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TURBULENCE IN THE CIRCUMGALACTIC MEDIUM OF FIRE SIMULATIONS

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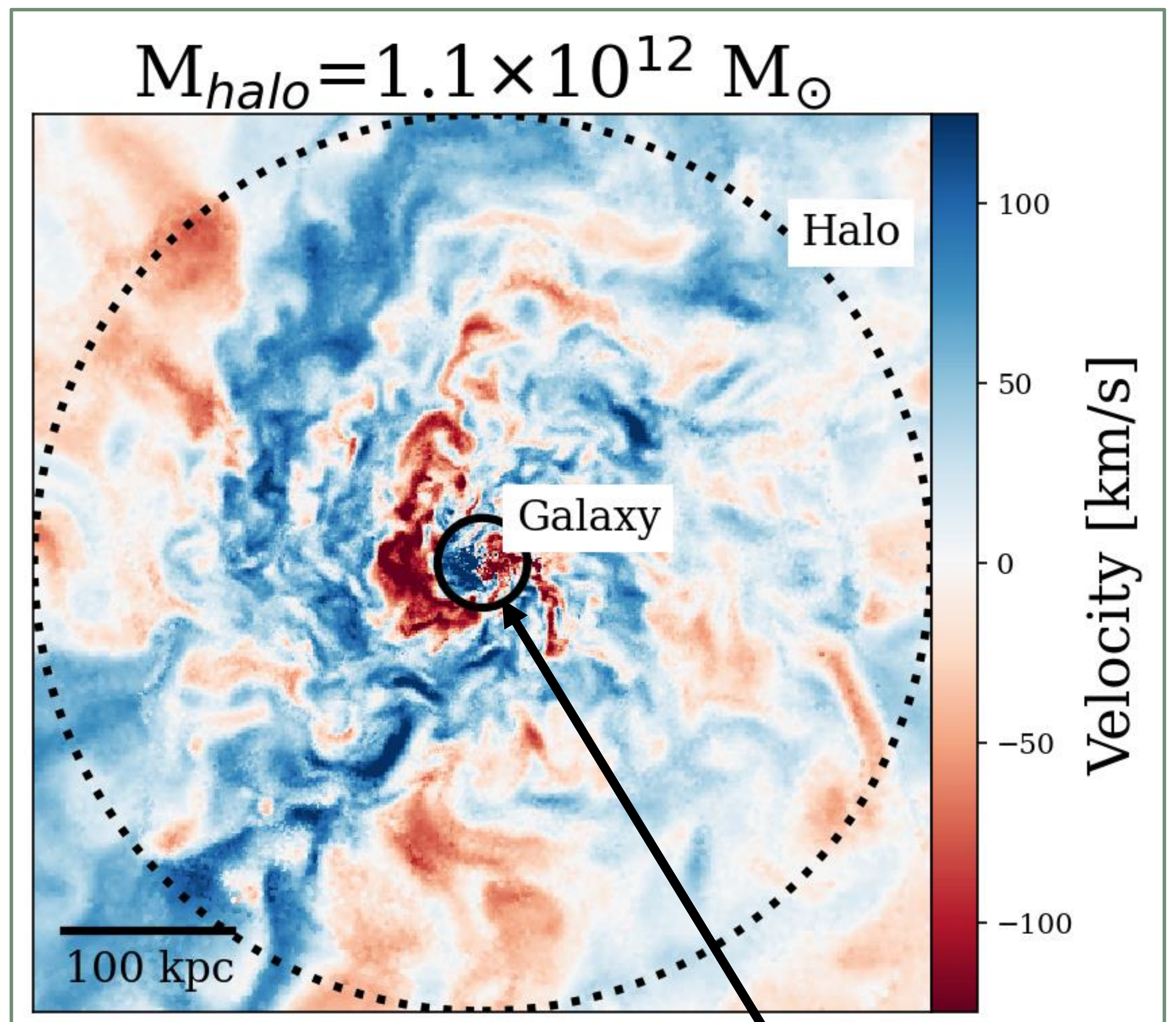
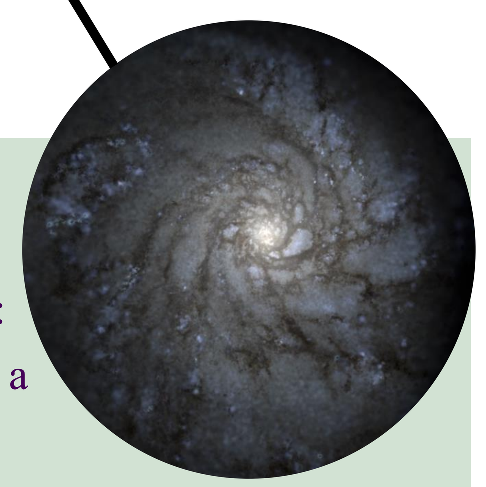




