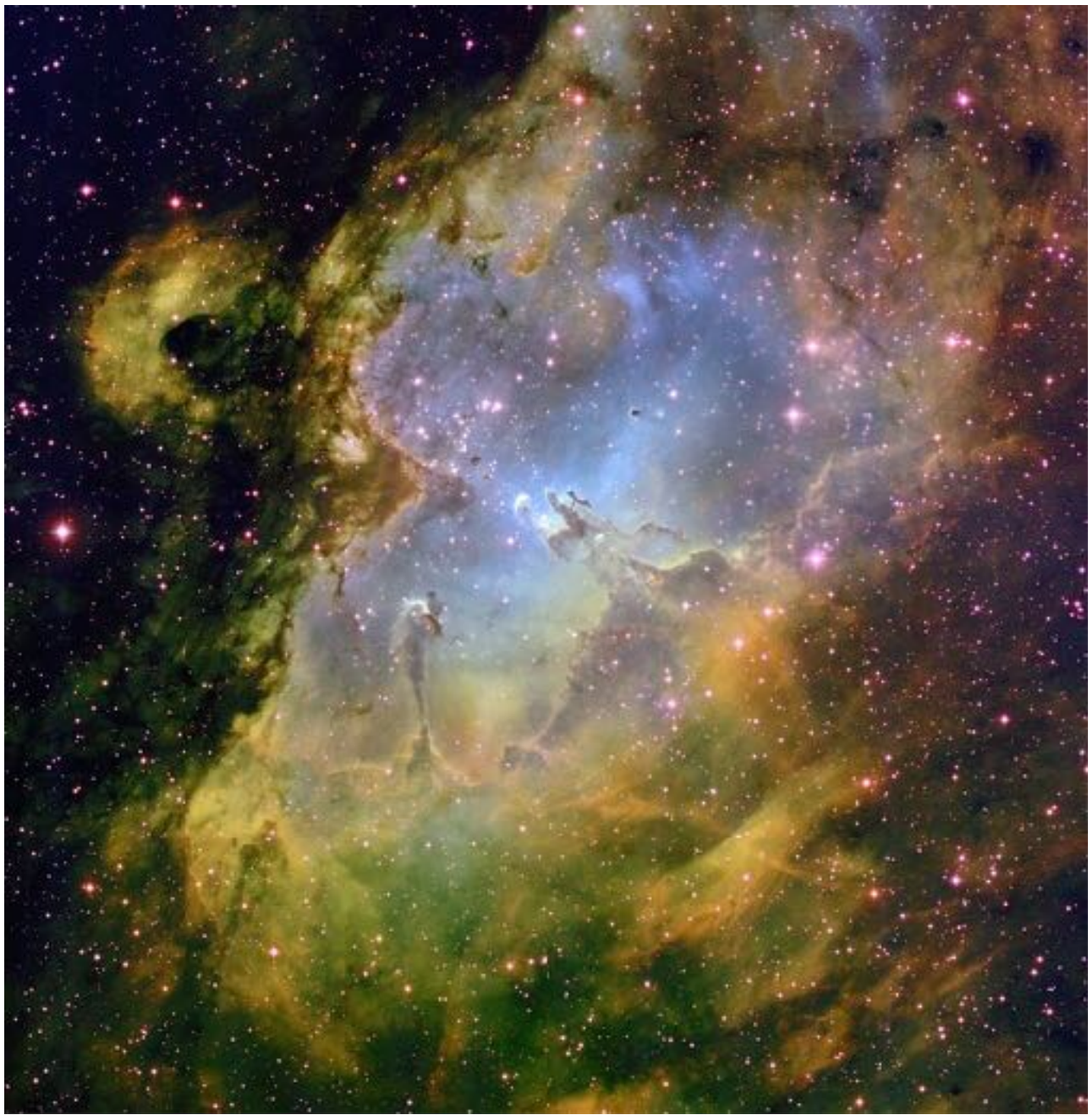
Measuring a dynamical aspect of DM - the velocity anisotropy



Steen H. Hansen,
Dark Cosmology Centre,
Niels Bohr Institute,

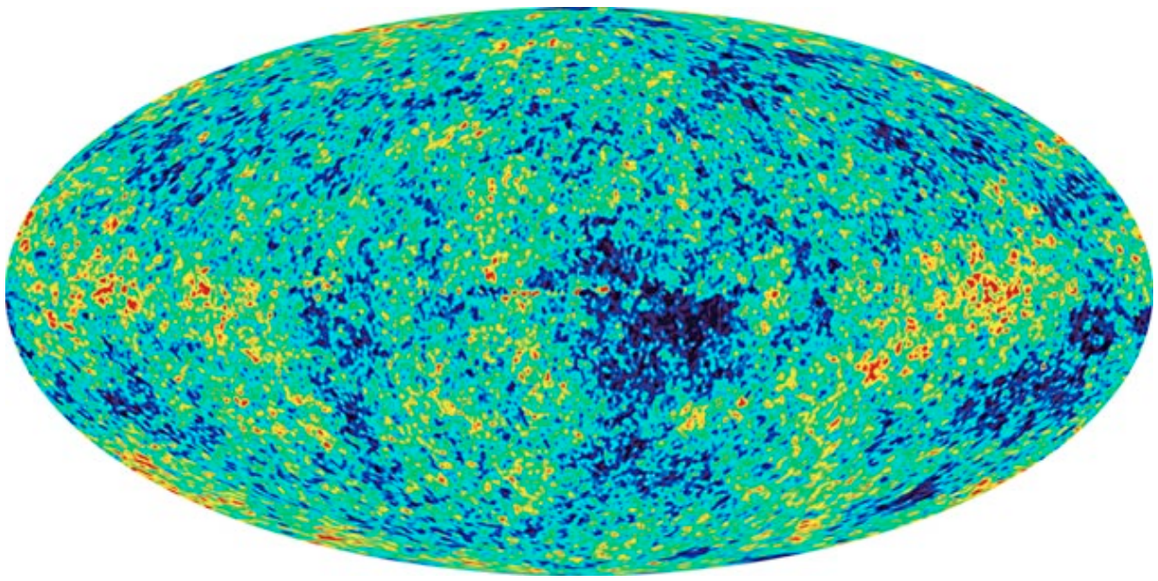
Melbourne

March, 2017

Dark Cosmology Centre

Steen H. Hansen
Dark Cosmology Centre

A numerical simulation



Initial conditions from the very young universe

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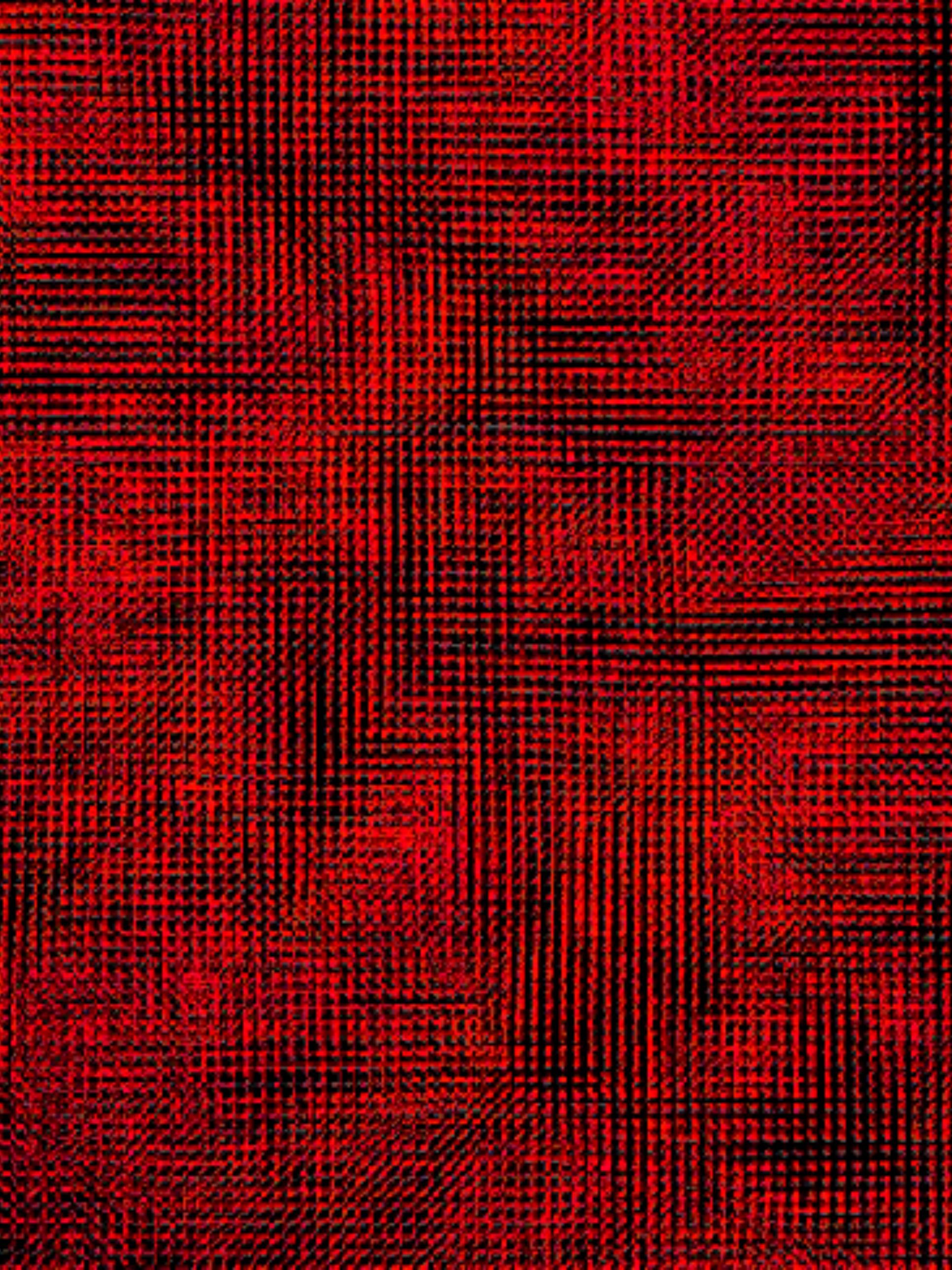
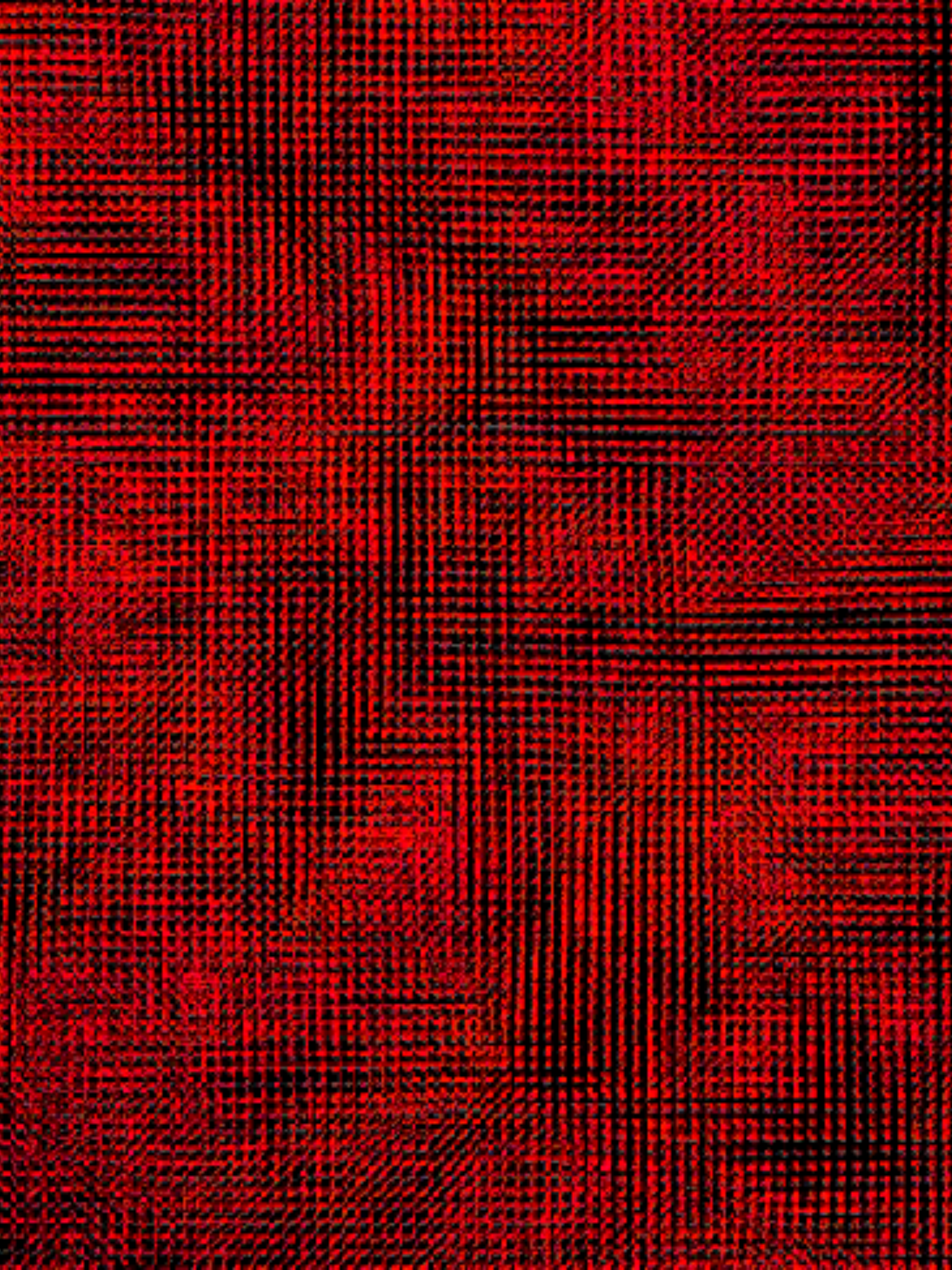
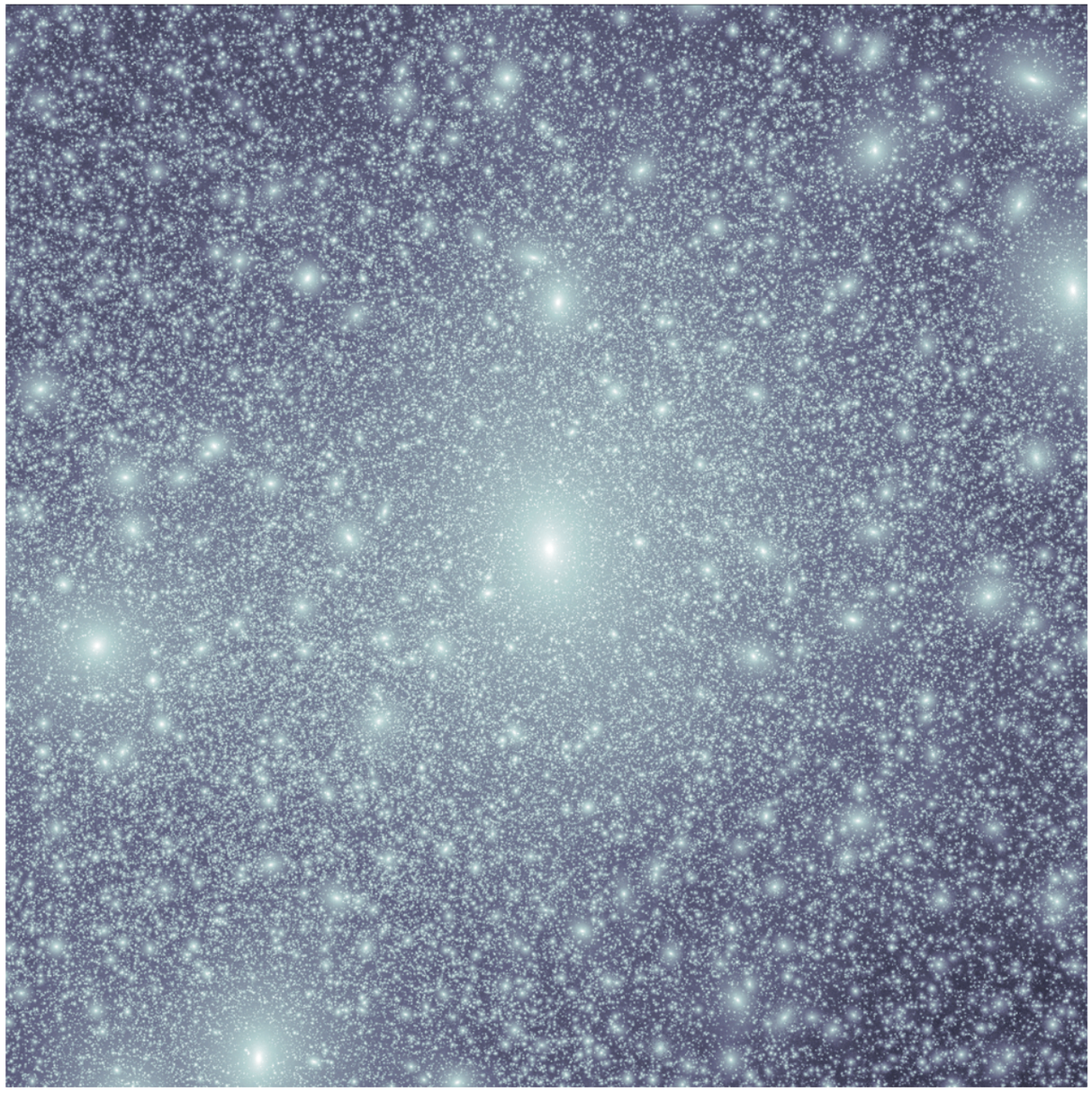
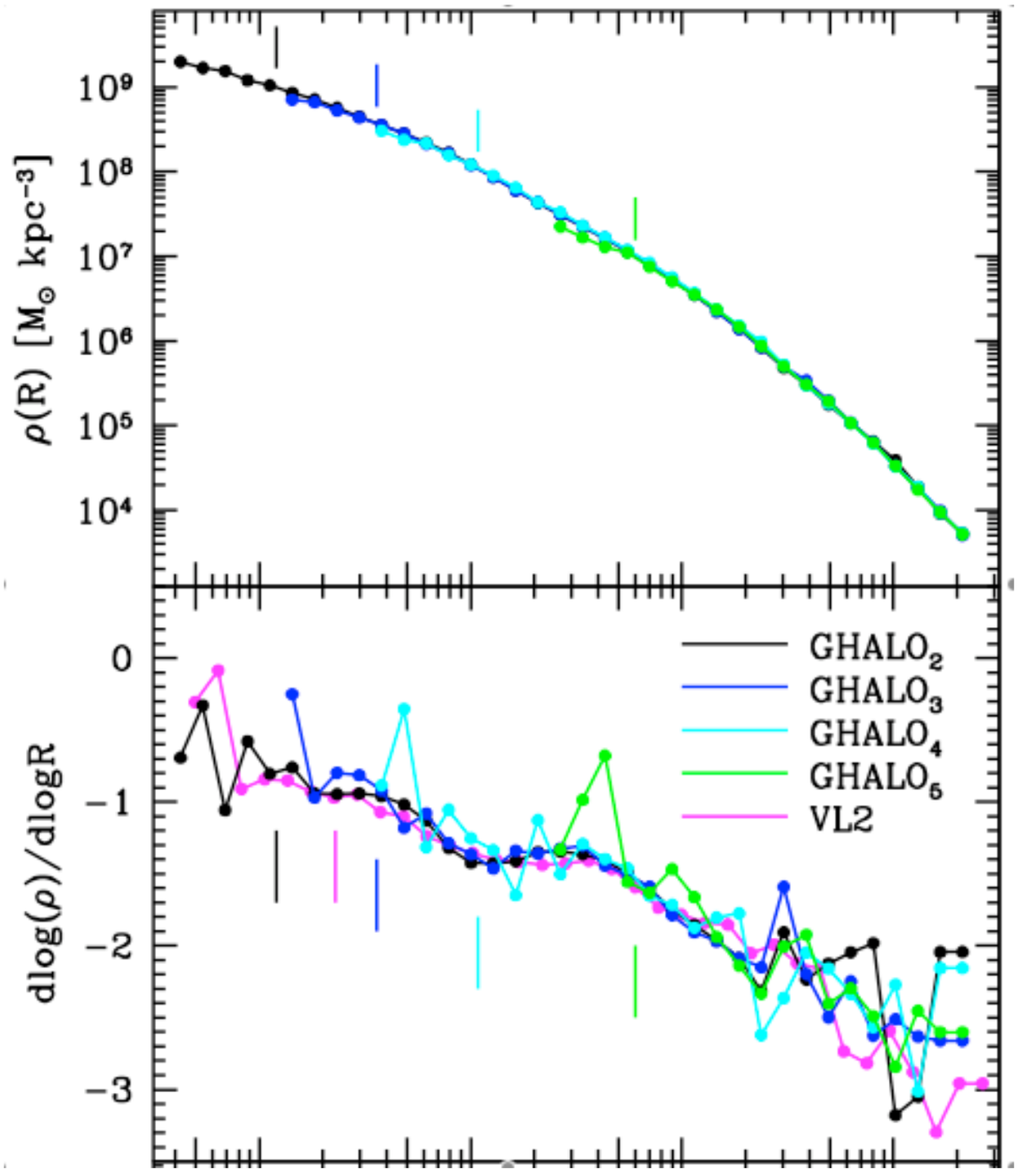




