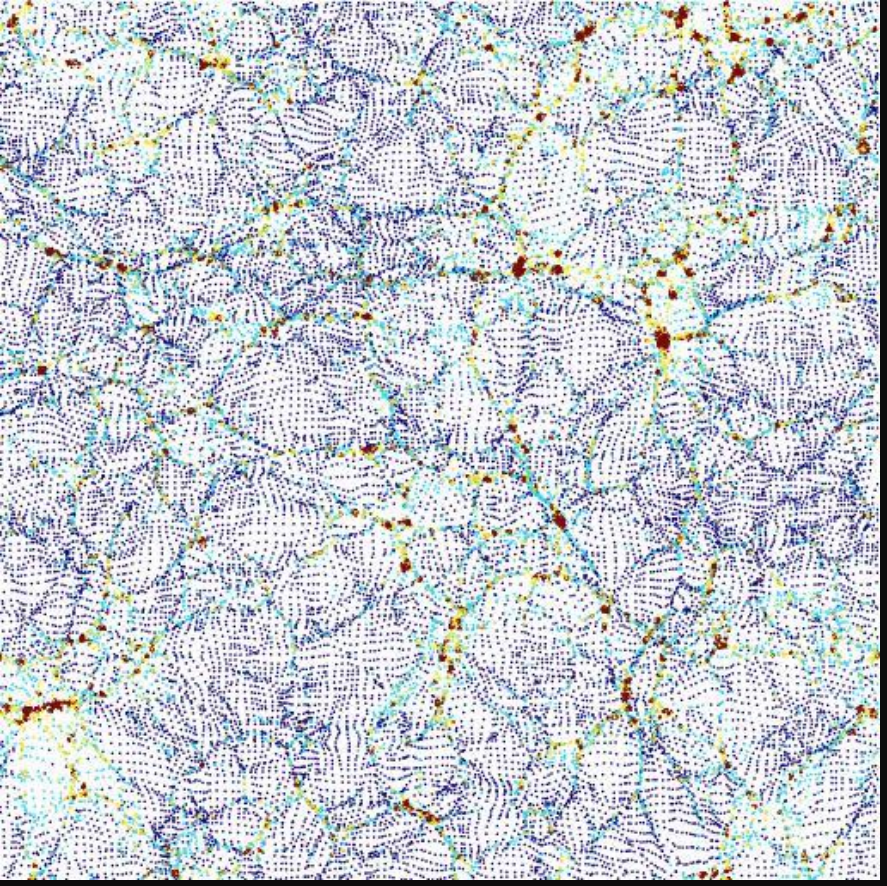


Testing Gravity in the Cosmic Web

Bridget Falck

Institute of Cosmology and Gravitation

University of Portsmouth, UK

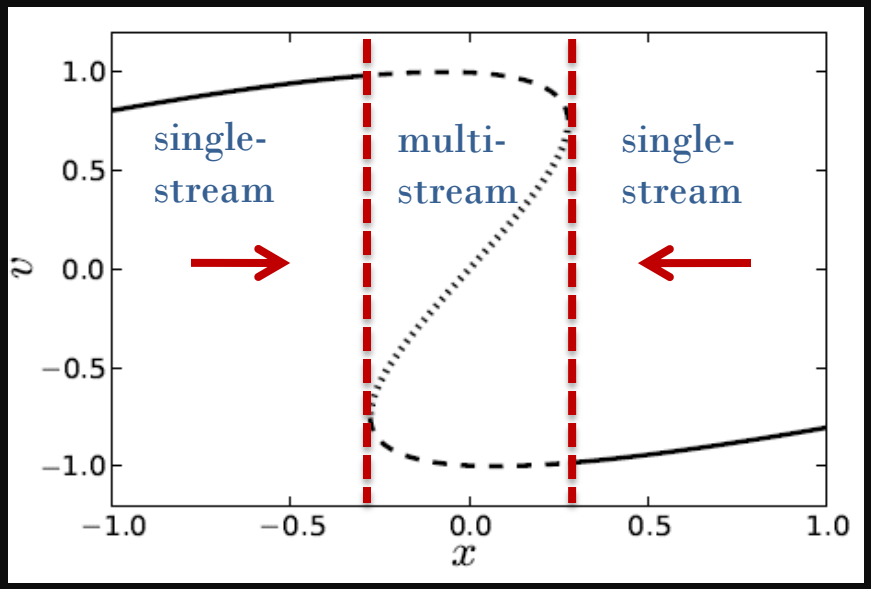
Screening the Fifth Force

- GR well-tested on small scales but not cosmological scales
  - *Chameleon*: in f(R) gravity, make mass of scalar field large in high density environments
  - *Vainshtein*: in massive gravity, galileon, and braneworld (DGP) models, derivative self-interactions hide fifth force, depending on dimensionality of the system (see Bloomfield, Burrage, & Davis 2014)
- Are there signatures of screening mechanisms in the cosmic web of large scale structure?
  - (BF+ 2014, 1404.2206; BF+ 2015, 1503.06673)

Simulations

- Models: nDGP (for Vainshtein), Hu-Sawicki f(R) (for chameleon), and LCDM
  - ECOSMOG (Li et al. 2012, 1110.1379; Li et al. 2013, 1303.0008)
  - 64 Mpc/h, 256^3 particles
- 3 model parameters: tuned parameters such that nDGP and f(R) simulations have same σ_8
  - Allows direct comparison of Vainshtein and chameleon screening
- Cosmic web of dark matter particles identified with ORIGAMI (BF+ 2012, 1201.2353)

