

# Dynamics of cold dark matter

---

Michael Joyce

*Formation : C. Balland*

*Partenariats & Valorisation : L. Lavergne*

**Directeur : G. Bernardi**

**Directeur Adjoint : J. Bolmont**

**Assistante de Direction: M. Carlosse**

*Sécurité : AP : J-M. Parraud, B. Canton*

*PCR : L. Lavergne*

### **Administration**

E. Méphane

*Ressources Humaines*

M. Carlosse

*Gestion Financière*

V. Criart

*Communication Documentation*

I. Cossin

### **Equipes Scientifiques / Projets / Activités**

#### **Origine des Masses & Interactions Fondamentales (OMIF)**

**ATLAS :** G. Calderini

- **ATLAS-Physique :** G. Marchiori

**ILD/CALICE :** D. Lacour

#### **Asymétrie Matière-Antimatière (ASMA)**

**LHCb :** E. Ben-Haim

**T2K,NA61,WA105 :** J. Dumarchez

#### **Rayonnement Cosmique de Haute Energie (RCHE)**

**Auger :** A. Letessier-Selvon

**HESS :** P. Vincent

**CTA :** J-P. Tavernet

#### **Matière Noire et Energie Noire (MNEN)**

**LSST :** P. Antilogus

- **SSP / WtG :** N. Regnault

**DESI/eBOSS :** J. Guy

#### **Activités Scientifiques EN COURS (FINISSANTES)**

**OMIF:** (BABAR), (D0)    **ASMA:** COMET, PMPP

**MNEN:** DAMIC, DARKSIDE, DSA, EUCLID,(SNF),(SNLS)

**Activités Sc. en devenir-coordonnateur:** S. De Cecco

### **Services Techniques**

L. Lavergne

*Mécanique*

D. Vincent

*Electronique et Instrumentation*

O. Le Dortz

*CAO/Câblage*

E. Pierre

*Microélectronique*

H. Lebbolo

*Services Généraux*

B. Canton

*Informatique*

F. Legrand

Directrice Technique  
 Laurence Lavergne

Directeur adjoint  
 Julien Bolmont

### Administration et Services Techniques

ADMINISTRATION	
Evelyne Méphane	
<b>Gestion financière</b>	Véronique Criart
Hager Baalouchi	Bernard Caraco
Souad Rey	
<b>Gestion RH</b>	Magali Carosse
Hager Baalouchi	
<b>Communication</b>	Isabelle Cossin
Laurence Marquet	Vera De Sa-Varanda

ELECTRONIQUE  
 Olivier Le Dortz

Philippe Bailly  
 Pascal Corona  
 Jacques David  
 Claire Juramy  
 Sonia Karkar  
 David Martin  
 Patrick Nayman  
 Jean-Marc Parraud  
 François Tousnencel  
 Alain Vallereau  
 Jean-Luc Meunier  
 Alassane Samb

**Micronélectronique**  
 Hervé Lebbolo  
 Francesco Crescioli

**CAO&Câblage**  
 Eric Pierre  
 Marc Dhellot  
 Julien Coridian

**INFORMATIQUE**  
François Legrand/  
Patricia Warin-Charpentier

Thomas Audo  
 Olivier Dadoun  
 Trung Ho  
 Victor Mendoza  
 Eduardo Sepulveda  
 Diego Terront  
 Vincent Voisin  
 Louis Gromb

### Administration et Services Techniques

MECANIQUE	
<u>Daniel Vincent</u>	
Bernard Canton	
William Ceria	
Guillaume Daubard	
Filipe De Matos	
Patrick Ghislain	
Didier Laporte	
Yann Orain	
Philippe Repain	

**SERVICES GENERAUX**  
Bernard Canton

Michael Roynel

**Chef de service / adjoint**  
**Chef de pôle**

### Equipes Scientifiques/Projets

Origine des Masses et Interactions Fondamentale  
 Asymétrie Matière Antimatière

**ATLAS**  
Giovanni Calderini

Tristan Beau  
 Gregorio Bernardi  
 Marco Bomben  
**Frédéric Derue**  
 Sandro De Cecco  
 Mieczyslaw Krasny  
 Didier Lacour  
 Bertrand Laforge  
**Sandrine Laplace**  
 Bogdan Malaescu  
**Giovanni Marchiori**  
 Irena Nikolic-Audit  
 José Ocariz  
 Mélissa Ridel  
 Lydia Roos  
 Sophie Trincaz-Duvoid  
Paolo Francavilla  
Ali Mirzaei  
Dimitris Varouchas  
 Audrey Ducourthial  
 Changqiao Li  
 Alvaro Lopez Solis  
 Pierre Luzi  
 Stefano Manzoni  
 Carlo Pandini  
 Dilia Portillo  
 Yee Yap

(BABAR)

**Jacques Chauveau**  
 Eli Ben-Haim

T2K, NA61, WA105  
Jacques Dumarchez

Bernard Andrieu  
 Claudio Giganti  
 Jean-Michel Levy

**Boris Popov**  
 Arnaud Robert

Pierre Bartet-Friburg  
 Simon Bienstock

Matej Pavin

COMET / PMPP

**Frédéric Kapusta**  
 Maurice Benayoun

Wilfrid Da Silva  
 Jean-Pierre Dedonder

Benoit Loiseau

(D0)  
**Gregorio Bernardi**

**ILD/CALICE**  
Didier Lacour

Jean-Eudes Augustin

**LHCb**  
Eli Ben-Haim

Pierre Billot  
 Matthew Charles

Luigi Del Buono  
 Vladimir Gligorov

**Francesco Polci**

Louis Henry  
 Andrea Mogini

(BABAR)

