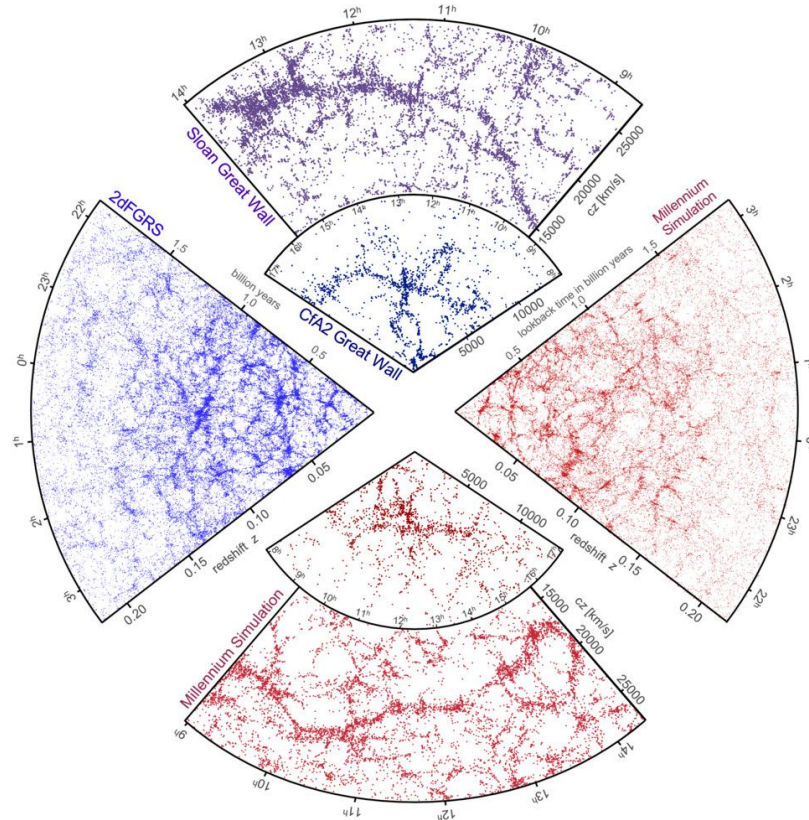# Dark matter simulations of structure formation in the Universe