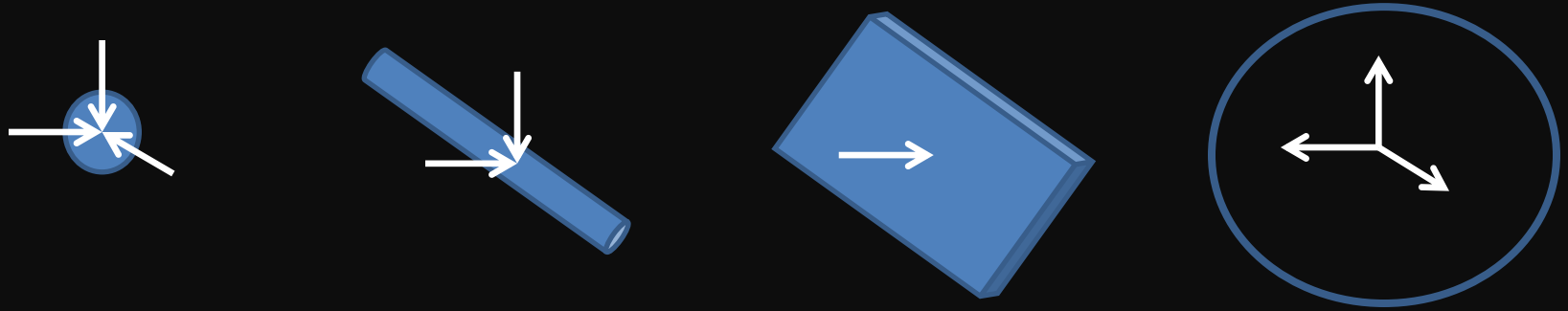
The ORIGAMI Cosmic Web

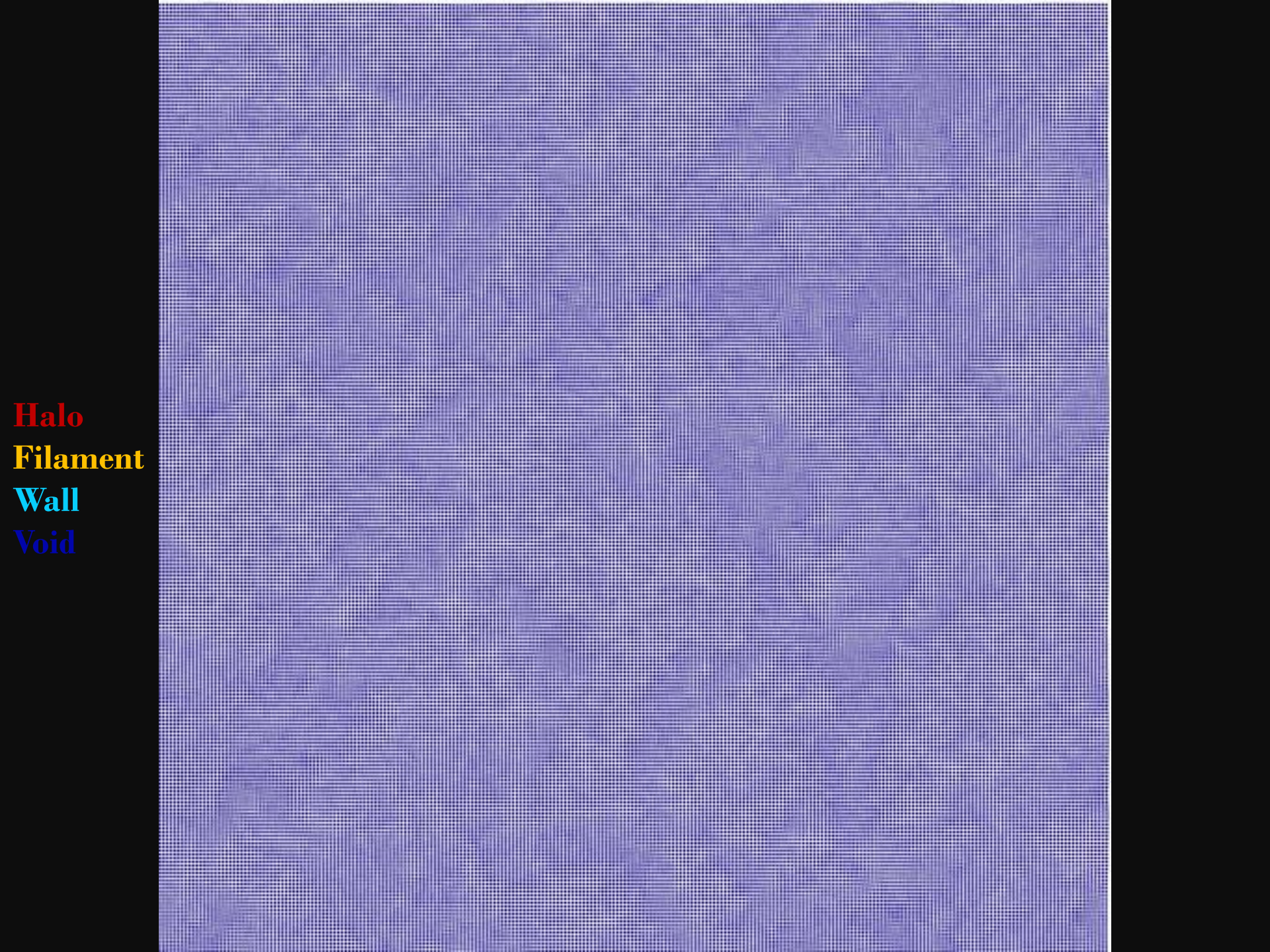


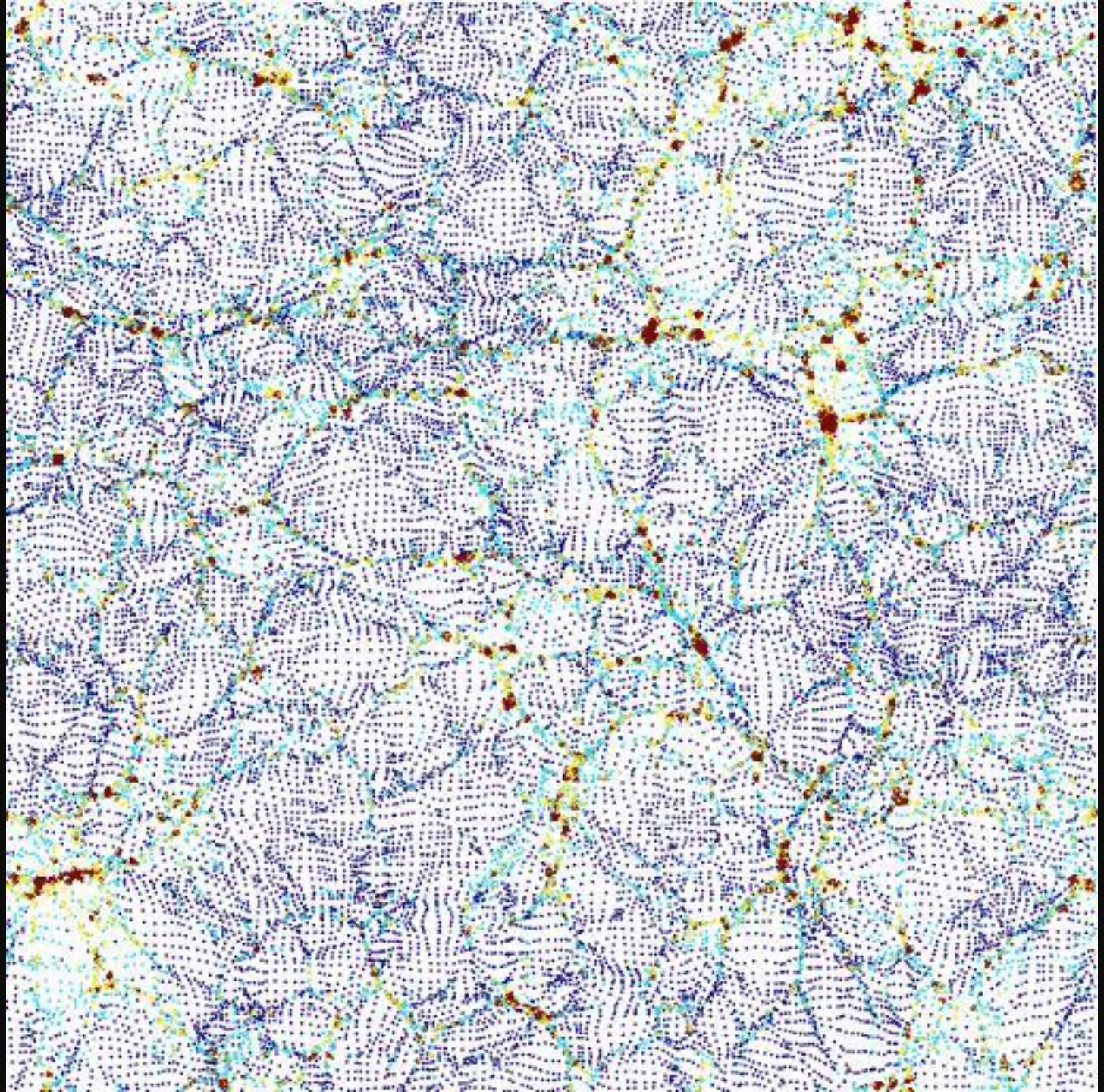
Find the phase-space folds by looking for simulation particles that are out of order along orthogonal axes