Simulated density-profiles





Stadel et al. 2008

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Observed galaxy cluster

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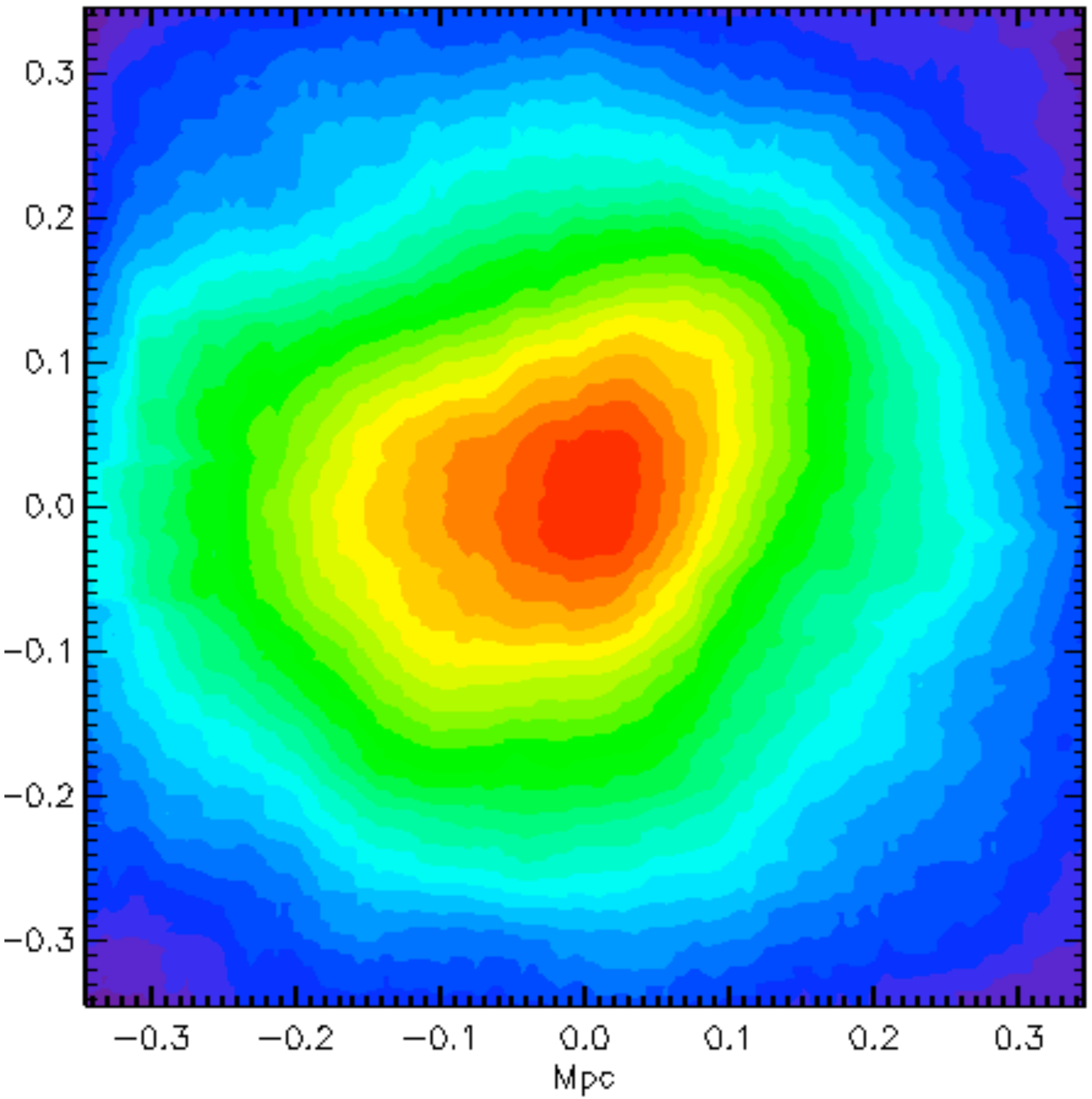

Hansen
nology Centre

X-ray is easy

Hydrostatic equilibrium

$$\frac{GM_{\rm tot}}{r} = -\frac{k_B T}{\mu m_p}\left(\frac{d\ln T}{d\ln r} + \frac{d\ln n_e}{d\ln r}\right)$$

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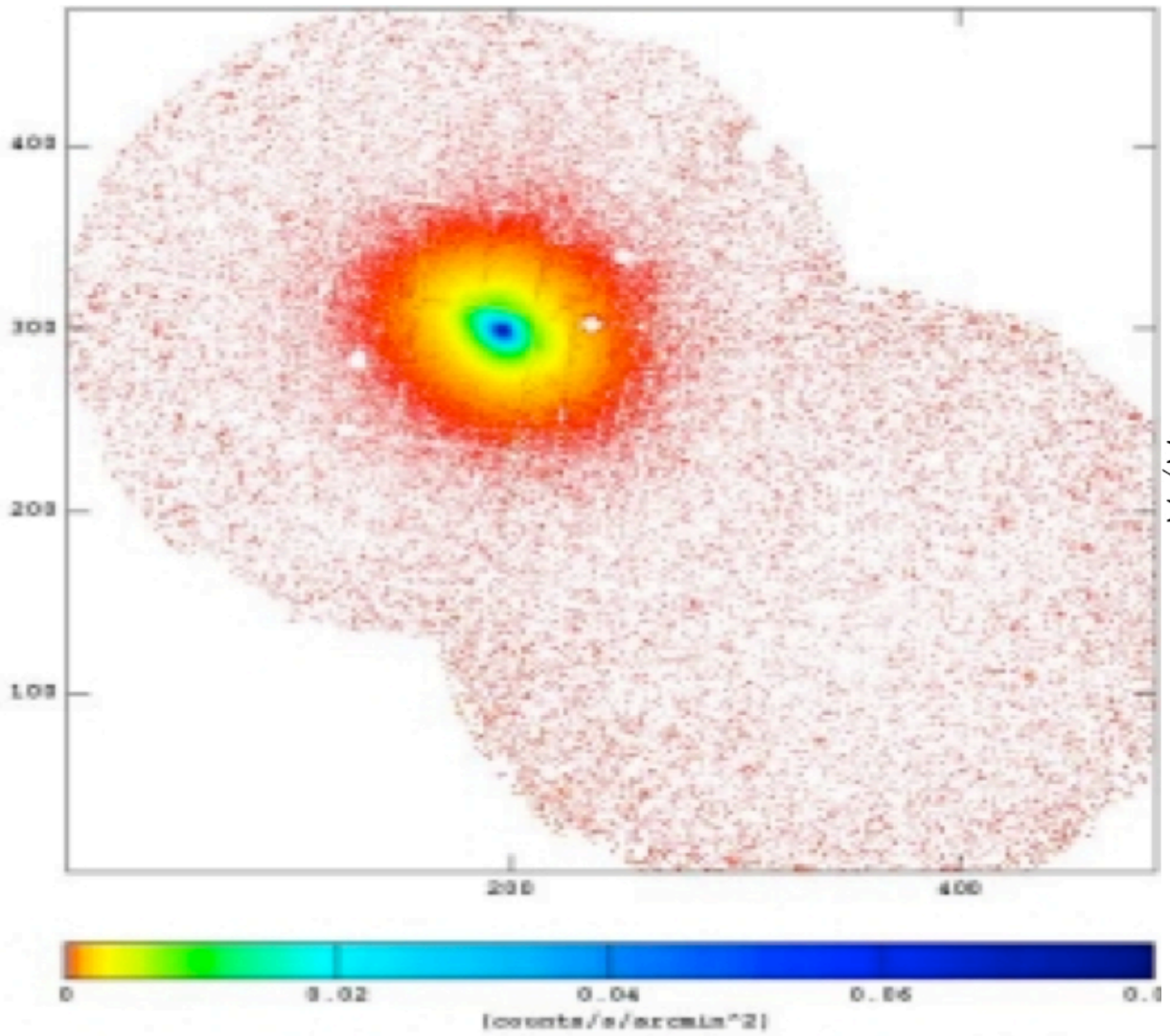
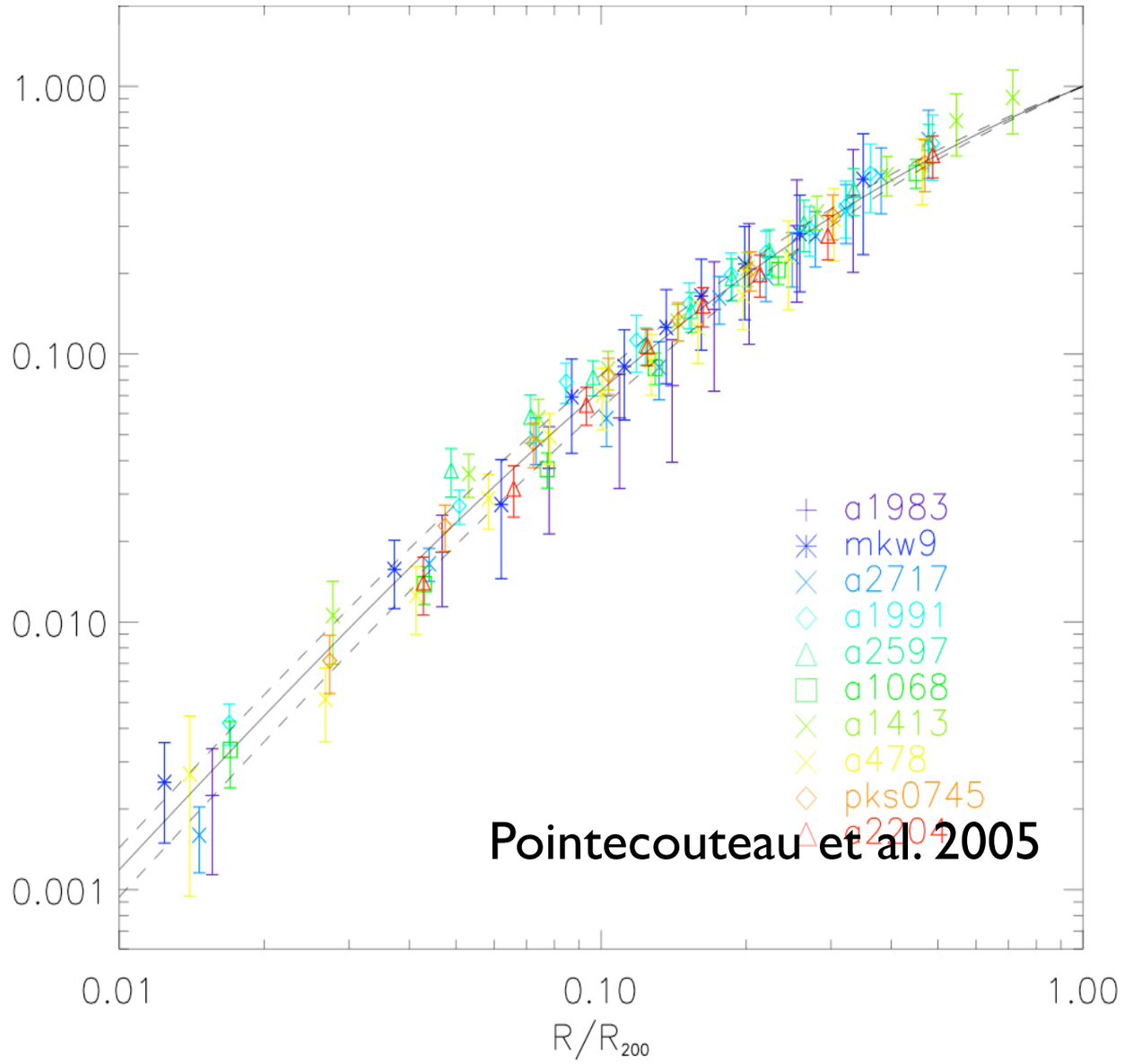
Observed mass-profiles

X-ray





Pointecouteau et al. 2005

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What is the DM velocity anisotropy?

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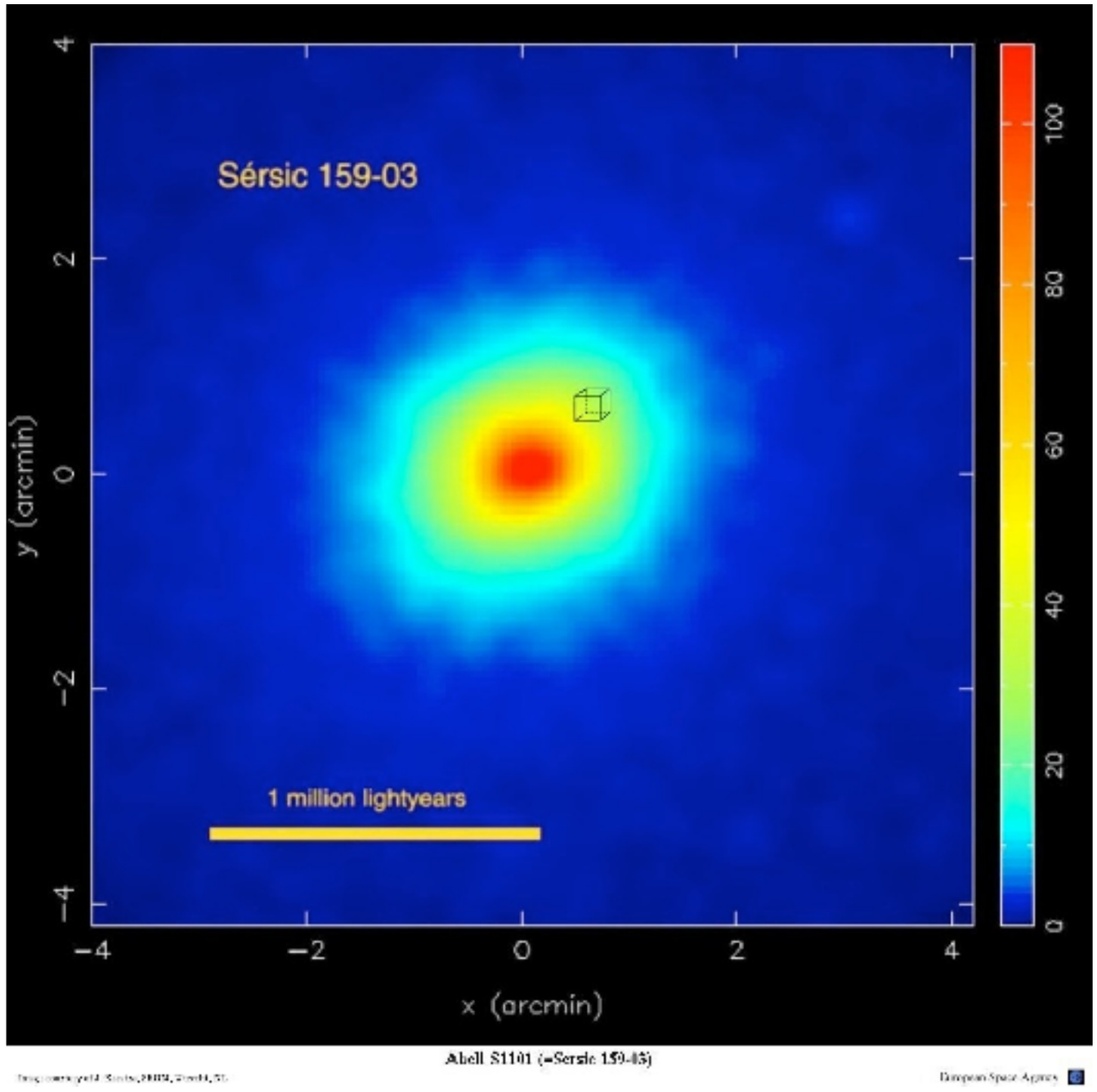
Velocity anisotropy profiles

velocity anisotropy = "different temperature in different directions"

$$\beta = 1 - \frac{\sigma_{\rm tan}^2}{\sigma_{\rm rad}^2}$$

Must be 0 for a gas!



Abell S1101 (=Sersic 159-03)

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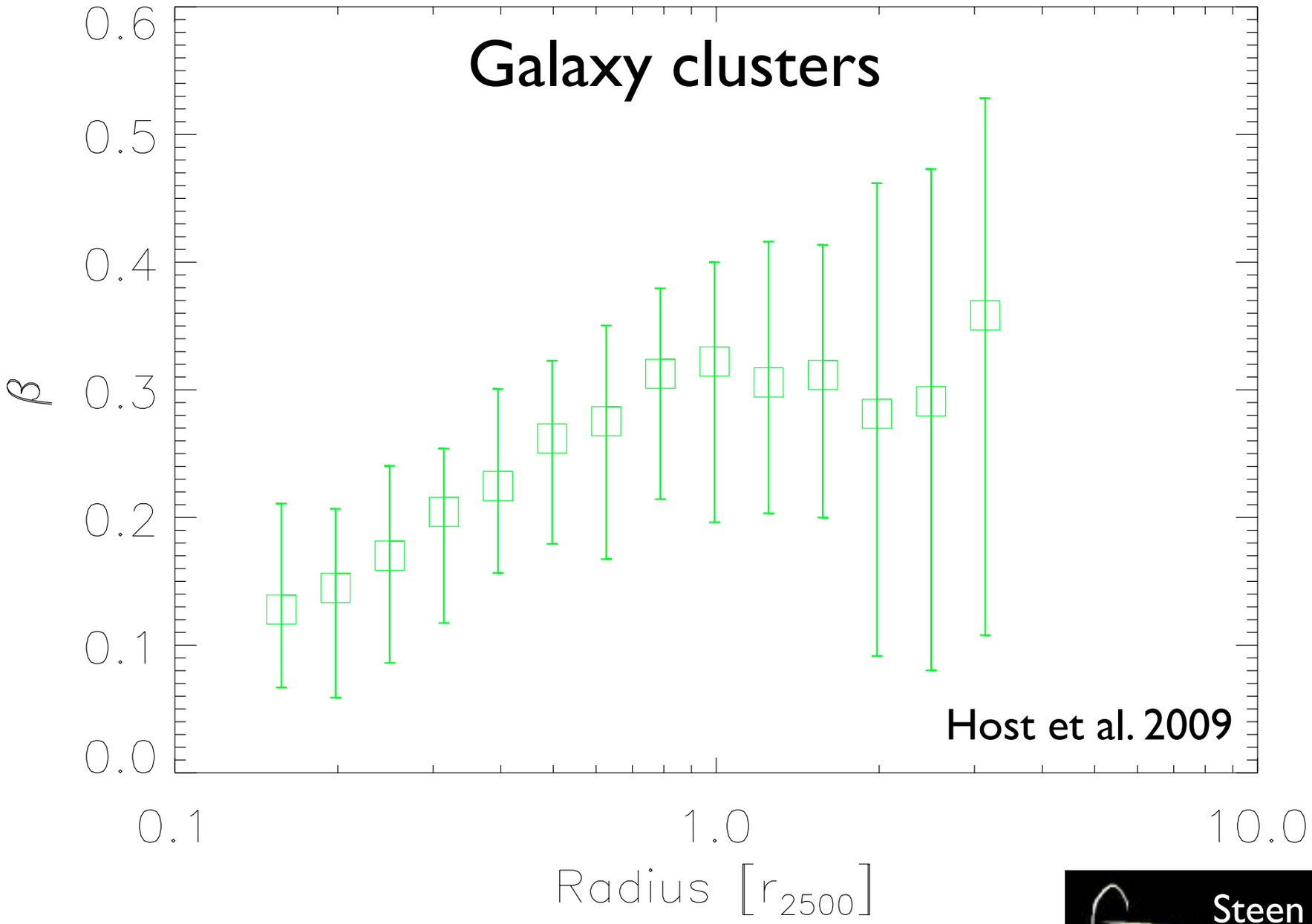
Simulated velocity anisotropy