**Jacques Chauveau**

Eli Ben-Haim

T2K, NA61, WA105  
Jacques Dumarchez

Bernard Andrieu  
 Claudio Giganti

Jean-Michel Levy

**Boris Popov**  
 Arnaud Robert

Pierre Bartet-Friburg  
 Simon Bienstock

Matej Pavin

COMET / PMPP

**Frédéric Kapusta**  
 Maurice Benayoun

Wilfrid Da Silva  
 Jean-Pierre Dedonder

Benoit Loiseau

(D0)  
**Gregorio Bernardi**

**ILD/CALICE**  
Didier Lacour

Jean-Eudes Augustin

**AUGER**

Antoine Letessier-Selvon

Julien Aublin

**Piera Ghia**

Imen Al Samarai

Mariangela Settimi

**HESS**

Pascal Vincent

Julien Bolmont

Agnieska Jacholkowska

Jean-Philippe Lenain

Jean-Paul Tavernet

**Matteo Cerruti**

Daniel Kerszberg

Cédric Perennes

**CTA**

Jean-Paul Tavernet

Julien Bolmont

Agnieska Jacholkowska

Jean-Philippe Lenain

Olivier Martineau

Pascal Vincent

**Activités en devenir**

SHiP, DUNE, Xenon...

S. de Cecco (coordinateur)

Jacques Chauveau

Luca Scotti Lavina

**Chercheurs Associés**

Gérard Bonneau

Hubert Krivine

Yvette Pons

Philippe Schwemling

François Vannucci

Rayonnement Cosmique de Hautes Energies,  
 Matière et Energie Noire

LSST/ SSP / WIG (SNF,SNLS)

Pierre Antilogus

Pierre Astier

Etienne Barrelet

Sylvain Baumont

Marc Betoule

Sébastien Bongard

Delphine Hardin

Laurent Le Guillou

Reynald Pain

Nicolas Regnault

Kyan Schahmaneche

Josquin Errard

Matthieu Roman

Augustin Guyonet

Rémy Le Breton

DSA

Michael Joyce

EUCLID

Pierre Astier

DESI/eBOSS

Julien Guy

Christophe Balland

Laurent Le Guillou

Hector Gil Marin

DAMIC

Antoine Letessier-Selvon

Mariangela Settimi

DARKSIDE

Sandro de Cecco

Claudio Giganti



PARIS

[Send Query](#)

[Return Query Form](#)

[Store Default Form](#)

[Clear](#)

Databases to query:  [Astronomy](#)  [Physics](#)  [arXiv e-prints](#)

**Authors:** (Last, First M, one per line)  [SIMBAD](#)  [NED](#)  [ADS Objects](#)

[Exact name matching](#)

[Object name/position search](#)

[Require author for selection](#)

[Require object for selection](#)

( OR  AND  [simple logic](#))

(Combine with:  OR  AND)

joyce, michael

---

## [SAO/NASA Astrophysics Data System \(ADS\)](#)

### **Query Results from the ADS Database**

[Go to bottom of page](#)

Retrieved **200** abstracts, starting with number **1**. Total number selected: **206**.

[Sort options](#)



- 4  [2015ApJ..814..142J](#) 1.000 12/2015 [A](#) [E](#) [F](#) [X](#) [D](#) [R](#) [S](#) [U](#)  
Joyce, M.; Chaboyer, B.  
Investigating the Consistency of Stellar Evolution Models with Globular Cluster Observations via the Red Giant Branch Bump
- 5  [2015arXiv150903292B](#) 1.000 09/2015 [A](#) [X](#) [R](#) [C](#) [U](#)  
Bilen Can, Mahir; Joyce, Michael;  
Wyser, Benjamin  
Wonderful Symmetric Varieties and Schubert Polynomials
- 129  [2000JHEP..07..018C](#) 1.000 07/2000 [A](#) [E](#) [X](#)  
Cline, James M.; Joyce, Michael;  
Kainulainen, Kimmo  
Supersymmetric electroweak baryogenesis
- 145  [1997PhRvL..79.1193J](#) 1.000 08/1997 [A](#) [E](#) [X](#) [R](#) [C](#)  
Joyce, M.; Shaposhnikov, M.  
Primordial Magnetic Fields, Right Electrons, and the Abelian Anomaly
- 183  [1994NuPhB.416..389J](#) 1.000 03/1994 [A](#) [E](#) [X](#) [R](#) [C](#)  
Joyce, Michael; Turok, Neil  
Family symmetry, fermion mass matrices and cosmic texture

# My hidden past...

---

129	<input type="checkbox"/>	<a href="#">2000JHEP..07..018C</a>	1.000	07/2000	<a href="#">A</a>	<a href="#">E</a>	<a href="#">X</a>	
		Cline, James M.; Joyce, Michael; Kainulainen, Kimmo						Supersymmetric electroweak baryogenesis
145	<input type="checkbox"/>	<a href="#">1997PhRvL..79.1193J</a>	1.000	08/1997	<a href="#">A</a>	<a href="#">E</a>	<a href="#">X</a>	<a href="#">R</a> <a href="#">C</a>
		Joyce, M.; Shaposhnikov, M.						Primordial Magnetic Fields, Right Electrons, and the Abelian Anomaly
183	<input type="checkbox"/>	<a href="#">1994NuPhB.416..389J</a>	1.000	03/1994	<a href="#">A</a>	<a href="#">E</a>	<a href="#">X</a>	<a href="#">R</a> <a href="#">C</a>
		Joyce, Michael; Turok, Neil						Family symmetry, fermion mass matrices and cosmic texture

\*

---

Current physical theory of the fundamental interactions in Nature:

The standard model + general relativity

(+ dark matter + dark energy)

# Dynamics of cold dark matter

---

Michael Joyce

Groupe: Matière et Energie Noire

# Plan

---

- Le groupe et ses collaborations
- Cadre général de recherche
- Quelques résultats récents
- Perspectives (+..)