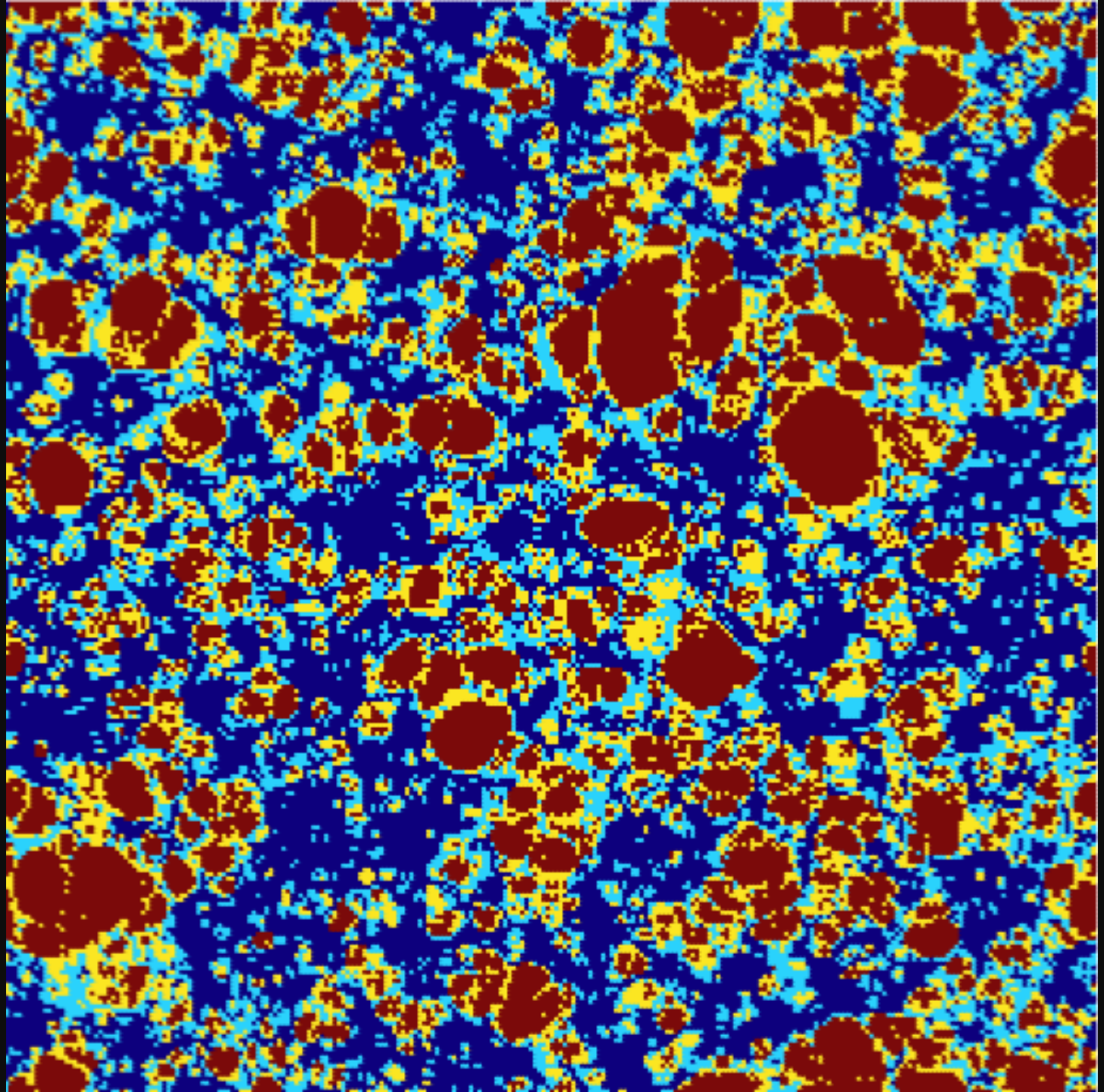
(Falck, Neyrinck, & Szalay 2012, 1201.2353)