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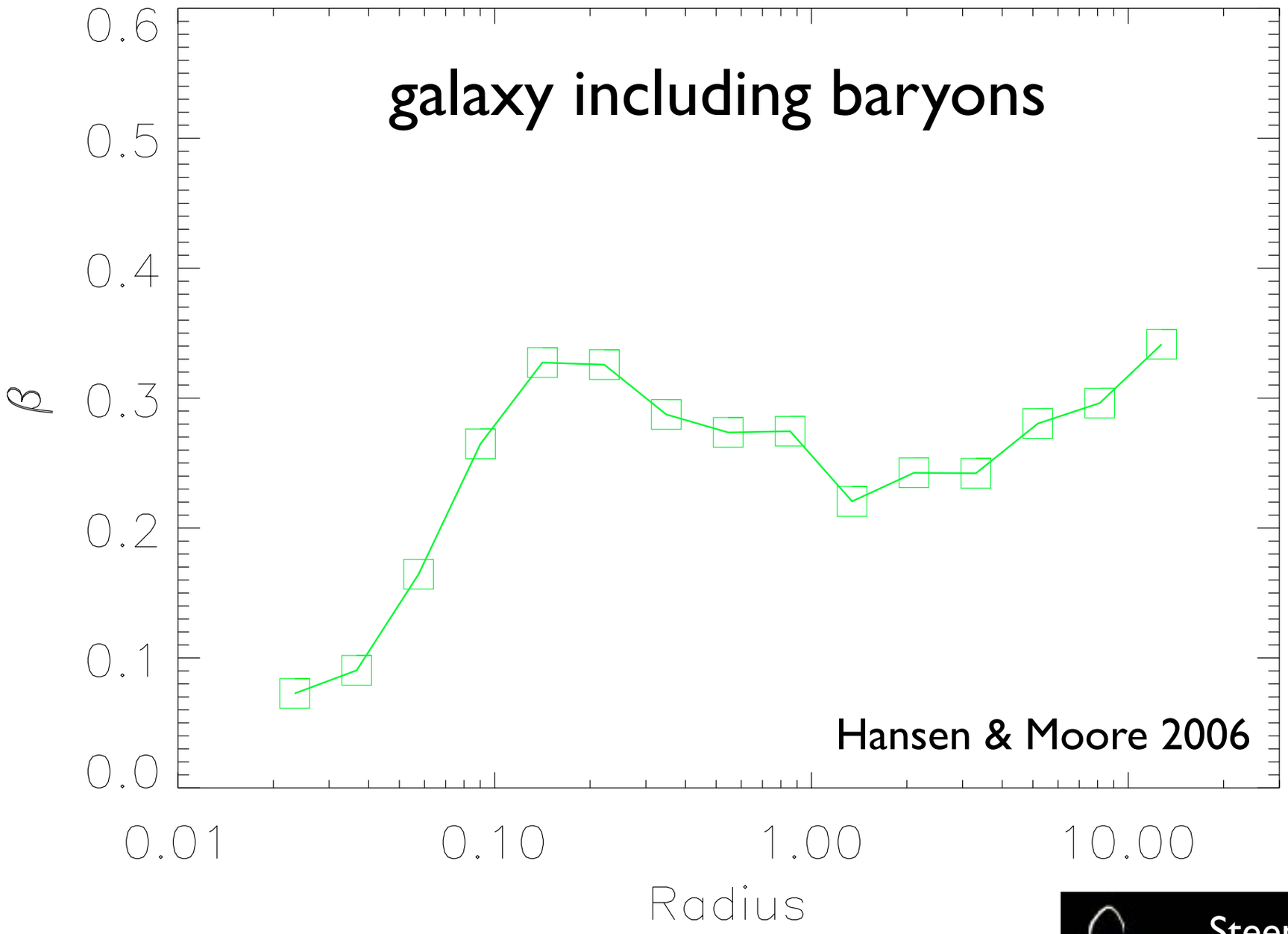
Simulated velocity anisotropy



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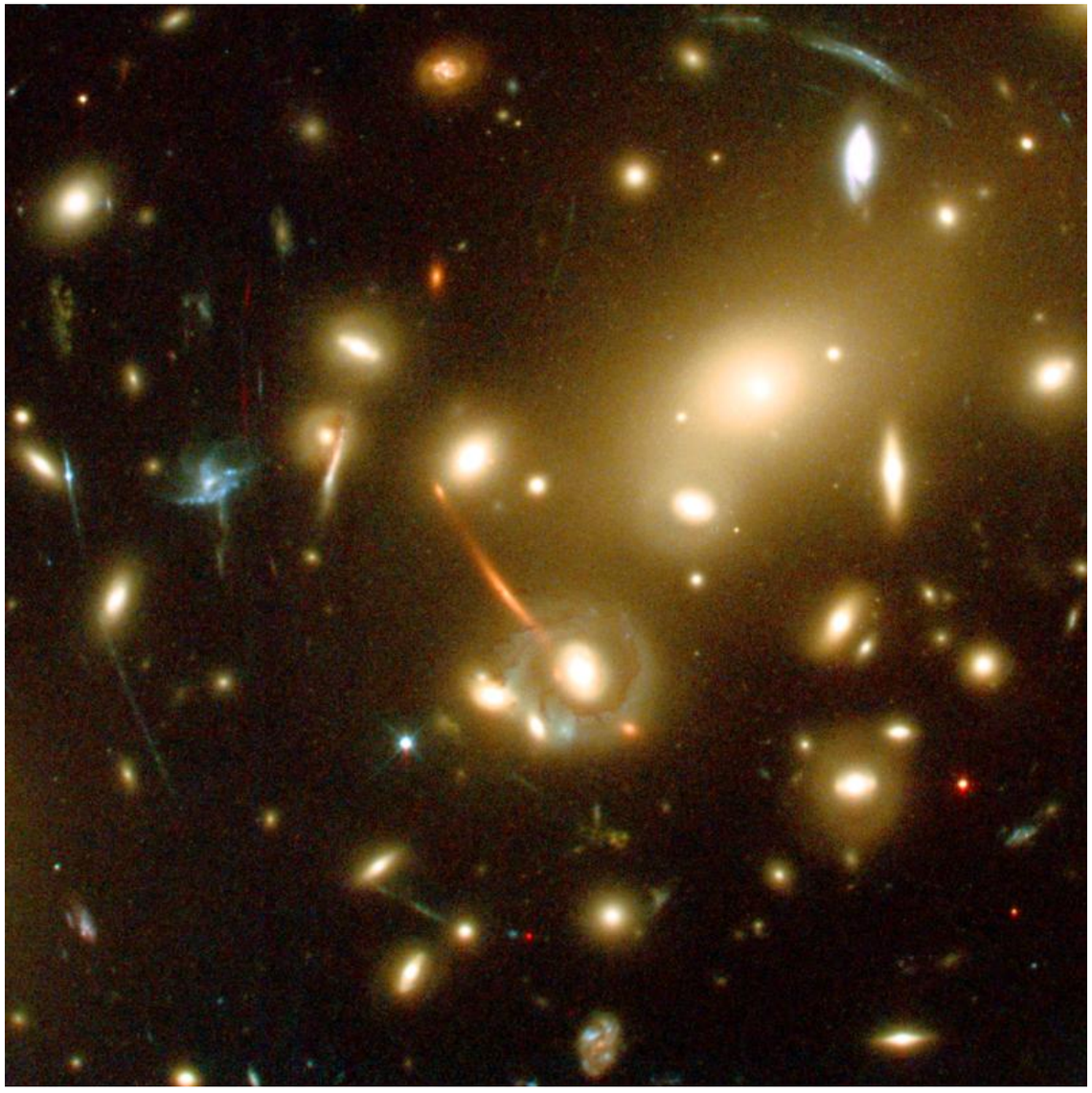
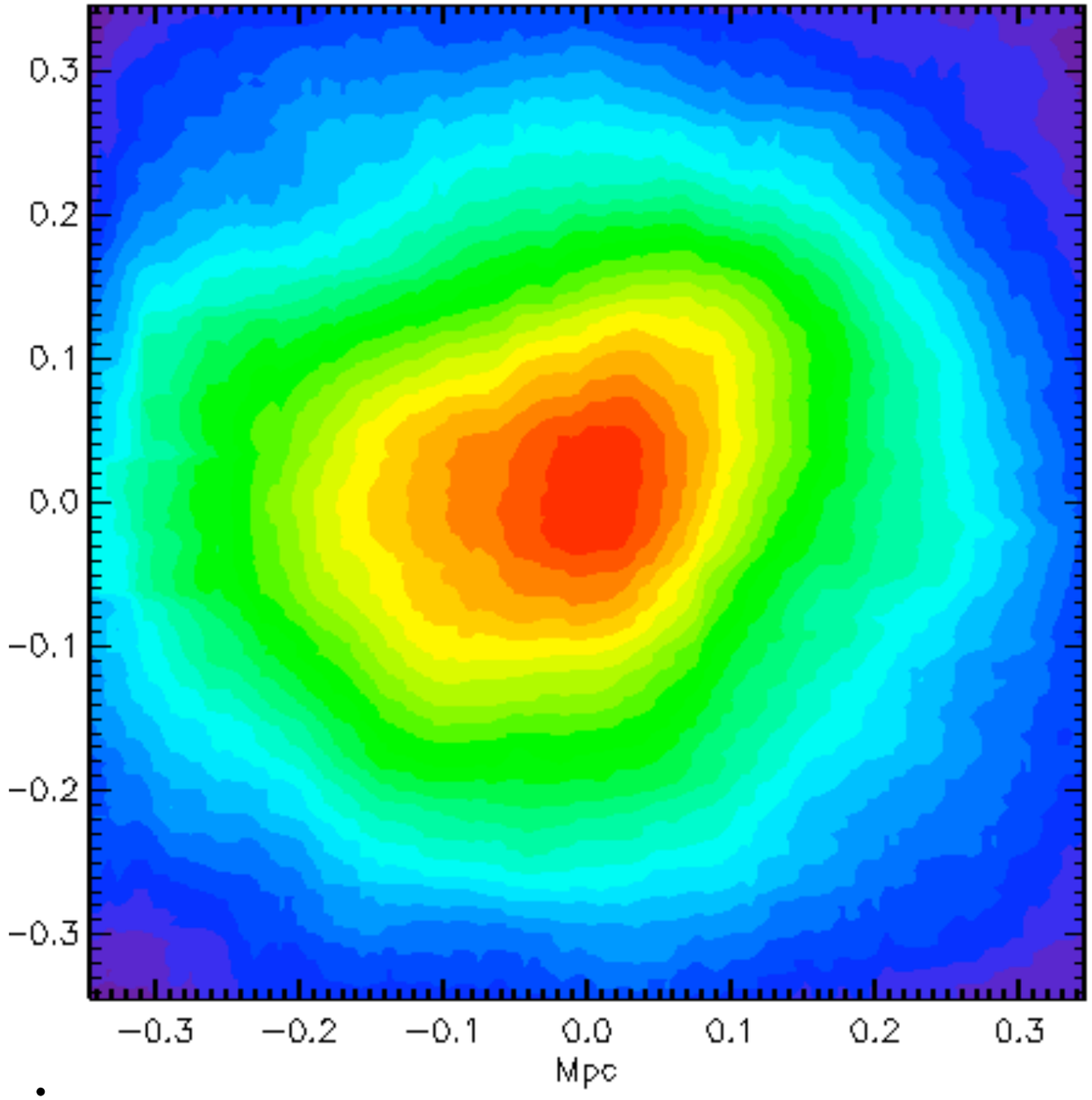
Observed velocity anisotropy





Galaxy cluster in equilibrium

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Dark Cosmology Centre

Observed velocity anisotropy

Hydrostatic equilibrium (gas)

$$\frac{GM_{\rm tot}}{r} = -\frac{k_B T}{\mu m_p}\left(\frac{d{\rm ln}T}{d{\rm ln}r} + \frac{d{\rm ln}n_e}{d{\rm ln}r}\right)$$

Jeans equation (dark matter)

$$\frac{GM_{\rm tot}}{r} = -\sigma_r^2\left(\frac{d{\rm ln}\sigma_r^2}{d{\rm ln}r} + \frac{d{\rm ln}\rho}{d{\rm ln}r} + 2\beta\right)$$

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Observed velocity anisotropy

Hydrostatic equilibrium (gas)

$$\frac{GM_{\rm tot}}{r} = -\frac{k_B T}{\mu m_p}\left(\frac{d{\rm ln}T}{d{\rm ln}r} + \frac{d{\rm ln}n_e}{d{\rm ln}r}\right)$$

Jeans equation (dark matter)

$$\frac{GM_{\rm tot}}{r} = -\sigma_r^2\left(\frac{d{\rm ln}\sigma_r^2}{d{\rm ln}r} + \frac{d{\rm ln}\rho}{d{\rm ln}r} + 2\beta\right)$$

If $\frac{T}{\sigma^2_{\rm tot}} \approx 1$, then we can solve for β

Hansen & Piffaretti 2007

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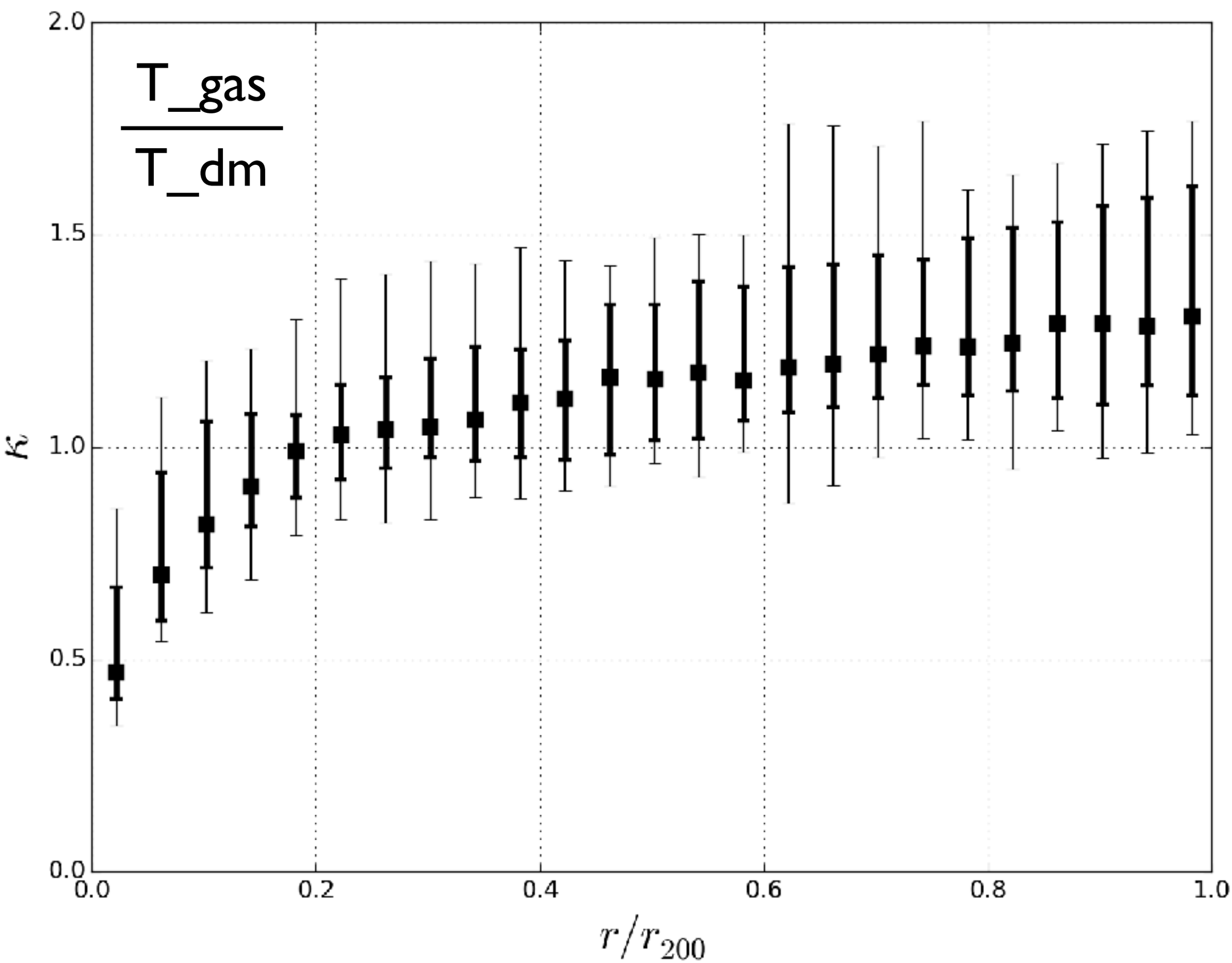
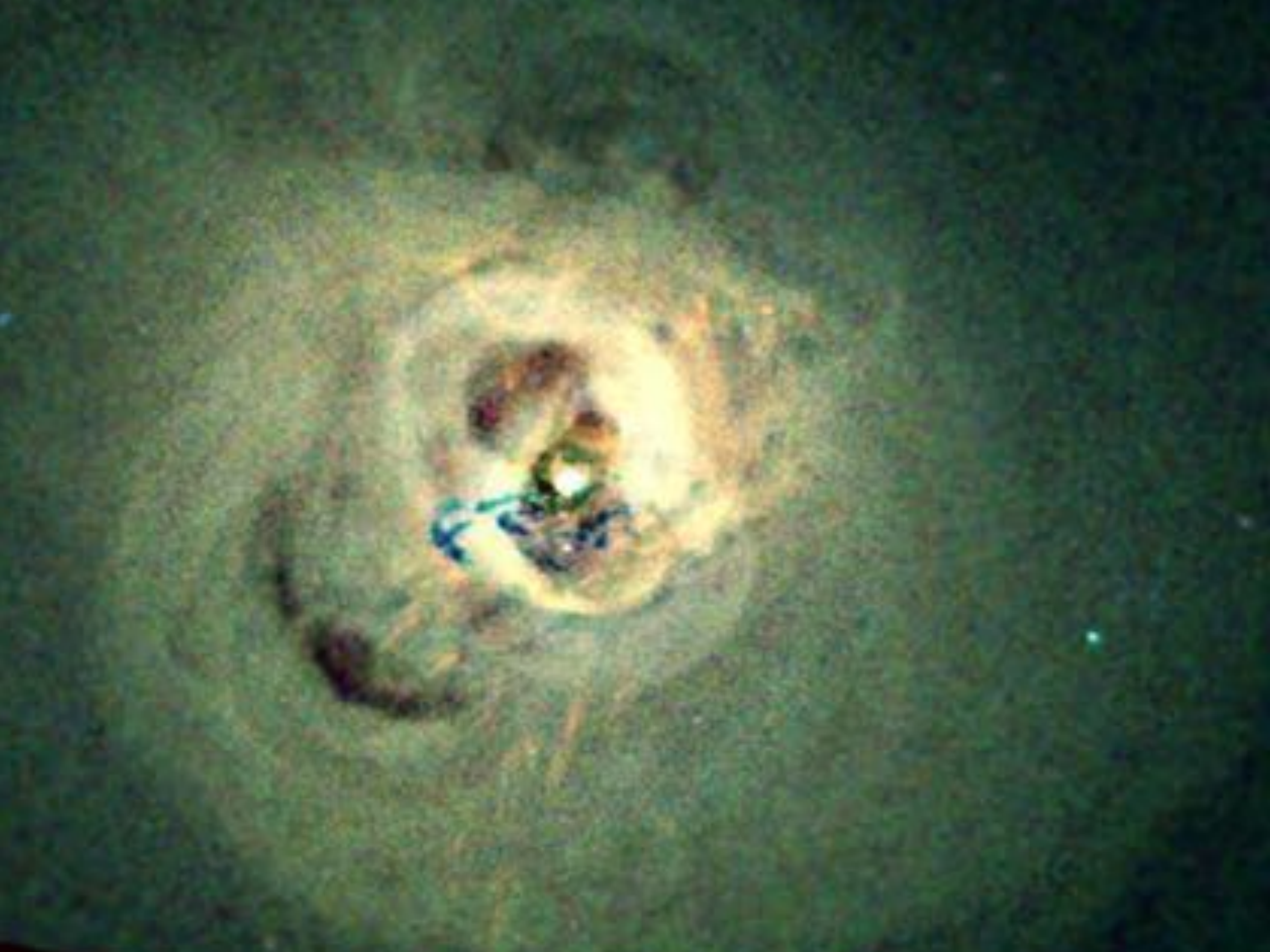
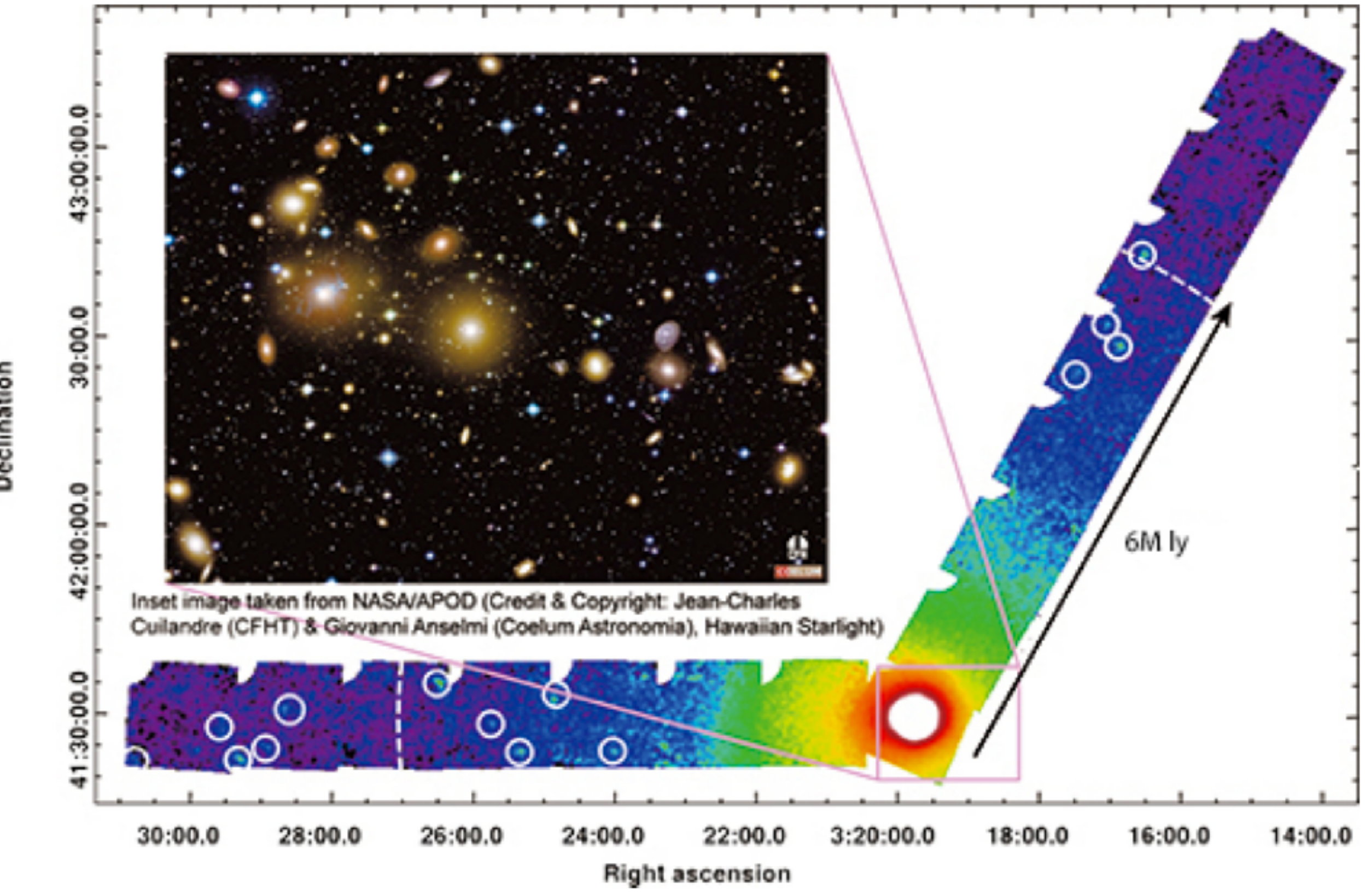
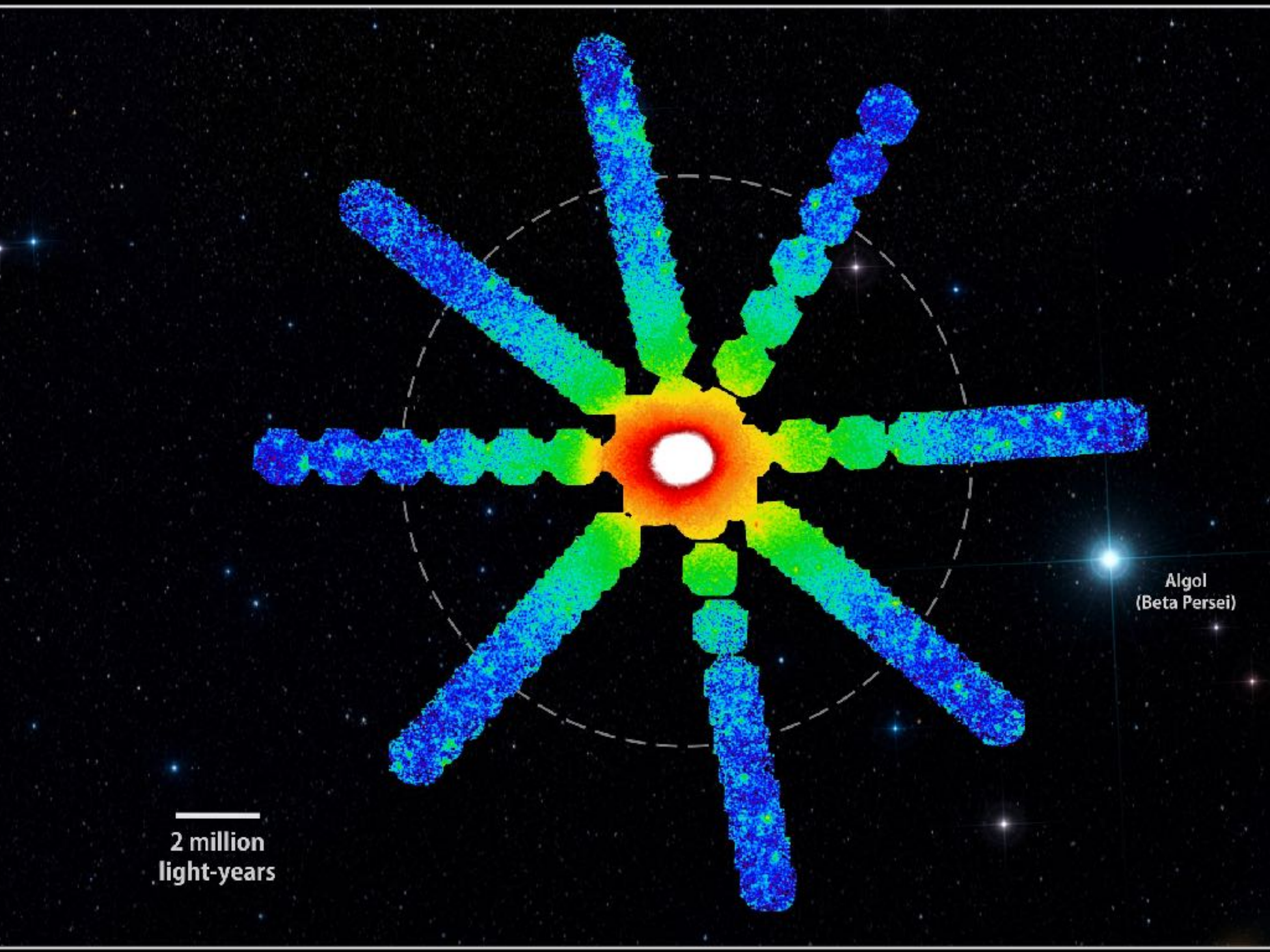
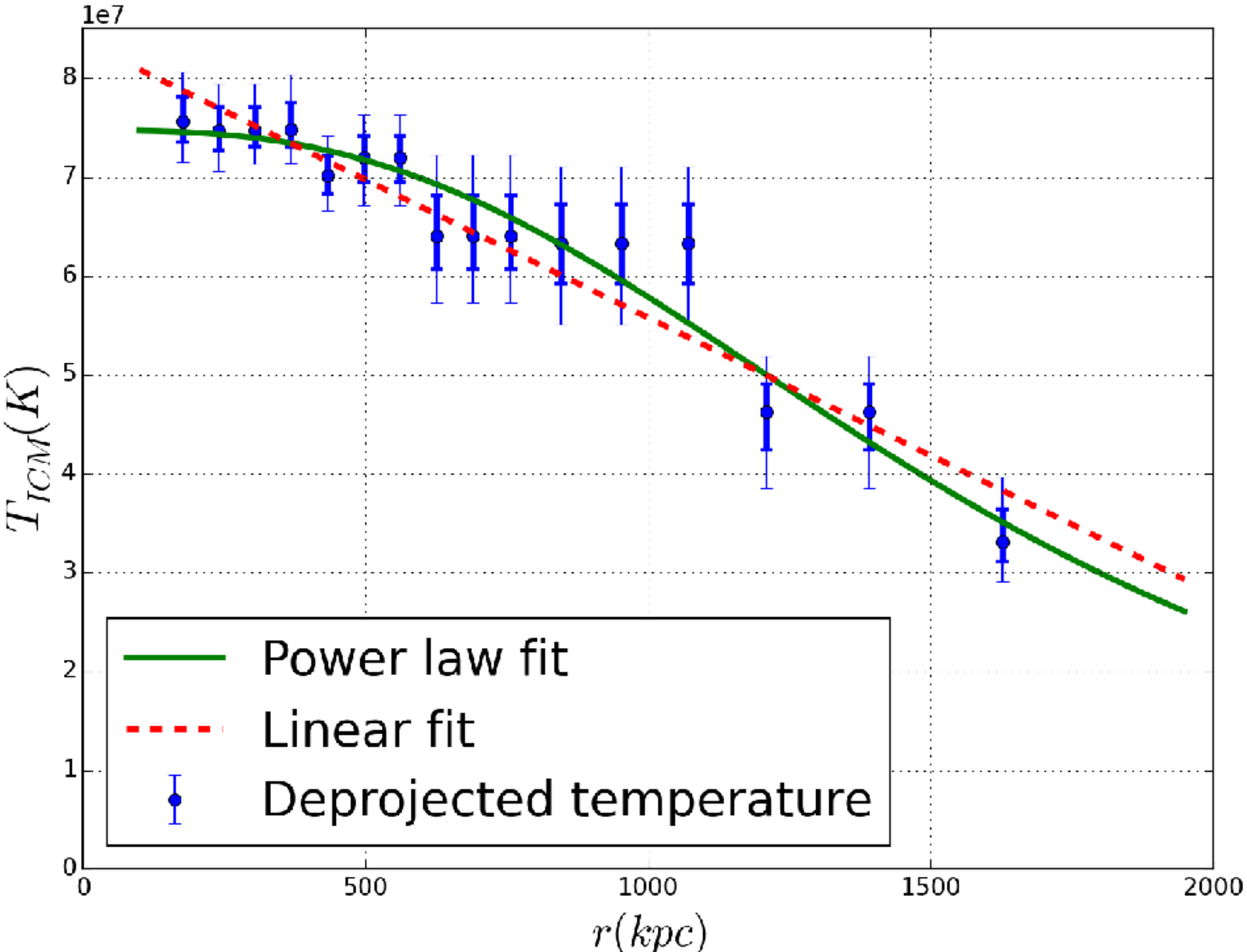

