POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

P I K

Urbanisierung: über das Gibratsche Gesetz, Kritikalität und Gravitation

Diego Rybski et al.

4.10.2013 – 9:00-9:25
Nikolakloster SR211

58. Deutscher Geographentag 2013 in Passau – 2.10.-8.10.2013
FS 60 Modellierung und Simulation von Flächennutzungswandel, seiner Ursachen und Folgen I

About the city-phenomenon

Major historical landmarks:

Neolithic Revolution 10 000 BCE
hunter-gatherer to agricultural practices
permament buildings next to working sites
settlements, villages, small cities

Industrial Revolution 18th..19th century
industrial sector, factories
employment in cities, migration, pop. growth
tall buildings (steel frame, elevators)
modern cities

Globalization complex and controversial
relocation of production processes
to less developed countries
corresponding cities
migration
mega-cities

Cities and climate?

Modern cities require excessive energy supply

(i) construction and growth

(ii) maintenance

Only possible from energy forms explored since the Industrial Revolution

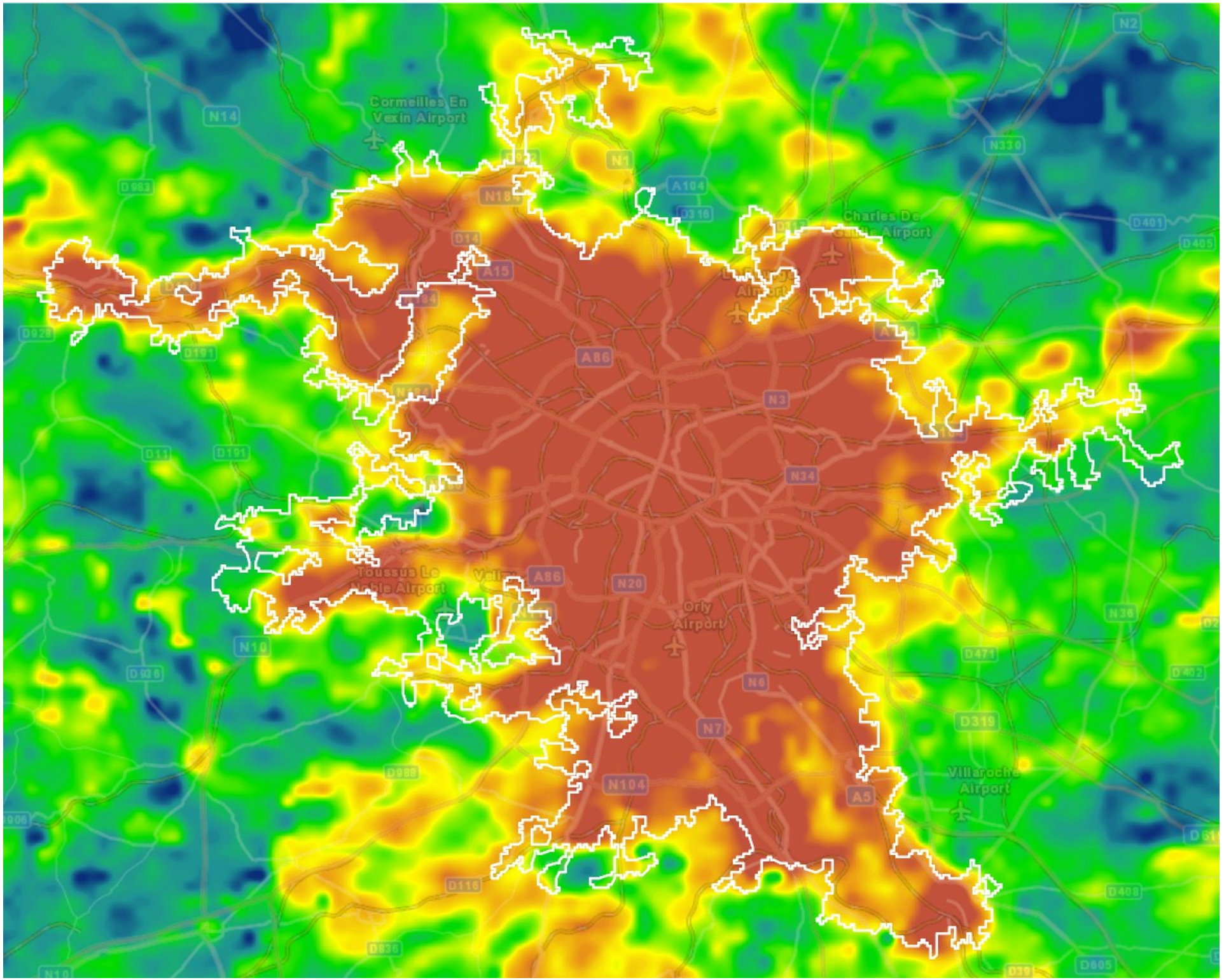
Fossil fuels, CO2-emissions, considerable amount attributed to cities.

Efficiency of cities?

Dense agglomerations of people and assets,
particularly vulnerable to impacts of climate change.

Cities are driving and suffering climate change.

city climate, Urban Heat Island effect


Cormeilles En Vexin Airport
Charles De Gaulle Airport
Toussus Le Noble Airport
Orly Airport
Villaroche Airport
N14
N1
N2
N330
A104
D983
D14
A15
D928
D191
A86
N3
D11
N34
N20
N10
D926
N6
N7
D471
D402
D319
N104
A5
D988
D906
D116
D836
D605
D408
D405
D401
N36

City definition

What is the unit of observation? (Berry 2012)

Definition of city depends on how one looks at it.

- Legal or administrative
- Planning
- Statistics
- Architecture
- Geography
- Physics

Effects such as the UHI are physical

→ makes sense to use physical definition

Explore City Clustering Algorithm (CCA)

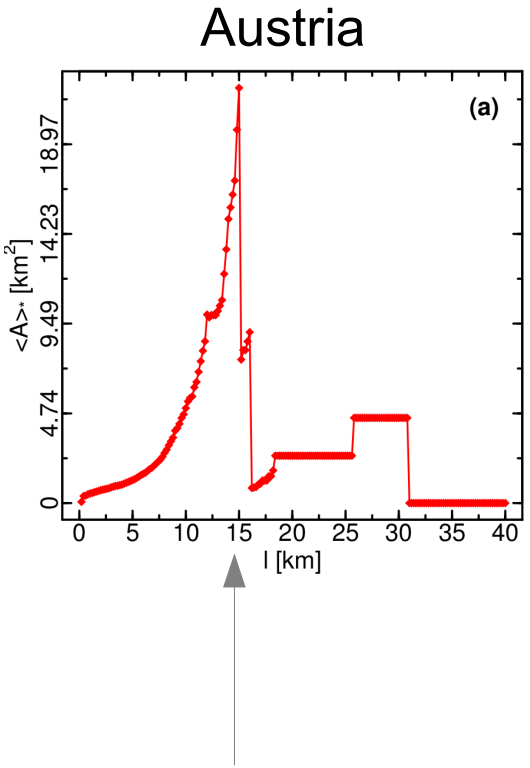
originally gridded population, now urban land cover data

cities as maximally connected spatial clusters

any two urban sites with distance</ belong to same cluster

Rozenfeld et al., PNAS, 2008; Rozenfeld et al., AER, 2011

Criticality of the urban fabric



approx. 15km
percolation transition
(infinite cluster)

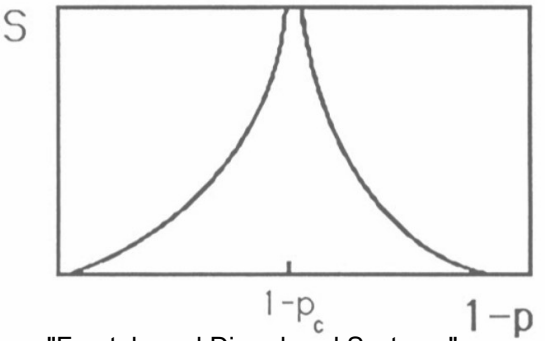
CCA parameter

tolerance in bridging non-urban gaps

coarse-graining (spatial resolution)

percolation problem

average cluster size without largest one



"Fractals and Disordered Systems"
(A. Bunde & S. Havlin)

Benchmarks for city modeling

(i) City size distribution (Zipf's law)

(ii) City growth (Gibrat's law)

(iii) Fractality

Auerbach's legacy

Das Gesetz der Bevölkerungskonzentration.

Von Prof. Dr. *Felix Auerbach*, Jena.

(Mit 3 graphischen Darstellungen, s. Tafel 14.)

Die Tatsachen des Menschenlebens scheinen sich auf den ersten Blick nicht, wie die Erscheinungen der Natur, bestimmten, allgemeinen Gesetzen unterzuordnen. Indessen lehrt uns die Statistik, daß das eben nur ein gradueller Unterschied ist, bedingt durch die größere Komplikation der Verhältnisse, und daß man nur die Zahlen der Statistik richtig zu lesen lernen muß, um allgemeinere Schlüsse ziehen zu können; und es ergeben sich dabei nicht selten interessante und merkwürdige Gesetze.

ihnen die Einwohnerzahl schreiben, so daß wir, mit der größten beginnend, zu immer kleineren fortschreiten, und schließlich wollen wir die Rangnummer mit der zugehörigen Einwohnerzahl multiplizieren. Um keine unnütz großen Zahlen zu bekommen und um das Wesentliche herauszuheben, wollen wir dabei fünf Nullen oder Stellen weglassen, d. h. wir wollen auf Hunderttausende abrunden; die so erhaltene Zahl wollen wir das »charakteristische Produkt« des Ortes oder die »absolute Konzentration« der Bevölkerung (die Be-

F. Auerbach, Petermanns Geogr. Mitteilungen 59, 73 (1913).

Auerbach's legacy

Broad city size distribution

Zipf's law for cities (1949)
after G.K. Zipf
(originally: word frequency)

Zipf: “The first person to my knowledge to note the rectilinear distribution of communities in a country was Felix Auerbach in 1913 …”

Abb. 10 EDVARD MUNCH, **Felix Auerbach**, 1906, Öl auf Leinwand, 83,8 x 76,2 cm, Verbleib unbekannt

Centenary jubilee

Caused considerable interest at the time
e.g. W. Christaller, Die zentralen Orte in Süddeutschland, 1933

Zipf-Auerbach-Law

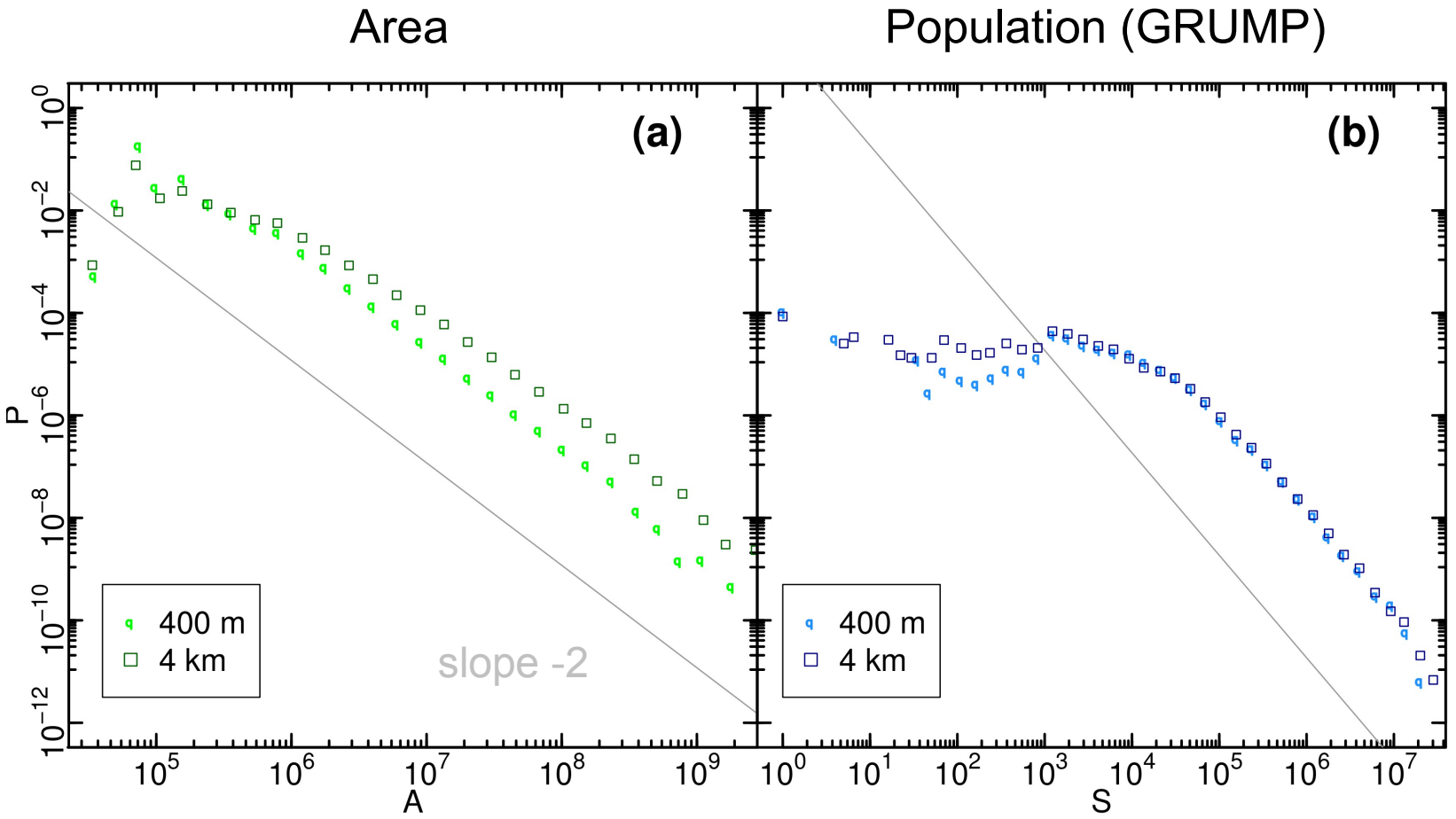
probability density to find a city of size X

$$p(X) \sim X^{-\zeta} \quad \text{with} \quad \zeta \simeq 2$$

where X can be population or area

Alternatively: rank-size-representation (exponent 1)