Jaime E. Forero-Romero (Uniandes)
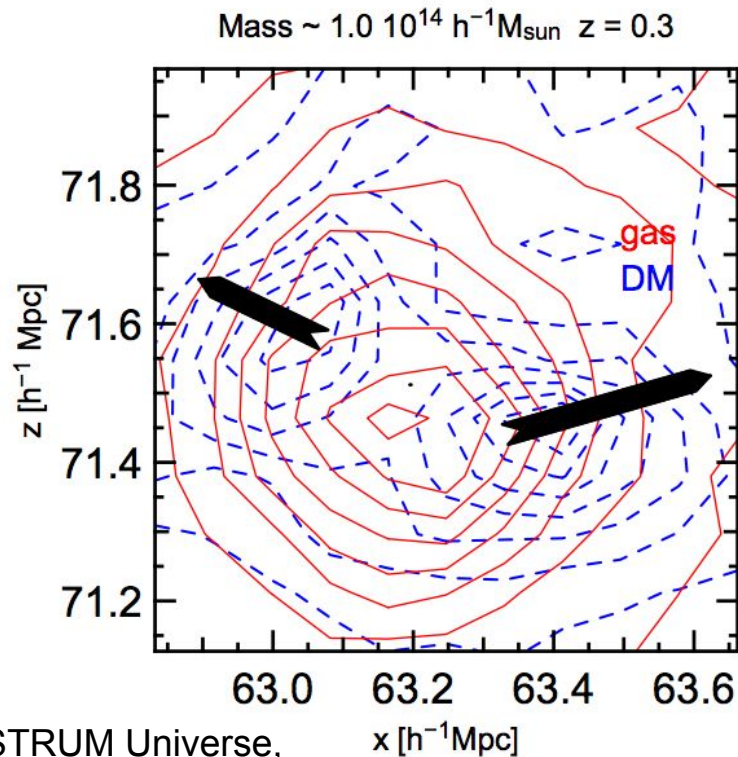MOCa at Uniandes
June 28 2017
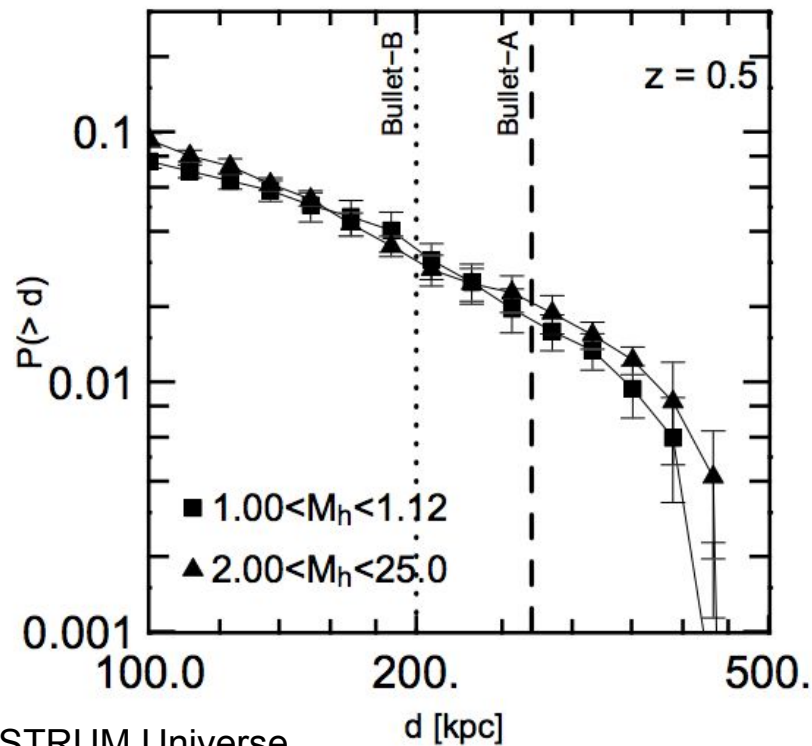
Dark Matter N-body simulations is a mature field

Volker Springel

Bullet Clusters can be simulated in great detail

Mass ~ 1.0 10^{14} h^{-1}M$_{sun}$ z = 0.3

Bullet Clusters in the MARENOSTRUM Universe,
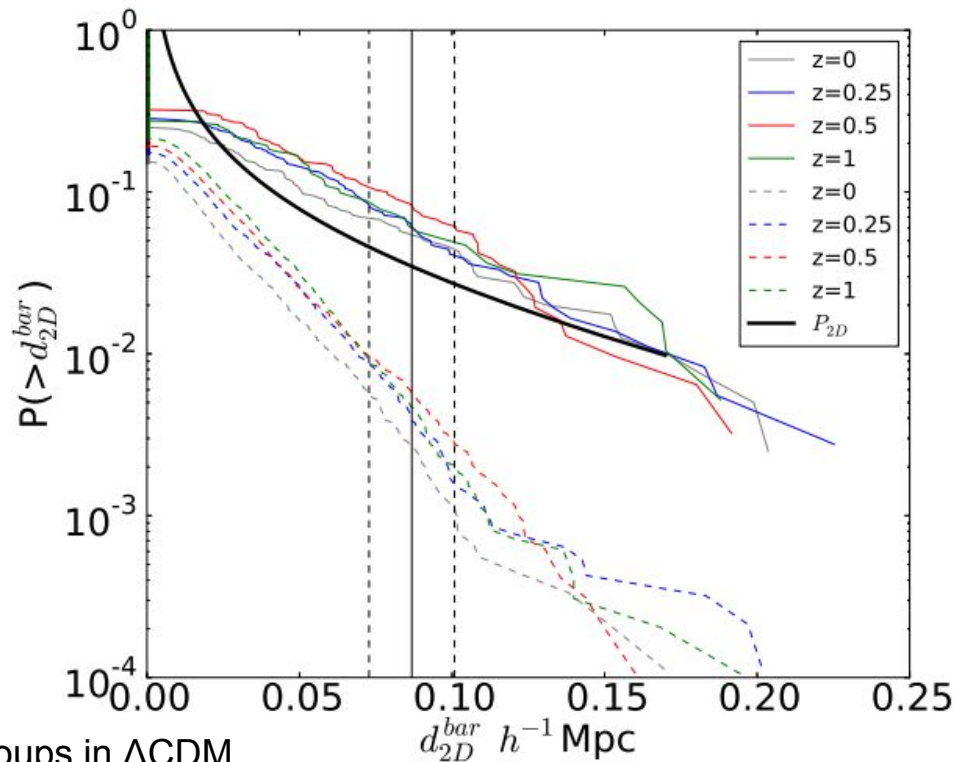JEFR; S. Gottlöber; G. Yepes, ApJ, 2010