T_gas
T_dm
2.0
1.5
1.0
0.5
0.0
κ
0.0
0.2
0.4
0.6
0.8
1.0
r/r_{200}

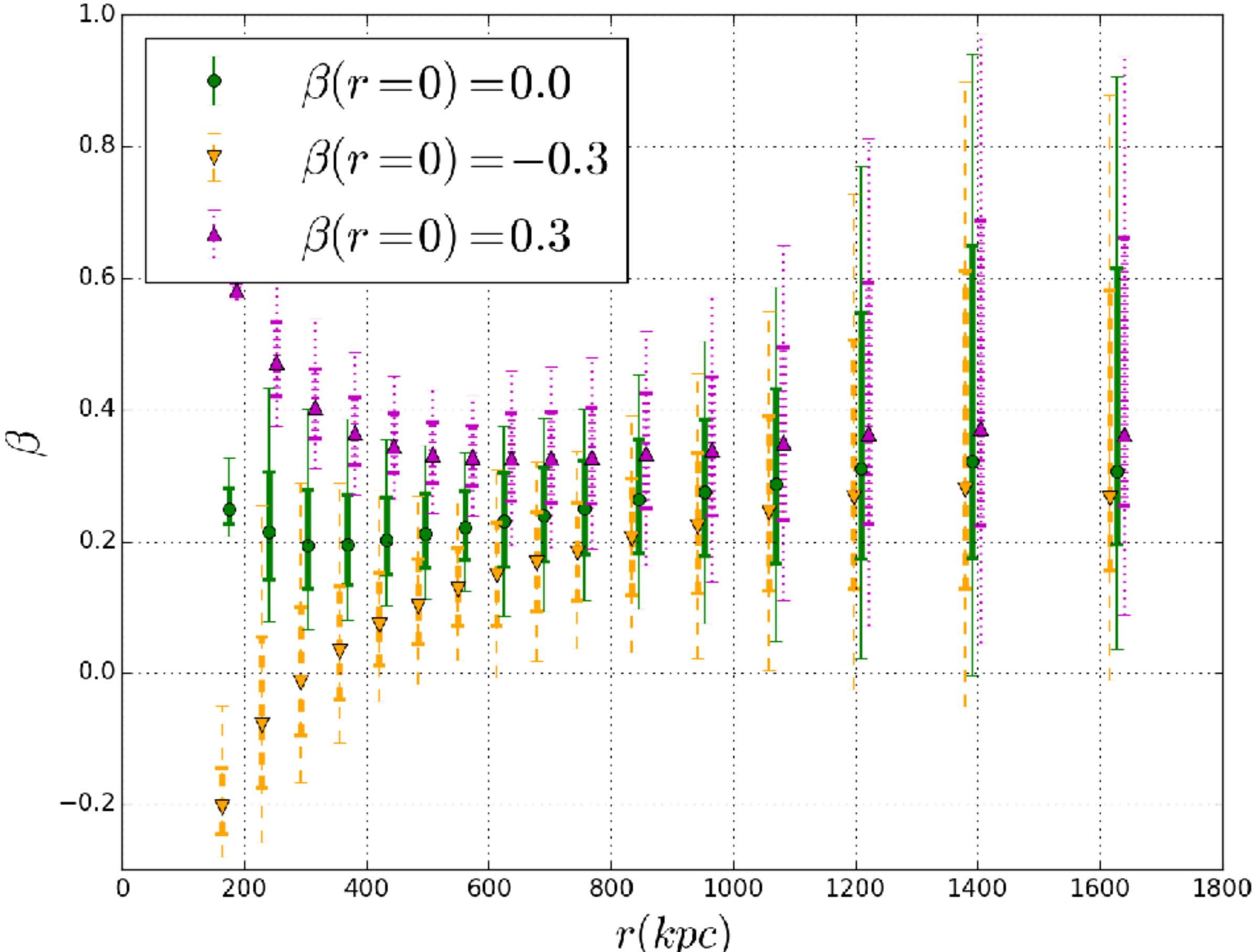


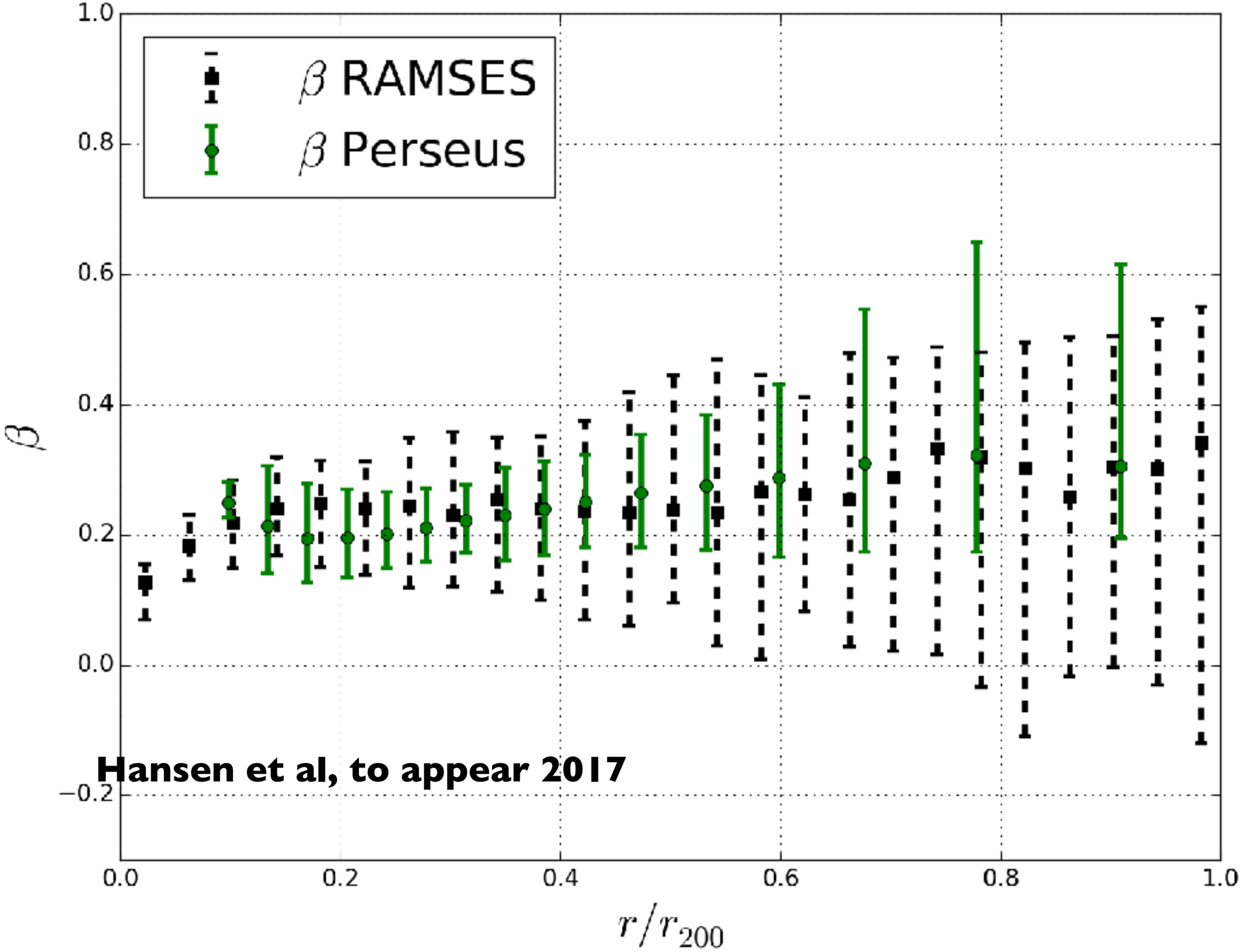

Declination
43:00:00.0
42:00:00.0
41:30:00.0
30:00.0
28:00.0
26:00.0
24:00.0
22:00.0
3:20:00.0
18:00.0
16:00.0
14:00.0
Right ascension
6M ly
Inset image taken from NASA/APOD (Credit & Copyright: Jean-Charles Cuilandre (CFHT) & Giovanni Anselmi (Coelum Astronomia), Hawaiian Starlight)


Algol
(Beta Persei)
2 million
light-years


1e7
8
7
6
5
4
3
2
1
0
0
500
1000
1500
2000
$T_{ICM}(K)$
$r(kpc)$
Power law fit
Linear fit
Deprojected temperature

Power law fit
Linear fit
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
β
0
200
400
600
800
1000
1200
1400
1600
1800
$r(kpc)$


$\beta(r=0)=0.0$
$\beta(r=0)=-0.3$
$\beta(r=0)=0.3$
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
β
0
200
400
600
800
1000
1200
1400
1600
1800
$r(kpc)$


β RAMSES
β Perseus
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
β
0.0
0.2
0.4
0.6
0.8
1.0
r/r_{200}
Hansen et al, to appear 2017

So, that means...

Dark matter structures do not achieve equilibrium through collisions (as normal particles do)

Steen H. Hansen
Dark Cosmology Centre

So, that means...

Dark matter structures do not achieve equilibrium through collisions (as normal particles do)

Dark matter behaves fundamentally different from baryons

Steen H. Hansen
Dark Cosmology Centre

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Dark matter structures do not achieve equilibrium through collisions (as normal particles do)

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This observation gives us an upper limit on the DM-DM scattering cross section

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So, that means...

Dark matter structures do not achieve equilibrium through collisions (as normal particles do)

Dark matter behaves fundamentally different from baryons

Steen H. Hansen
Dark Cosmology Centre

So, that means...

Dark matter structures do not achieve equilibrium through collisions (as normal particles do)

Dark matter behaves fundamentally different from baryons

Dark matter does **not** have an equation of state!