\*

# Members and collaborations

---

1 permanent (MJ) + doctorants (quatre depuis 2007)

+ **Un post-doc** à mi-temps au LPNHE jusqu'au 3/2017

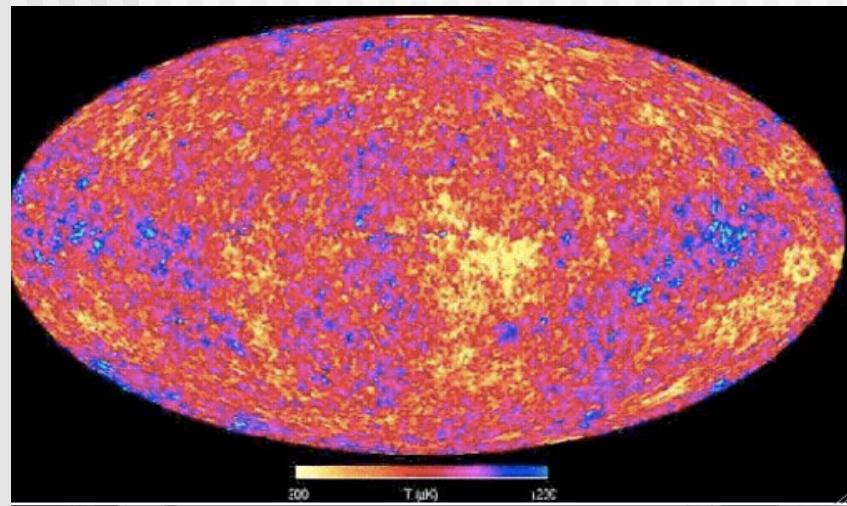
+ External french collaborations: **LPTMC(UPMC), Université de Nice**

+ External non-french collaborations: Université de **Rome « la Sapienza »**, Rajamanghala University, **Thailand**

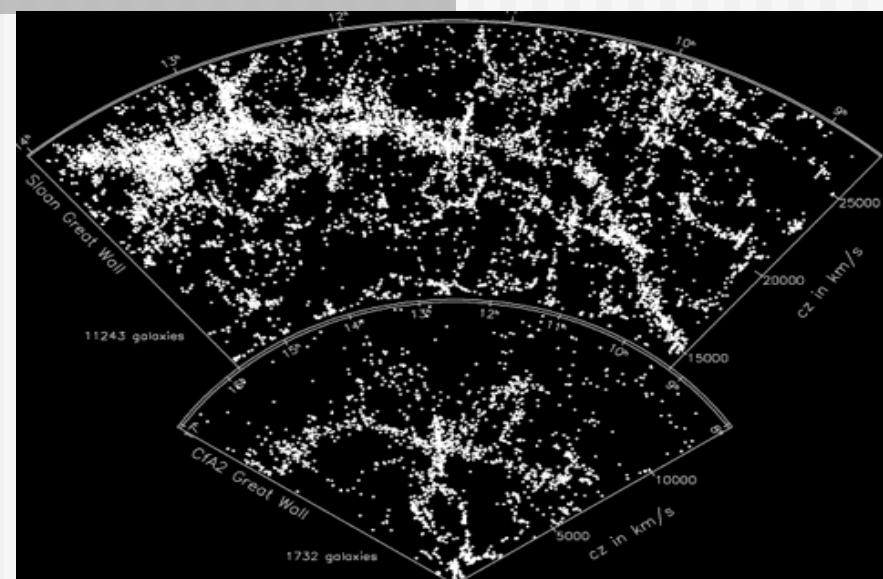
---

Central (current) research theme:  
**dynamics of *non-relativistic* purely gravitating matter**

Principal Motivation:  
The problem of structure formation



??  
→



WMAP : the universe aged  $\sim 10^5$  years...  
Density fluctuations  $\sim 10^{-5}$

SDSS : the universe today ( $10^{10}$  years)  
Fluctuations  $\gg 1$

**How do these structures come from these initial conditions ?**

Theory furnishes predictions also for other observations  
(weak lensing, dark matter searches...)

## Motivation

# Cosmological structure formation

---

**Linear Regime:** simple and resolved analytically

**Non-linear regime:** intractable, essentially numerical resolution

Simulations lead to purely phenomenological descriptions  
(e.g halo models)

**Poor understanding of physics, poor control of resolution**

# Goals of research

---

## Broad goal

- **To improve understanding of non-linear regime of structure formation**

More specific goals:

- Accurate description of DM clustering e.g « halos models » or beyond..?  
(→ Control precision/resolution of numerical results)
- Address more fundamental physics issues about self-gravitating systems  
(→ Stat Mech of Long Range Interactions)

# Thèses récentes

---

• **David BENHAIEM**

Self-similarity and stable clustering in **scale-free cosmological models** in  
one and three dimensions **soutenue décembre 2013**

• **Jules MORAND**

Dynamics of **long-range interacting systems** beyond the Vlasov limit  
**soutenue décembre 2014**

# Recent publications (2015-2016)

				A	X	R	U
<input type="checkbox"/>	<a href="#">2016arXiv160904580B</a>	1.000	09/2016	<a href="#">A</a>	<a href="#">X</a>	<a href="#">R</a>	<a href="#">U</a>
	Benhaim, David; Joyce, Michael; Sylos Labini, Francesco				Stable clustering and the resolution of dissipationless cosmological N-body simulations		
<input type="checkbox"/>	<a href="#">2016PhRvE..93e2129J</a>	1.000	05/2016	<a href="#">A</a>	<a href="#">E</a>	<a href="#">X</a>	<a href="#">R</a> <a href="#">C</a> <a href="#">U</a>
	Joyce, Michael; Morand, Jules; Viot, Pascal				Attractor nonequilibrium stationary states in perturbed long-range interacting systems		
<input type="checkbox"/>	<a href="#">2016A&amp;A...585A.139B</a>	1.000	01/2016	<a href="#">A</a>	<a href="#">E</a> <a href="#">F</a>	<a href="#">R</a>	<a href="#">U</a>
	Benhaim, D.; Joyce, M.; Sylos Labini, F.; Worrakitpoonpon, T.				Generation of angular momentum in cold gravitational collapse		
<input type="checkbox"/>	<a href="#">2015MNRAS.449.4458S</a>	1.000	06/2015	<a href="#">A</a>	<a href="#">E</a> <a href="#">F</a>	<a href="#">X</a>	<a href="#">R</a> <a href="#">C</a> <a href="#">U</a>
	Sylos Labini, Francesco; Benhaim, David; Joyce, Michael				On the generation of triaxiality in the collapse of cold spherical self-gravitating systems		

