The Baryon Cycle on FIRE
Tracing Cosmic Inflows, Galactic Outflows, and Gas Recycling in Realistic Environments

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The interplay between local and global processes in galaxies
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The Baryon Cycle in Galaxy Evolution

The Baryon Cycle in Galaxy Evolution


Non-externally processed

Fresh gas accretion

Galaxy mergers: Gas + stars

Wind recycling

Wind loss

Externally processed
The Baryon Cycle in Galaxy Evolution

- Fresh gas accretion
- Non-externally processed
- Wind recycling
- Wind loss
- Galaxy mergers: Gas + stars
- Intergalactic transfer: Wind transfer
- Stripping
- Externally processed

FIRE simulations
Connecting local and global processes in galaxies

High resolution cosmological zoom simulations with mass, momentum, energy, and metal feedback from stellar population synthesis models

Mass–Metallicity relation: Ma+15

HI in z=2 CGM: Faucher-Giguère+15

Powerful outflows: Muratov+15

M_STAR – M_HALO relation: Hopkins+14
Origin of stellar content of galaxies

\[ \log M_{\text{HALO}} (z=0) = 12 \]

→ Fresh gas accretion dominates first but wind recycling takes over
→ Stars + gas from galaxy merger at \( z=2 \), but wind transfer dominates
Origin of stellar content of galaxies

\[
\log M_{\text{HALO}}(z=0) = 12
\]

→ **Fresh gas** accretion dominates first but **wind recycling** takes over
→ **Stars** + **gas** from galaxy merger at \(z=2\), but **wind transfer** dominates
Fraction of $z = 0$ $M_{\text{STAR}}$

From dwarfs to elliptical galaxies

Increasing halo mass: $\log M_{\text{HALO}} = 10 \rightarrow 13$
Trends with halo mass

→ Mass-loading factor larger for low mass galaxies (Muratov+15)
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→ Wind recycling more important in low mass galaxies
Trends with halo mass

- Mass-loading factor larger for low mass galaxies (Muratov+15)
- Wind recycling more important in low mass galaxies
- Wind transfer increases with halo mass
Never ejected

Gas is recycled more in lower mass halos prior to forming stars
50% of mass recycled more than [1, 2, 3, 6] times in log $M_{\text{HALO}} = [13, 12, 11, 10]$
Metallicity implications

- Track number of times ejected gas cycles through the galaxy

- Gas increasingly enriched as it cycles through the galaxy
The Baryon Cycle in MW-mass galaxies

% stellar mass at z=0 averaging 3 MW-mass galaxies

Non-externally processed
50%

Fresh gas accretion
40%

Wind recycling

Wind loss
60%

Galaxy mergers: Gas + stars
25%

Intergalactic transfer: Wind transfer Stripping
75%

Externally processed
50%

Gas mass loss equivalent to z=0 stellar mass
1) On-going particle tracking analysis of FIRE zoom-in simulations to quantify the cycling of baryons in galaxy evolution

2) Recycling of galactic winds represents a significant contribution to galaxy growth, but also the transfer of gas between galaxies via winds!

3) Currently exploring the implications of fresh accretion, gas recycling, wind transfer, and mergers for chemical evolution and structural properties of galaxies

4) Develop observational diagnostics of the baryon cycle

Anglés-Alcázar et al. in preparation
The baryon cycle in simulations

Oppenheimer et al. (2010)

Galactic winds required to match GSMF and wind recycling contributes a lot!
The baryon cycle in simulations

SINS galaxies (Förster Schreiber+09)

$R_{1/2, sfr}$ (kpc)

$M_{\text{star}}$ ($M_{\odot}$)

no winds

winds

$z = 2$

Anglés-Alcázar et al. (2014)

→ Galactic winds required to match structural/kinematic properties of $z=2$ disks
Tracing stars back to the original gas source

Stellar content of Galaxy at $z = 0$

Externally processed

- Mergers
  - Gas: ISM
  - Stars
  - Gas: wind transfer
  - Stars: stripping

- Intergalactic transfer

Non-externally processed

- Gas: wind recycling

- Fresh accretion

- Wind transfer

- Wind recycling

- Wind loss

- Stripping

- Direct mergers: ISM gas + stars
Stellar content of Galaxy at $z = 0$

% mass from each mode for $\log M_{\text{HALO}} = [13, 12, 11]$

- **Externally processed**
  - [49, 45, 28]
  - Mergers
    - [68, 24, 23]
    - Gas: ISM
      - [41, 70, 60]
    - Stars
      - [58, 30, 40]
  - Intergalactic transfer
    - [32, 76, 77]
  - Gas: wind transfer
    - [98, 98, 96]
    - Stars: stripping
      - [2, 2, 4]
  - Gas: wind recycling
    - [47, 62, 81]
  - Gas: fresh accretion
    - [53, 38, 19]

Globally: [35, 56, 78]