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End of part I …

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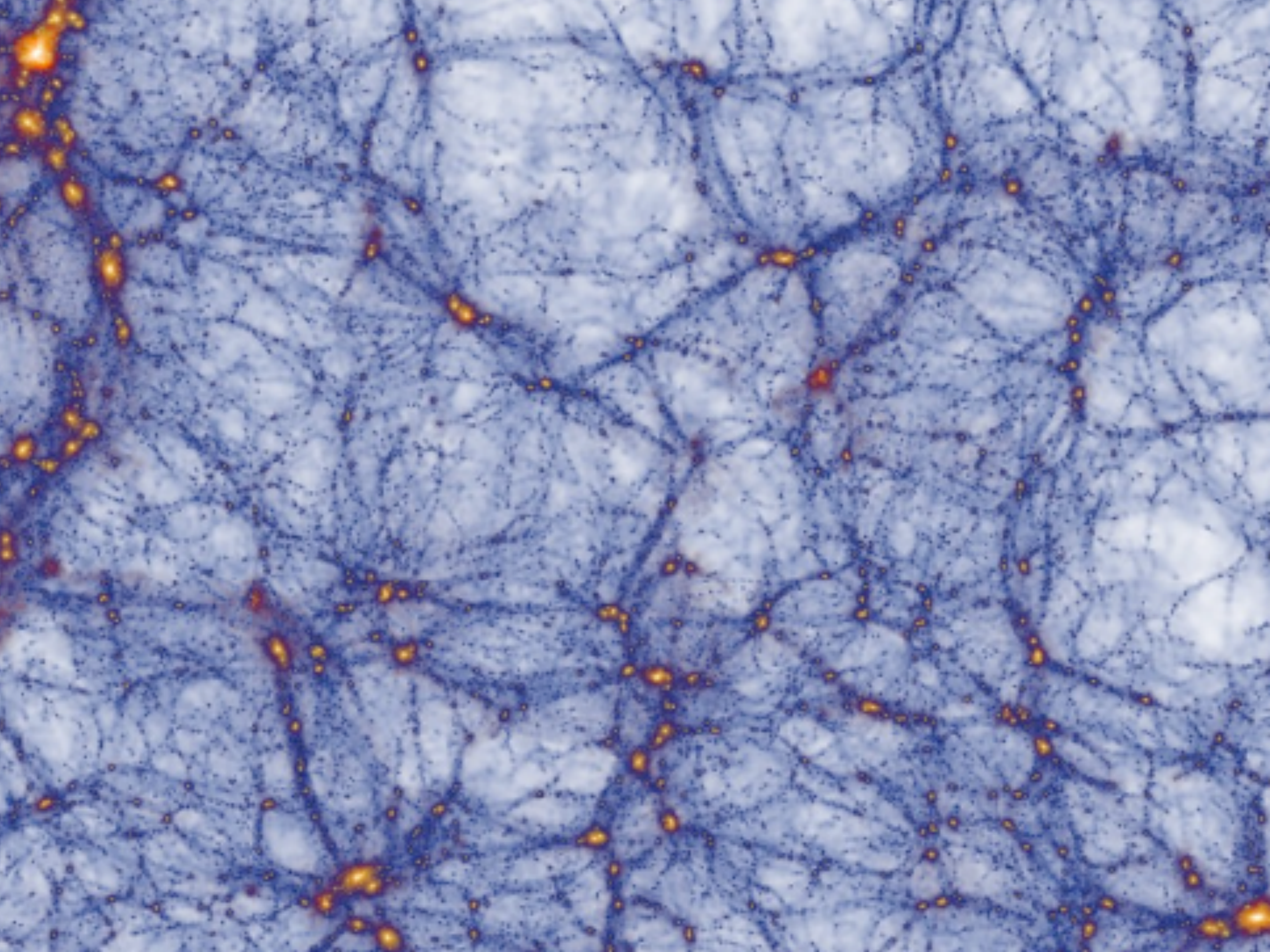
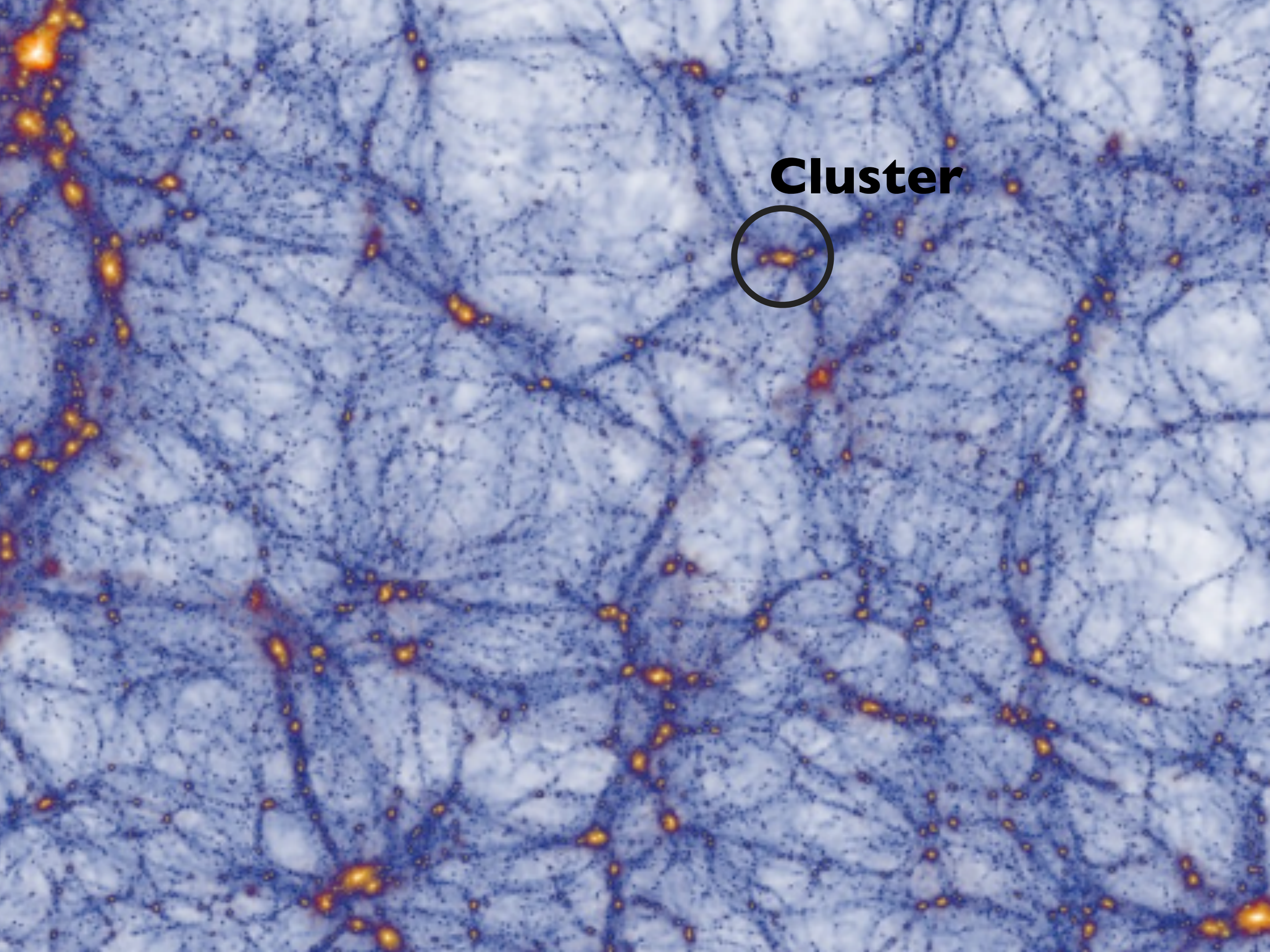
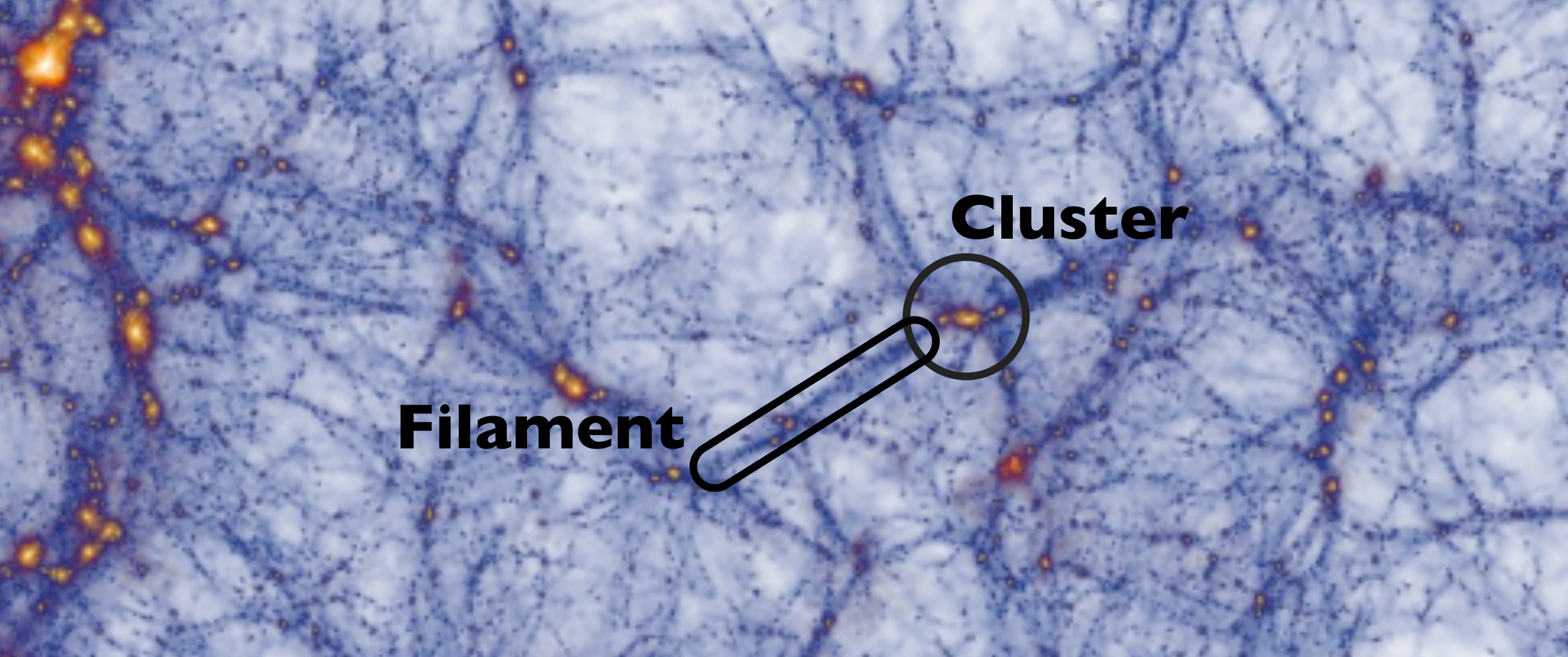
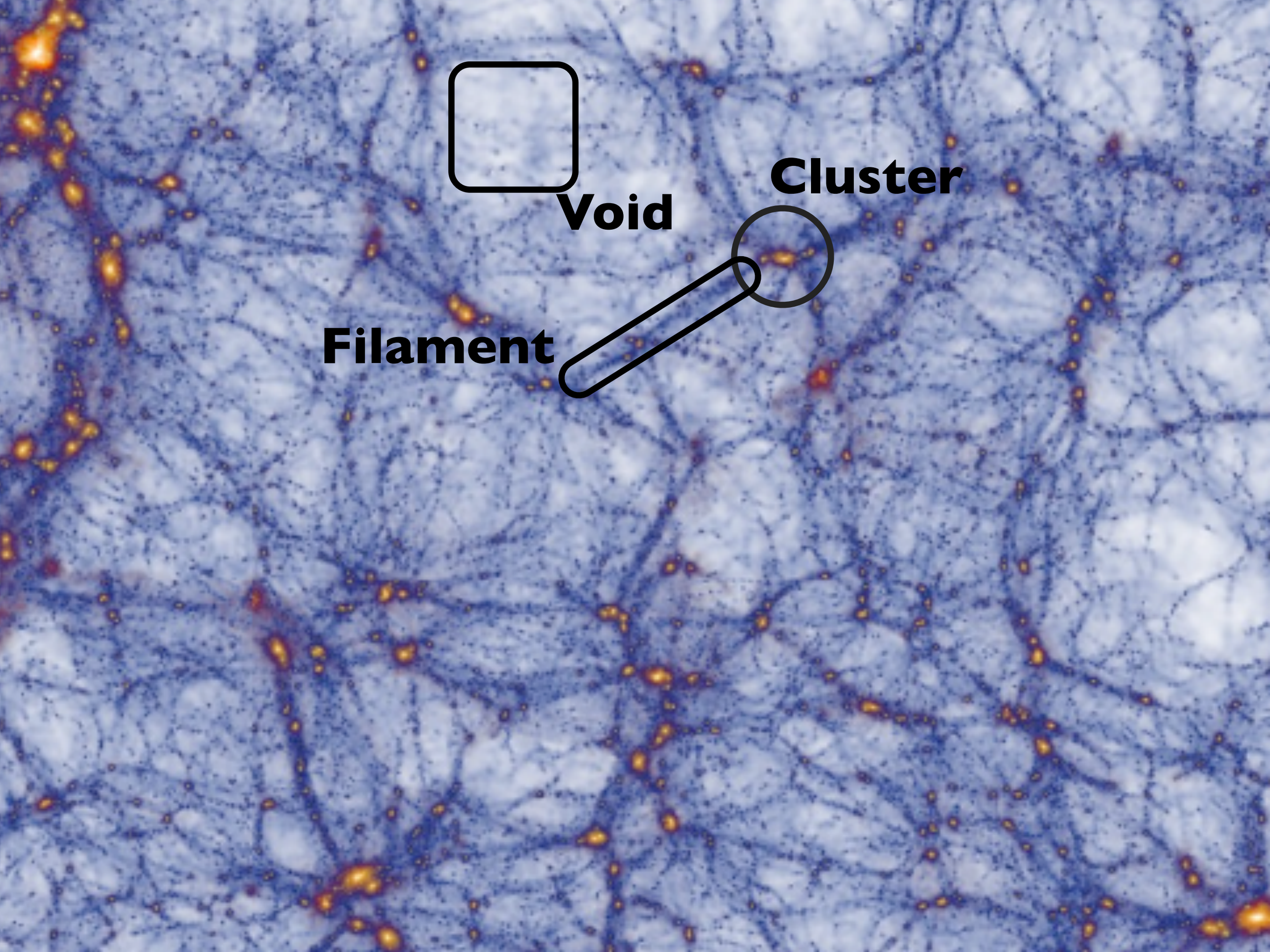
Pancakes in Space

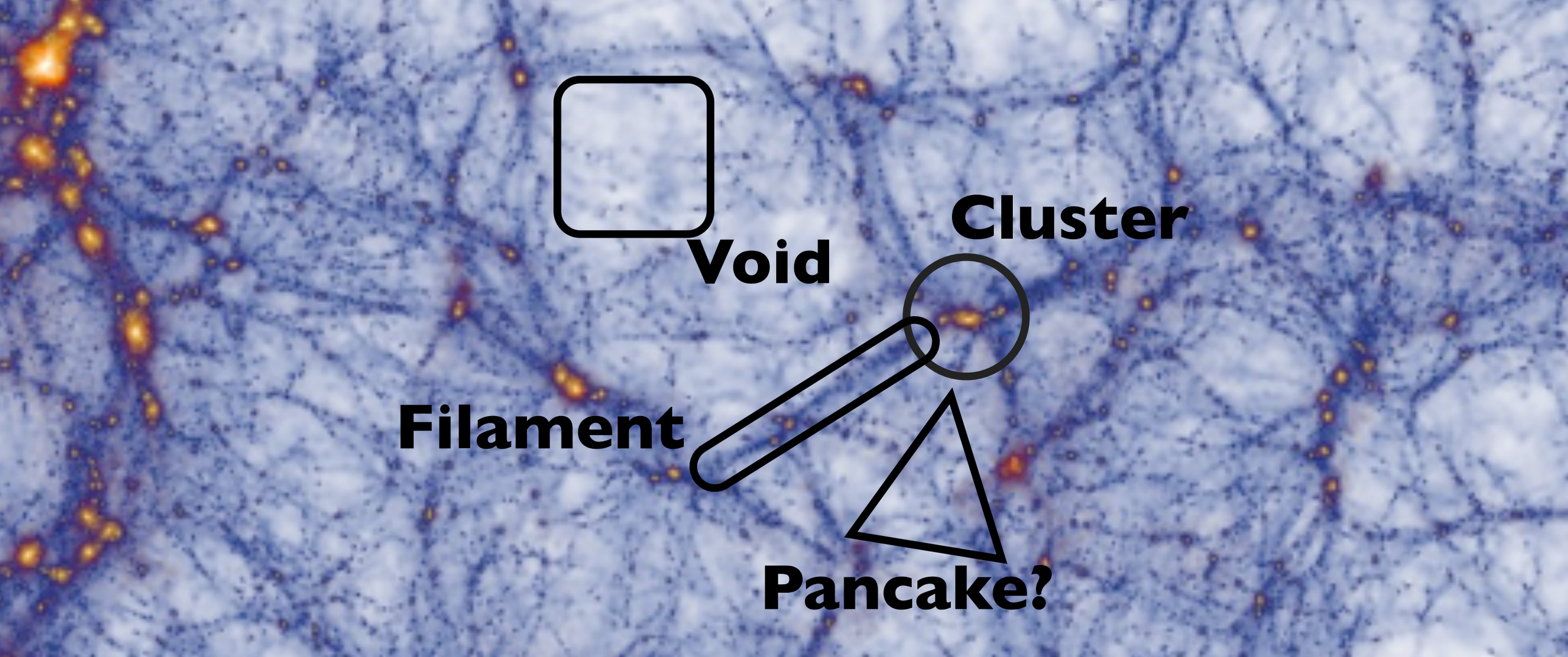
Brinkmann et al. JCAP 2016,
Wadekar & Hansen MNRAS 2015,
Falco et al. MNRAS 2014



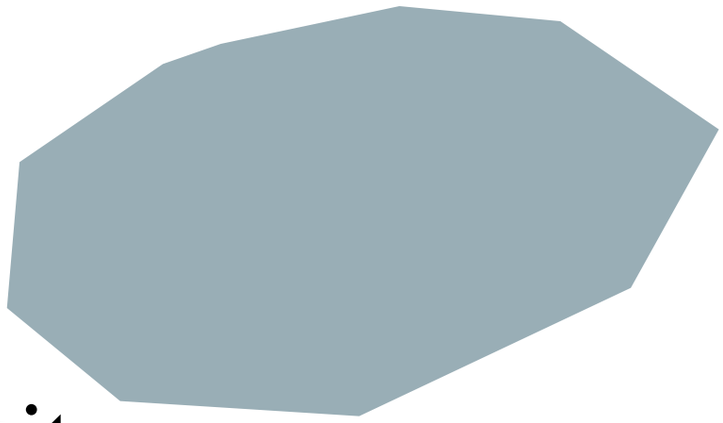

Cluster


Cluster
Filament


Void
Cluster
Filament

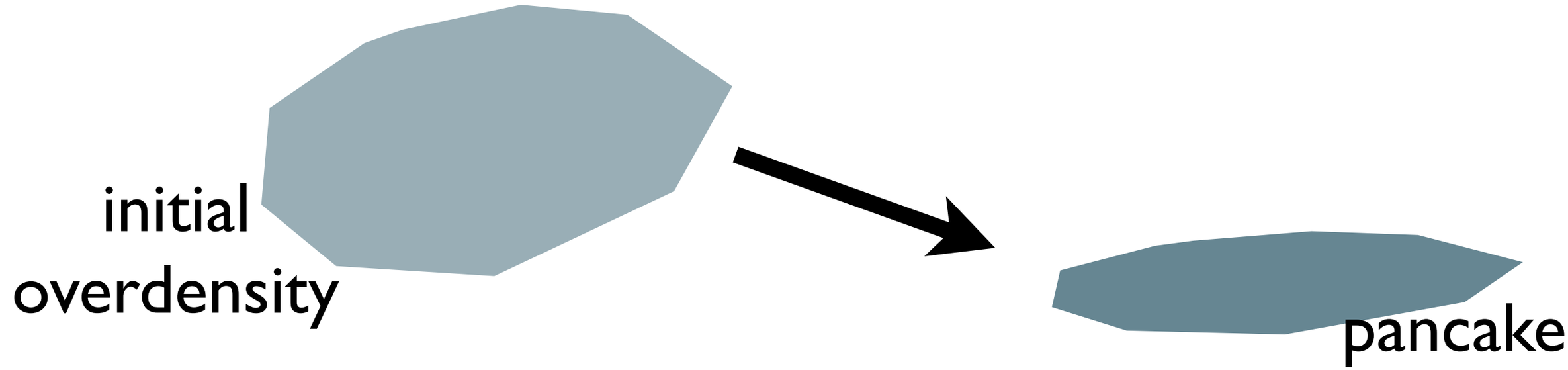

Void
Cluster
Filament
Pancake?

