

The WEFT project: simulating small-scale gas

dynamics in cosmic filaments

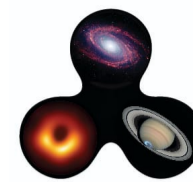
Théo Lebeau^{1,2}, Saleem Zaroubi^{1,2} et al

¹Kapteyn Astronomical Institute, University of Groningen, The Netherlands

²Astrophysics Research Center of the Open University of Israel



Kapteyn astronomical
institute



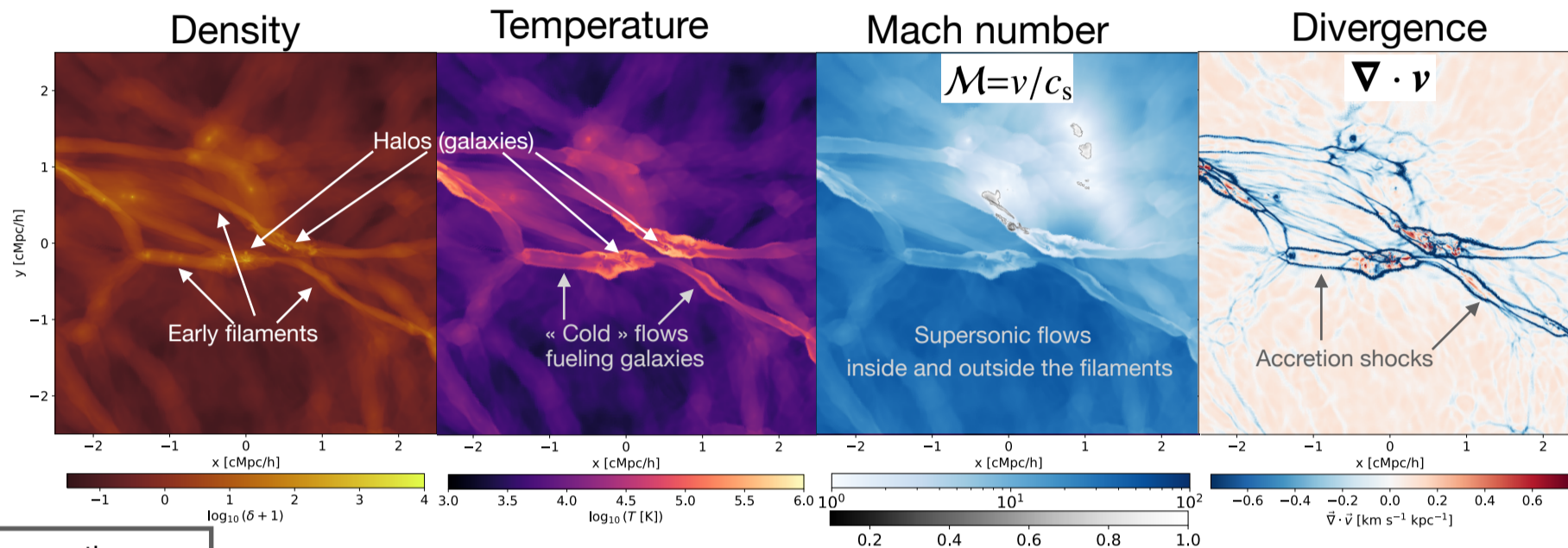
ARCO

Astrophysics Research Center
of the Open university

The missing baryons of the cosmic web reside mostly in filaments, a gas phase now becoming observable in the outskirts of galaxy clusters and in short bridges. Understanding the detailed gas dynamics of filaments — and their influence on the intracluster medium they feed — has therefore become crucial.

I present the first results of the **WEFT project (Web Evolution in Filament Targeted zoom simulations)**, a new suite of high-resolution AREPO zoom-in simulations of a cosmic filament from $z=63$ to $z=0$, reaching a few kiloparsecs of resolution. I investigate the formation and drivers of turbulence using tracers such as enstrophy, helicity and baroclinicity.

Redshift $z=2$: Formation of the filament and early gas rotation



Run properties

Code: AREPO

Subgrid: Cooling, UVB, SF

UV self-shielding, SN feedback

Next run: GFM model, BH, AGN

50 Mpc/h box

Zoom region $\sim 10 \times 8 \times 6$ Mpc/h

Target mass $\sim 3 \times 10^4 M_\odot$

Mean cell size ~ 8 kpc

~ 50 M cells in the zoom

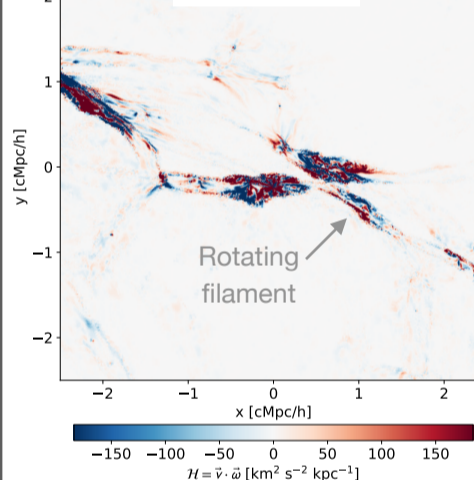
118 snapshots from $z=63$ to $z=0$

~ 500 000 CPU hours

On Hábbrók (Groningen Univ.)