Halos collapse along 3 axes, Filaments 2, Walls 1, and Voids 0

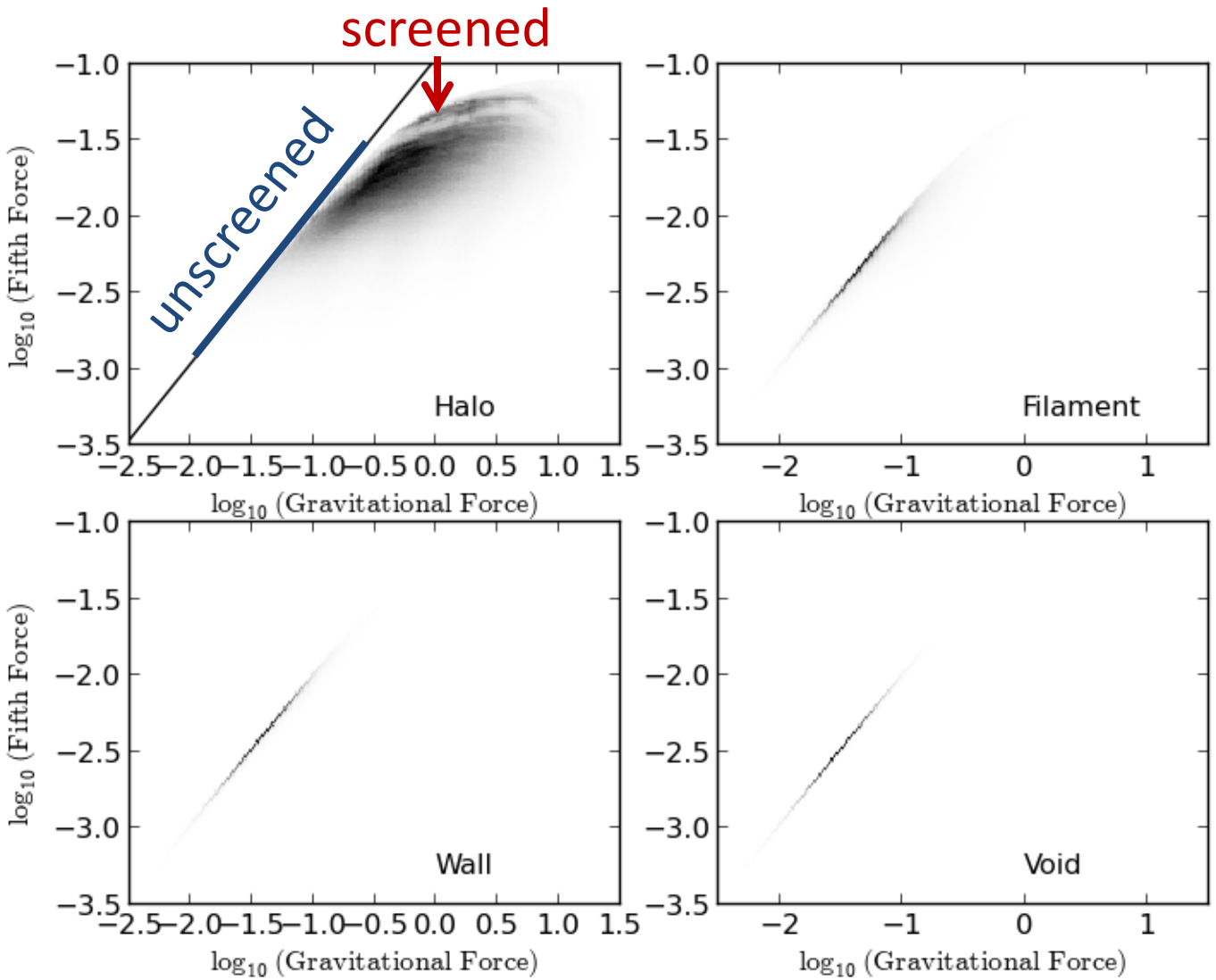



Halo
Filament
Wall
Void

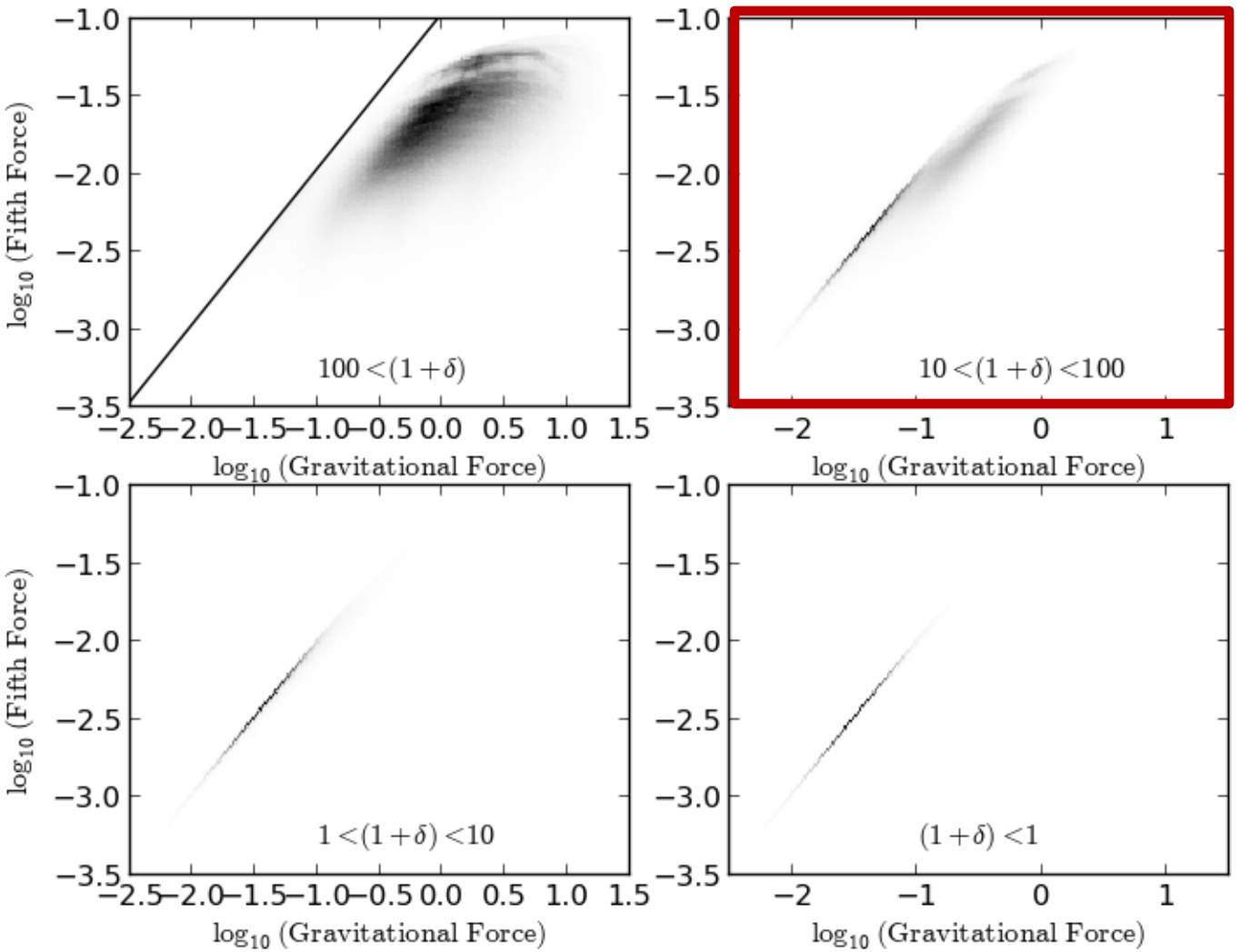