Bullet Clusters are rare but expected in LCDM

Bullet Clusters in the MARENOSTRUM Universe,
JEFR; S. Gottlöber; G. Yepes, ApJ, 2010

Bullet groups are another frontier for colliders

The Abundance of Bullet Groups in ΛCDM
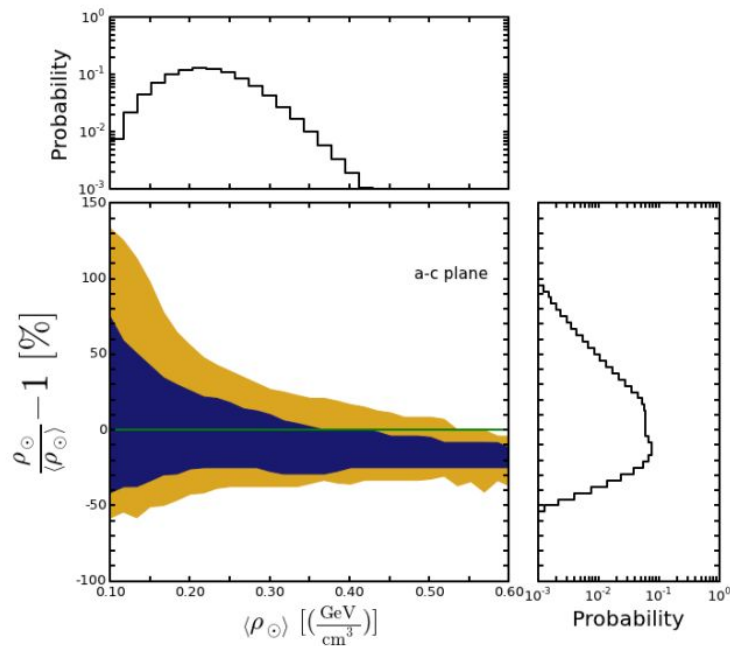J.G. Fernández-Trincado; JEFR; G. Foex; T. Verdugo; V. Motta, ApJLetters, 2013

Astrophysical information is entangled with particle physics

$$R \approx \frac{\rho_\odot \, \sigma \, \langle v \rangle}{m_\chi \, m_A}$$

$$\frac{d\Phi_{\mathrm{ann}}}{dE}(E, \Delta\Omega) = \frac{\langle \sigma v \rangle}{2 \, m_\chi^2} \sum_i \mathrm{BR}_i \, \frac{dN_{\mathrm{ann}}^i}{dE} \, \bar{J}_{\mathrm{ann}}(\Omega) \, \frac{\Delta\Omega}{4\pi}$$

$$\frac{d\Phi_{\mathrm{dec}}}{dE}(E, \Delta\Omega) = \frac{1}{m_\chi \, \tau_\chi} \sum_i \mathrm{BR}_i \, \frac{dN_{\mathrm{dec}}^i}{dE} \, \bar{J}_{\mathrm{dec}}(\Omega) \, \frac{\Delta\Omega}{4\pi}$$