Pancakes have only collapsed along one direction

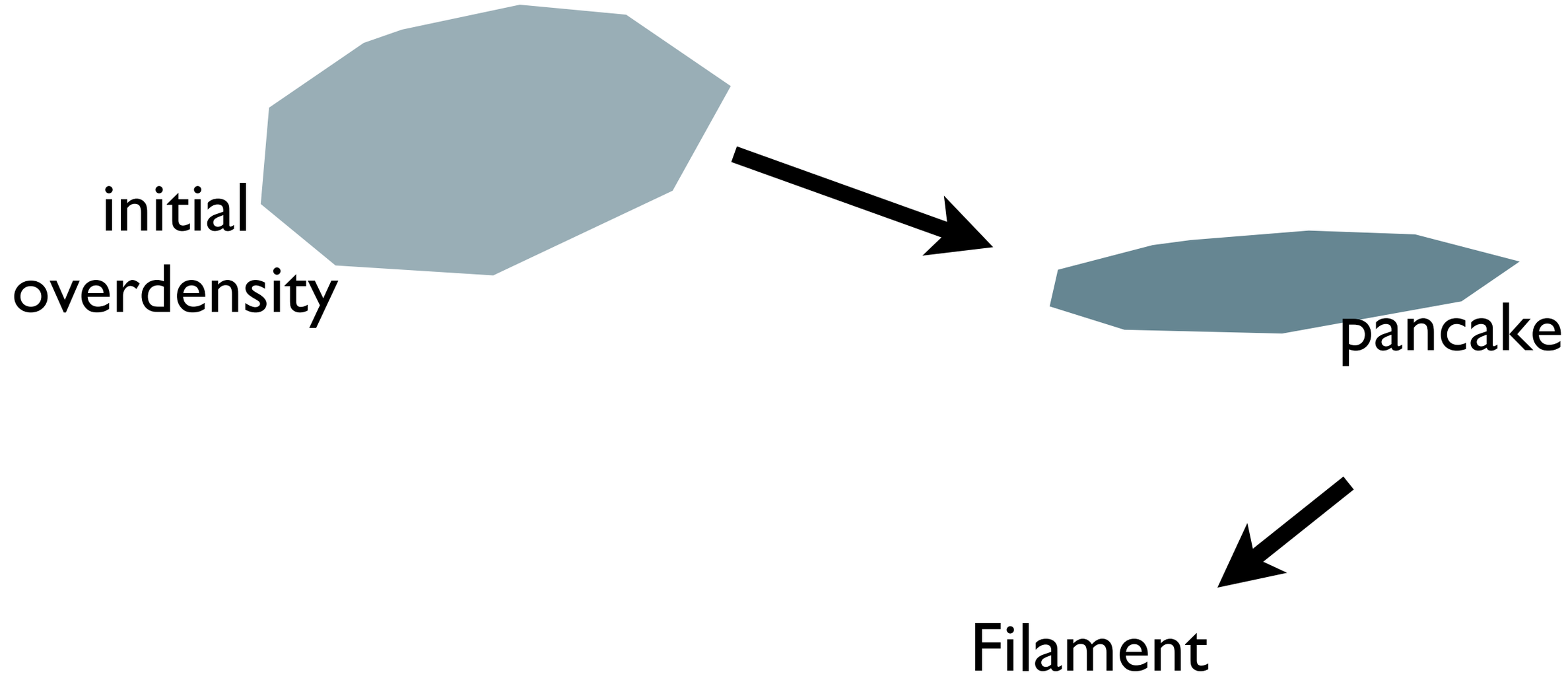


initial overdensity

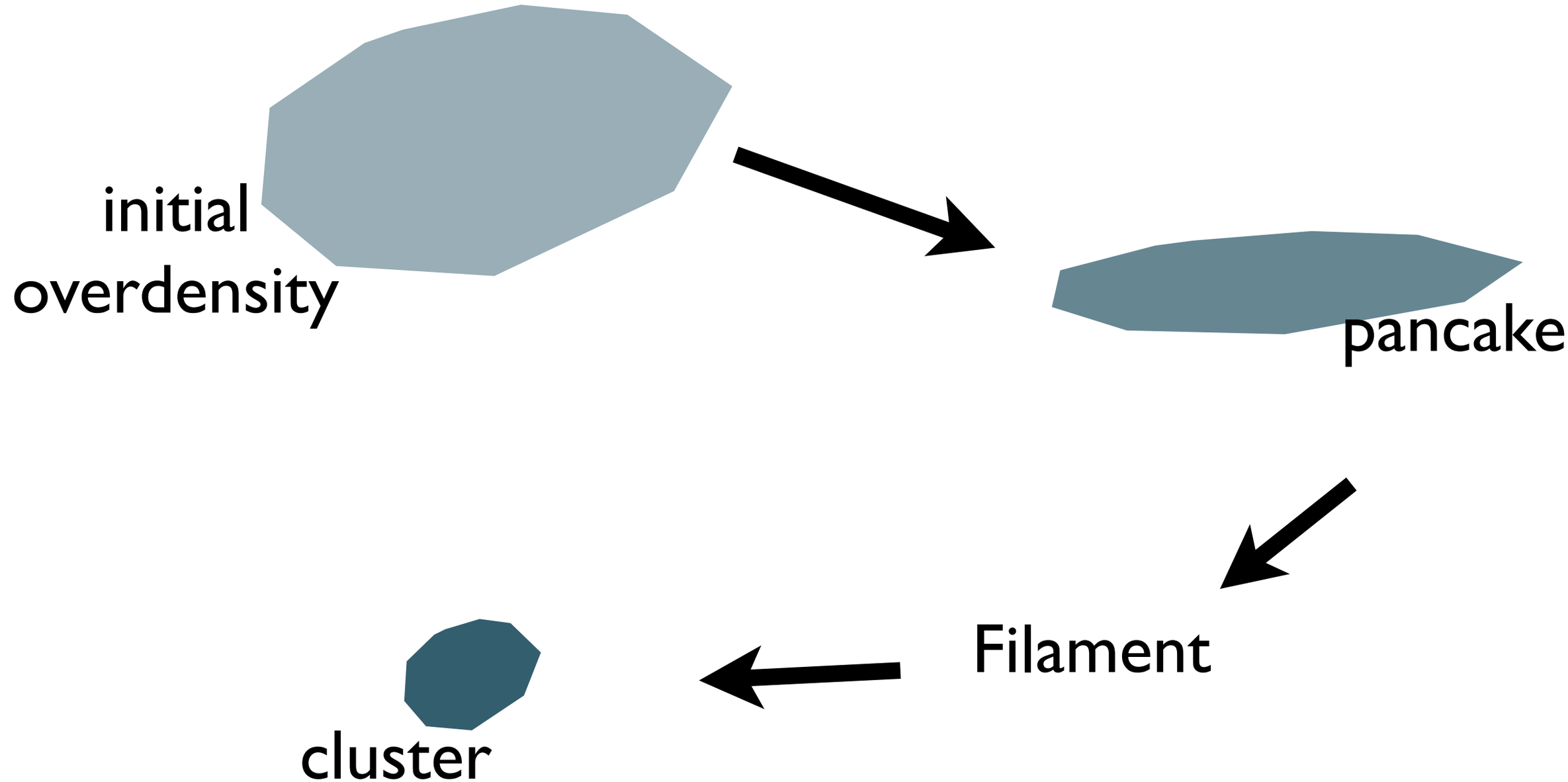
Pancakes have only collapsed along one direction

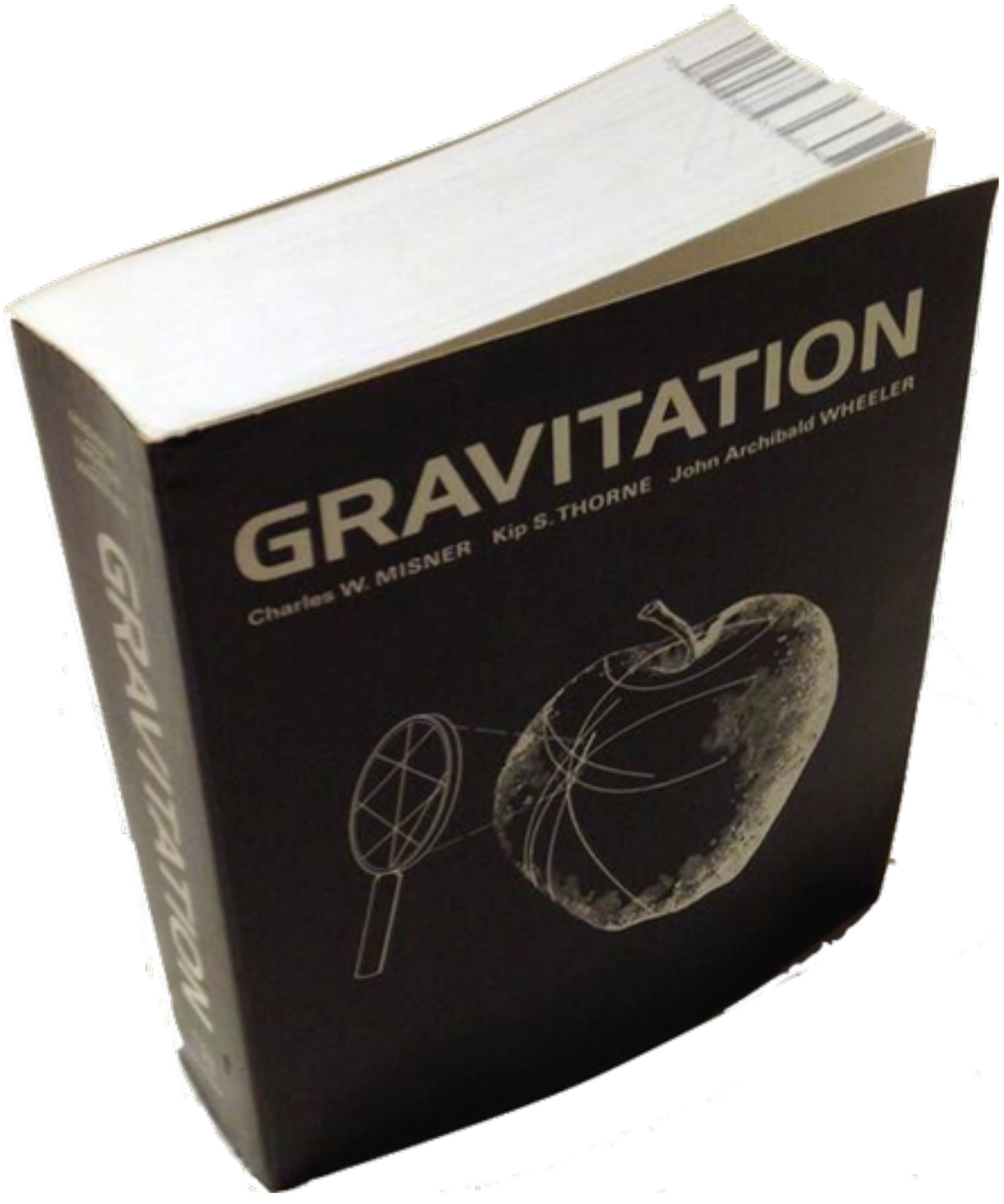


Pancakes have only collapsed along one direction

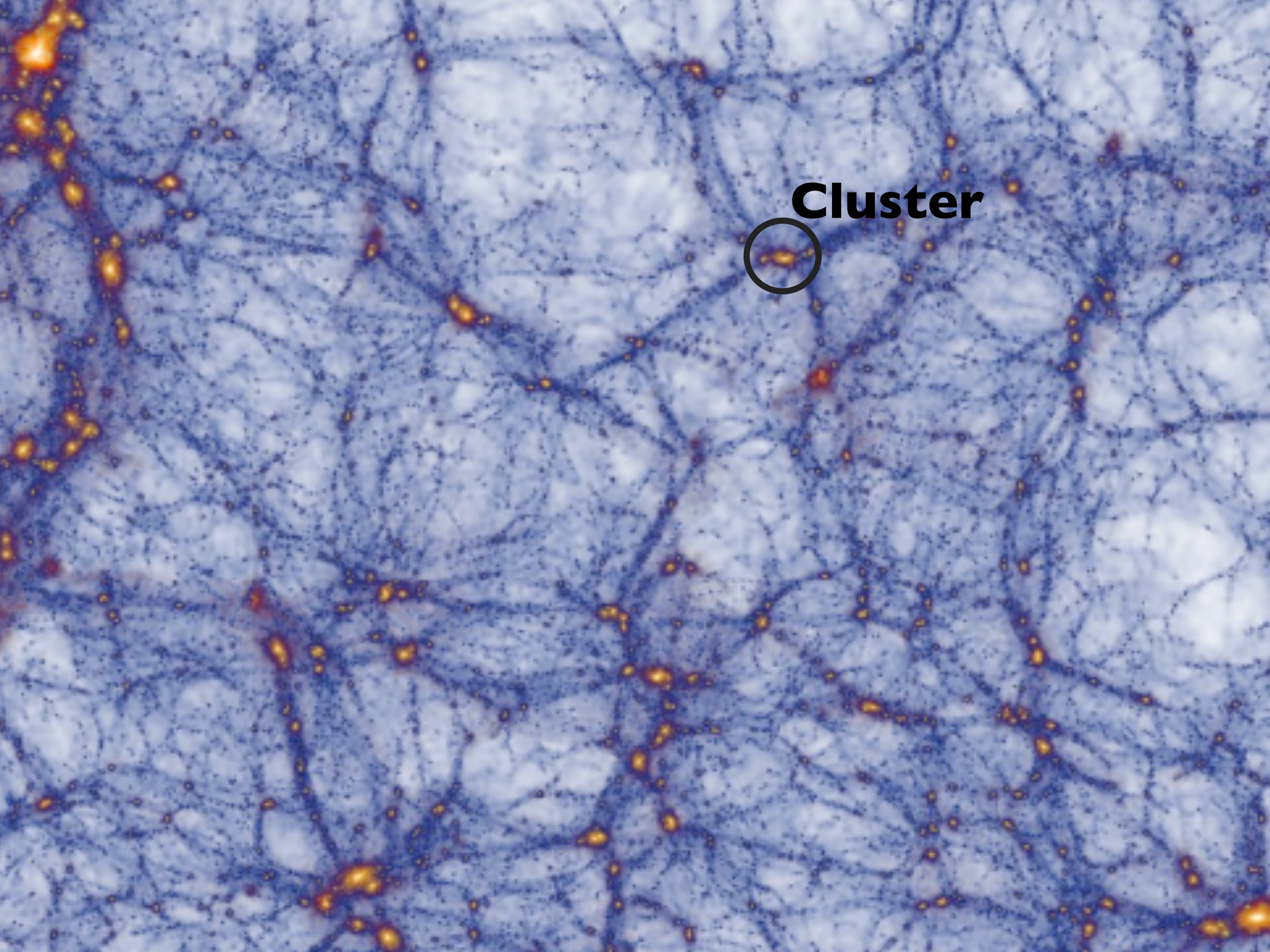


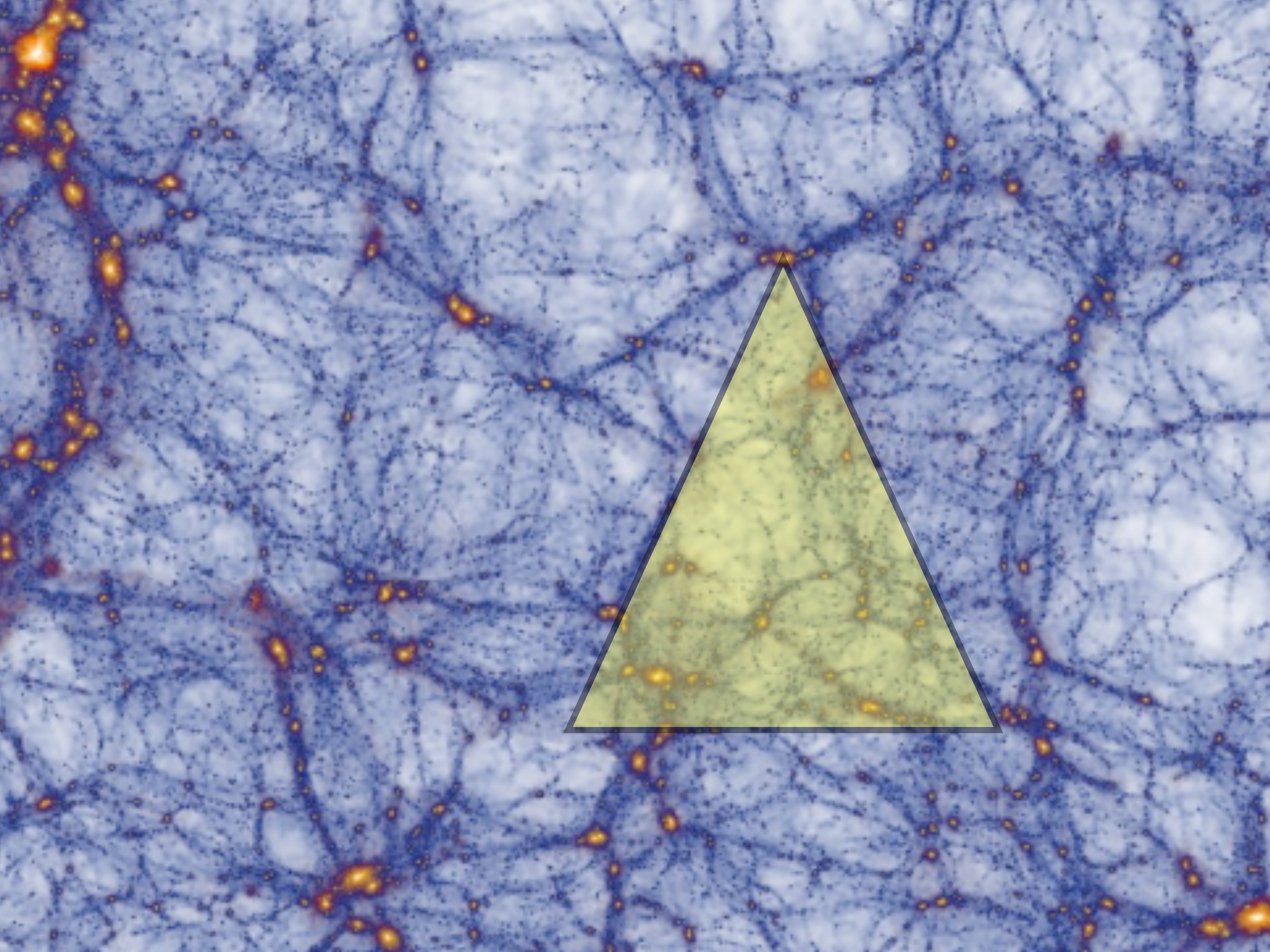
Pancakes have only collapsed along one direction