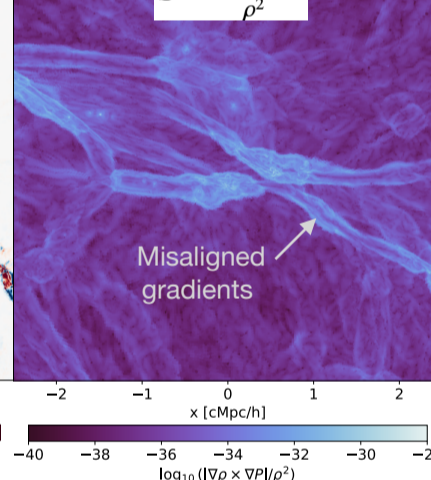
Helicity

$$\mathcal{H} = \mathbf{v} \cdot \boldsymbol{\omega}$$



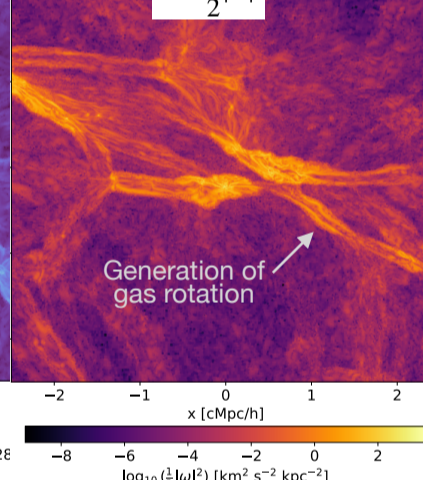
Baroclinicity

$$\mathcal{B} = \frac{|\nabla \rho \times \nabla P|}{\rho^2}$$



Enstrophy

$$\mathcal{E} = \frac{1}{2} |\boldsymbol{\omega}|^2$$



$$\boldsymbol{\omega} = \nabla \times \mathbf{v}$$

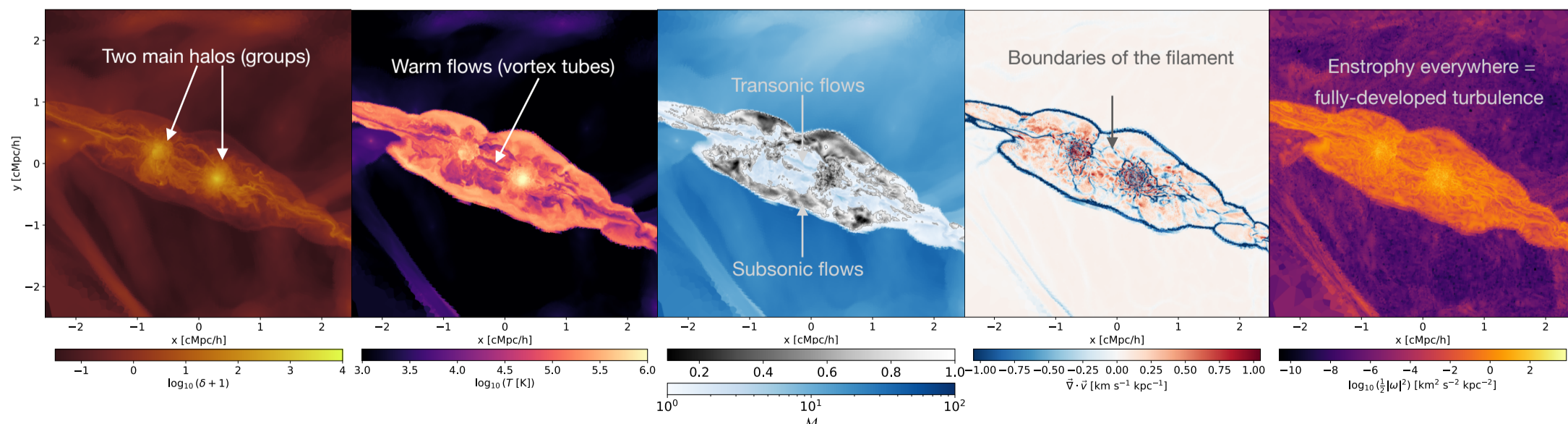
Vorticity: how much the gas rotates normally to an axis

(e.g. ω_z traces rotation in the xy plane)

Enstrophy: unsigned tracer of the overall gas rotation (components don't cancel out)

At $z=2$, early filaments form around halos (galaxies), matter is accreted to the filaments by supersonic flows and then to the halos by « cold » flows (see e.g. Mandelker + 2019) inside the filaments. At the boundaries of the filaments, accretion shocks heat up the gas and generate gas rotation (traced by enstrophy) due to the baroclinic effect, that is the misalignment between the density and the pressure gradients since the shocks are oblique and the filament rotates around itself (see helicity panel).

Redshift $z=0$: Fully-developed turbulence in the filament



At $z=0$, the filament results from the merging of the early ones, it contains two main halos (groups). Warm and transonic flows made of vortex tubes populate the core of the filament, the boundaries of the filament are well defined and turbulence is fully developed

Quantifying turbulence beyond Kolmogorov (in development): Localized and intense structures seem responsible for the generation and dissipation of turbulence, it is called intermittency. To trace this, we compute velocity structure functions at multiple orders to search for deviations from the Kolmogorov self-similar scaling (see e.g. She & Lévéque 1994 and Boldyrev 2002)