Spherical symmetry assumptions in the Milky Way halo structure can introduce large errors
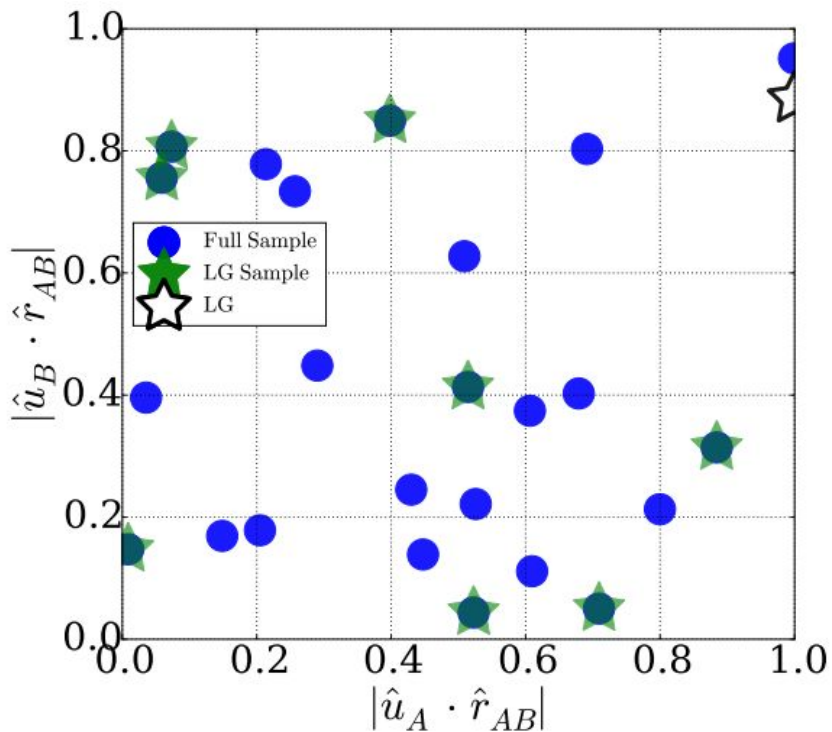

Systematic uncertainties from halo asphericity in dark matter searches,
N. Bernal; JEFR.; R. Garani; S. Palomares-Ruiz, JCAP, 2014

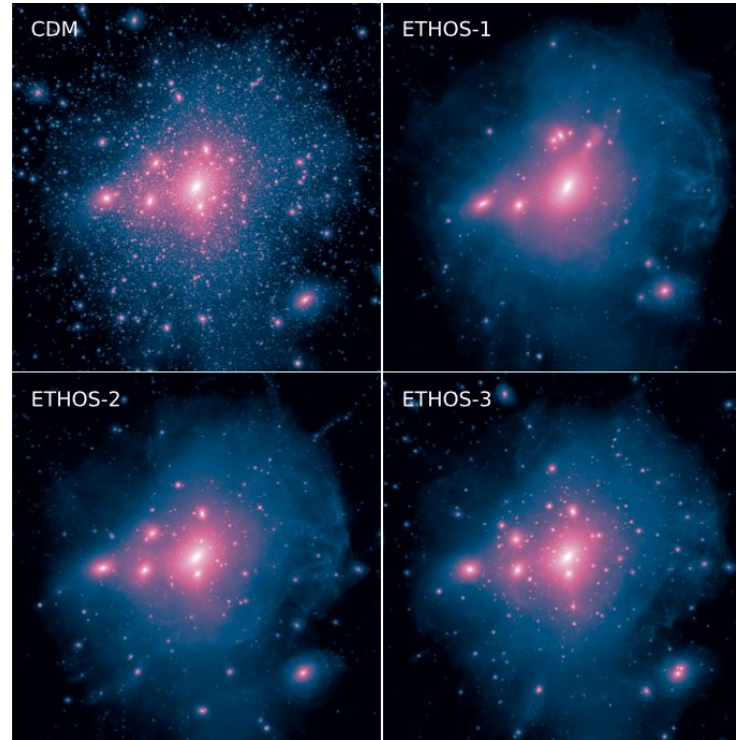# MW dark matter halo structure is grainy