Global city-size distribution



all city clusters on the Globe (approx. 250k)

connecting land-cover clusters with geo-coded population figures

City growth

Gibrat's law: growth rates are independent of size

in particular mean and standard deviation

Central Limit Theorem … log-normal distribution

Minor modification: power-law size distribution

Common assumption

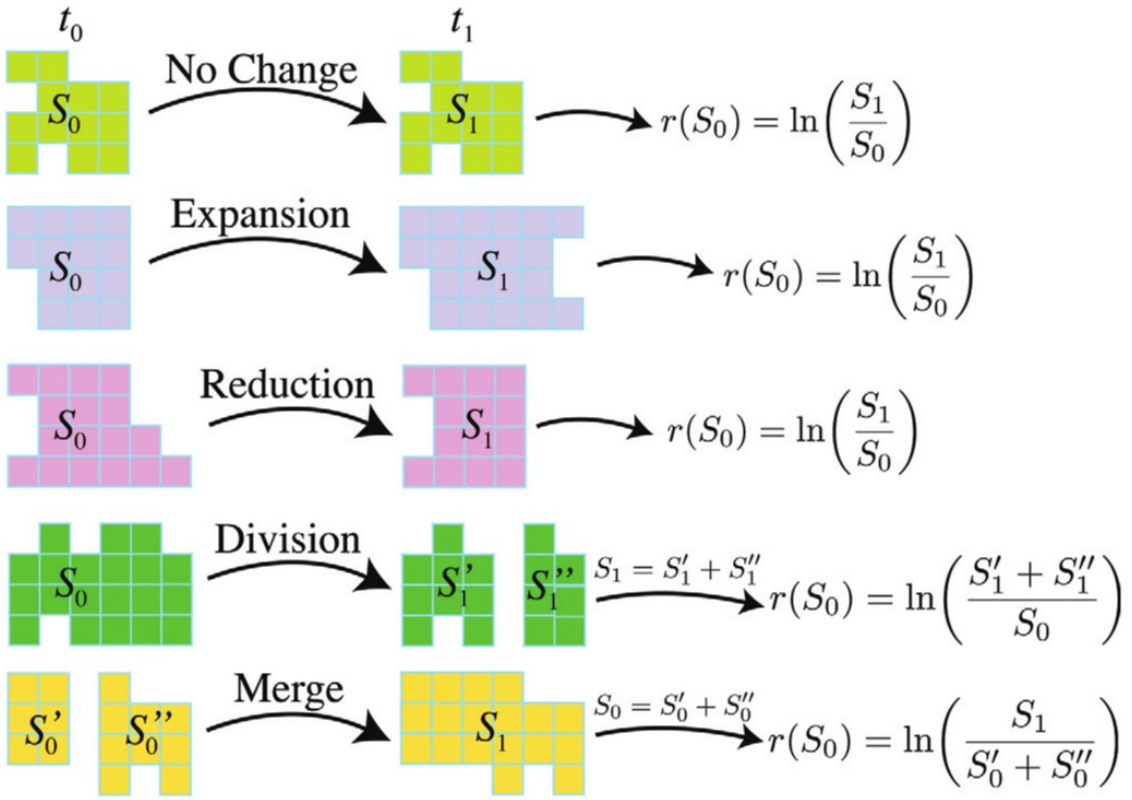
City growth does not follow Gibrat's law

Similar to other data, e.g. companies

(M.H.R. Stanley et al., nature 1996)

City growth

1. two time steps
2. OR operation
3. CCA
4. logarithmic growth rates



Does the city growth obey Gibrat's Law?

City growth

S_0 Population of a city at time 0.

S_1 Population of a city at time 1.

$S_1 = R(S_0)S_0 \longrightarrow R$ growth factor

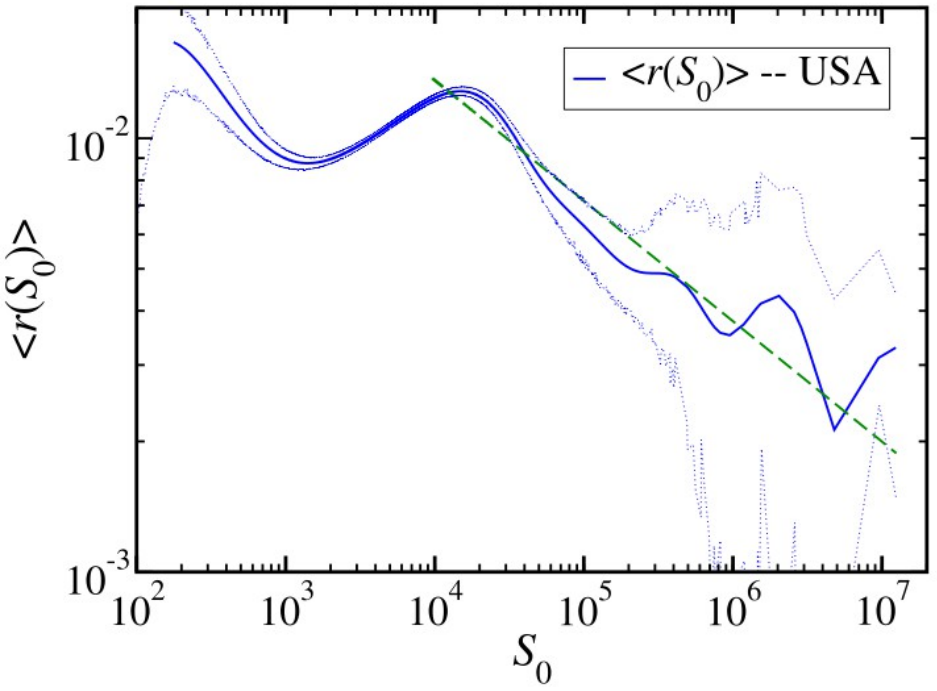
$r(S_0) \equiv \ln R(S_0) = \ln(S_1/S_0) \longrightarrow r$ log. growth rate

$\langle r(S_0) \rangle \sim S_0^{-\alpha}$ average growth rate

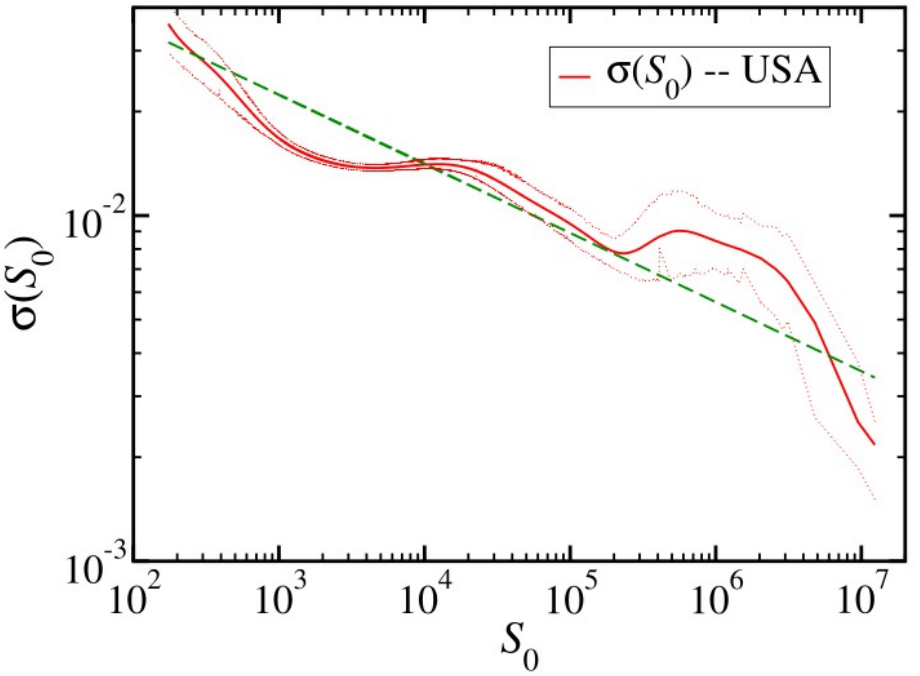
$\sigma(S_0) = \sqrt{\langle r(S_0)^2 \rangle - \langle r(S_0) \rangle^2}$ standard deviation

$\sigma(S_0) \sim S_0^{-\beta}$

City growth in the USA (1990-2000)



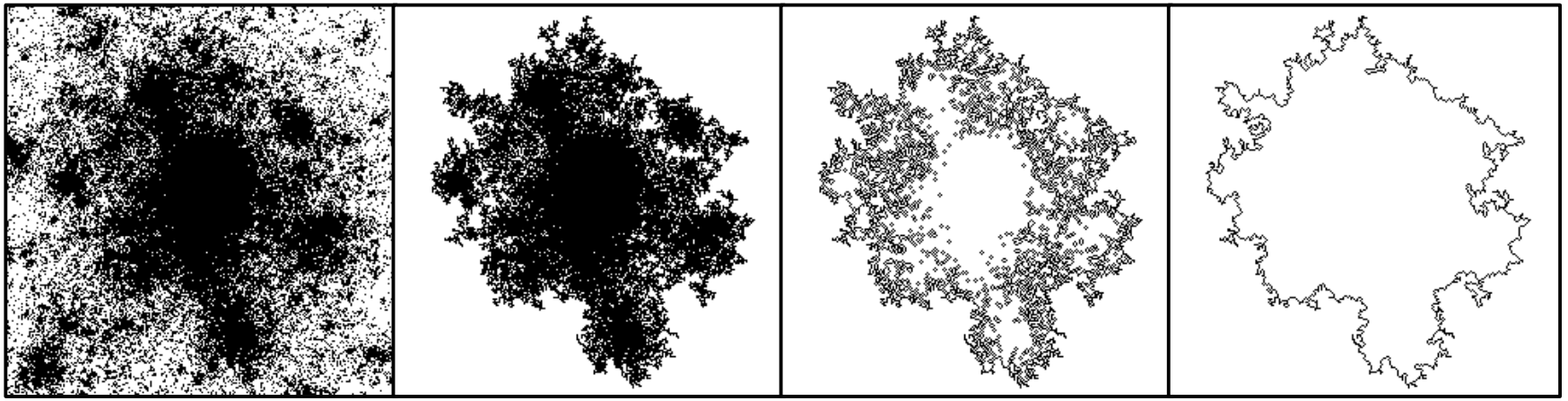
$$\langle r(S_0)\rangle \sim S_0^{-\alpha}, \quad \alpha = 0.28$$



$$\sigma(S_0) \sim S_0^{-\beta}, \quad \beta = 0.20$$

Are not in agreement with Gibrat's Law
(stating that growth rates are size- independent)

Fractality



1 configuration

largest component

boundary

disregarding inclusions

Urban envelop

Box covering

Literature: size dependence of fractal dimension

Gravitational City Model

First Law of Geography

"*Everything is related to everything else, but near things are more related than distant things.*"

(W.R. Tobler, 1970)