Halo
Filament
Wall
Void


Halo
Filament
Wall
Void

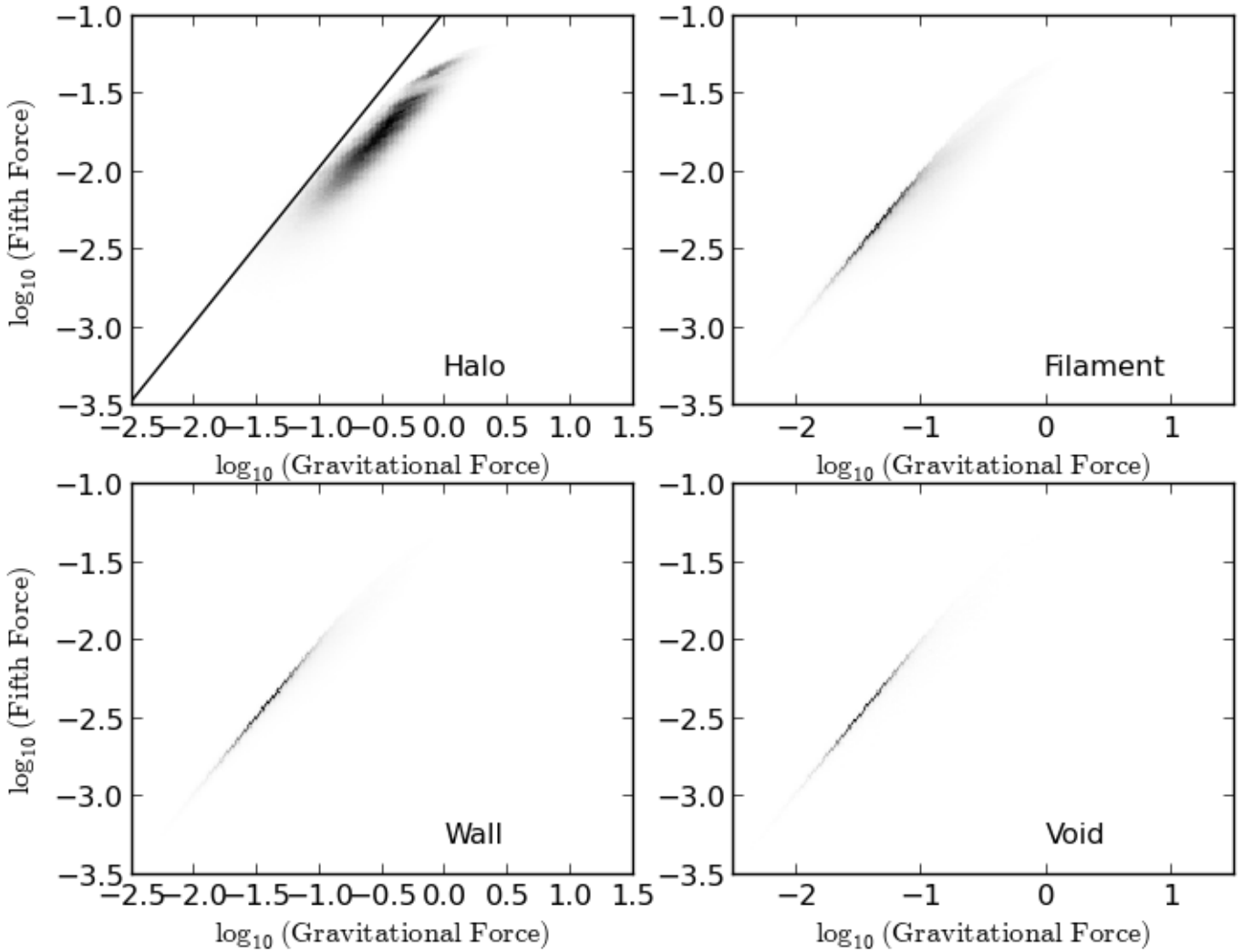
Vainshtein Screening of Dark Matter Particles