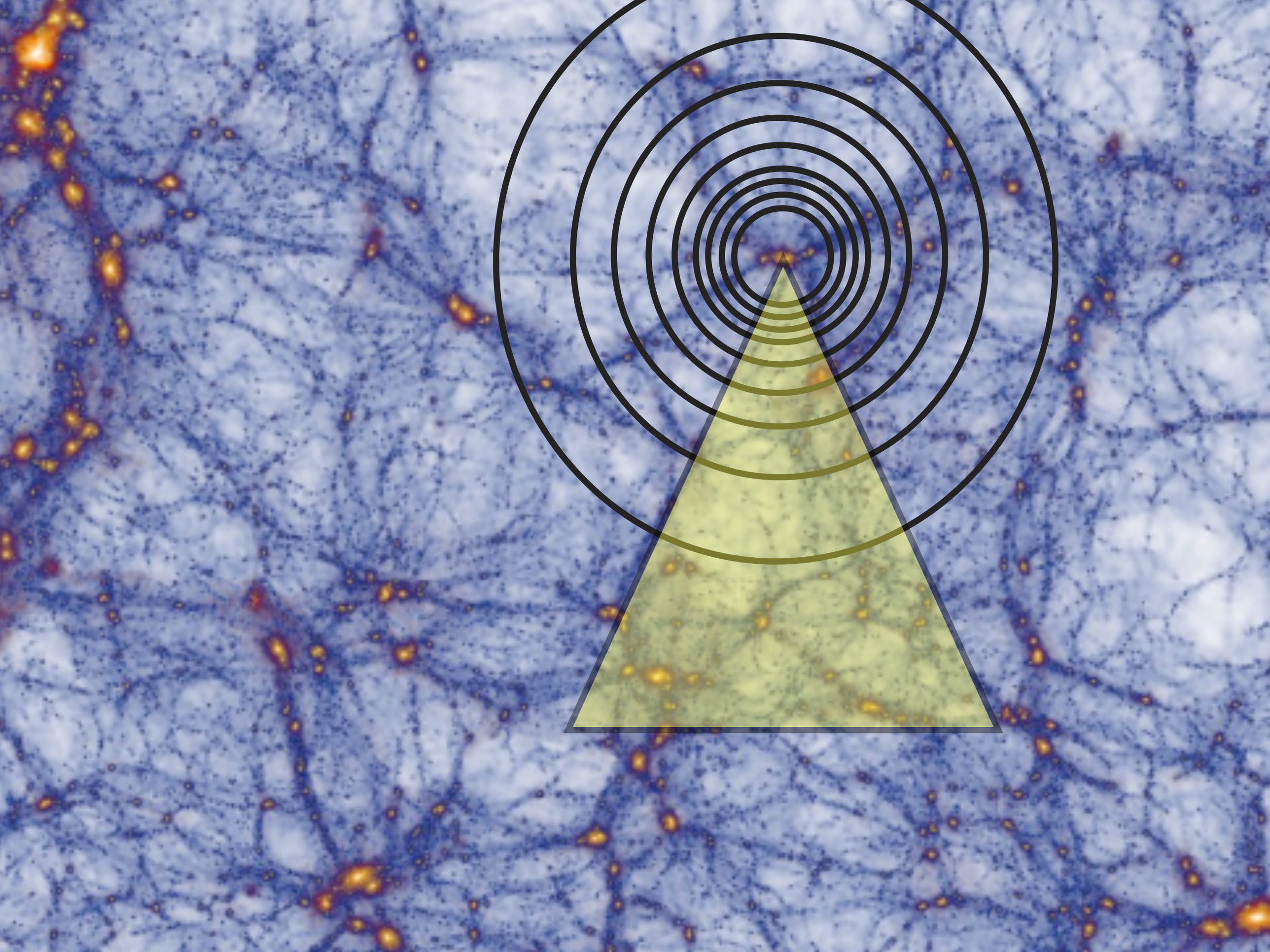


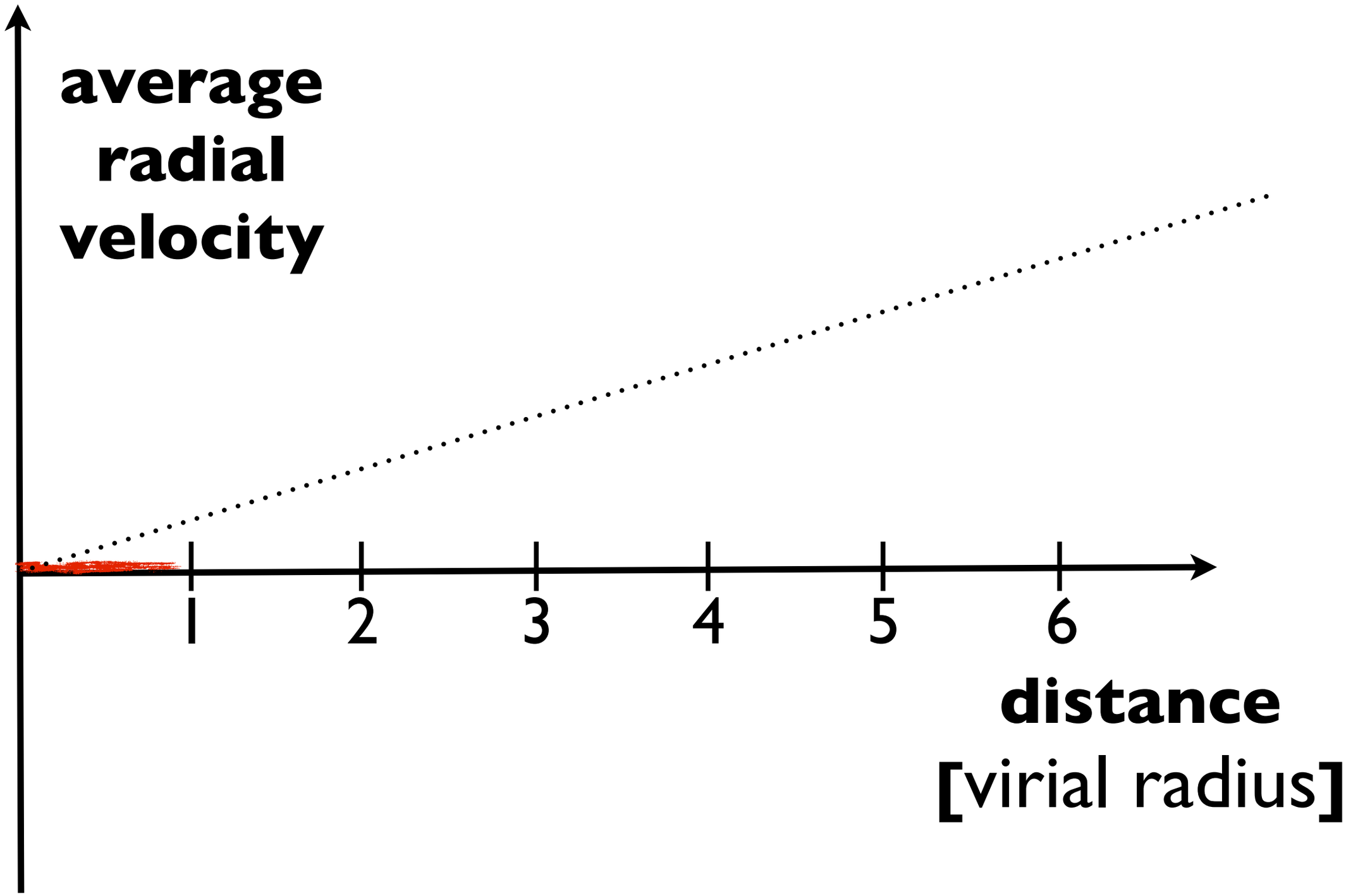

GRAVITATION
Charles W. MISNER Kip S. THORNE John Archibald WHEELER
GRAVITATION

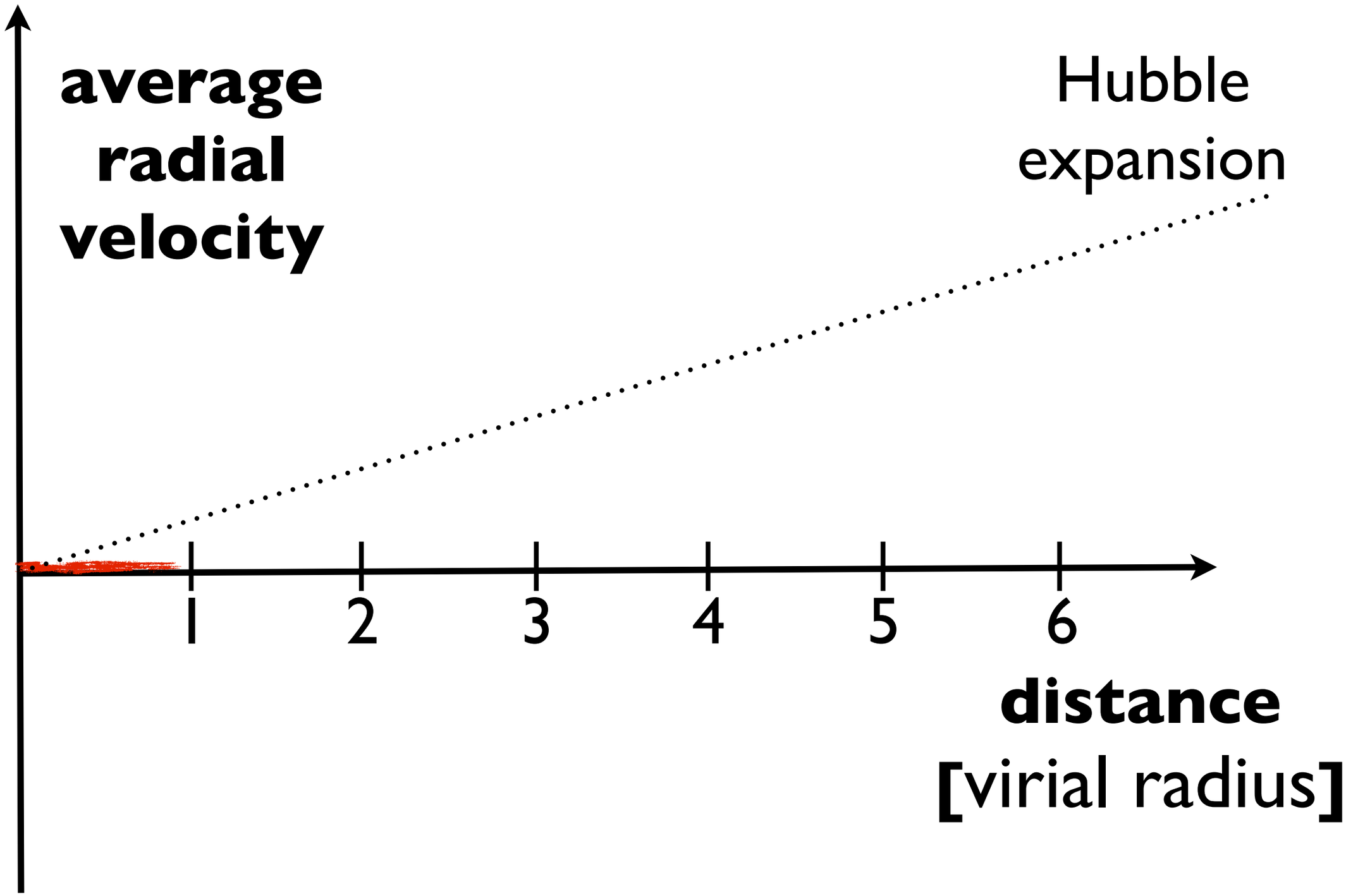
How to find pancakes

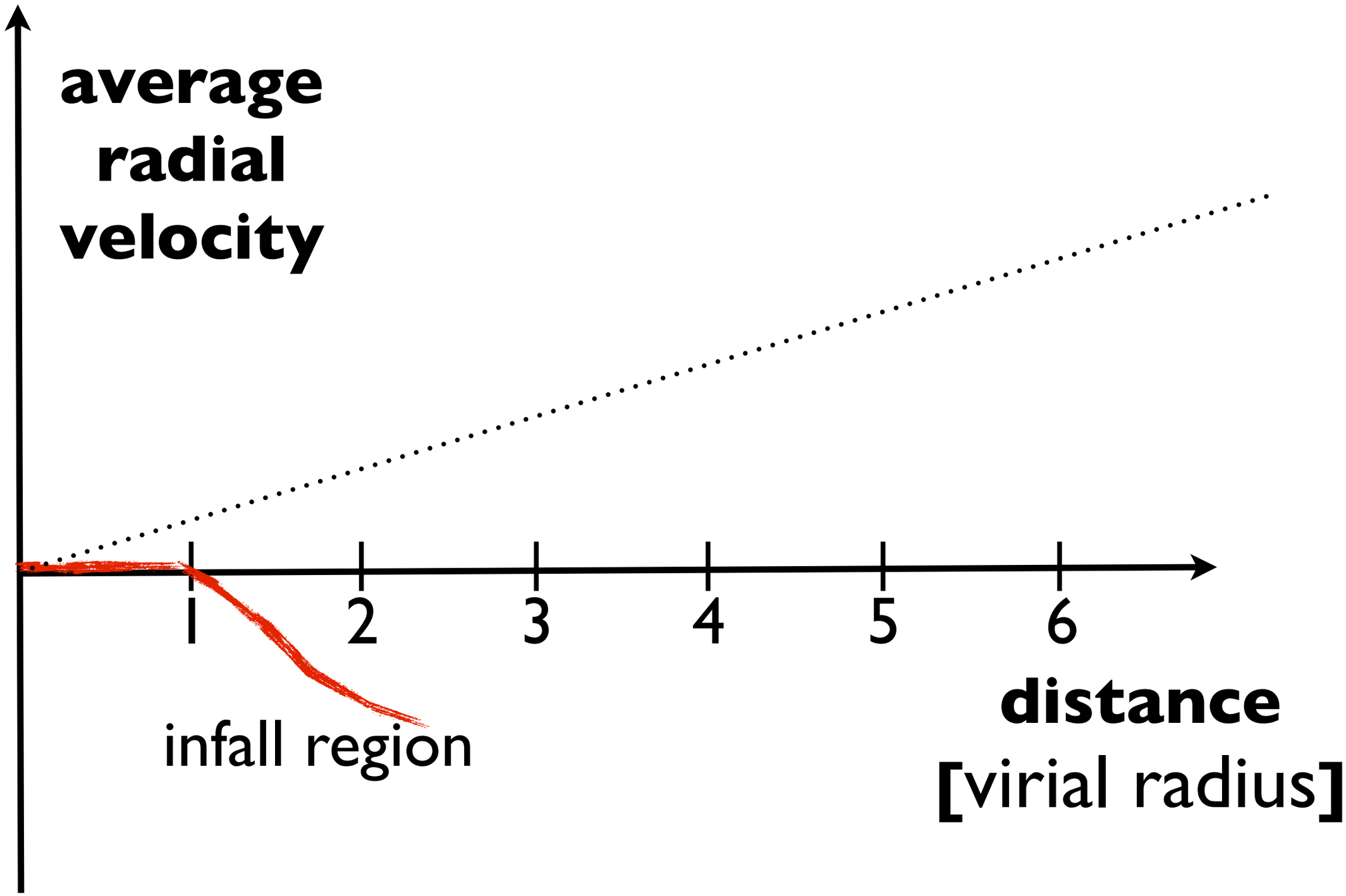

Cluster

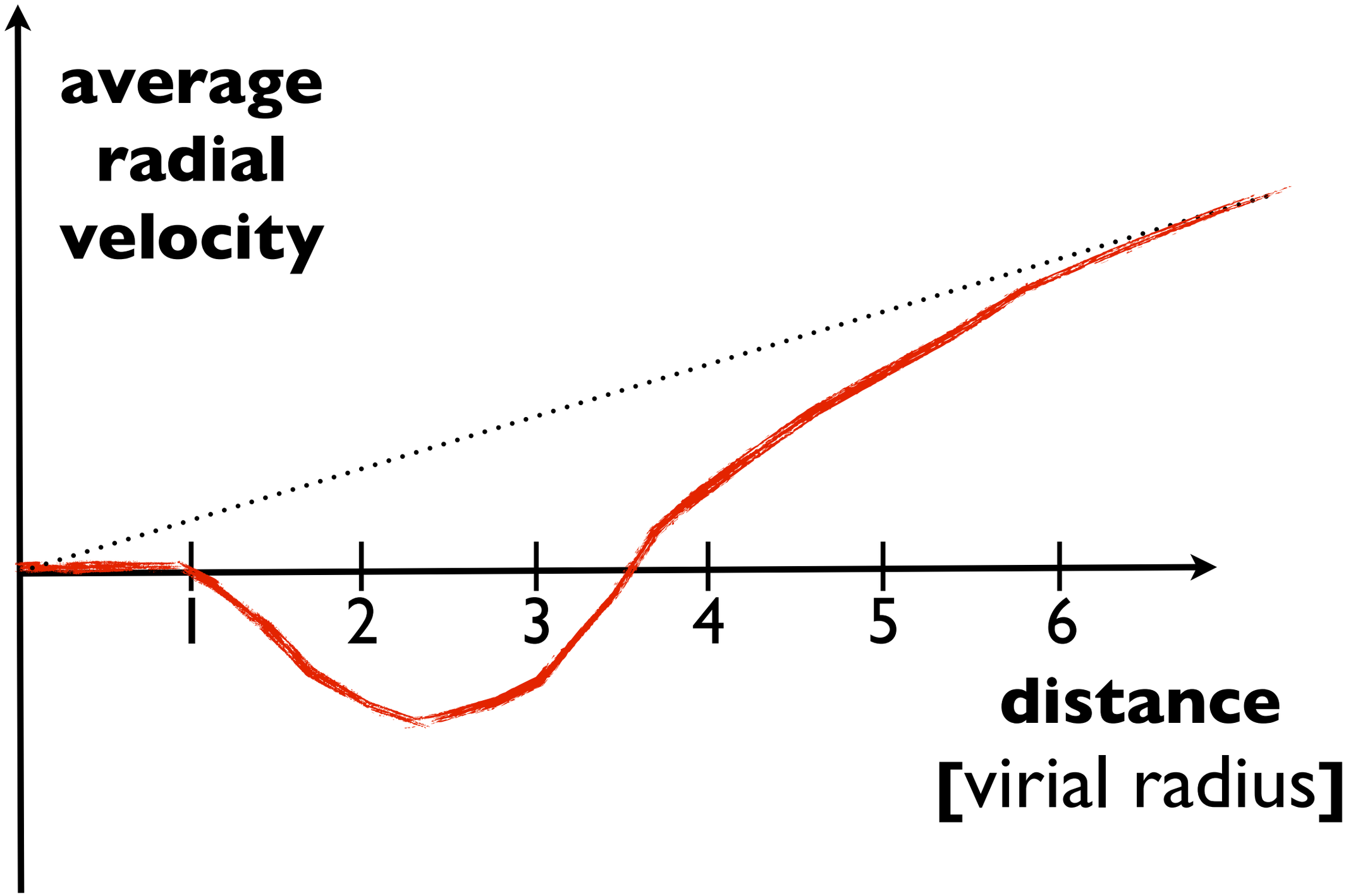


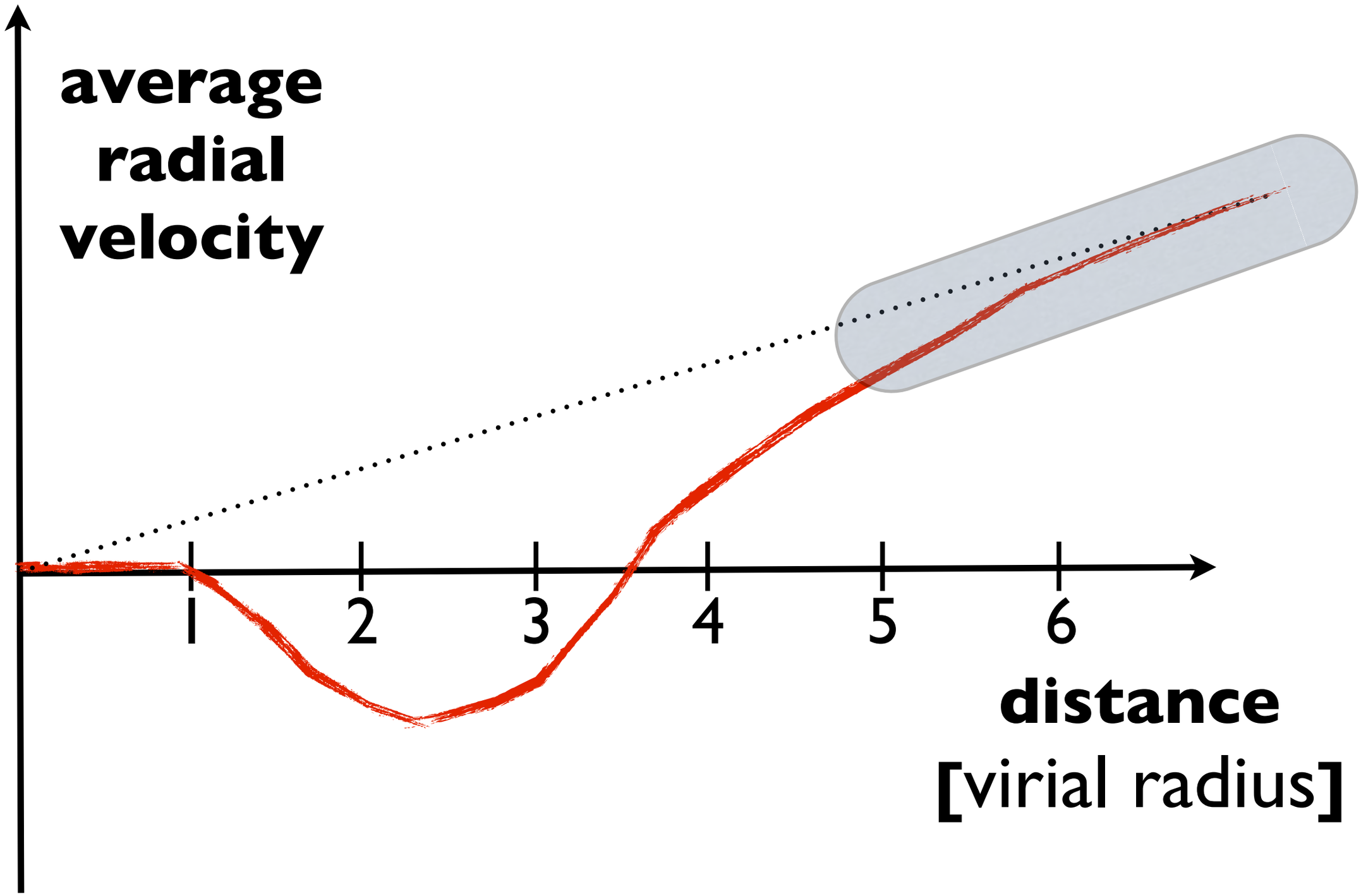



average
radial
velocity
1
2
3
4
5
6
distance
[virial radius]

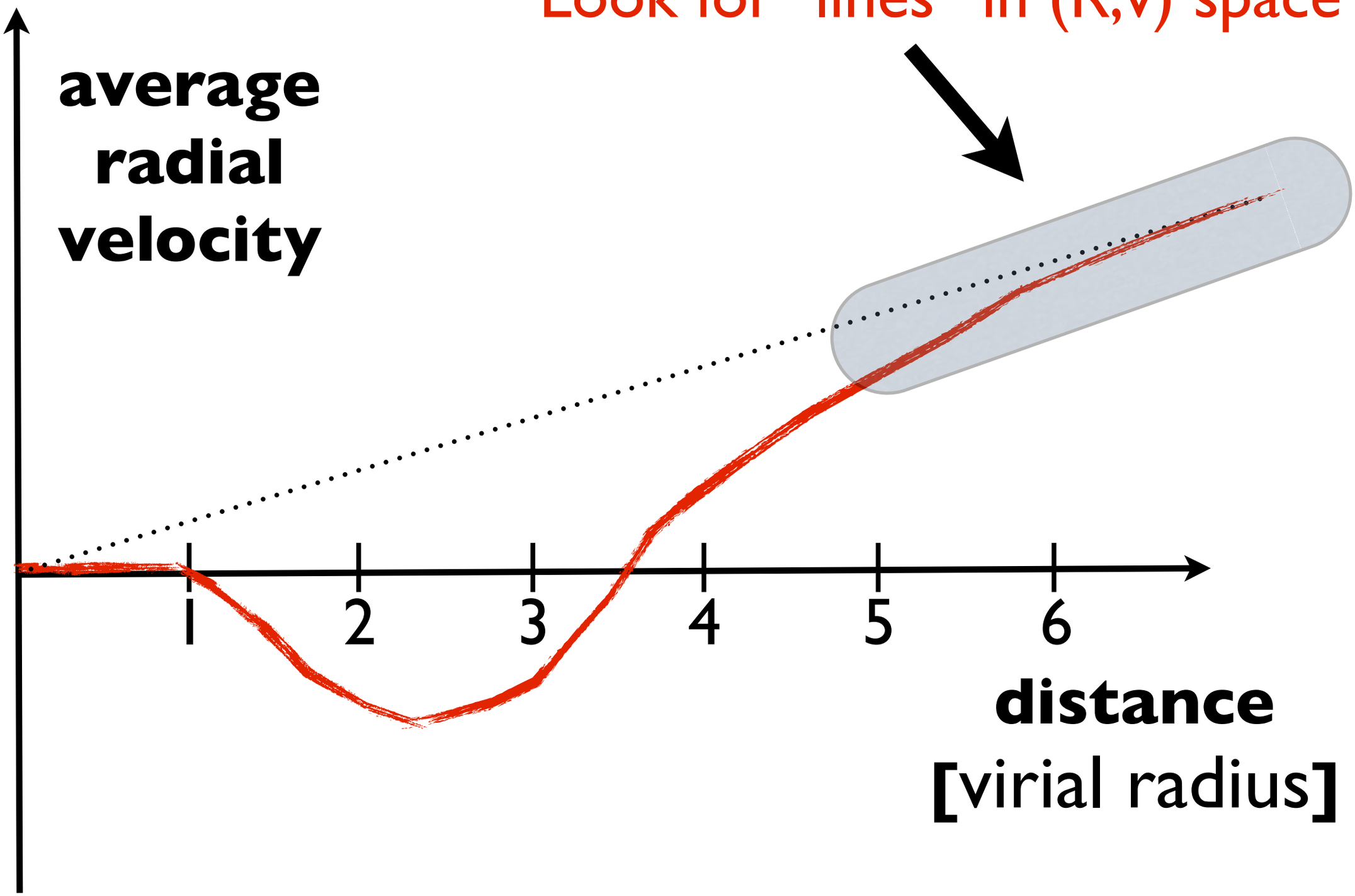

average
radial
velocity
Hubble
expansion
1
2
3
4
5
6
distance
[virial radius]


average
radial
velocity
1
2
3
4
5
6
infall region
distance
[virial radius]