r = 8 kpc
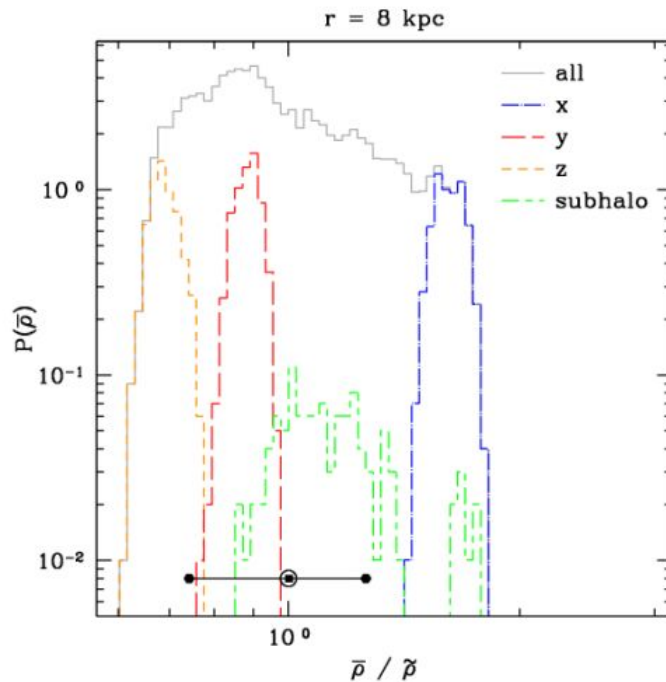
The graininess of dark matter haloes
Zemp et al., MNRAS 2009

Local Group dwarfs show atypical alignments

JEFR et al., in prep, 2017

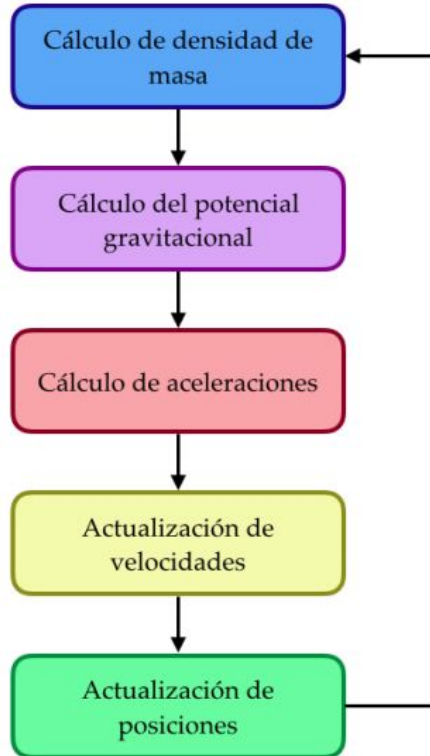# Dwarfs signal the end of non-collisional dark matter

ETHOS – An Effective Theory of Structure Formation: Dark matter physics as a possible explanation of the small-scale CDM problems,
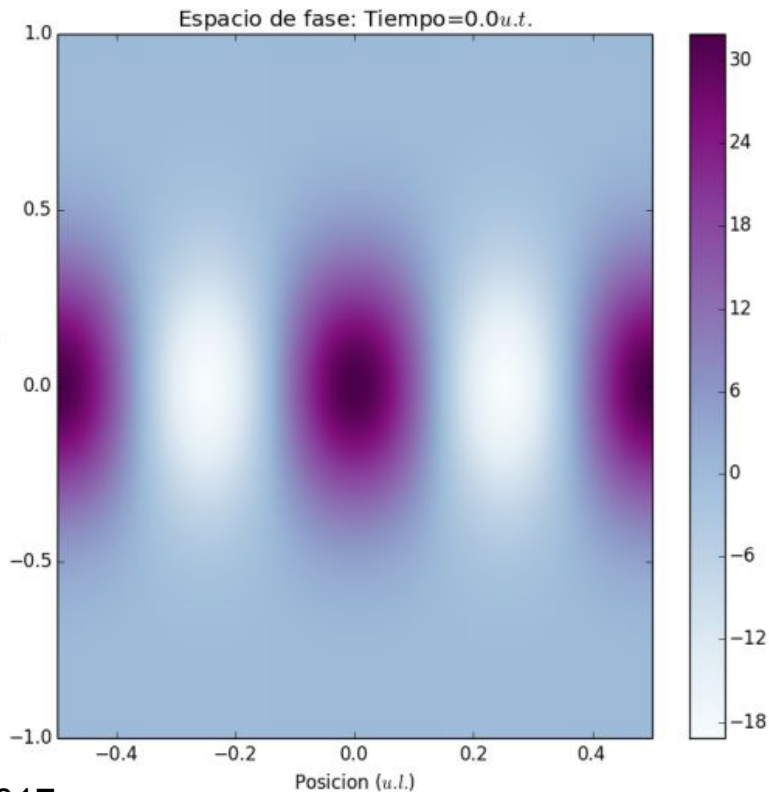Vogelsberger et al., MNRAS 2016