Vainshtein Screening of Dark Matter Particles

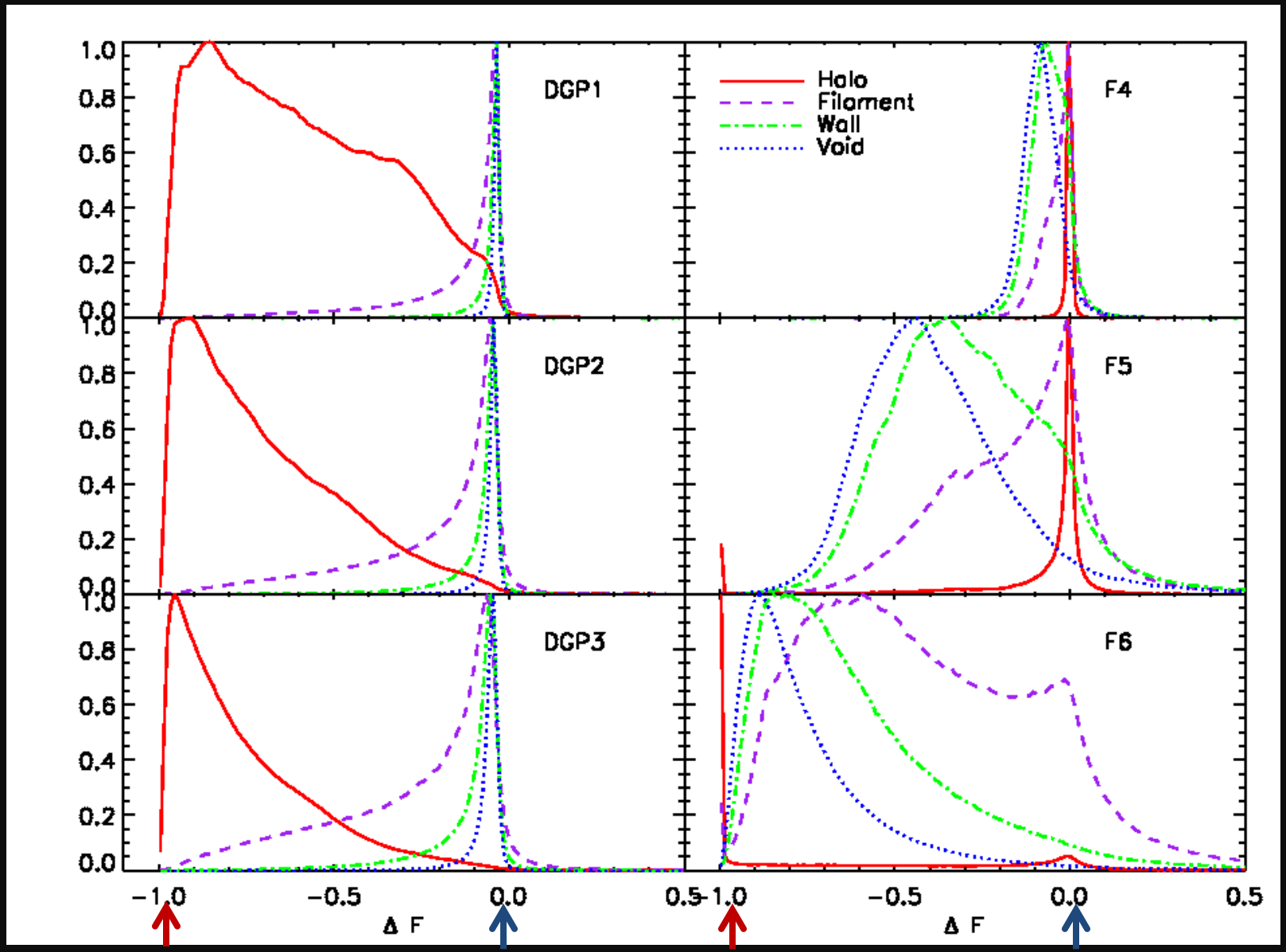


Vainshtein Screening of Dark Matter Particles



Vainshtein

Chameleon



screened

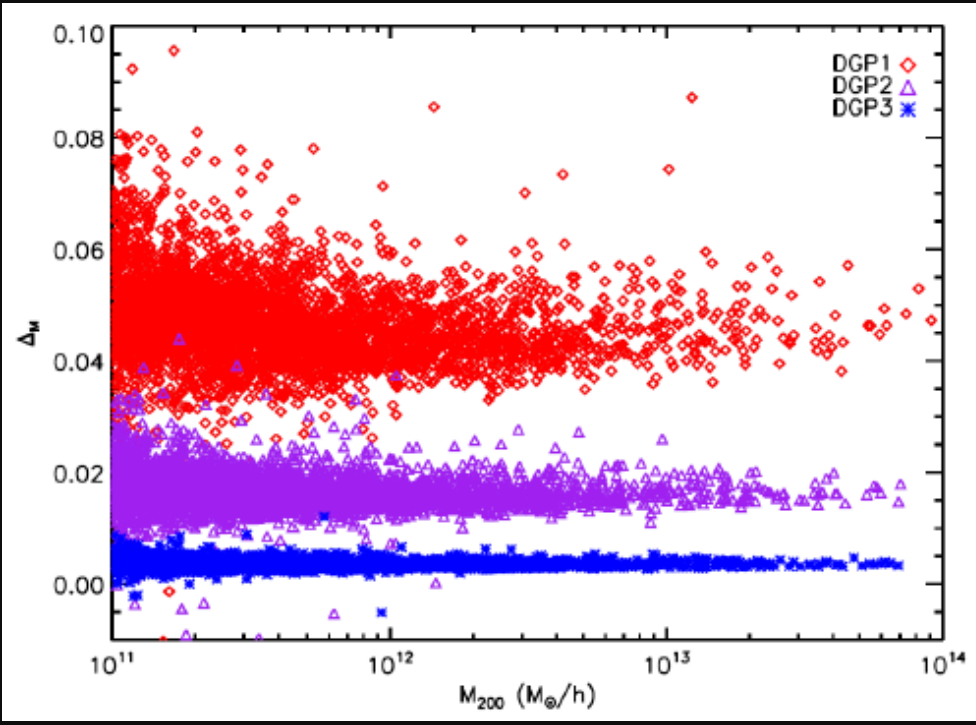
unscreened

screened

unscreened

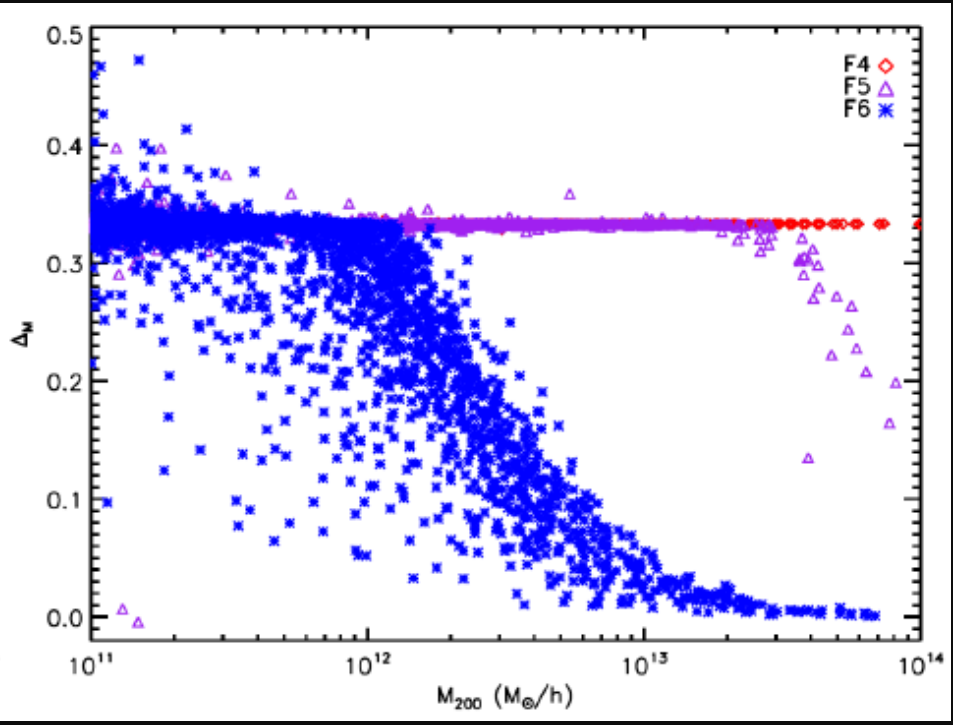
Screening vs. Halo Mass

Vainshtein



Linear (unscreened) $\Delta_M = 0.2$ (red), 0.11 (purple), 0.03 (blue)