**D. Benhaim, M. Joyce, F. Sylos Labini and T. Worrakitpoonpon**  
**Particle number dependence in the non-linear evolution of N-body self-gravitating systems, submitted to Mon. Not. R. Astron. Soc. (2016)**

---

**Some recent results on  
symmetry breaking  
in “cold spherical collapse”**

# « Spherical Collapse » in Newtonian gravity

---

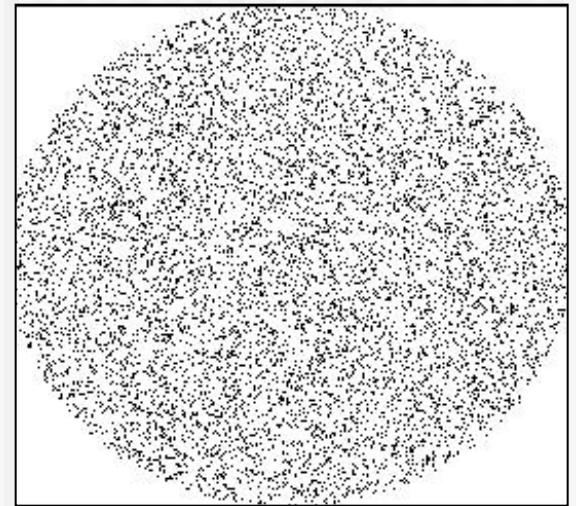
## **SPHERICAL**

N point particles randomly distributed in a sphere

Radial power-law density profile

## **COLD**

Small (=“subvirial”) velocity dispersion



## **THREE PARAMETERS:**

N

b (“virial ratio”)

$\alpha$  (exponent of density profile)

Paradigmatic toy model for non-linear structure formation

---

## **Questions:**

What is evolution?

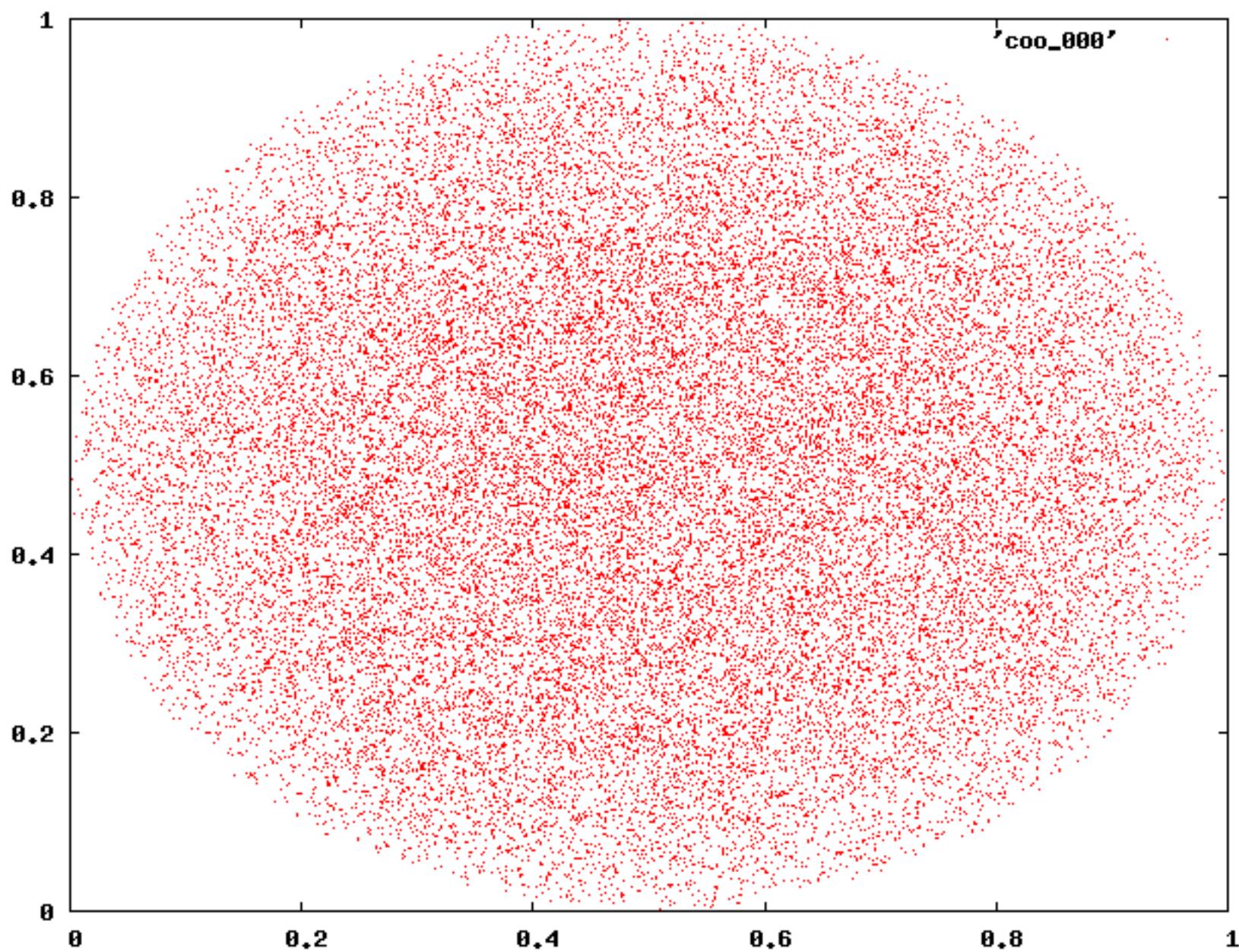
What is “final” state ? ( $\sim$  dark matter halo)