Velocity map for galaxy and halo + zoom in on galaxy. Image Credit: Hopkins 2017

Introduction

The Circumgalactic Medium (CGM): massive envelope of gas surrounding a galaxy containing most of the halo's baryonic matter (for Milky Way ~60%)

CGM contains both hot (10^6~10^7 K) and cold phase gas; both important in **shaping inflows and outflows** as the intermediary between galaxy and the intergalactic medium; most/all is hot in high mass (≳ Milky Way) galaxies

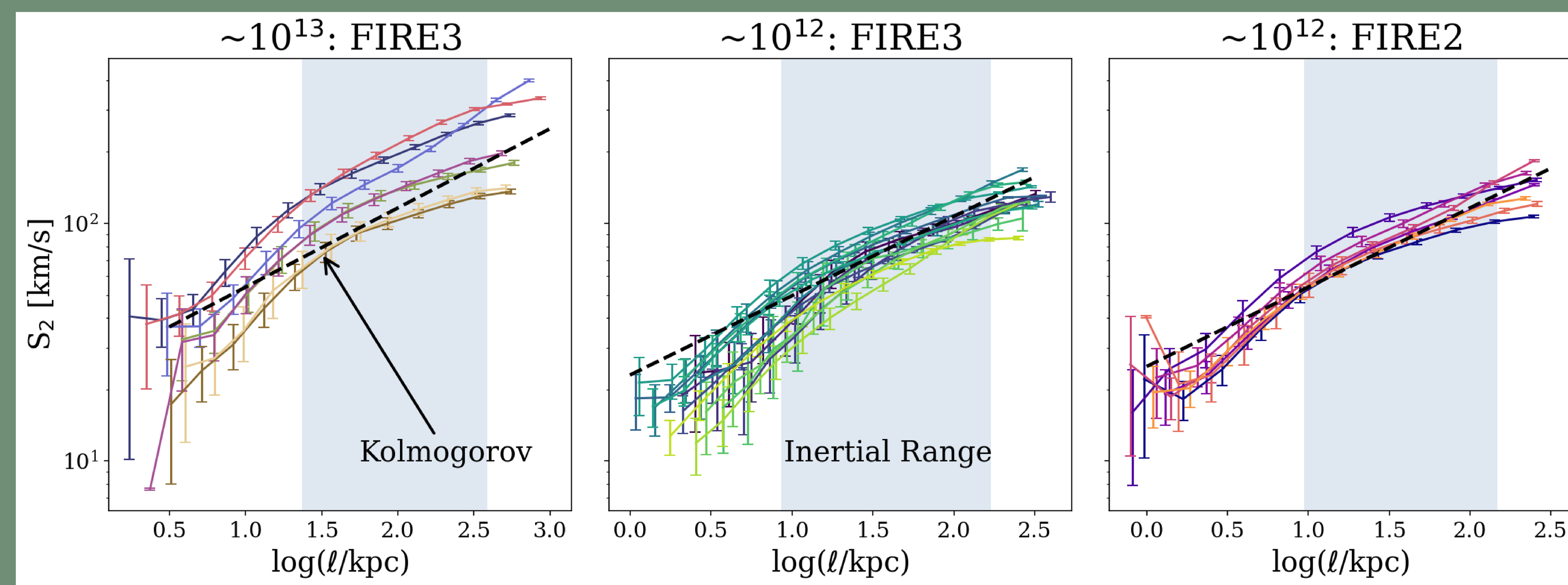
Goal: **understand the turbulence of the hot phase CGM**