Approach

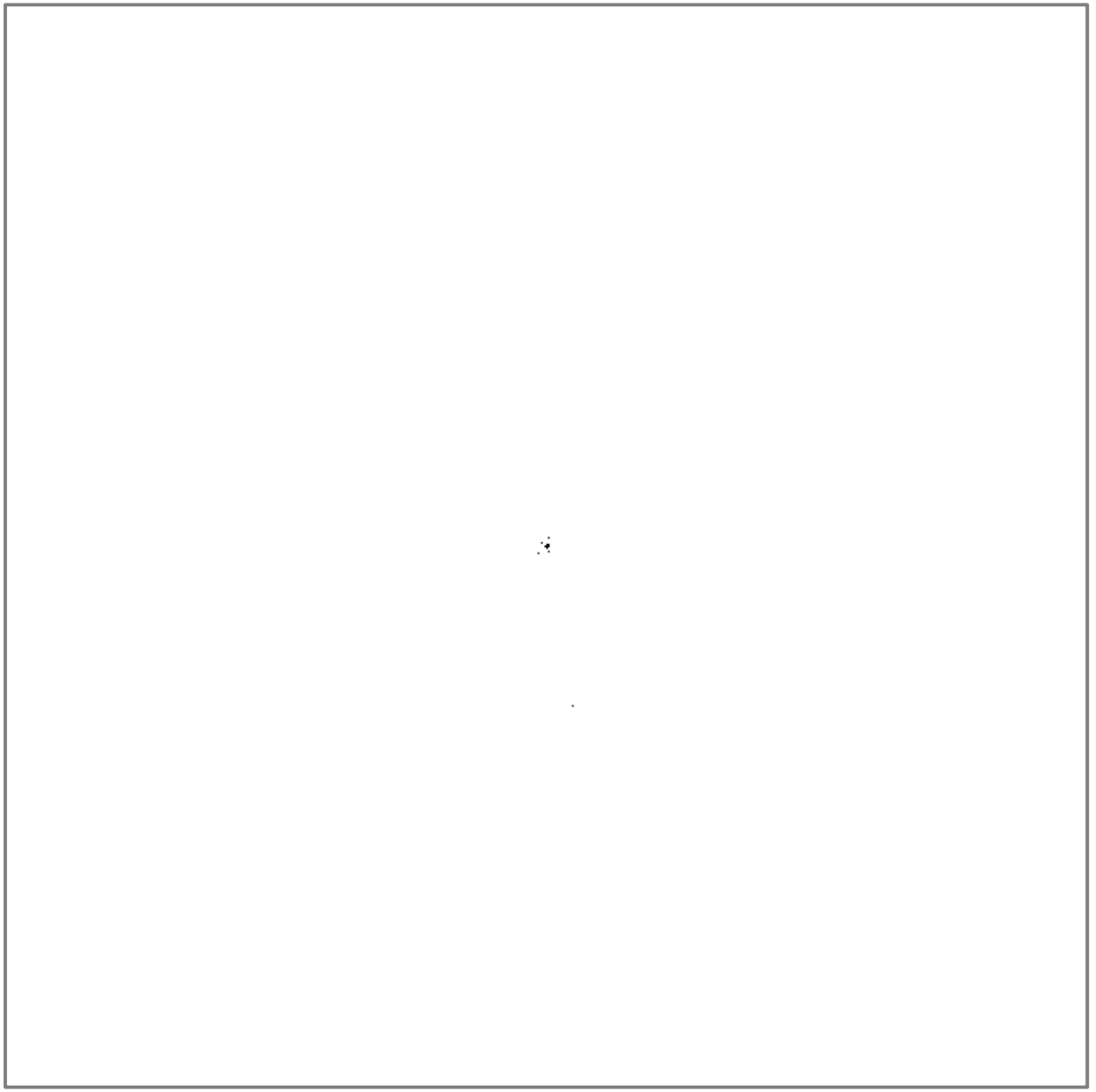
The cells of a grid with the coordinates i can either be occupied ($w_i = 1$) or empty ($w_i = 0$). Iteratively each site is tested for being populated. Therefore, the probability to become populated is given by

$$p_i = C \frac{\sum_{j \neq i} w_j d_{i,j}^{-\gamma}}{\sum_{j \neq i} d_{i,j}^{-\gamma}} \quad , \tag{1}$$

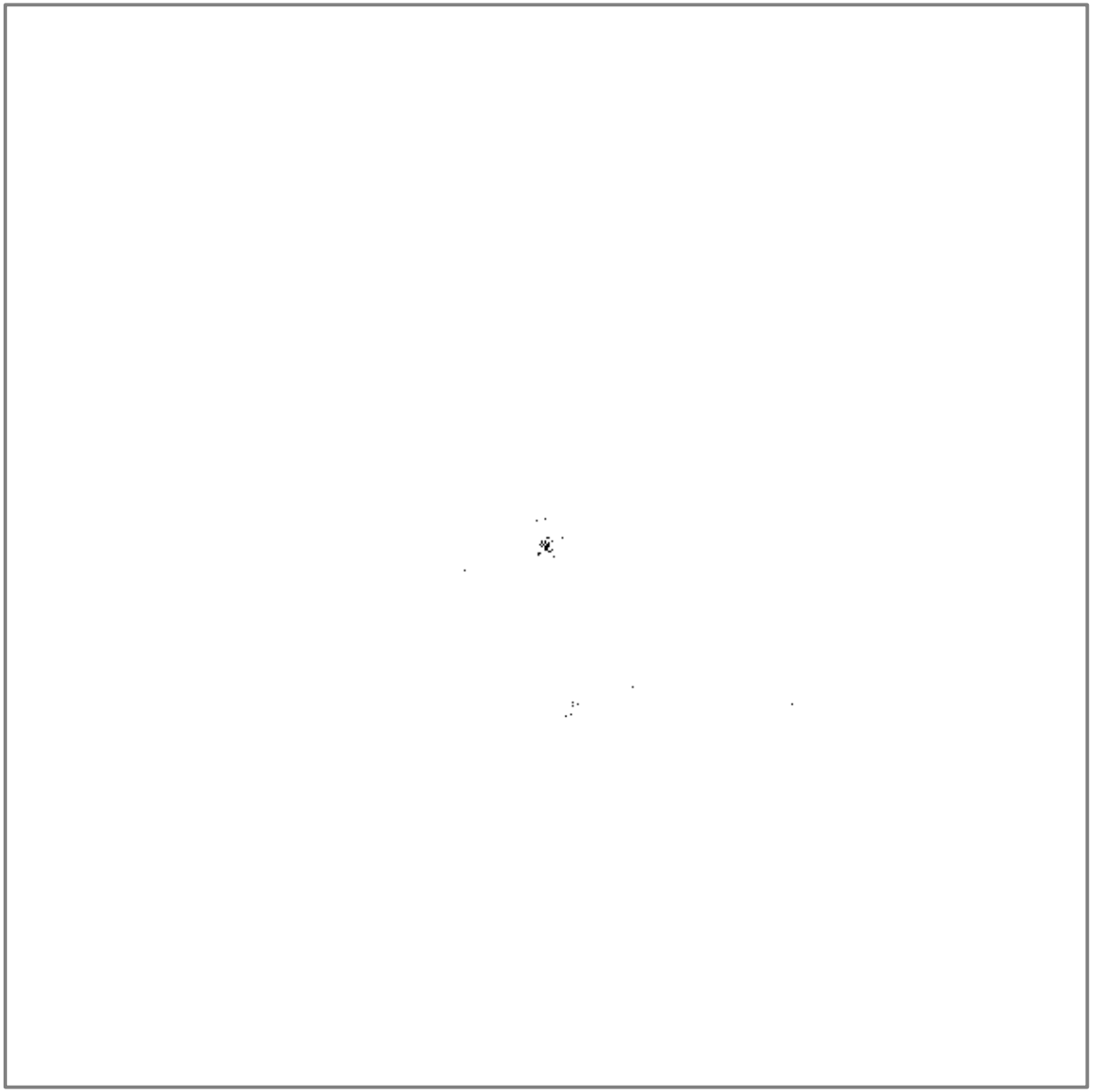
where $d_{i,j}$ is the distance between the points i and j. The index j runs over all sites with $w_j = 0$, i.e. already populated sites are not further considered. Finally, the probabilities are normalized according to $\max(p_i) = 1$.