Chameleon

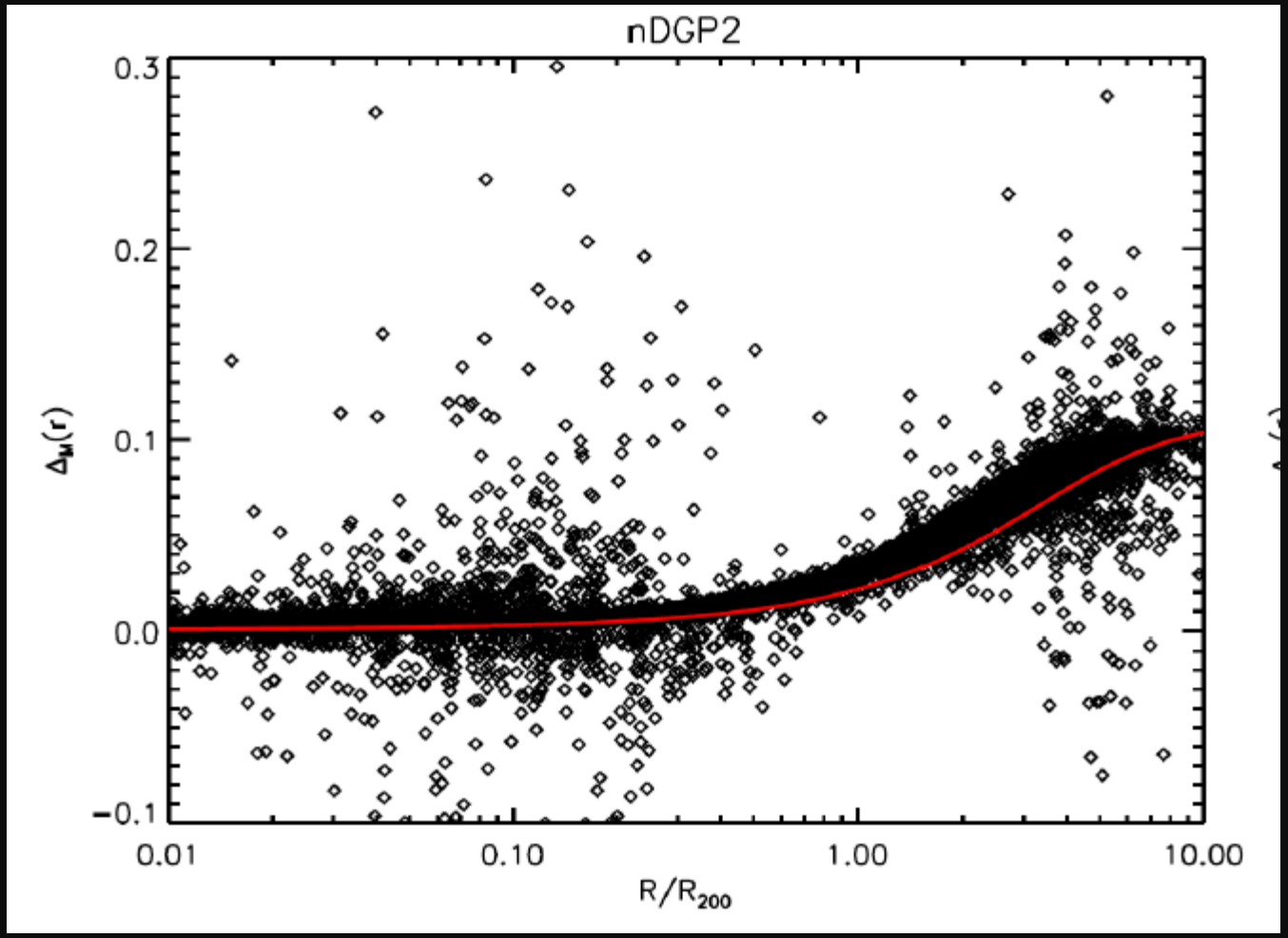


Linear (unscreened) $\Delta_M = 0.33$

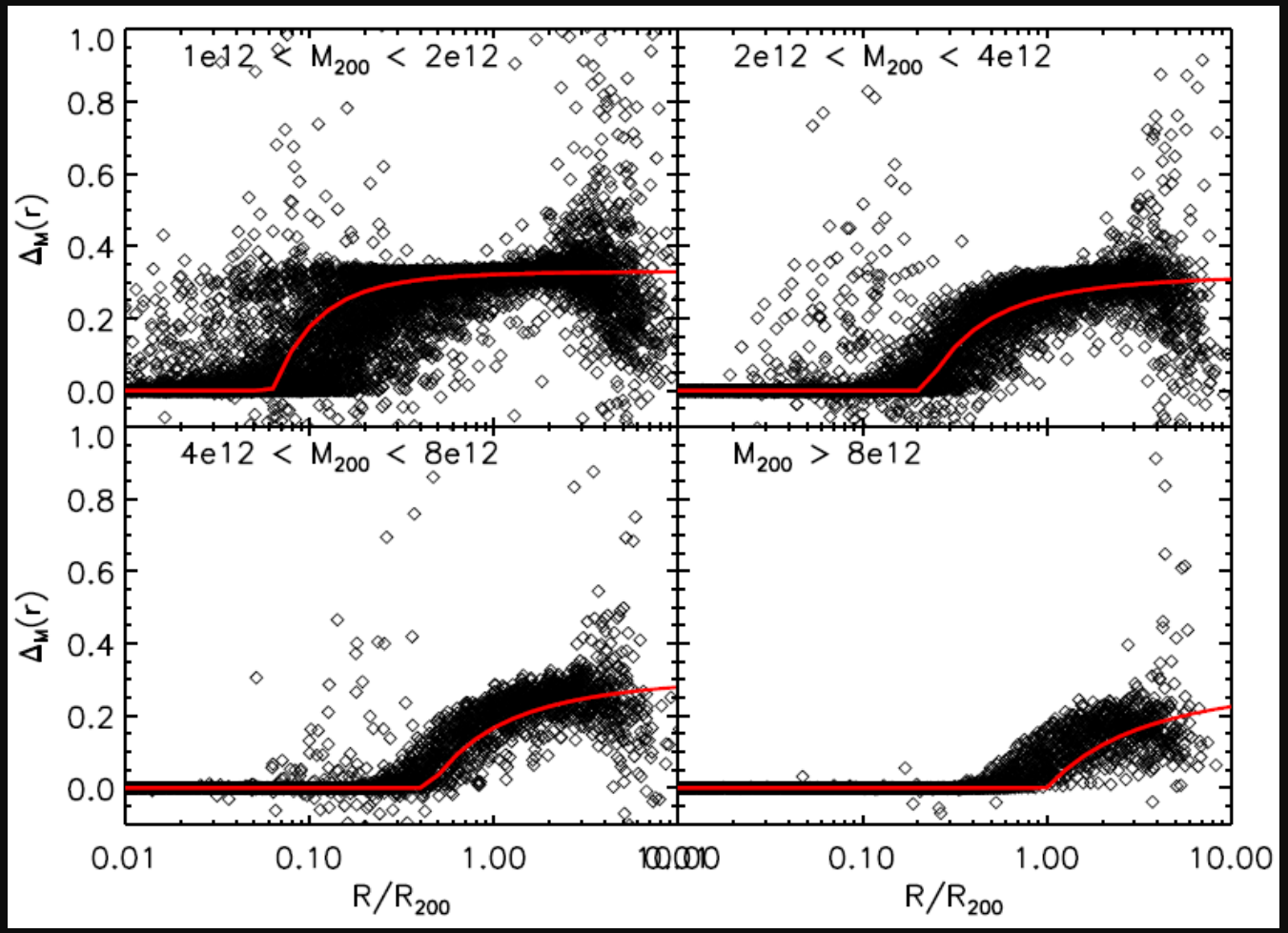
(see also Schmidt 2010, 1003.0409)