Understanding Turbulence

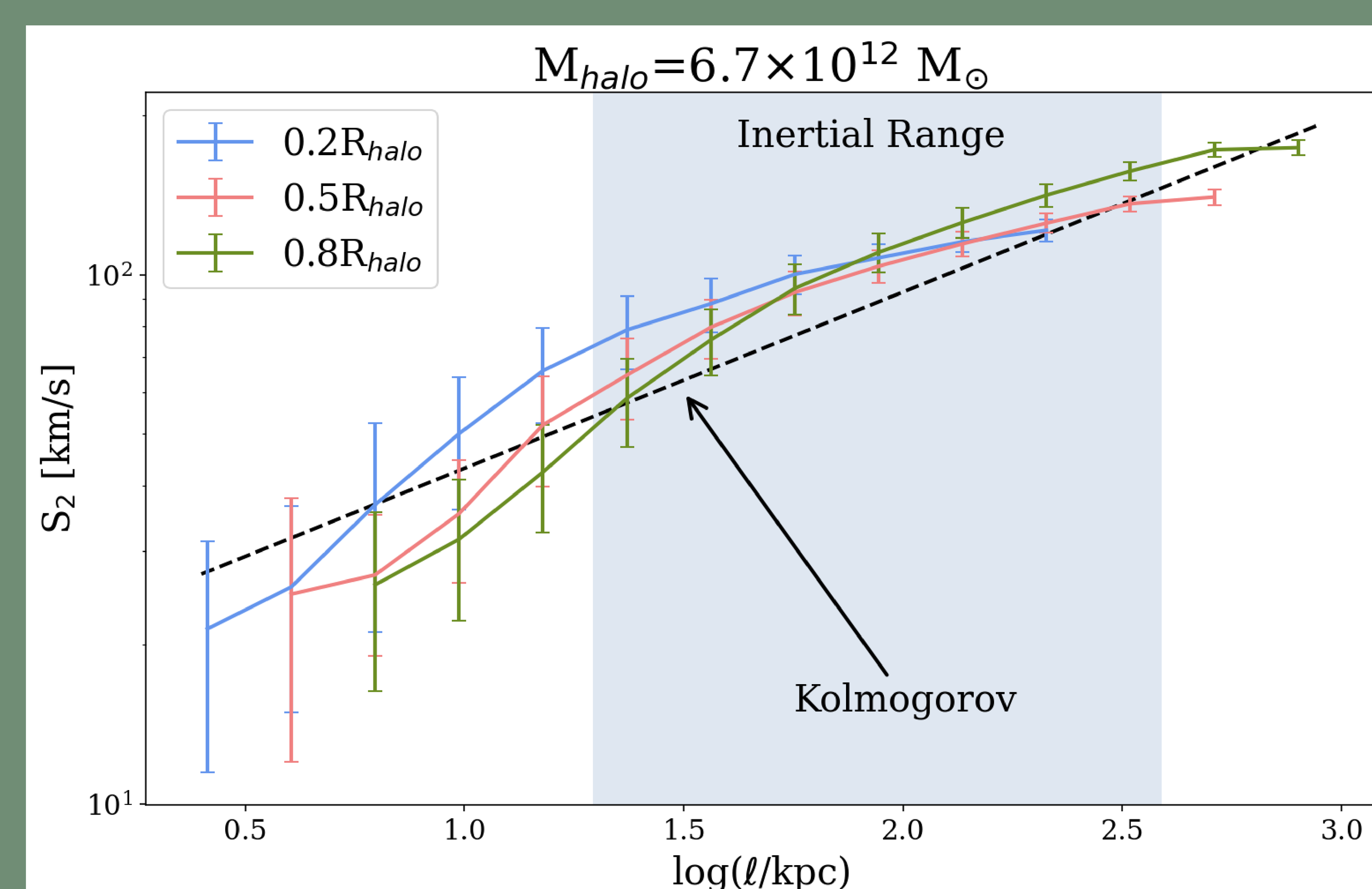
Turbulence is caused by nonlinear terms in fluid dynamics equations – and is described by **circular/twisting motions called eddies in turbulent theory**; no analytical solutions so we need to make simplifying assumptions

Why is turbulence important? Turbulence provides **10-40% of the energy** that supports the CGM. Astronomers are starting to measure the turbulence in the CGM using emission and absorption lines

Velocity Structure Functions for FIRE CGM Compared to Kolmogorov Prediction



Velocity Structure Function for 3 different mass ranges/simulation codes at r=0.5R_{halo}



Velocity Structure Function for different radial shells in one selected halo

For many simulations, the VSF slope **agrees well with the Kolmogorov** prediction in the inertial range

In some halos, the measured VSF shows more curvature in the expected inertial range than the power-law predicted by Kolmogorov

We hypothesize this is due to energy injection occurring on a wide range of scales in the simulations, in contrast to energy injection being restricted to the largest scales in the idealized Kolmogorov theory

Methods

We use the high-resolution cosmological zoom-in galaxy simulations from the FIRE Project – which implements **realistic stellar feedback in cosmological context** and can resolve multiphase CGM/ISM

Mass Resolution: ~10^3-10^5 M_{sun}
Spatial Resolution: ~1 kpc in hot gas

CGM is approximately 0.1-1R_{halo} we select hot phase

Velocity Structure Function (VSF) Calculation:

$$S_p(\ell) = \langle \left| \vec{v}(\vec{x}) - \vec{v}\left(\vec{x} + \vec{\ell}\right) \right|^p \rangle^{1/p}$$

Velocity variation between two points at separation ℓ

Radial Shells – VSF is calculated in radial shells to reduce the effect of velocity gradients along the radial direction

Kolmogorov Prediction – Idealized turbulence for incompressible, homogeneous, isotropic, stationary turbulence, predicts a power law relation between VSF and separation:$S_p \propto \ell^{1/3}$

Inertial Range – range between large-scale energy injection and small-scale dissipation, where a steady turbulent cascade is expected

Future Work

1. Explore in greater depth the physical effects that give rise to deviations from Kolmogorov theory to better understand the turbulence in realistic simulations
2. Expand analysis to halos that include black hole feedback to provide a more complete view of the processes affecting turbulence in the CGM
3. Recently many **observations of CGM turbulence have been published**. To compare with these observations, investigate the effects of projecting the turbulence onto the sky (2D vs. 3D)

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← For more information visit

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