Example

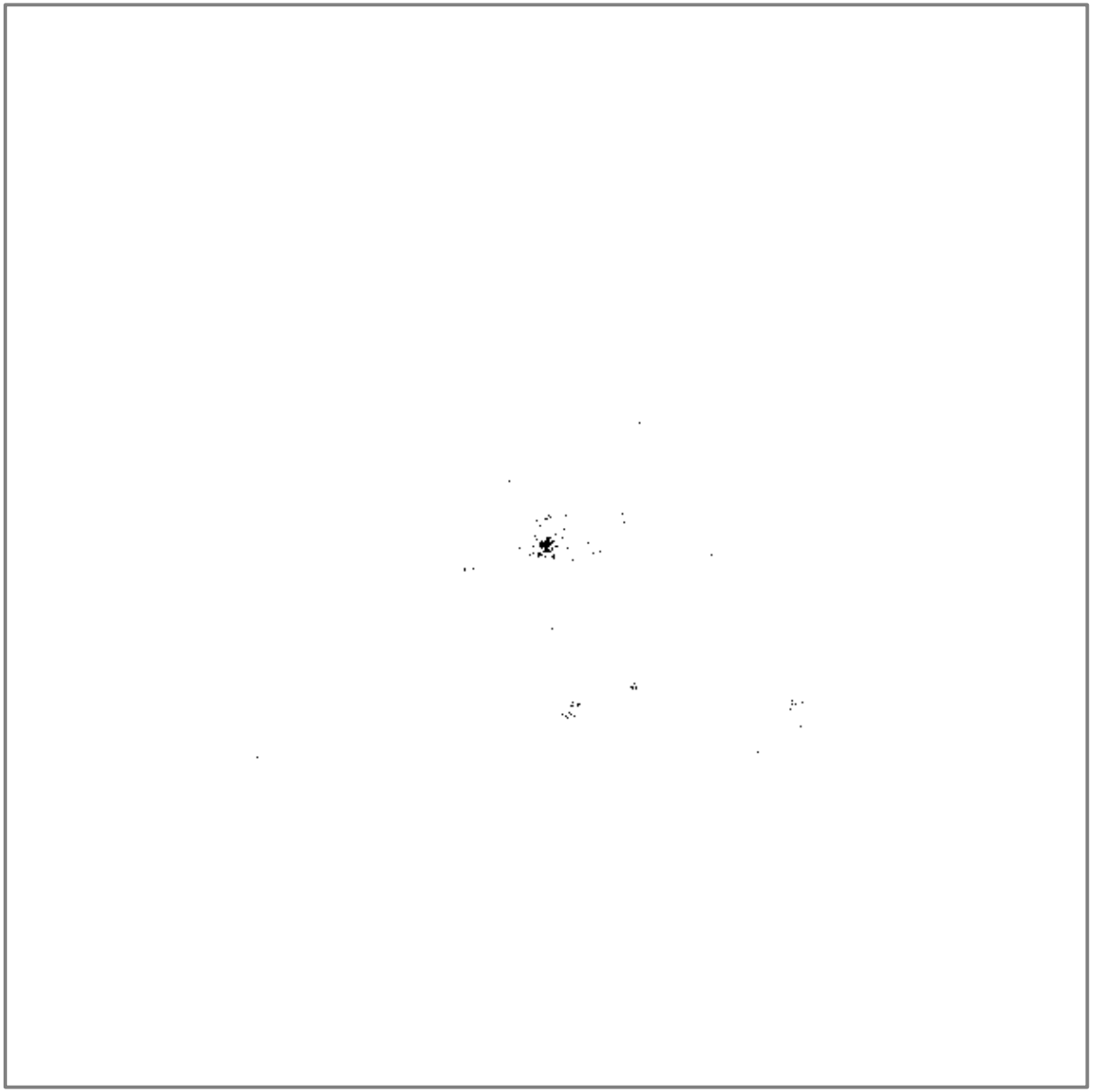
630 x 630
γ=2.5



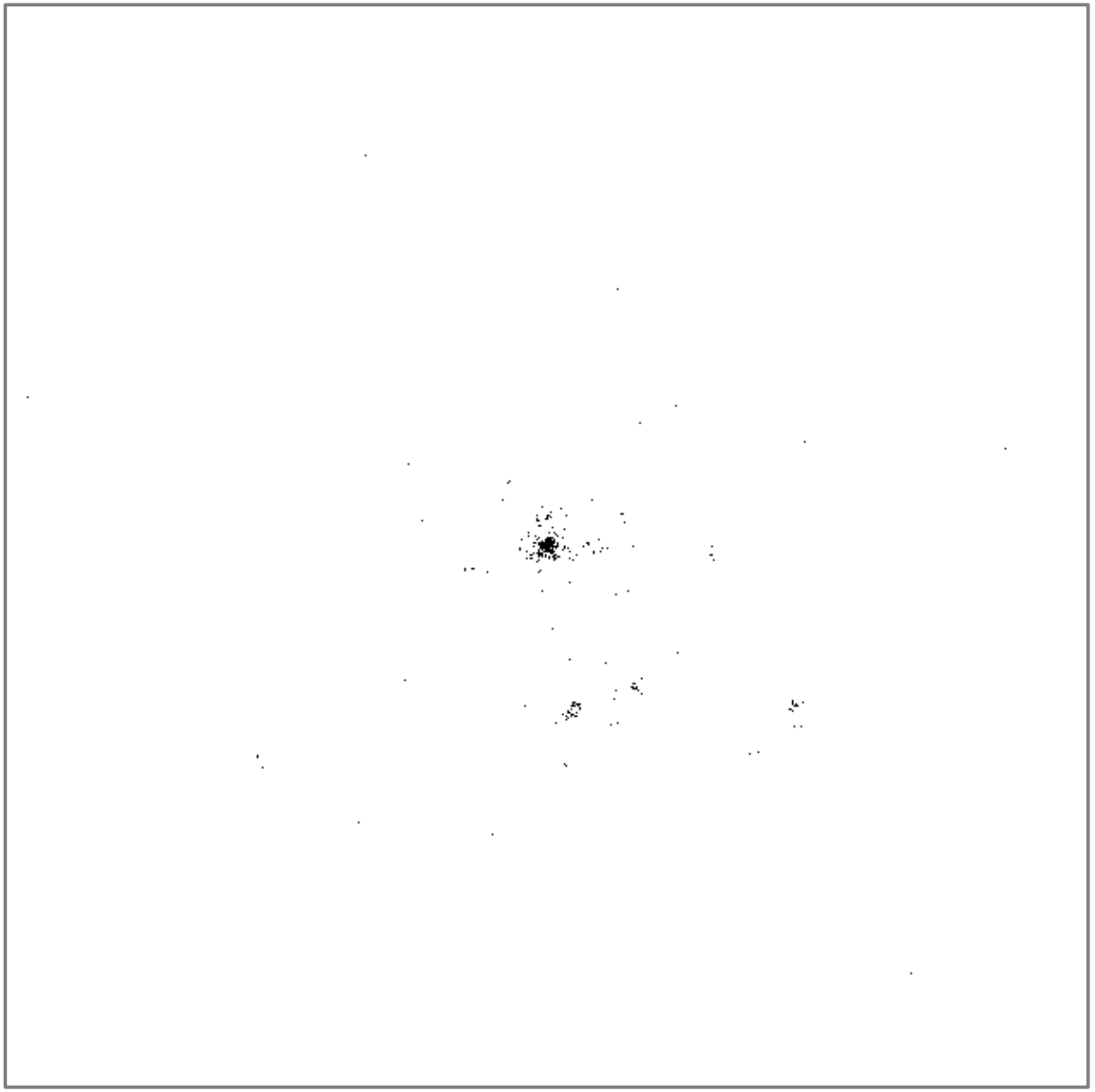
Example



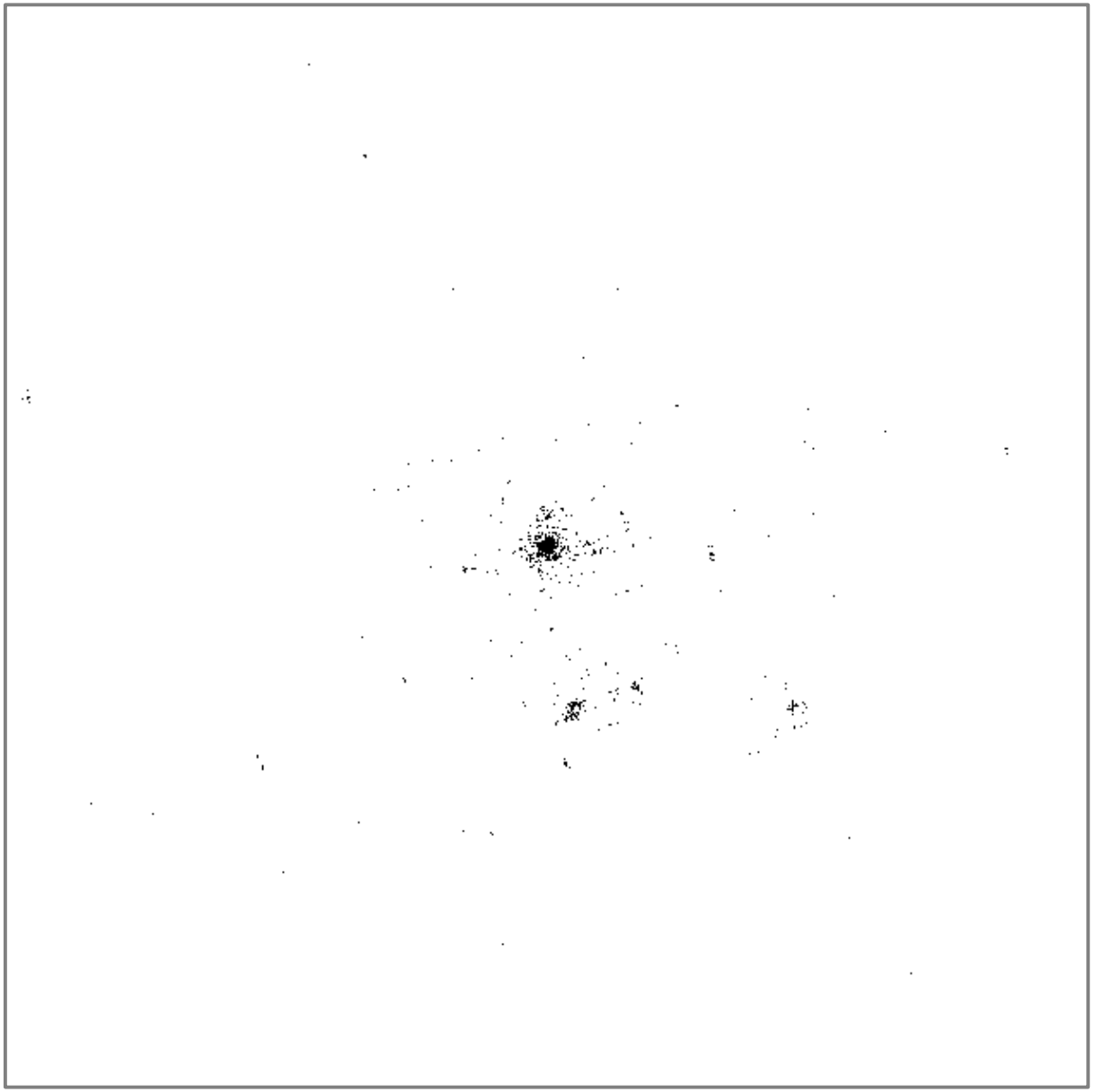
Example



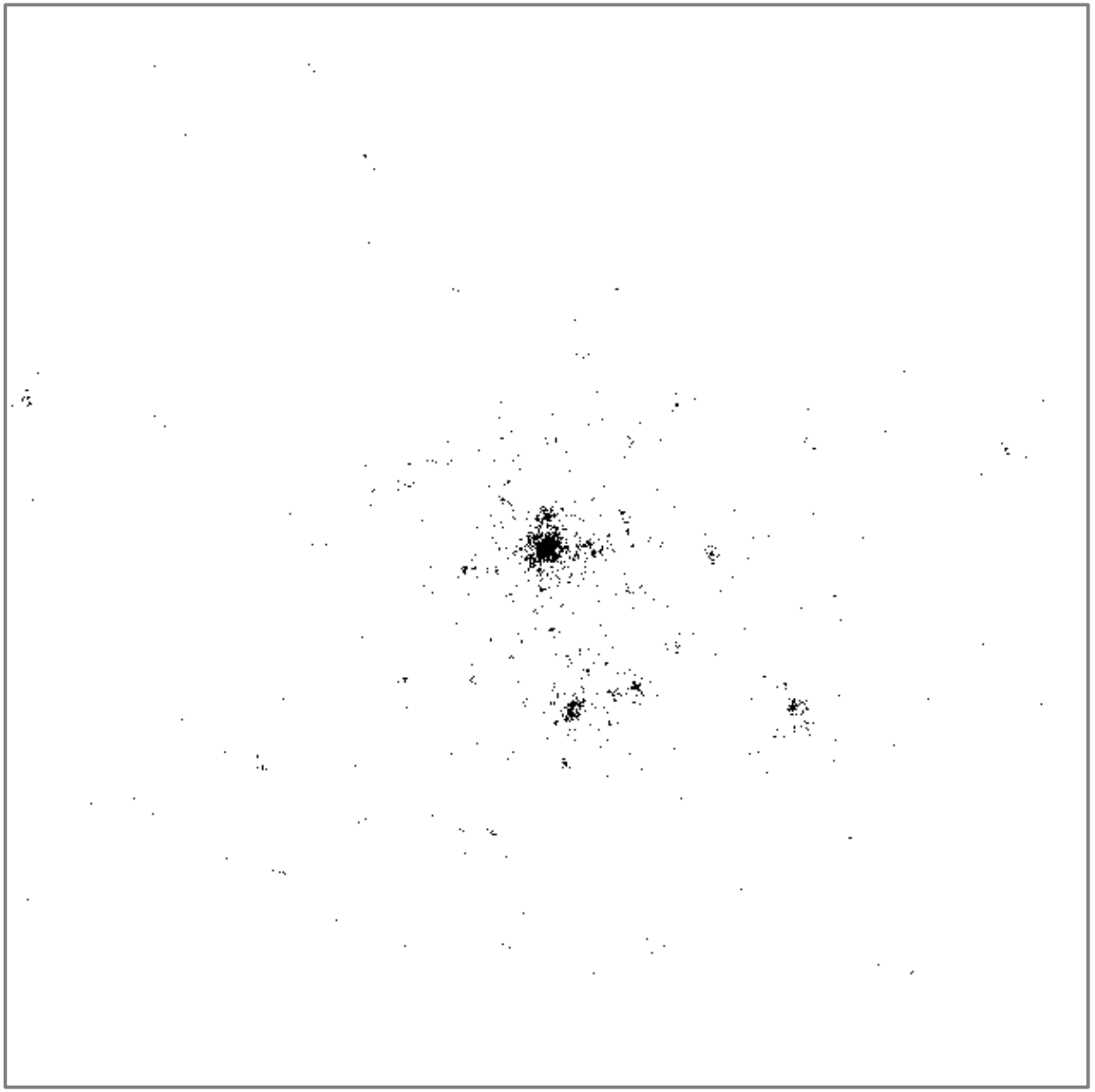
Example



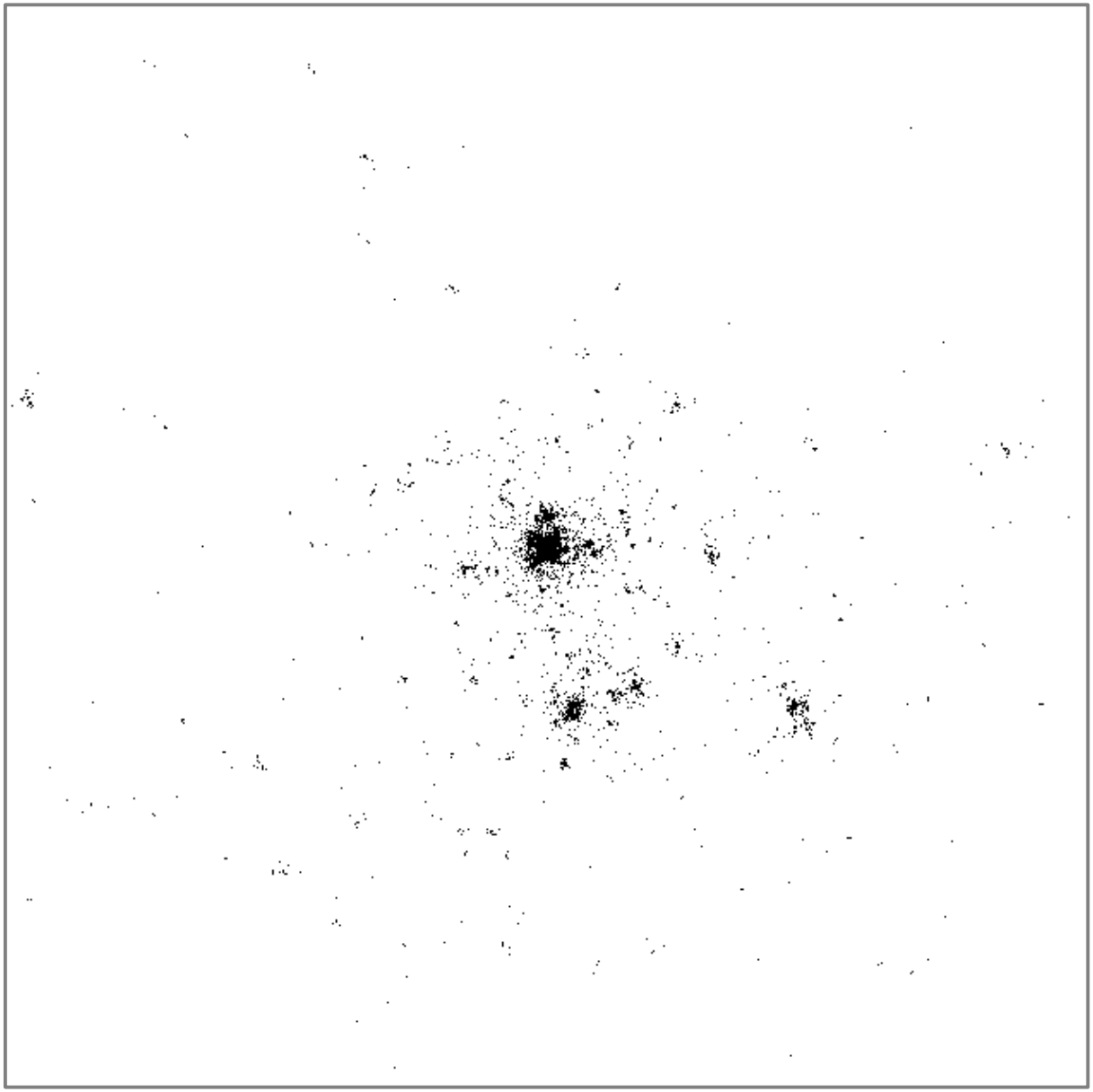
Example



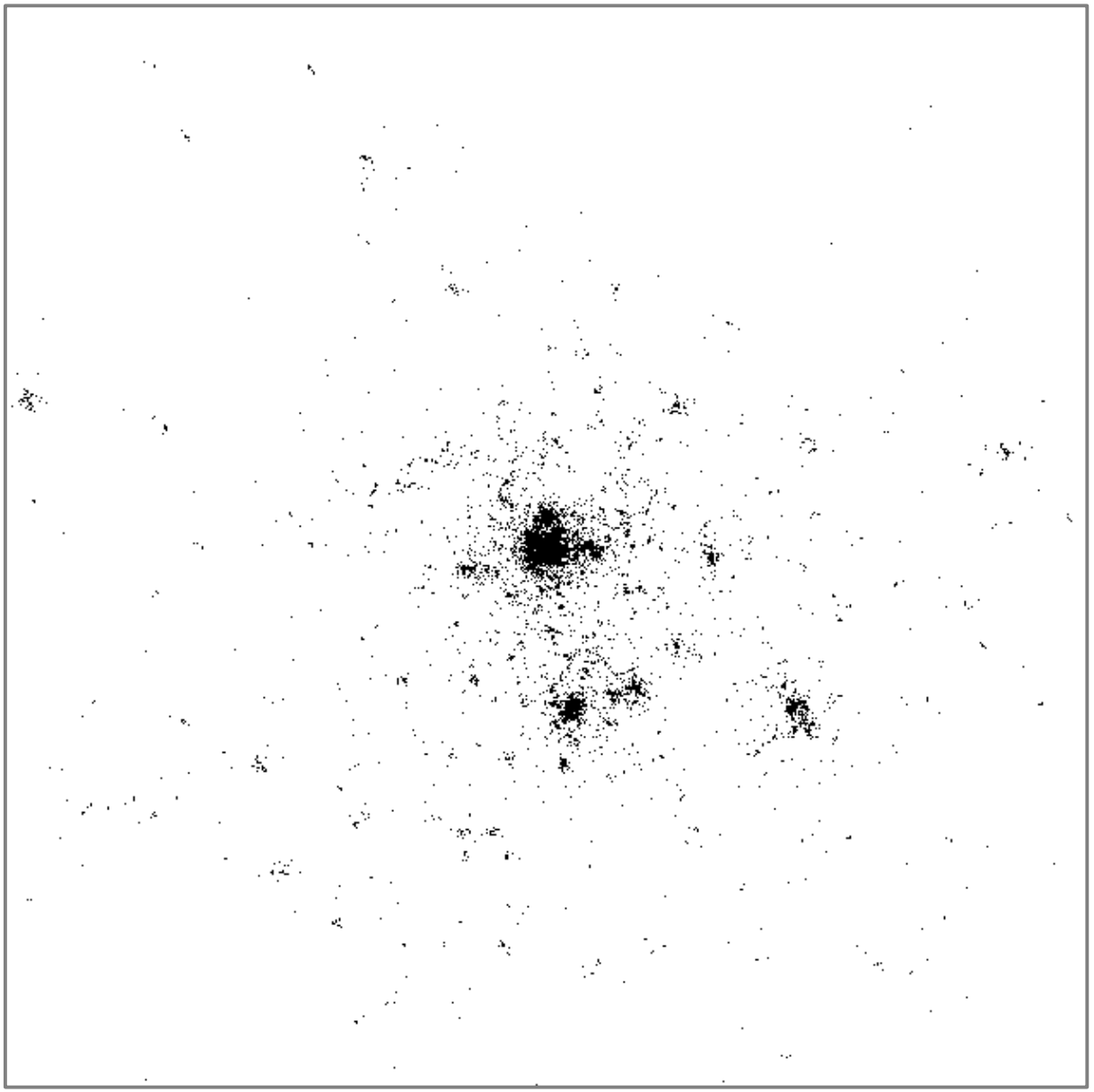
Example



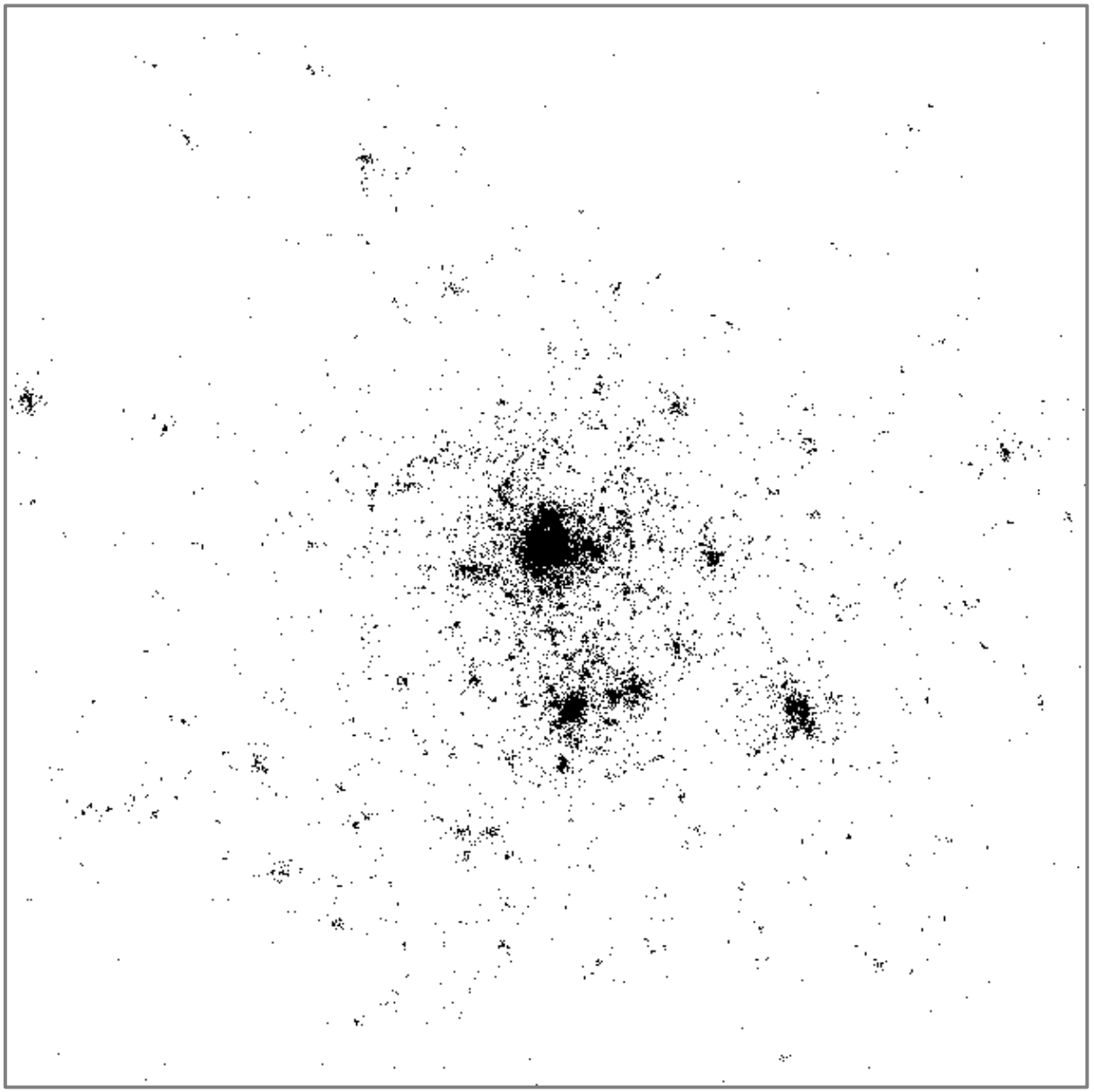
Example



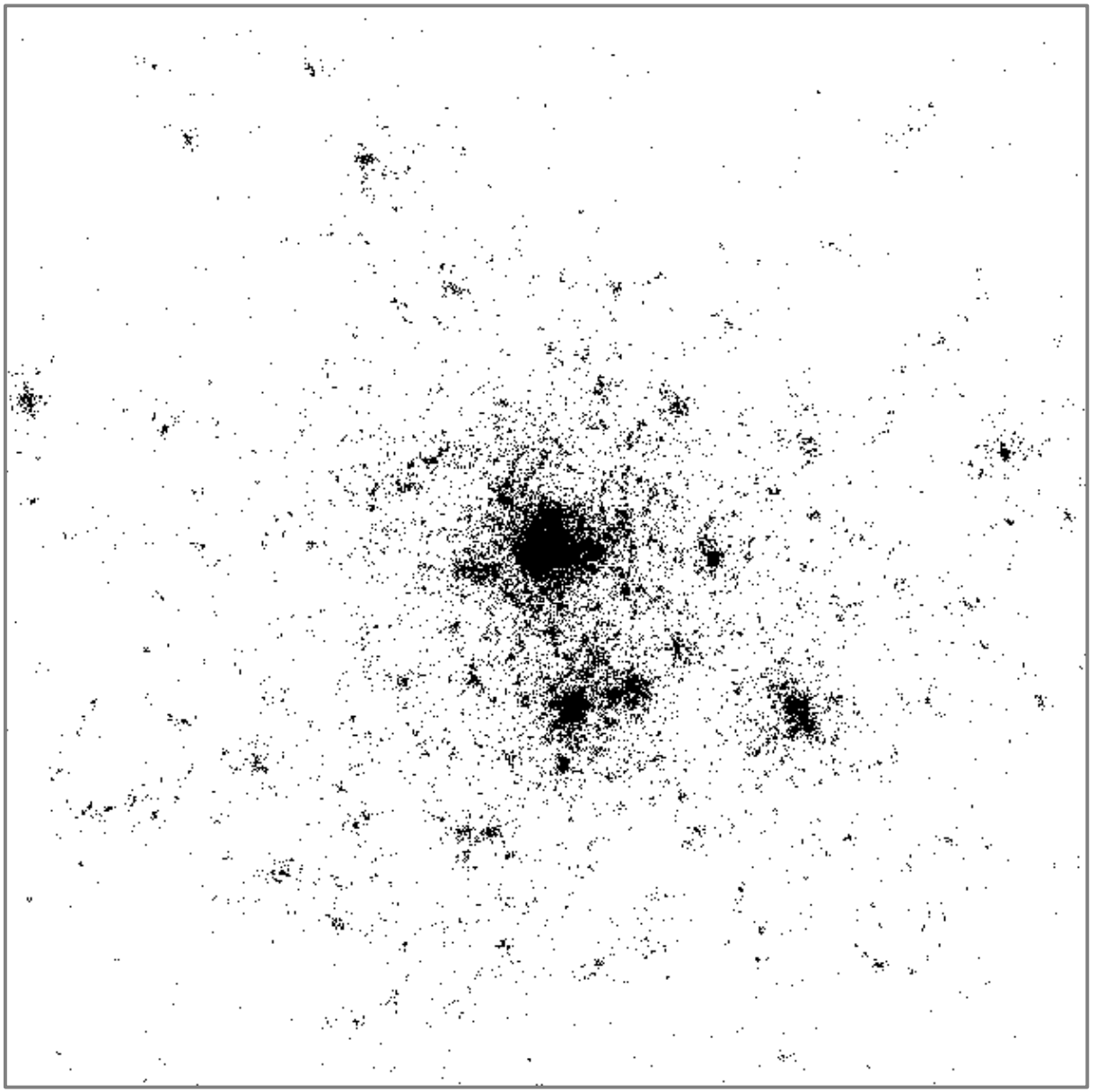
Example