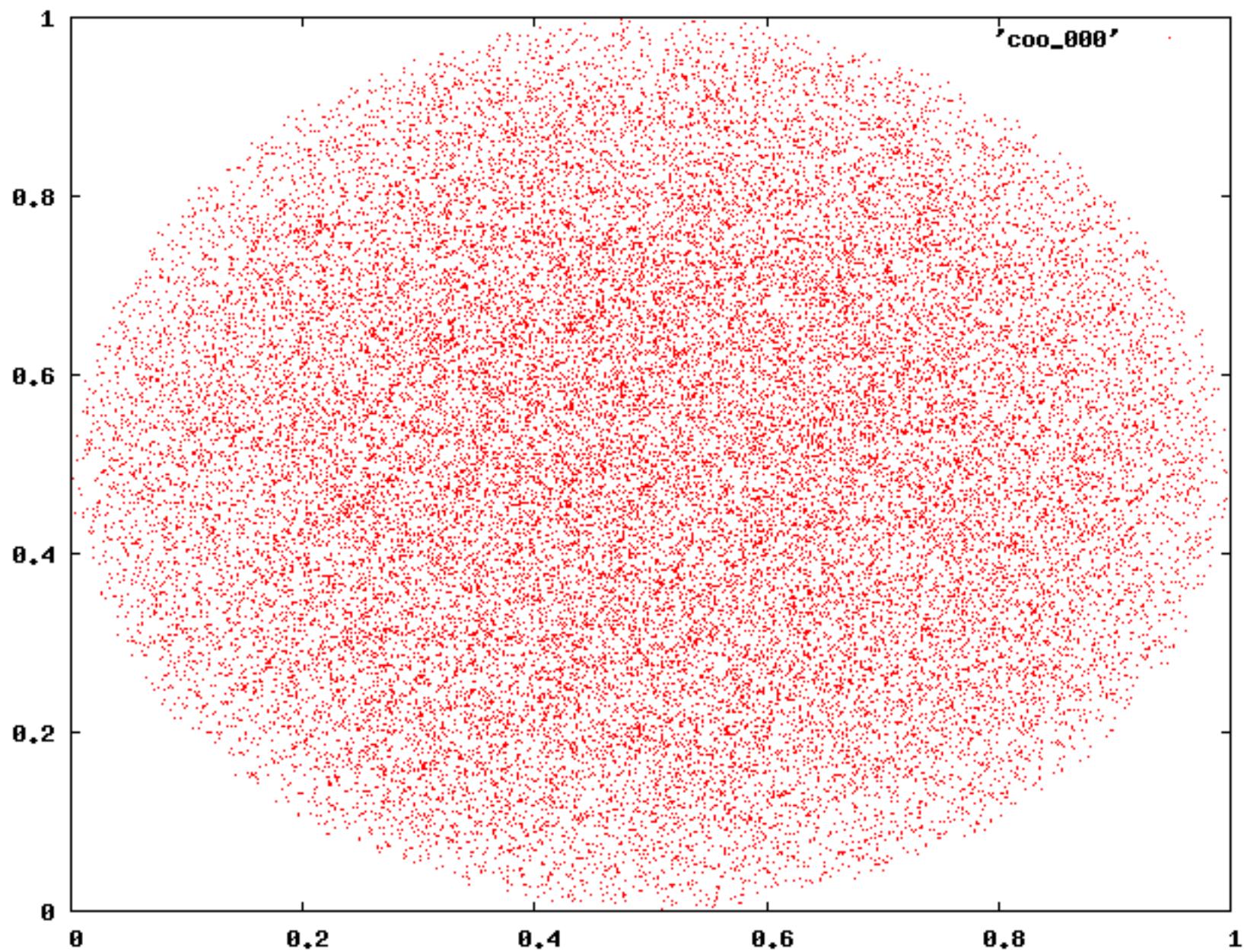
How do these depend on initial conditions..?

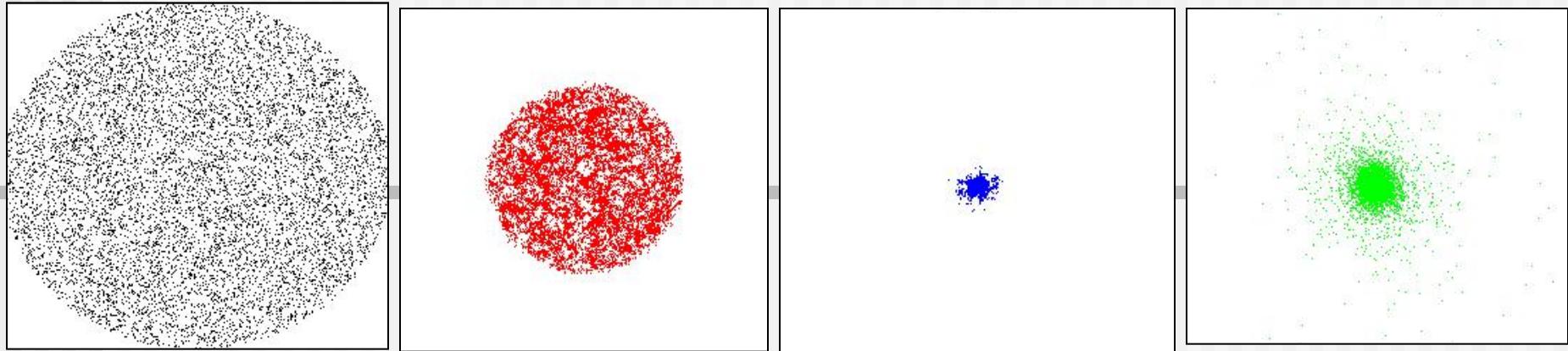
.....