Vainshtein Screening Profile

Fifth Force / Gravitational Force



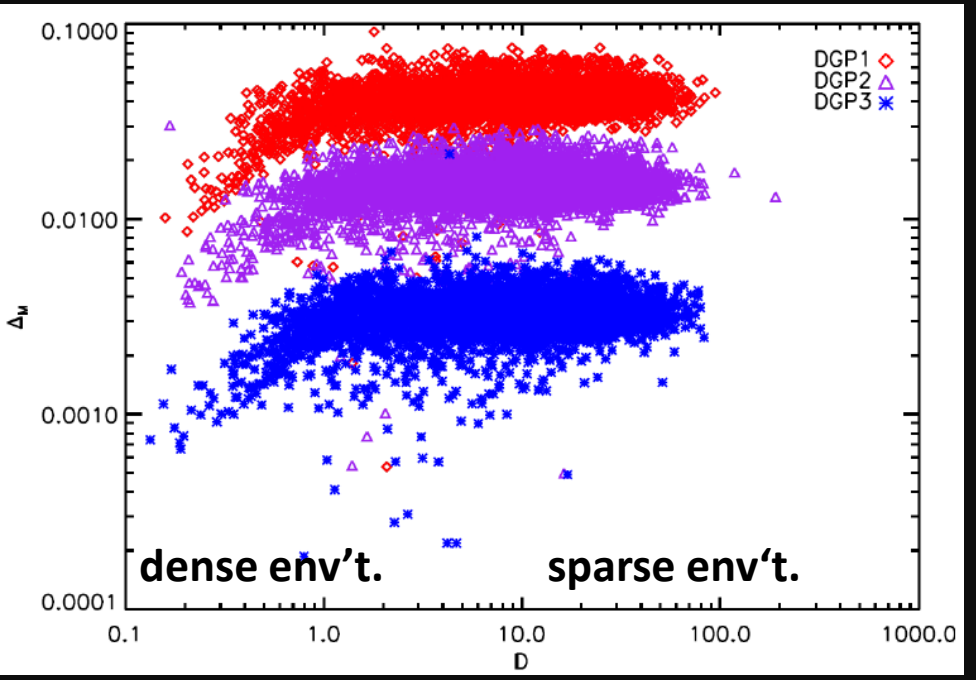
Chameleon Screening Profiles



Screening vs. Environmental Density

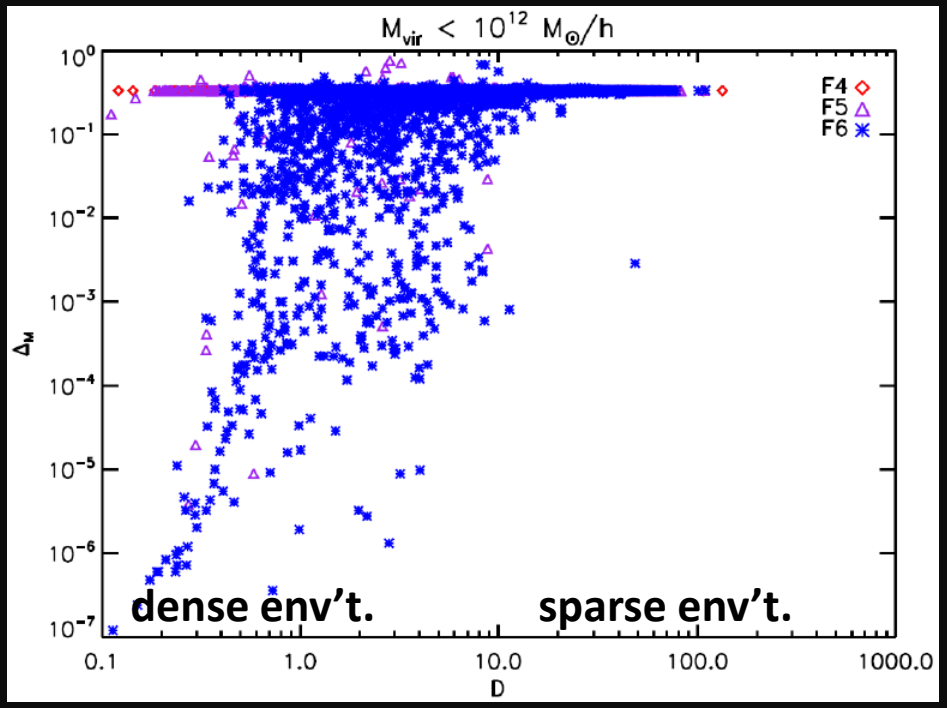
$$D = d/r_{nbr}$$

Vainshtein



Linear (unscreened) $\Delta_M = 0.2$ (red), 0.11 (purple), 0.03 (blue)

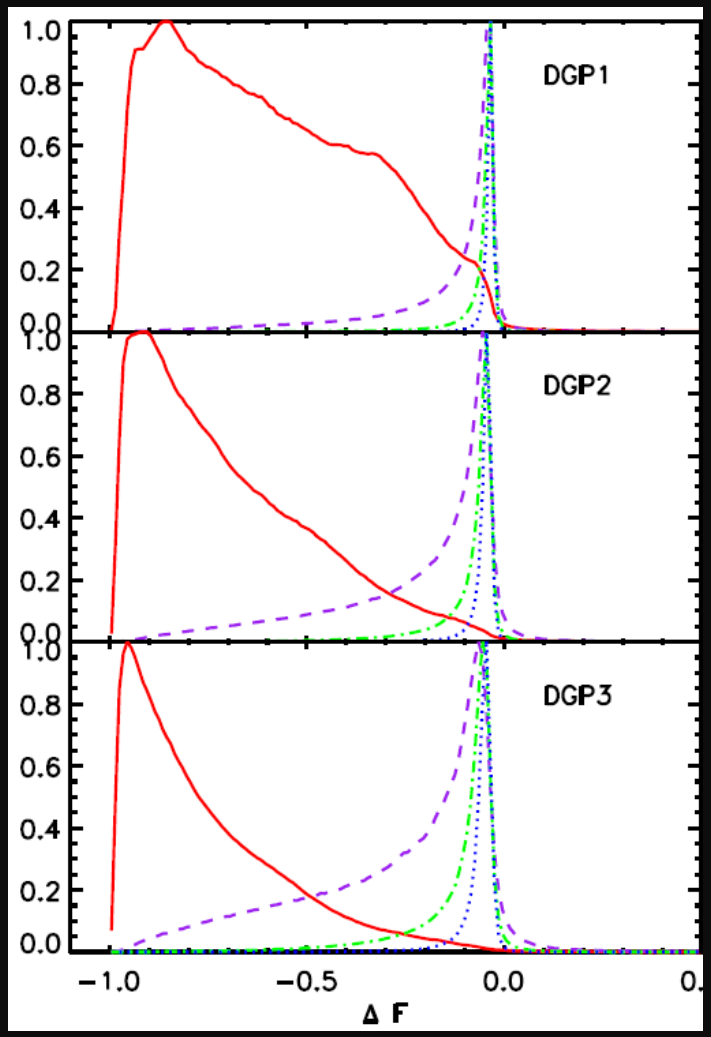
Chameleon

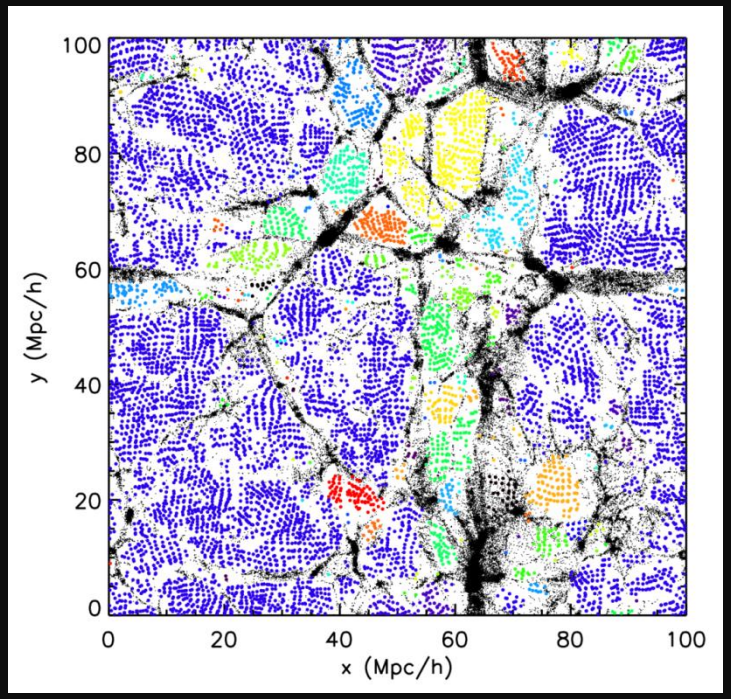


Linear (unscreened) $\Delta_M = 0.33$

(see also Zhao et al. 2011, 1105.0922)

What about voids?





But single-stream regions not surrounded on all sides by walls & filaments, thus *percolate*
(Falck & Neyrinck 2015, 1410.4751)

In progress: watershed voids in Vainshtein

Summary

- ORIGAMI identifies cosmic web by finding folds in phase space
  - (Falck, Neyrinck, & Szalay 2012, 1201.2353)
- The *Vainshtein mechanism* depends on cosmic web morphology of dark matter particles, not mass or environment
  - (Falck, Koyama, Zhao, & Li 2014, 1404.2206)
- The *chameleon mechanism* depends on mass and environment, not cosmic web
  - (Falck, Koyama, & Zhao 2015, 1503.06673)
- Single-stream regions (voids) *percolate*, not surrounded by walls
  - (Falck & Neyrinck 2015, 1410.4751)

The Indra Simulations (ask me later!)

- Suite of dark matter *N*-body simulations
  - 512 different random instances, WMAP7 cosmology
  - Each 1 Gpc/h-sided box, 1024^3 particles, 64 snapshots
- About 1 PB of data!
  - All particle positions and velocities, halo catalogs, and Fourier modes
  - Data accessible through python interface, will allow parallel access and spatial searches
  - Available to the public. Stay tuned!