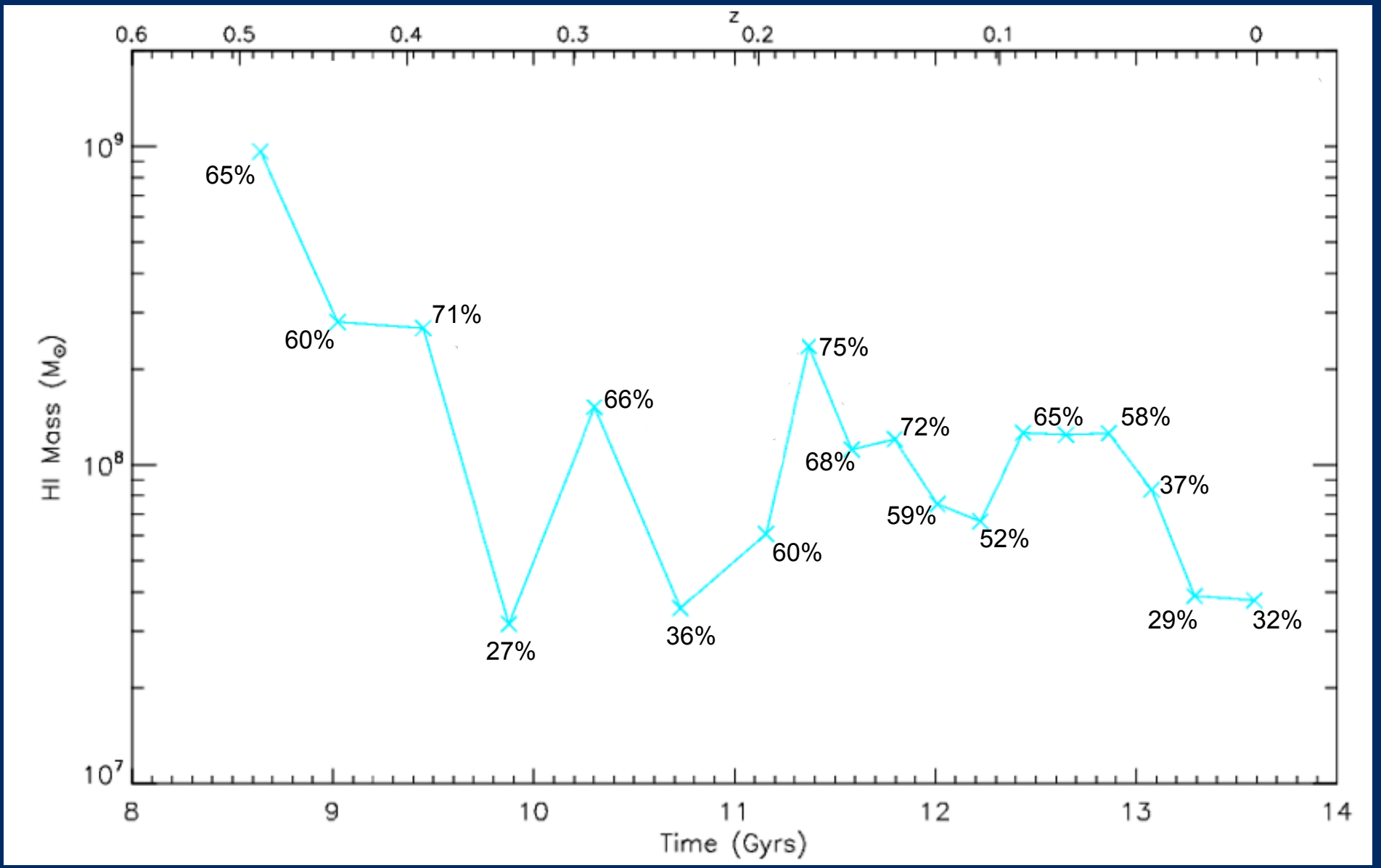

z=0
z=0.1
z=0.2
z=0.3
Metallicity ($Z_\odot$)
0.1
0.2
0.3
0.4
0.5

Halo Gas at Different z



Halo Gas at Different z




z
0.6
0.5
0.4
0.3
0.2
0.1
0
HI Mass ($M_\odot$)
10^9
10^8
10^7
65%
60%
71%
27%
66%
36%
60%
75%
68%
72%
59%
52%
65%
58%
37%
29%
32%
8
9
10
11
12
13
14
Time (Gyrs)

Summary

- Distribution and amount of HI is overall consistent with observations

- Origin of the gas is both satellite debris and cold flows
  - Most satellites are losing gas (high Z)
    - 11/19 are losing 80% or more
  - Cold flows are more active at certain redshifts (low Z)
    - 27-75%
  - Supernova winds contaminate the cold flow gas (high Z)