---

**Exactly cold uniform case**





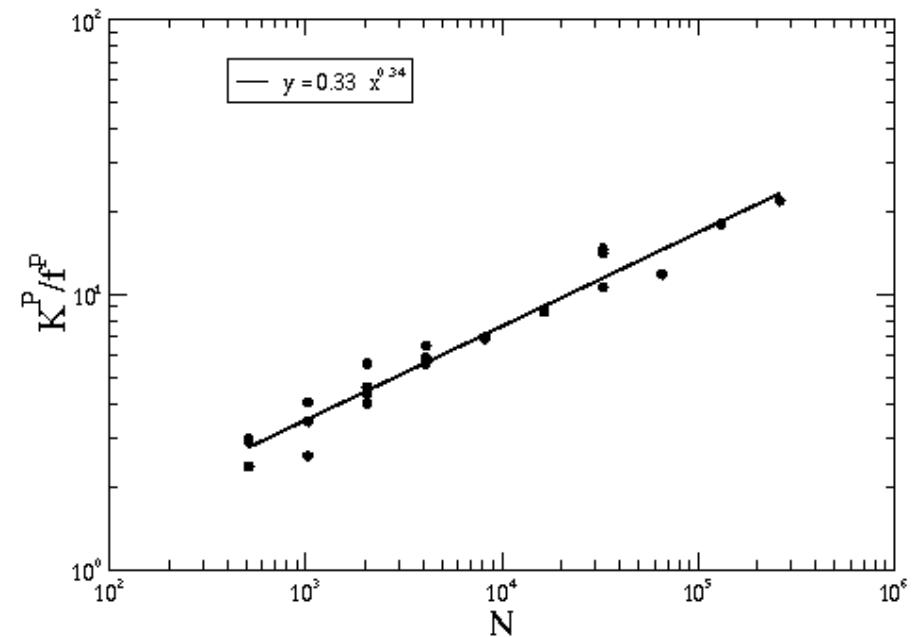
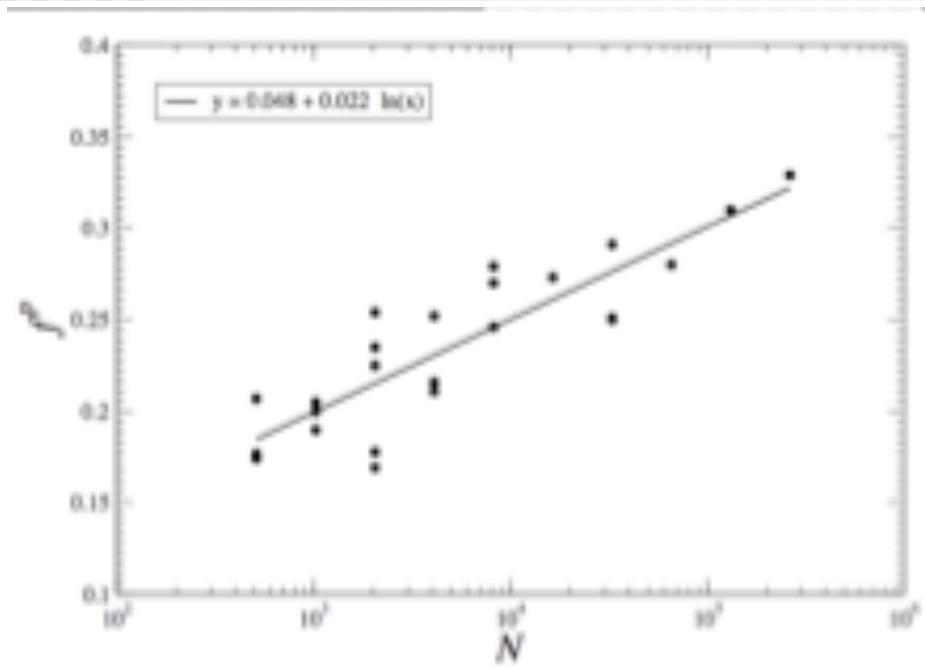


## 1) Structure “virializes” rapidly after collapse

[NB: This is a dynamical equilibrium, NOT a thermal equilibrium]