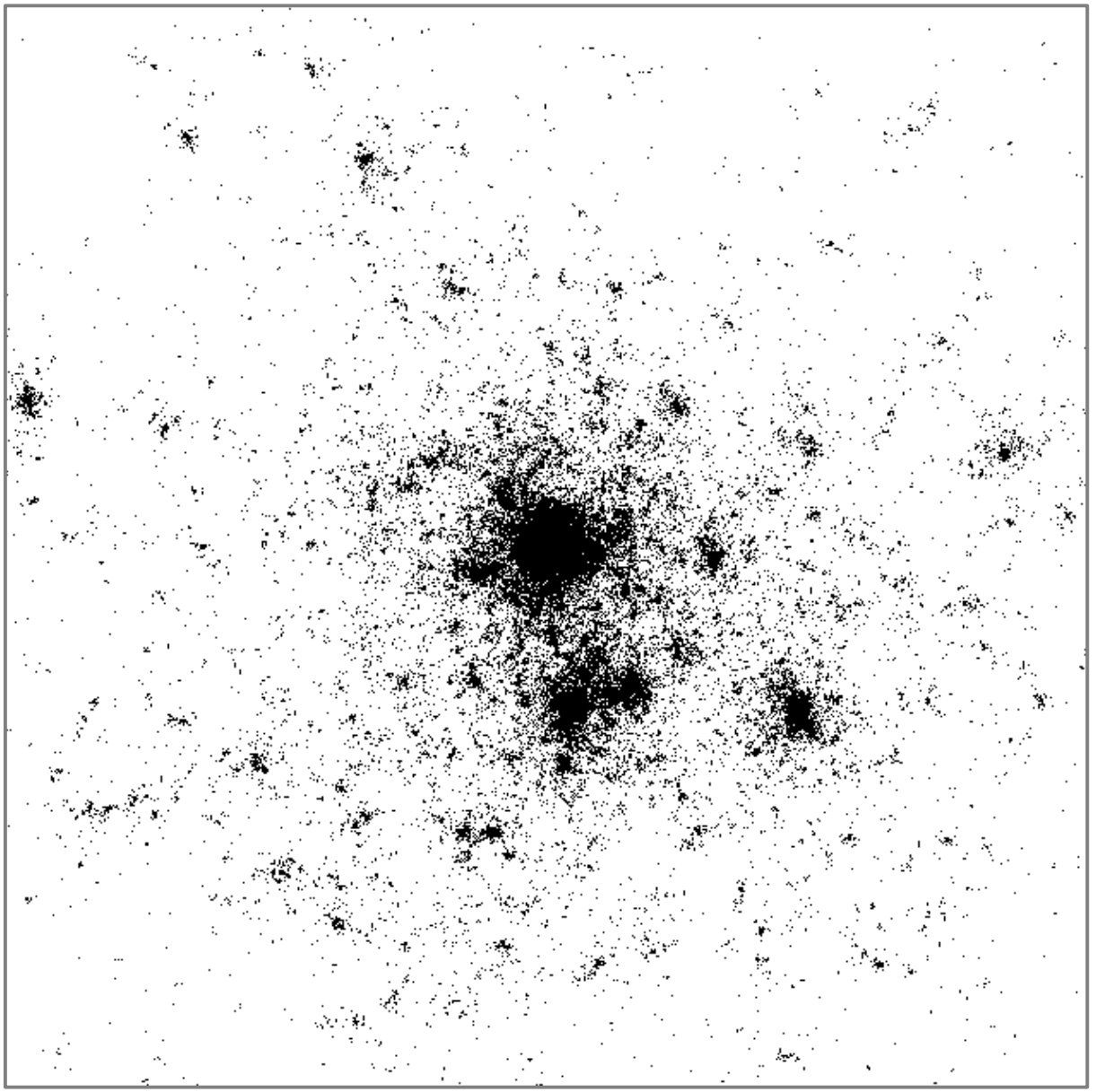
Example



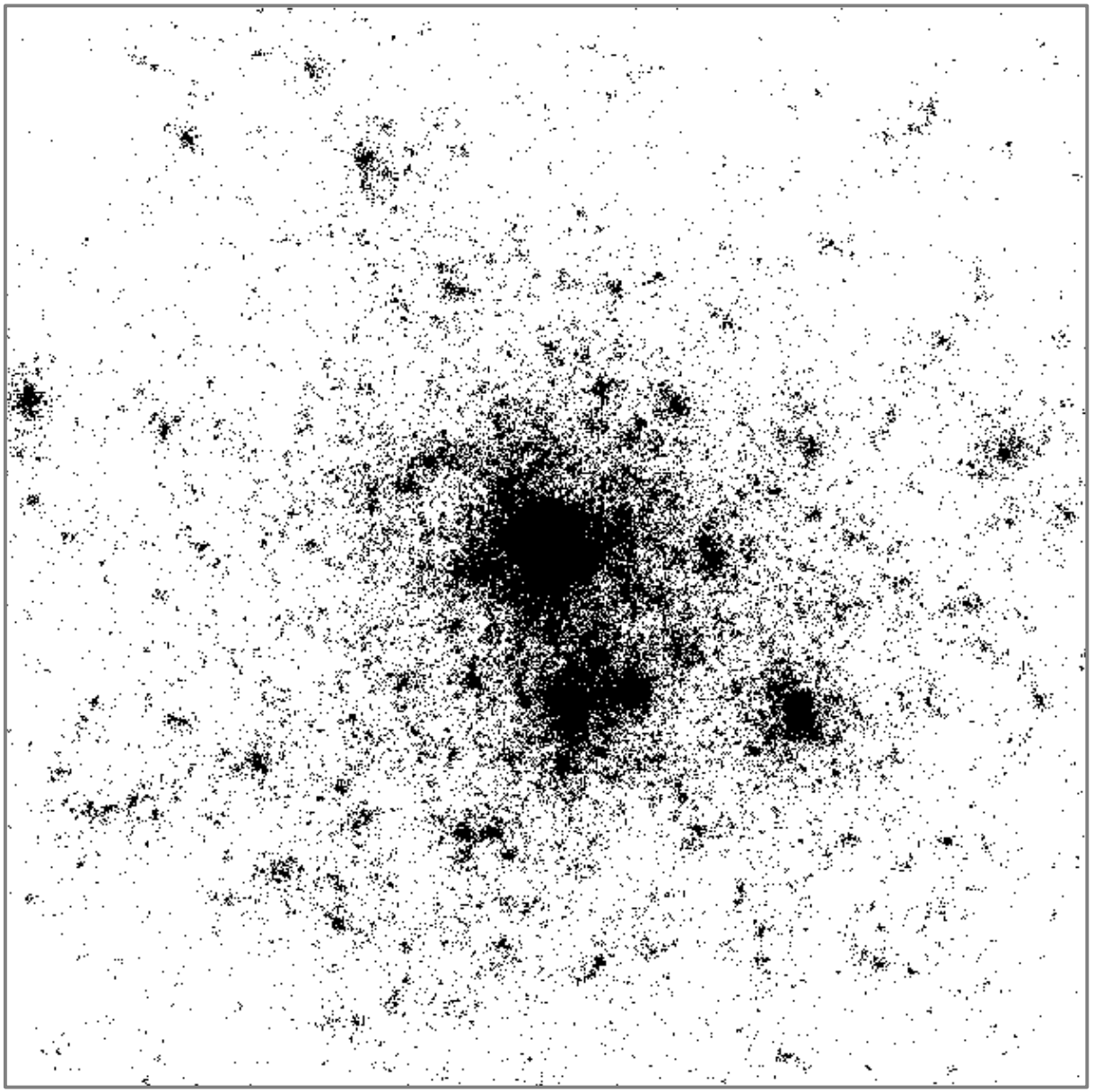
Example



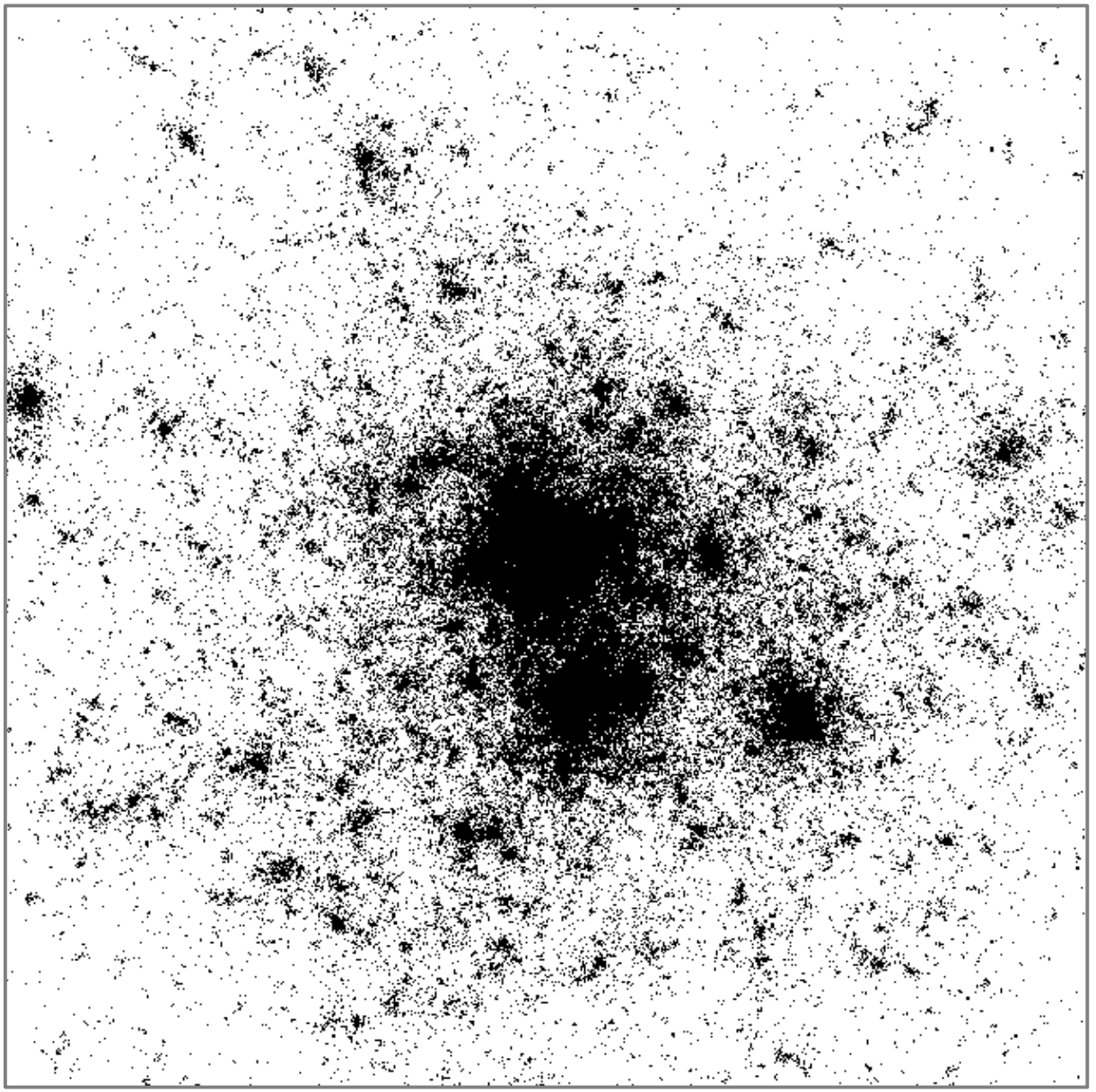
Example



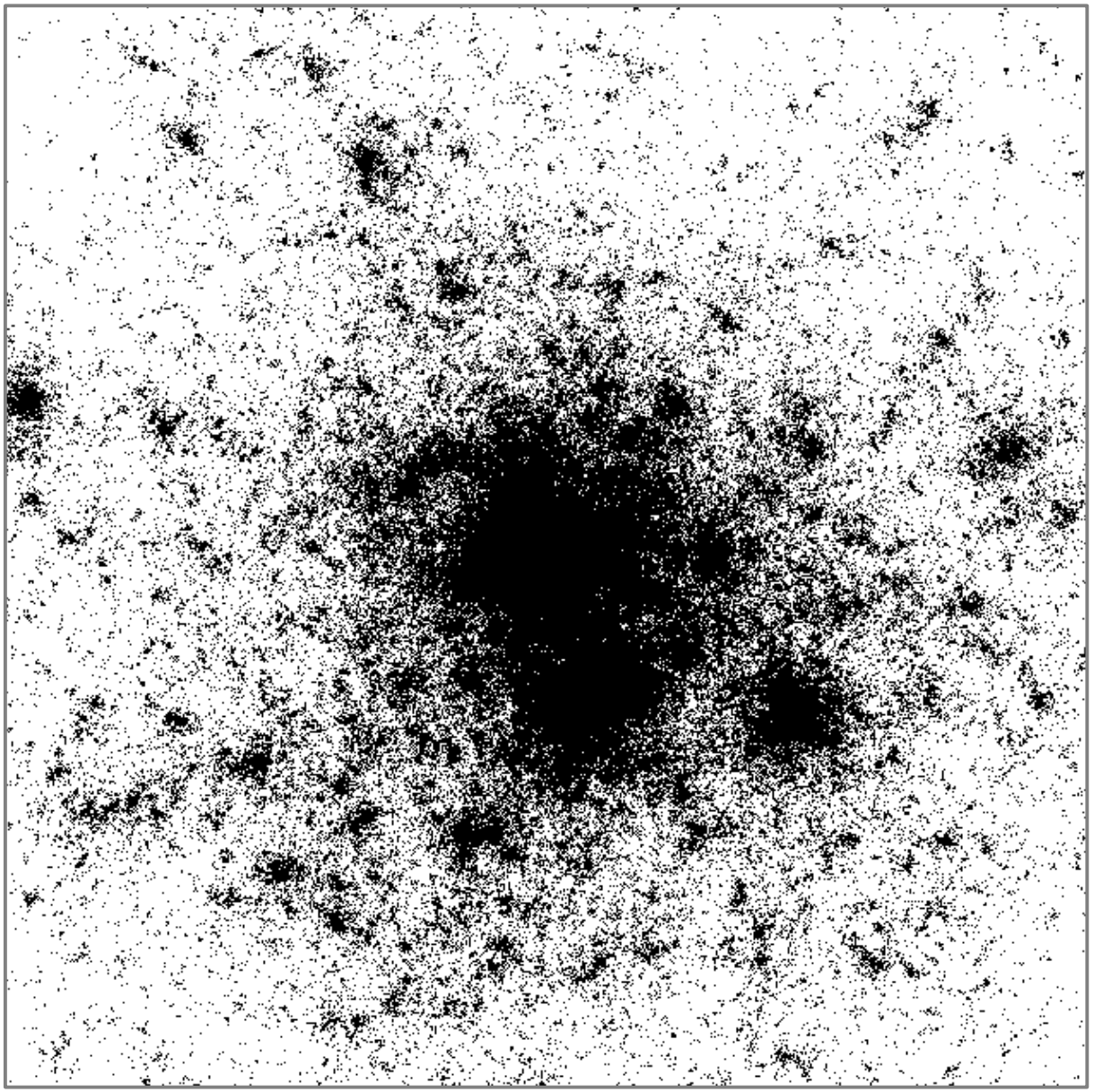
Example



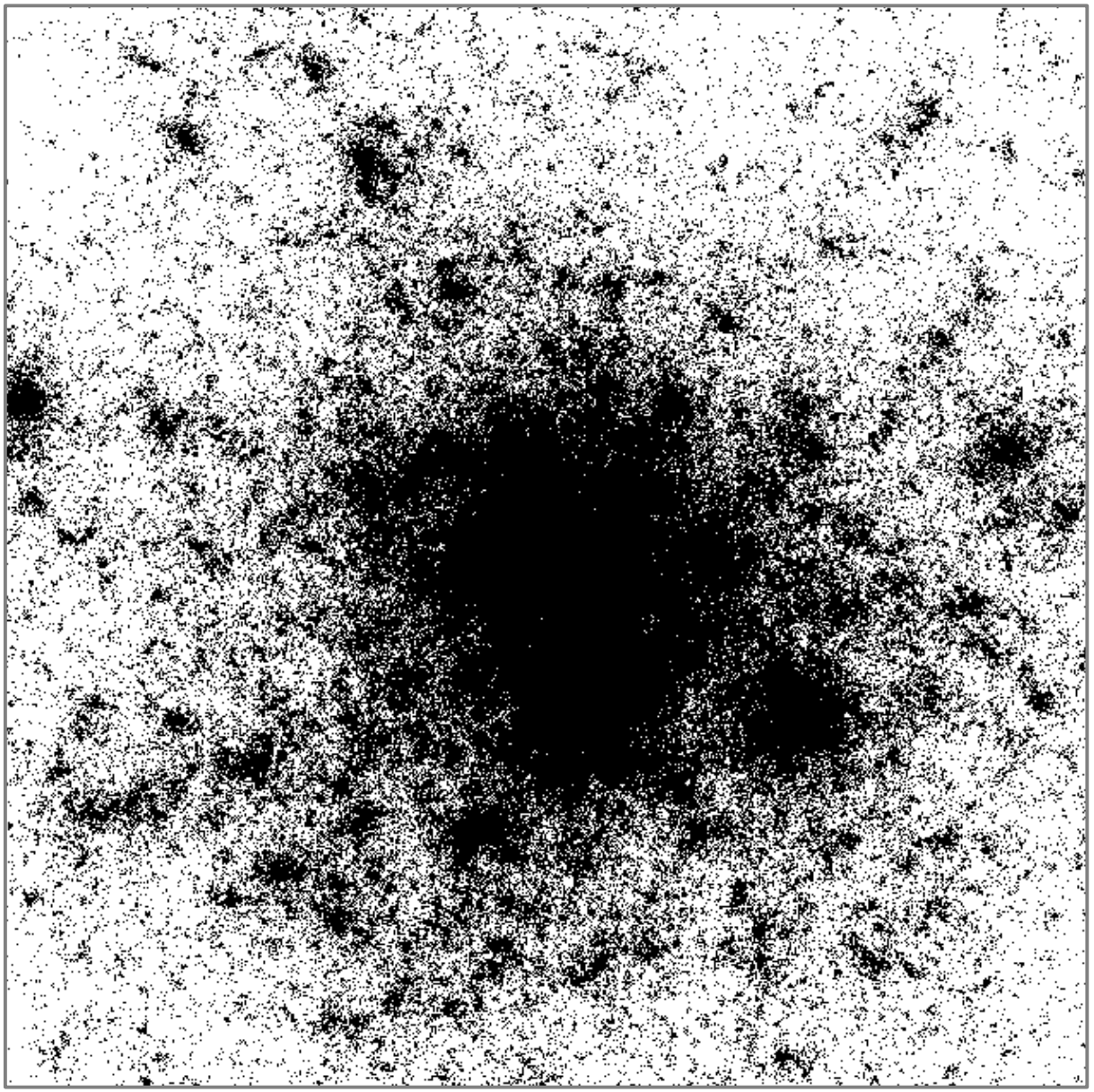
Example



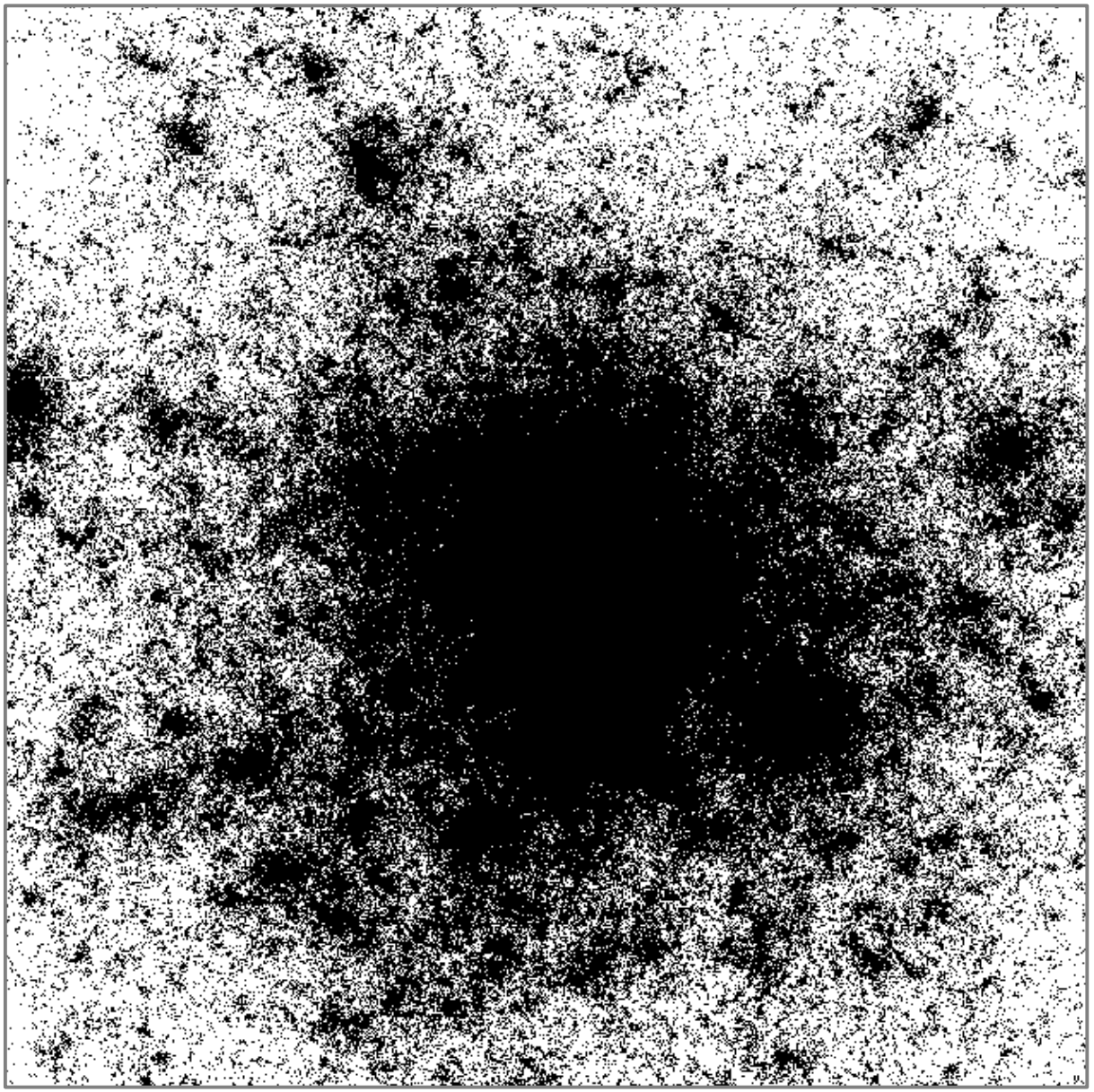
Example



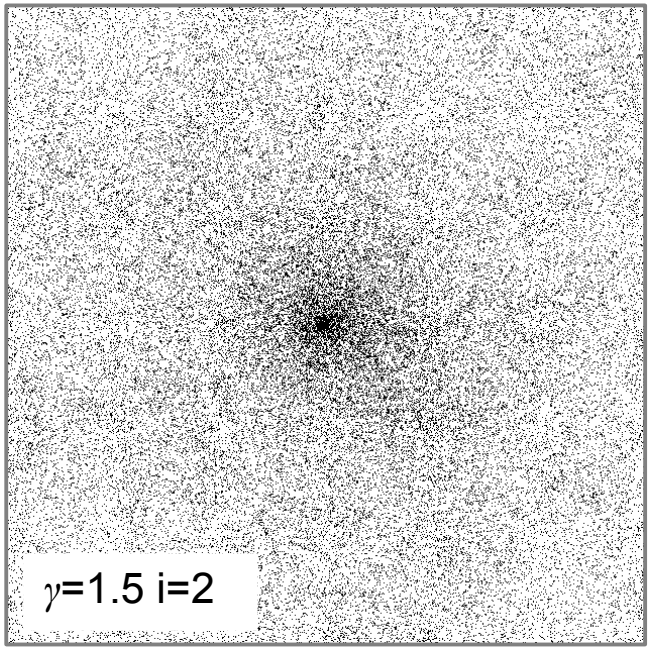
Example

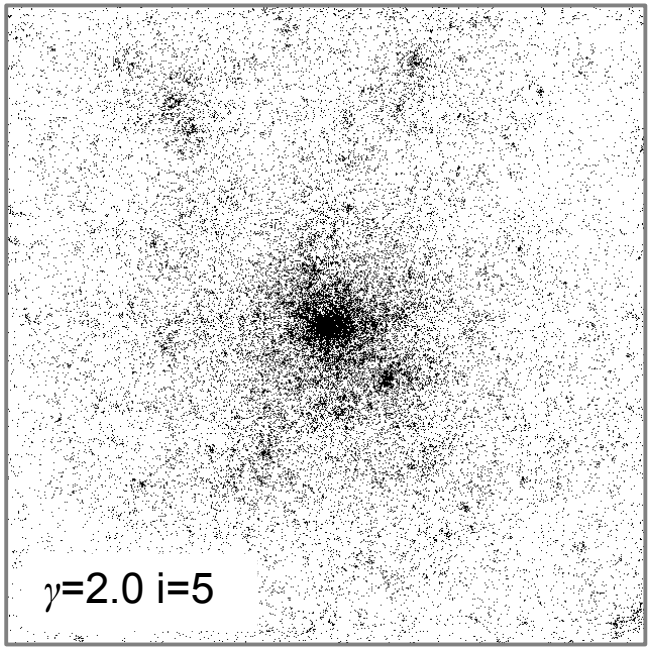


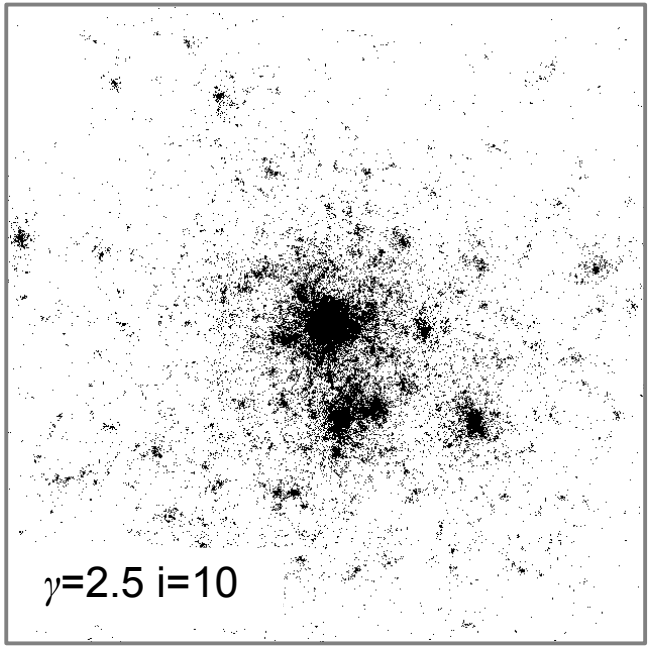
Example .. end