Dark matter is thought as a non-collisional fluid

$$\frac{\partial f}{\partial t} + \frac{\vec{p}}{m} \cdot \vec{\nabla}_{\vec{r}} f + \vec{F} \cdot \vec{\nabla}_{\vec{p}} f = 0.$$
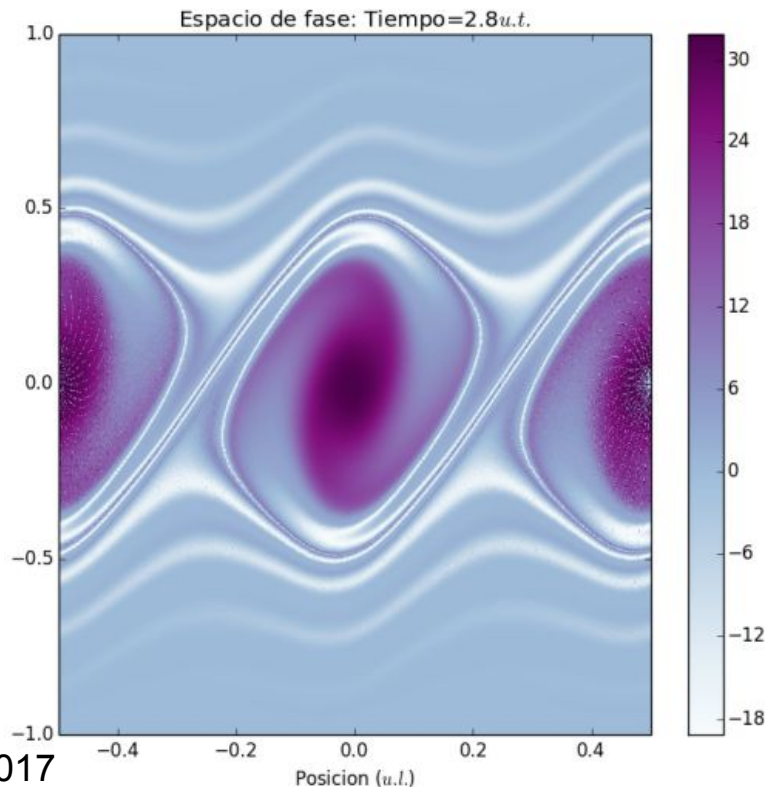
S. Franco-Ulloa et al., in prep, 2017