## 2) A significant amount of mass can be ejected, and carry away energy..

# Cold collapse Mass and energy ejection

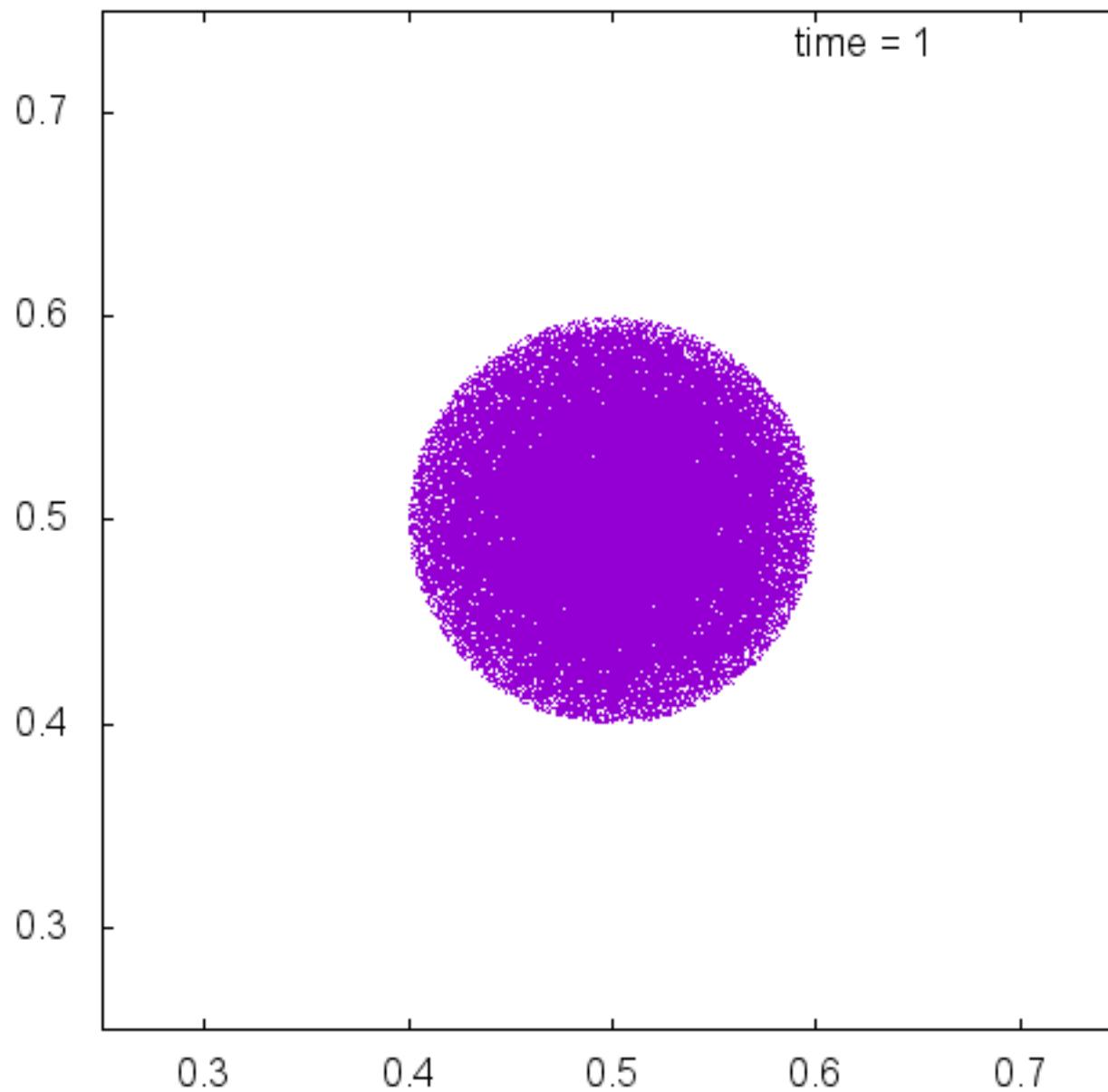


$$K^p / f^p \propto N^{1/3}$$

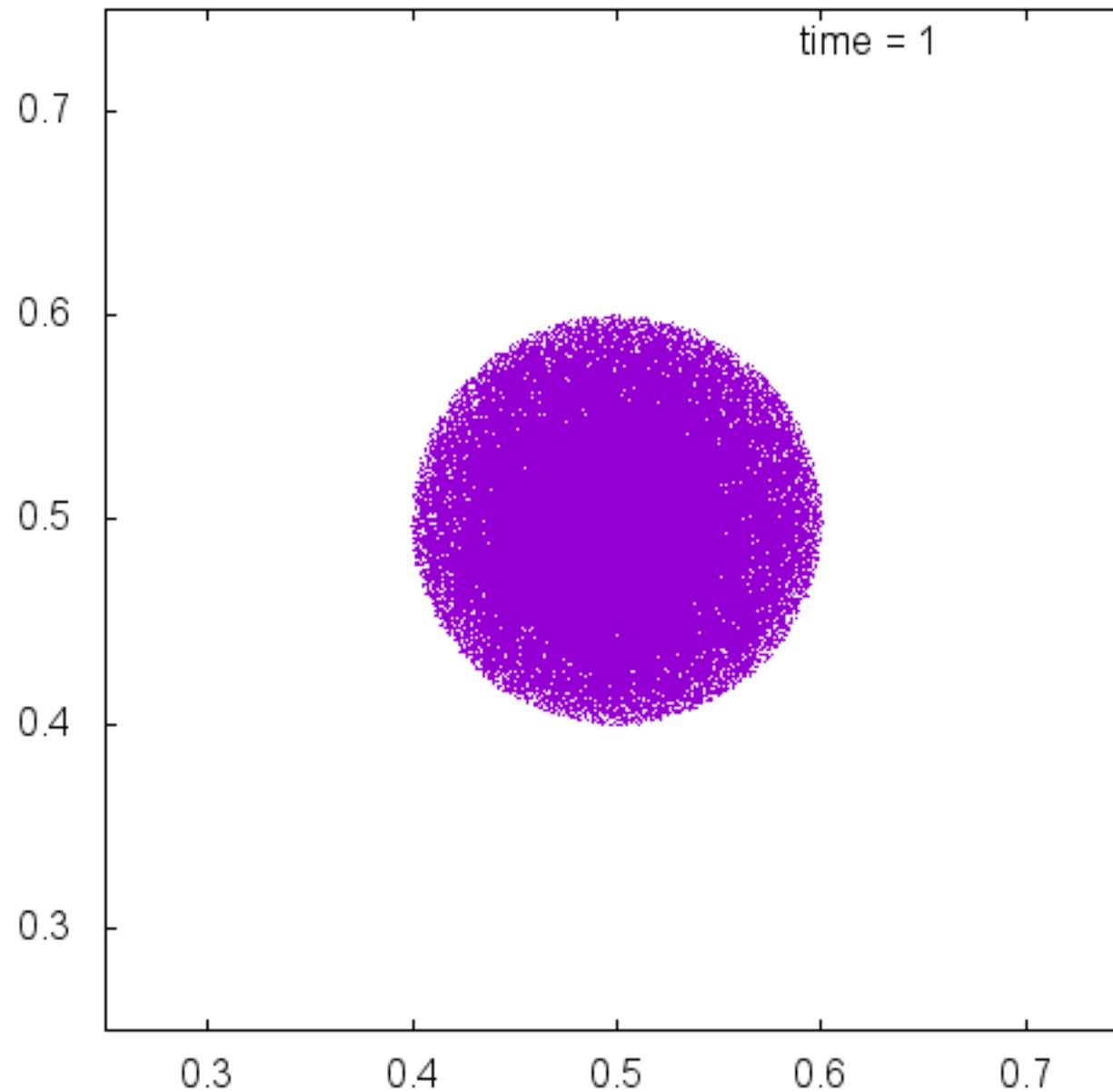
---

## Symmetry breaking in spherical

# $1/r$ profile, “warm” ( $N=10^5$ , $\alpha=1$ , $b=0.15$ )



# $1/r$ profile, “cold” ( $N=10^5$ , $\alpha=1$ , $b=0$ )



---

## **Questions we address:**

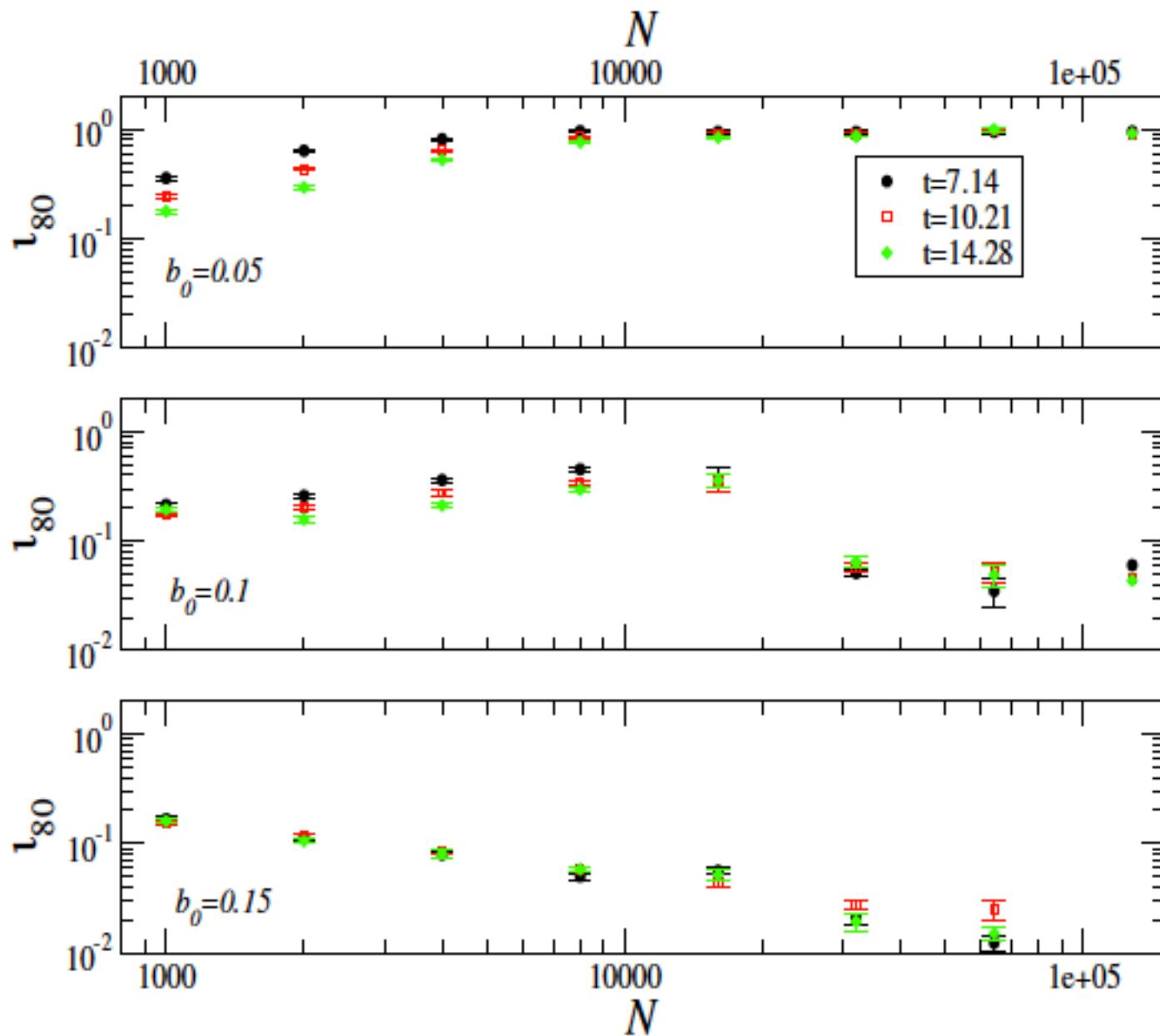
- 1) What is mechanism of symmetry breaking?**
  
- 2) Can angular momentum be generated in bound structure?**

---

TWO distinct mechanisms for symmetry breaking:

- “**GI**”: **gravitational instability** (amplification of initial finite N fluctuations)
- ROI: “**Radial orbit instability**” (instability of equilibria with radial velocities)

## e.g. Asymmetry as a function of N



---

## **Conclusion of our study:**

- Very cold/smaller N: GI plays central role
- “Coldish”/sufficiently large N: ROI dominates
- Warmer IC: GI only

+

**Yes, angular momentum is generated**, most significant in first case.

---

## **Relevance to cosmology??**

### **1) Discreteness issue in cosmological simulations**

Study illustrates difficulties of uncovering finite N effects  
in non-linear regime