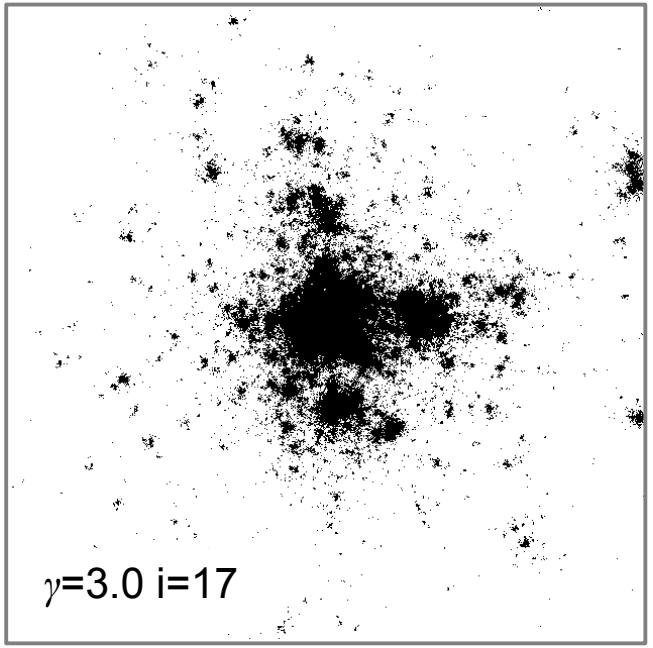


Exponent







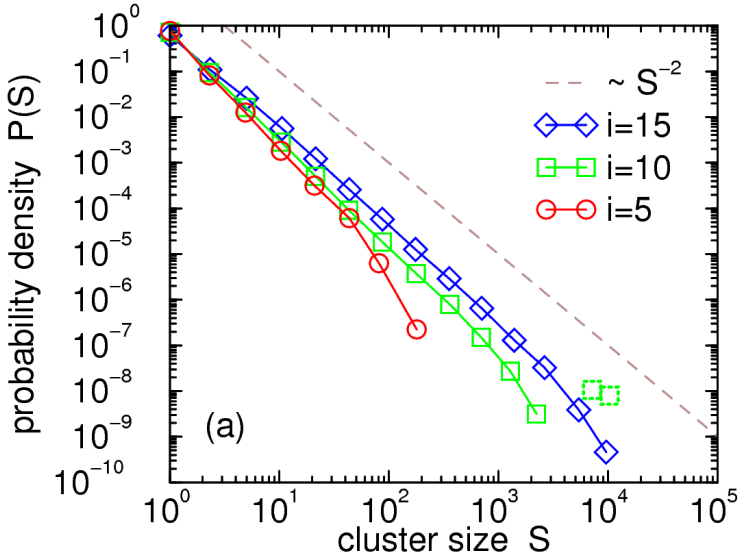


- small exponent fills faster

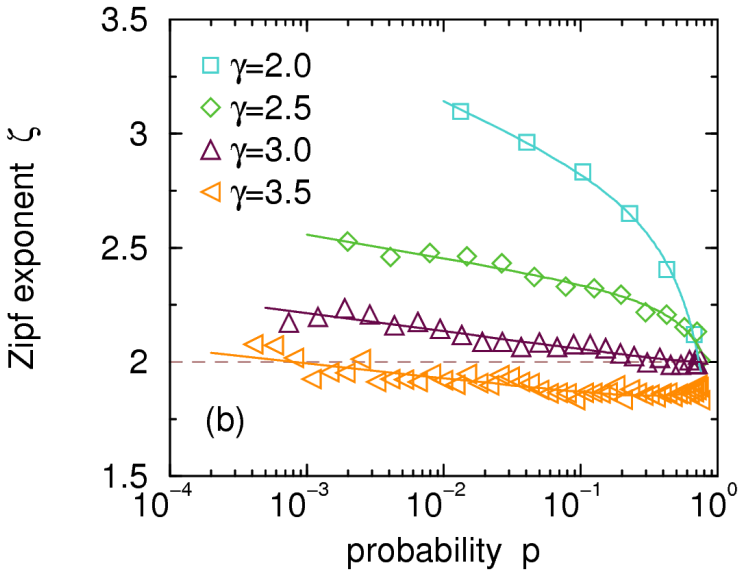
- large exponent more compact

- large exponent less rad. sym.

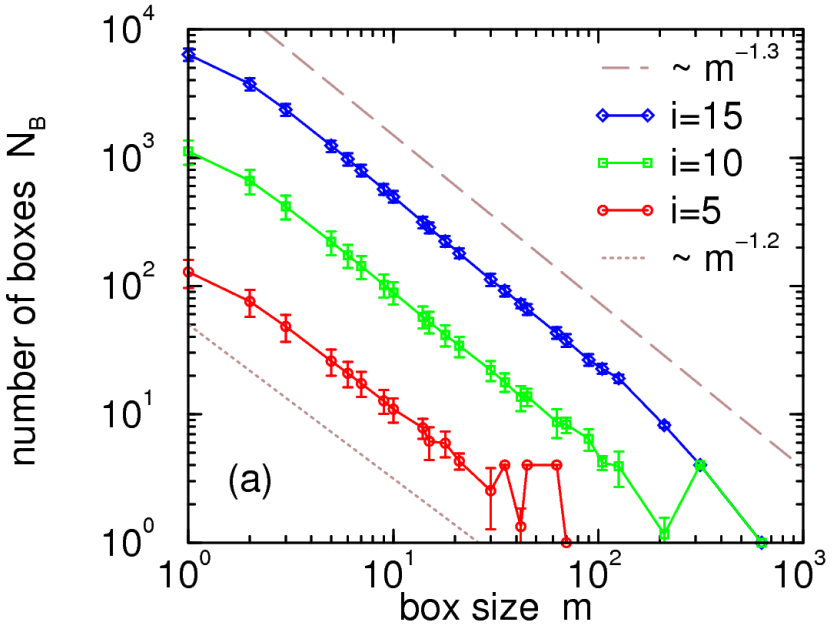
Cluster size distribution (without largest)

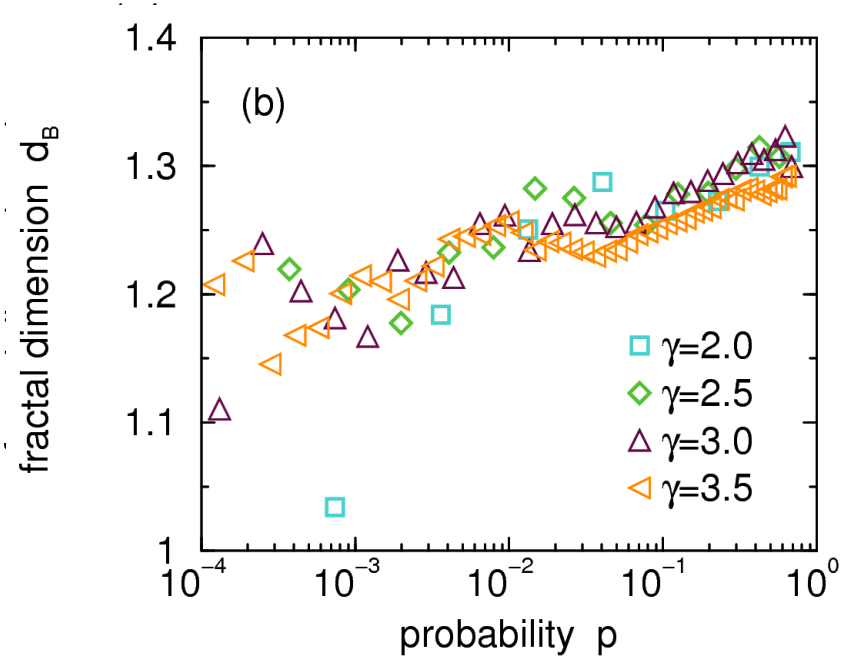


$$P(S) \sim S^{-\zeta}$$



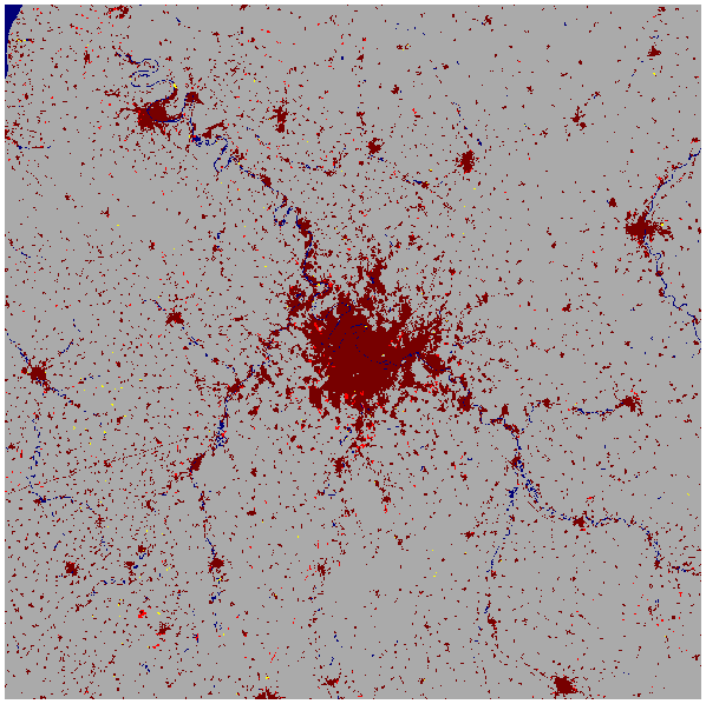
