Turbulence in The Halos of Galaxies

By: Ed Buie II
Date: 3/3/2021
First, I want to acknowledge all those who have been negatively impacted by the COVID-19 pandemic. And thank you to all of the essential workers for their efforts. We will get through this.
14,500,000,000 mi
or
156 Astronomical Unit or AU
Circumgalactic Medium (CGM)
How do we observe the Circumgalactic Medium (CGM)?
Quasars or Active Galactic Nuclei (AGN)!

Core of Galaxy NGC 4261

Credit: NASA/JPL-Caltech
Halo Surveys

Can turbulence explain observable features of hot halo?
First simulations


Isotropic stirring + non-equilibrium

Neutral Hydrogen
Slices at t = 0 (left) and 3 Gyr (right) along the z-axis showing the number density (top row) and temperature (bottom). A black circle shows the virial radius at r ≈ 220 kpc.

Turbulence sets up a convective flow in the halo. Hot gas moves outward to be replaced by cooler, inflowing material.
Full halo slices

Face-on (density)

Side-view (temperature)

x (kpc) y (kpc) z (kpc)

hot warm cold

a lot some little

$t = 0.0 \text{ s}$ 30 kpc
Magnetic field growth

face-on

$t = 0.0 \text{ s}$

30 kpc
Magnetically supported gas

Face-on (density)  Plasma Beta = thermal pressure/magnetic pressure

![Diagram showing the density profile and plasma beta in a galaxy.](image)

- Face-on (density) showing the distribution of gas in the galaxy.
- Plasma Beta, defined as the ratio of thermal pressure to magnetic pressure, is visualized with a color scale.
- The images show different times (t = 0.0 s and 30 kpc) for both density and plasma beta.
How does the neutral Hydrogen (H I) look?

- a lot
- some
- little

Hubble Data
Ion ratios

![Graph showing ion ratios](image)

- **Mag + Rot**
- **Rot only**

- **Log** $\frac{N_{\text{SiII}}}{N_{\text{OVI}}}$
- **Log** $\frac{N_{\text{NV}}}{N_{\text{OVI}}}$

- **Hubble Data**
- **Simulation**
Galaxies have an “invisible” halo of gas surrounding them called the Circumgalactic Medium. This medium is important to the central galaxy evolution.

- It's where gas is recycled.
- Gas flows outward and inward.

Turbulence allows for cycling of hot and cooling gas.

Magnetic field rises steeply and decreases slowly in the halo over time.

- May be a consequence of density profile in the halo.

Extended magnetized co-rotating disk of gas.

Non-equilibrium chemistry produces neutral hydrogen profile and ion ratios that match Hubble data.