### **2) Cold vs warm dark matter signatures?**

---

## Perspectives

# Perspectives

---

- **Current focus:** external collaborations, conclusion of ongoing projects  
Sabbatical MJ next year? (1/2 CRCT obtenu + 1/2 délégation 01?)
  - **Medium-long term:** focus more on cosmological applications ?  
e.g. issue of precision of theoretical predictions?  
Opening to “gastro-physics”/galaxy formation?
  - **Demande personnel :** Recrutement of post-doc/CDD with numerical orientation, would help to develop link to cosmological observations
  - **Thèses:** après sabbatique (rentrée 2018, 2019..)  
(remarque: membre de l’EDPIF, responsable suivi des étudiants)
- \* IN2P3 affiche volonté de soutenir **et développer** la théorie à l’in2p3...

---

Et..

---

**Vue d'un théoricien sur les expériences au labo...**

---

## **Deux catégories d'expérience:**

**Celles qui cherchent quelquechose où on pourrait rien trouver**  
(et où ce n'est pas clair ce qu'on va apprendre si c'est le cas):

[LHCb, ATLAS, Dark Matter Searches..]

**Celles qui vont faire des mesures nouvelles de quantités connues** et peuvent être assez certain d'apprendre quelquechose,

[Rayons Gamma, Supernovae, BAO...]

Dans le 2ème cas seulement c'est sur qu'il y a du travail pour les théoriciens..??