Fractal dimension of urban envelop: box covering



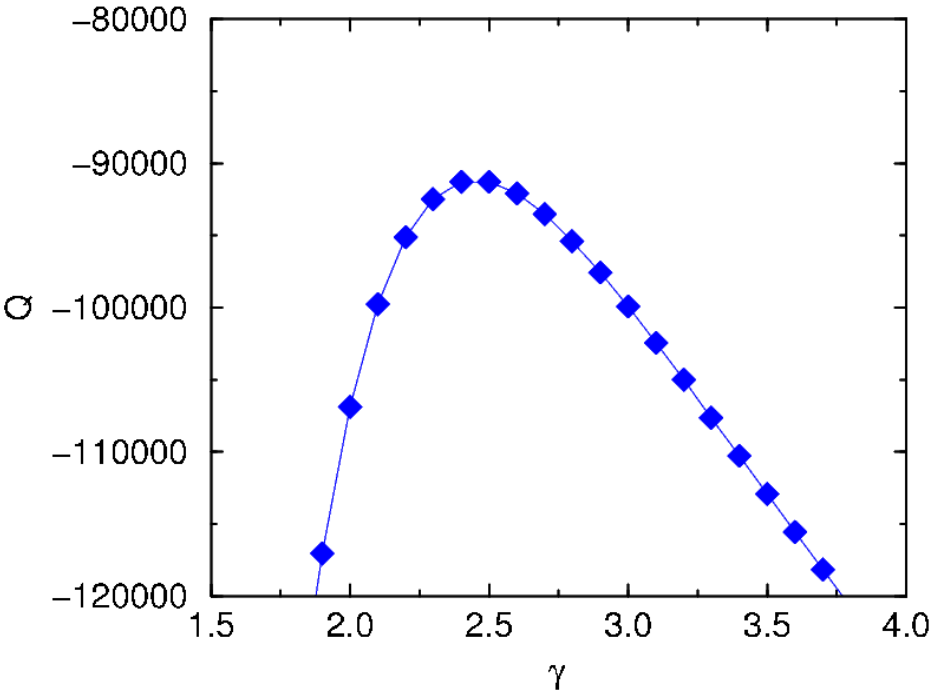


in qualitative agreement with literature

Estimating exponent in real data



Paris 2000-2006



log-likelihood

Summary

RAMSES
Reconciling Adaptation, Mitigation and Sustainable Development for Cities

H.D. Rozenfeld, D. Rybski, J.S. Andrade Jr., M. Batty, H.E. Stanley, H.A. Makse, *PNAS*, 2008
CCA, city growth (Zipf)

H.D. Rozenfeld, D. Rybski, X. Gabaix, H.A. Makse, *AER*, 2011
CCA, city-size (Gibrat)

D. Rybski, *Env. Plan. A*, 2013
Auerbach

D. Rybski, A.G.C. Ros, J.P. Kropp, *PRE*, 2013
Gravitational model

B. Zhou, D. Rybski, J.P. Kropp, submitted
Urban Heat Island

T. Fluschnik, S. Kriewald, A.G.C. Ros, B. Zhou, D.E. Reusser, J.P. Kropp, D. Rybski, in preparation
land cover, percolation

Thank you for your attention

http://diego.rybski.de/

http://www.pik-potsdam.de/members/rybski/