We need to be able to simulate a weakly interacting dark matter fluid

Cálculo de densidad de masa

Cálculo del potencial gravitacional

Cálculo de aceleraciones

Actualización de velocidades

Actualización de posiciones

S. Franco-Ulloa et al., in prep, 2017

Phase space simulations provide a basic framework for SIDM

S. Franco-Ulloa et al., in prep, 2017

Phase space simulations provide a basic framework for SIDM

Espacio de fase: Tiempo=2.8$u.t.$

S. Franco-Ulloa et al., in prep, 2017

We can simulate a 1D Bullet Cluster in phase space

S. Franco-Ulloa et al., in prep, 2017
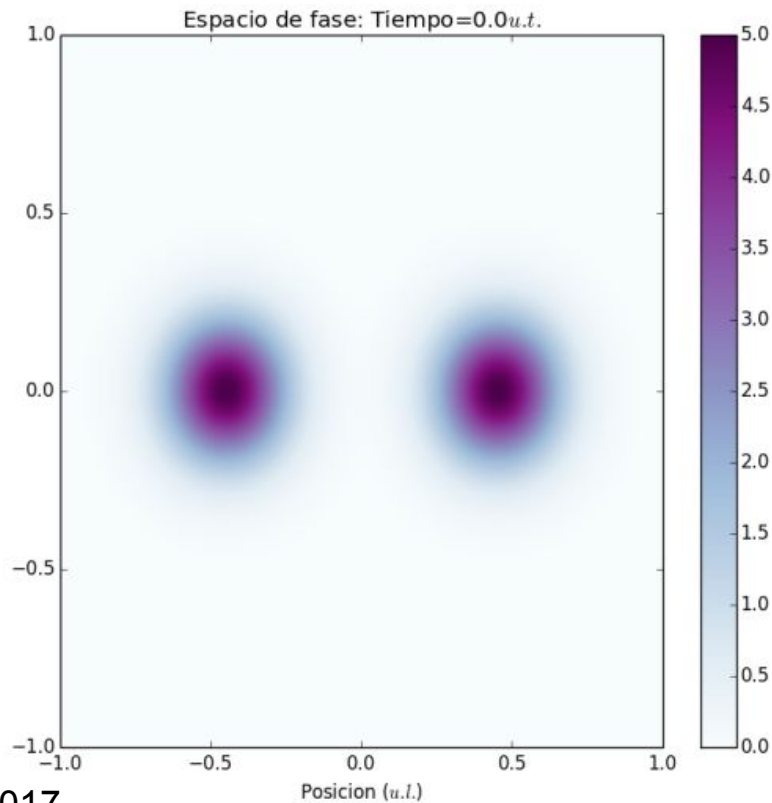
There is rich phase space structure in the Bullet Cluster

S. Franco-Ulloa et al., in prep, 2017
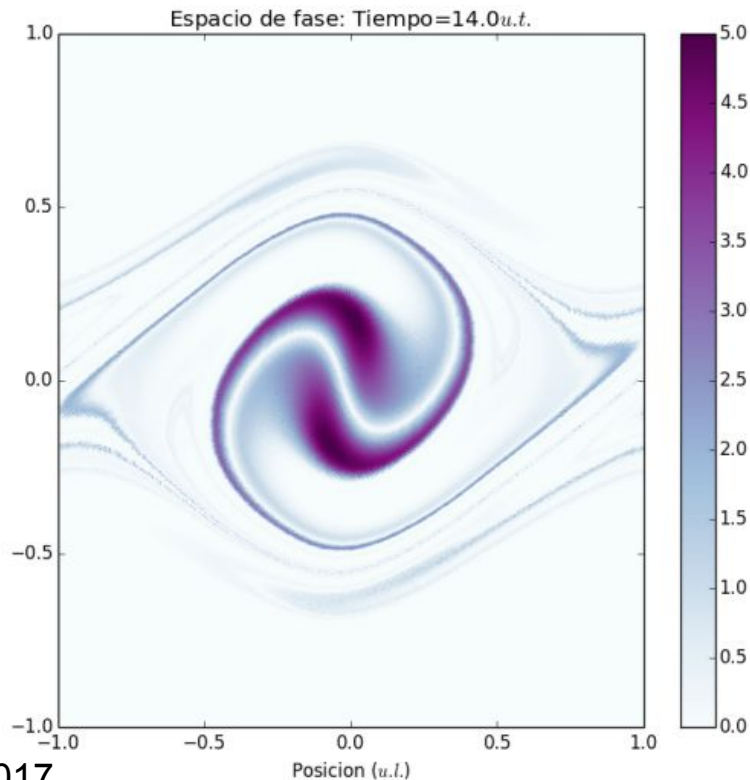
Conclusions

- Clusters, groups and galaxies hold clues about the nature of the dark matter particle physics.
- The times of non-collisional dark matter seem to be over.
- Direct phase-space simulations are the best promise to include the collisional term in the Boltzmann equation.