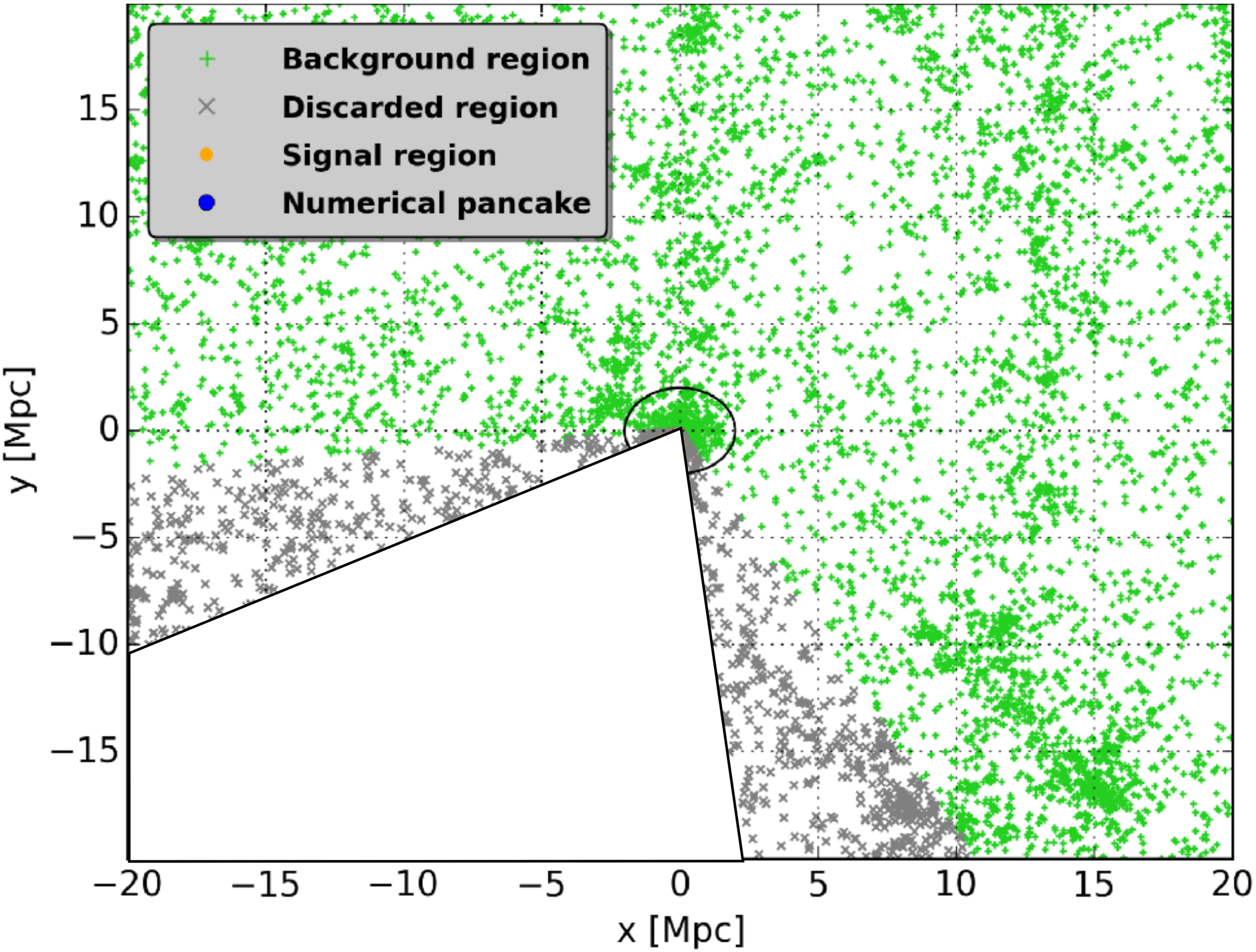

average
radial
velocity
1
2
3
4
5
6
distance
[virial radius]

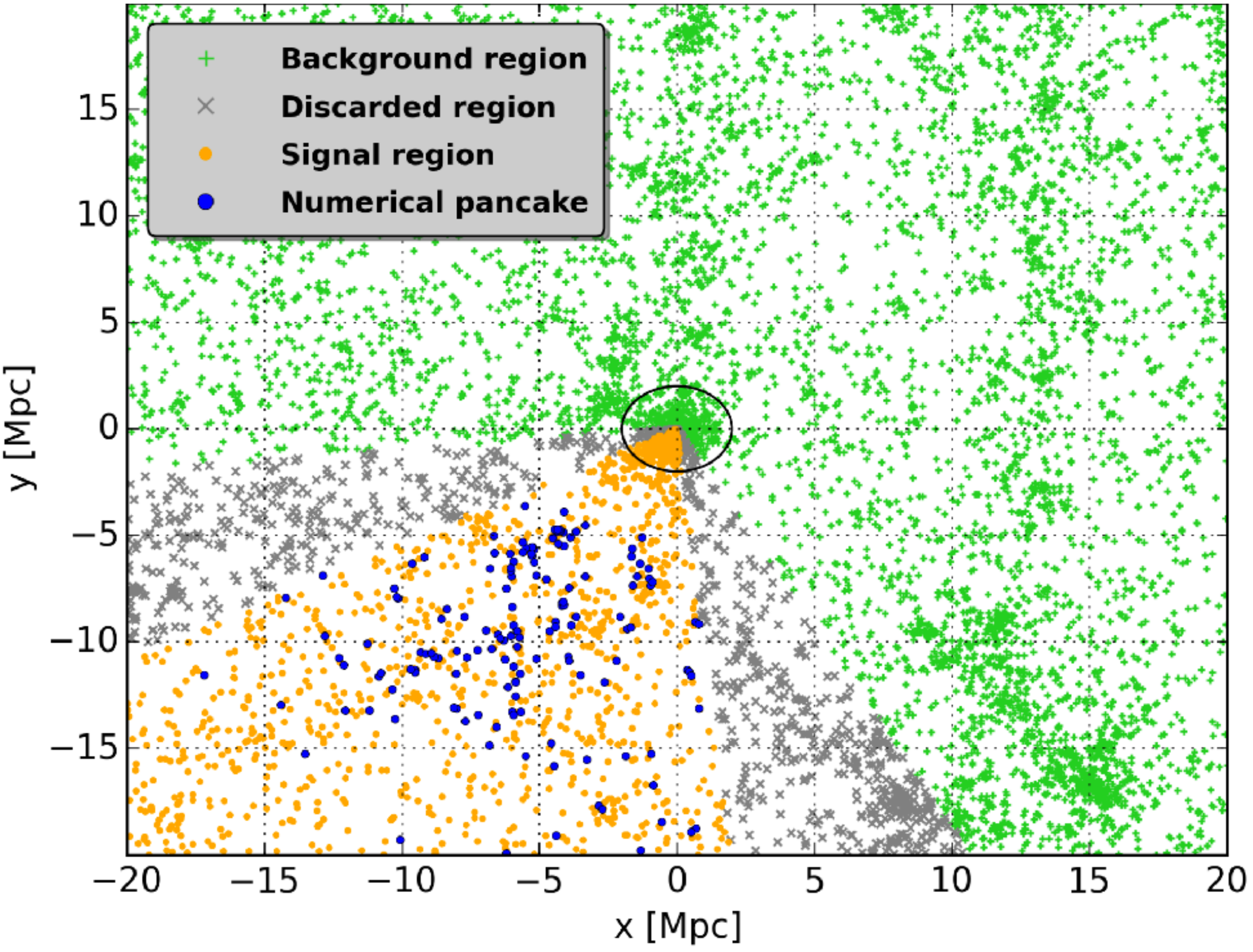

average
radial
velocity
1
2
3
4
5
6
distance
[virial radius]

Look for "lines" in (R,v) space



In real space


Background region
Discarded region
Signal region
Numerical pancake
y [Mpc]
x [Mpc]
15
10
5
0
−5
−10
−15
−20
−15
−10
−5
0
5
10
15
20


Background region
Discarded region
Signal region
Numerical pancake
15
10
5
0
−5
−10
−15
y [Mpc]
−20
−15
−10
−5
0
5
10
15
20
x [Mpc]

In phase-space

Background region

Signal region

Numerical pancake

v_{los} [km/s]

3000
2000
1000
0
−1000
−2000
−3000

0
5
10
15
20
25

R [Mpc]

Background region

Signal region

Numerical pancake

v_{los} [km/s]

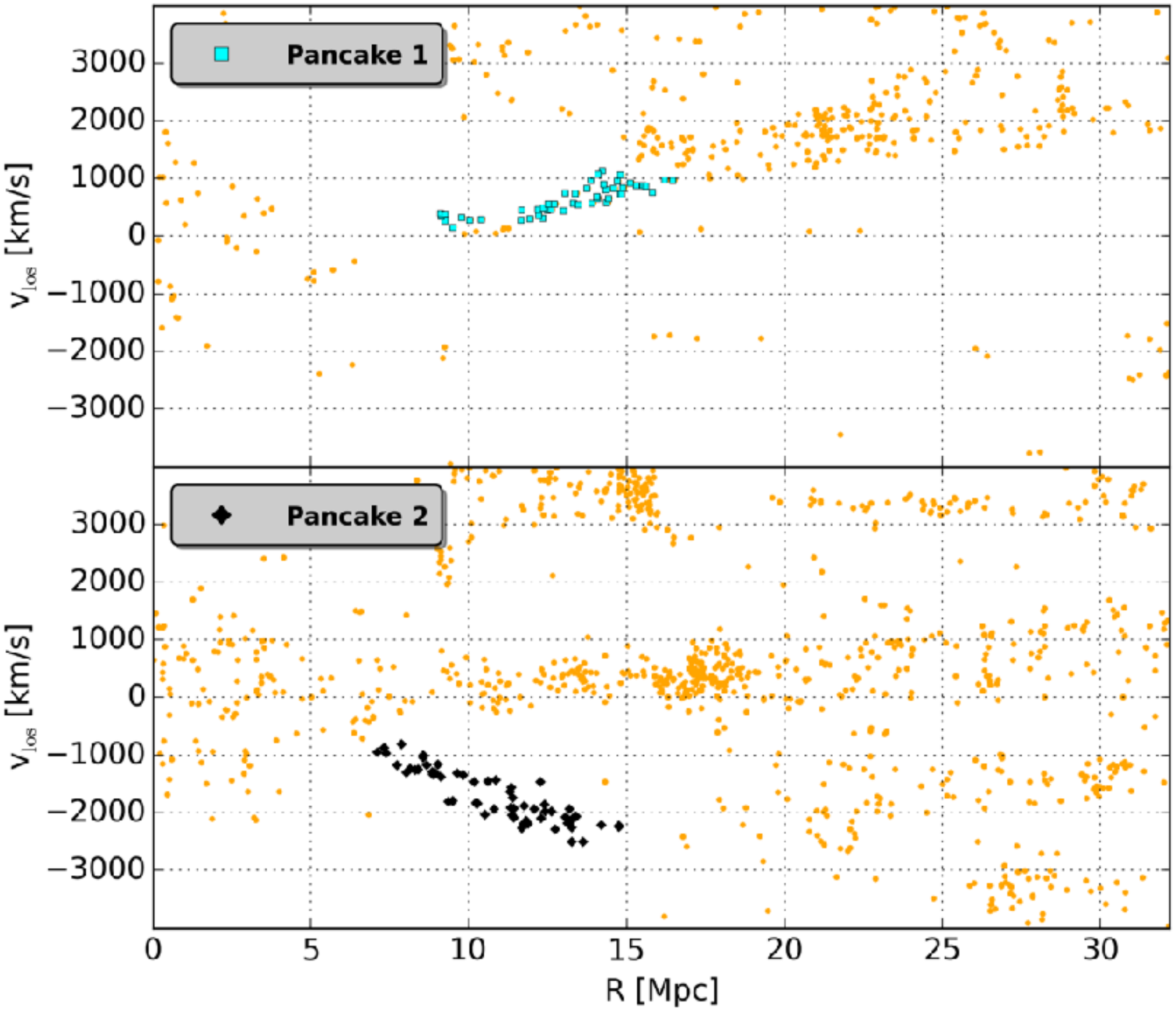
3000
2000
1000
0
−1000
−2000
−3000

0
5
10
15
20
25

R [Mpc]

Coma

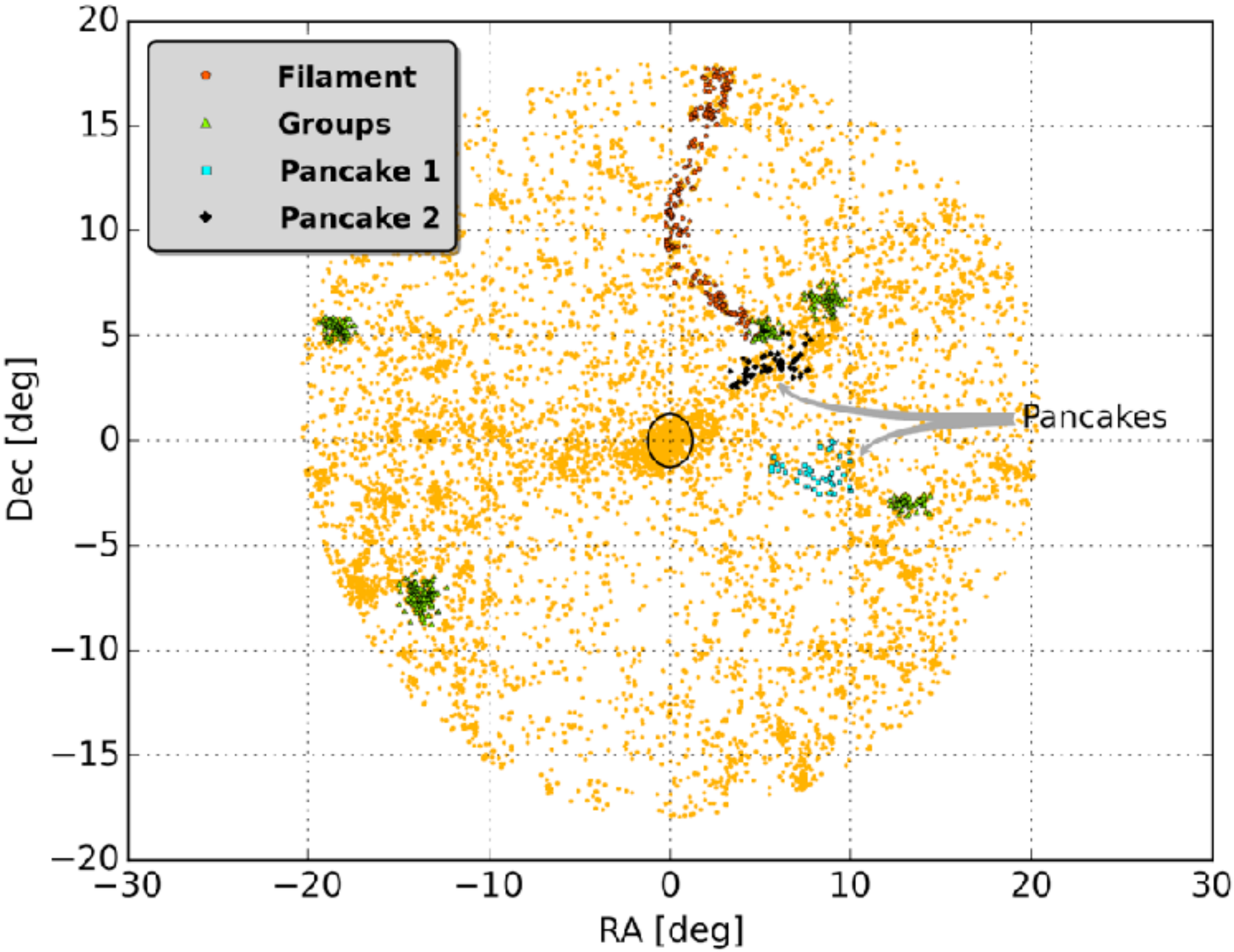
In phase space

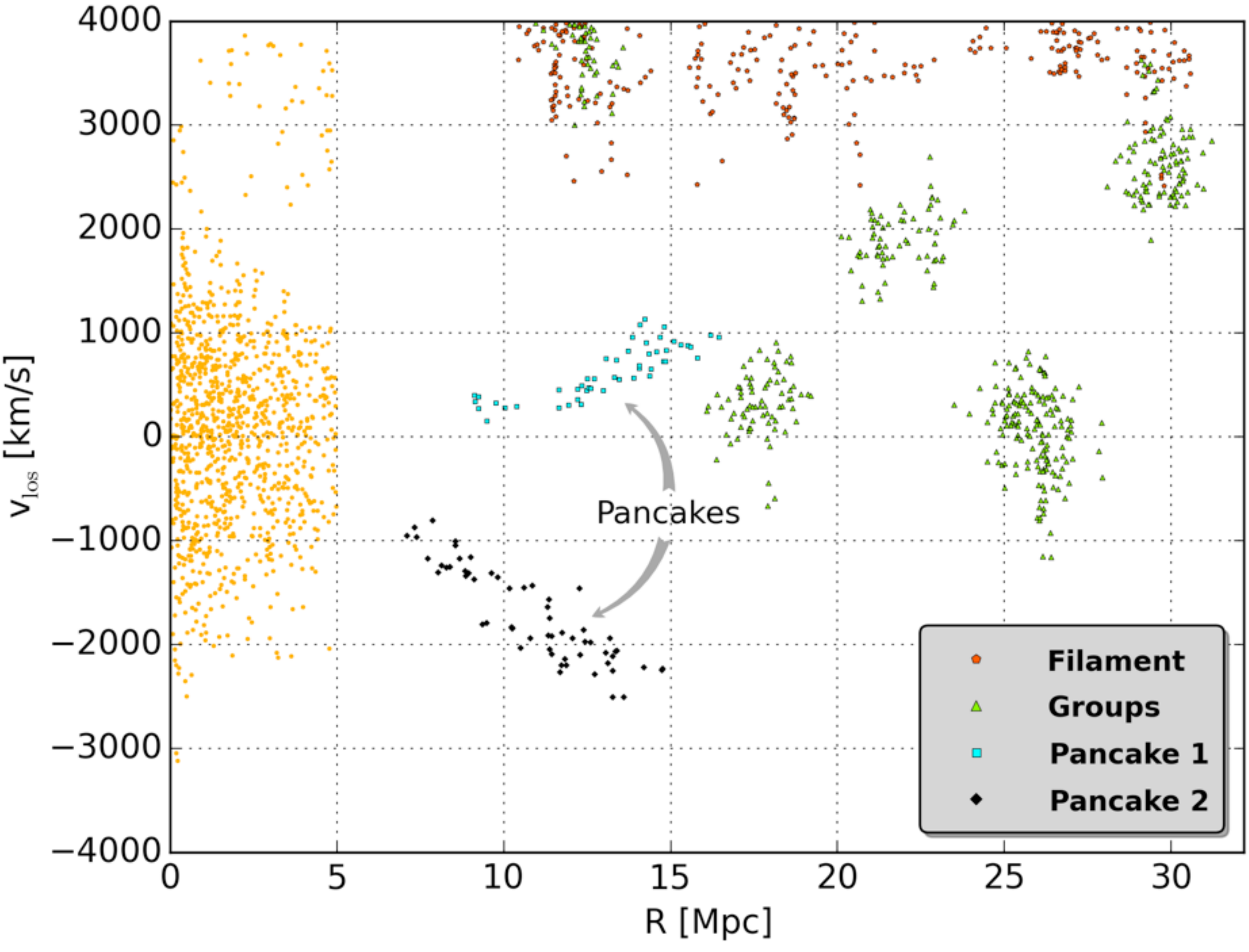

Pancake 1
Pancake 2
3000
2000
1000
0
−1000
−2000
−3000
v_{los} [km/s]
0
5
10
15
20
25
30
R [Mpc]

Coma

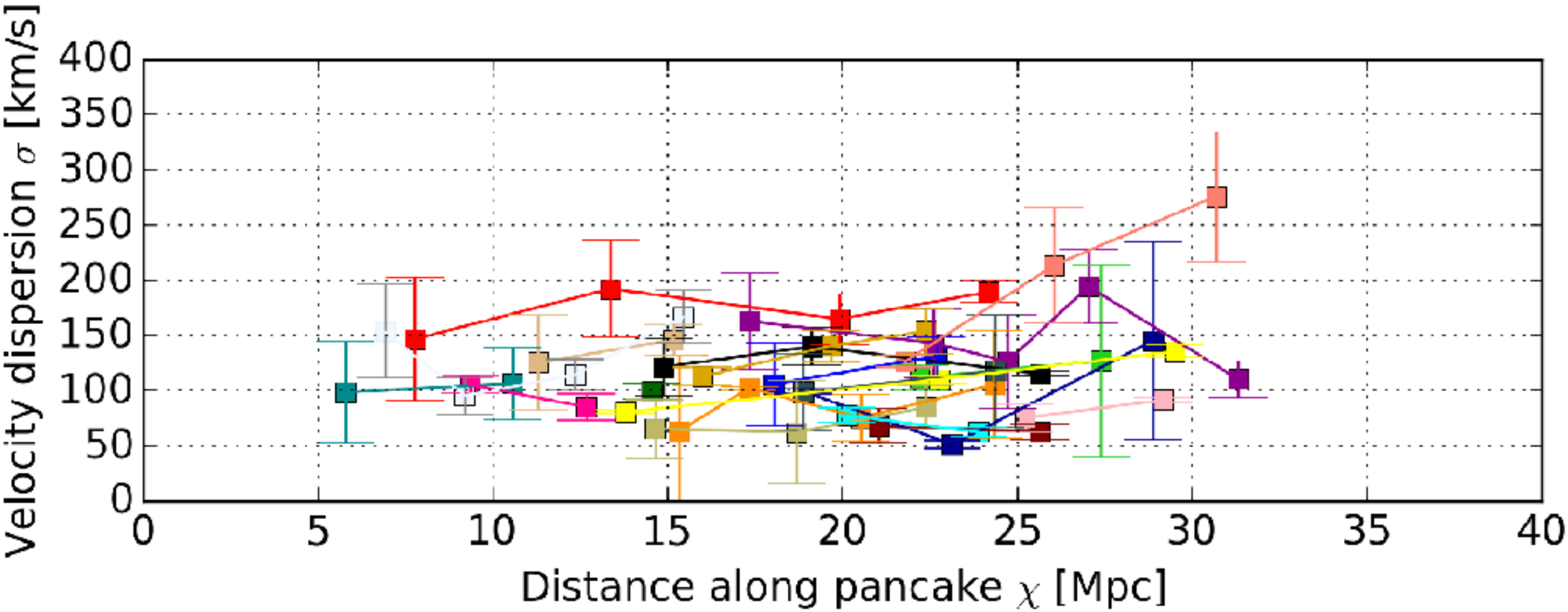
In real space

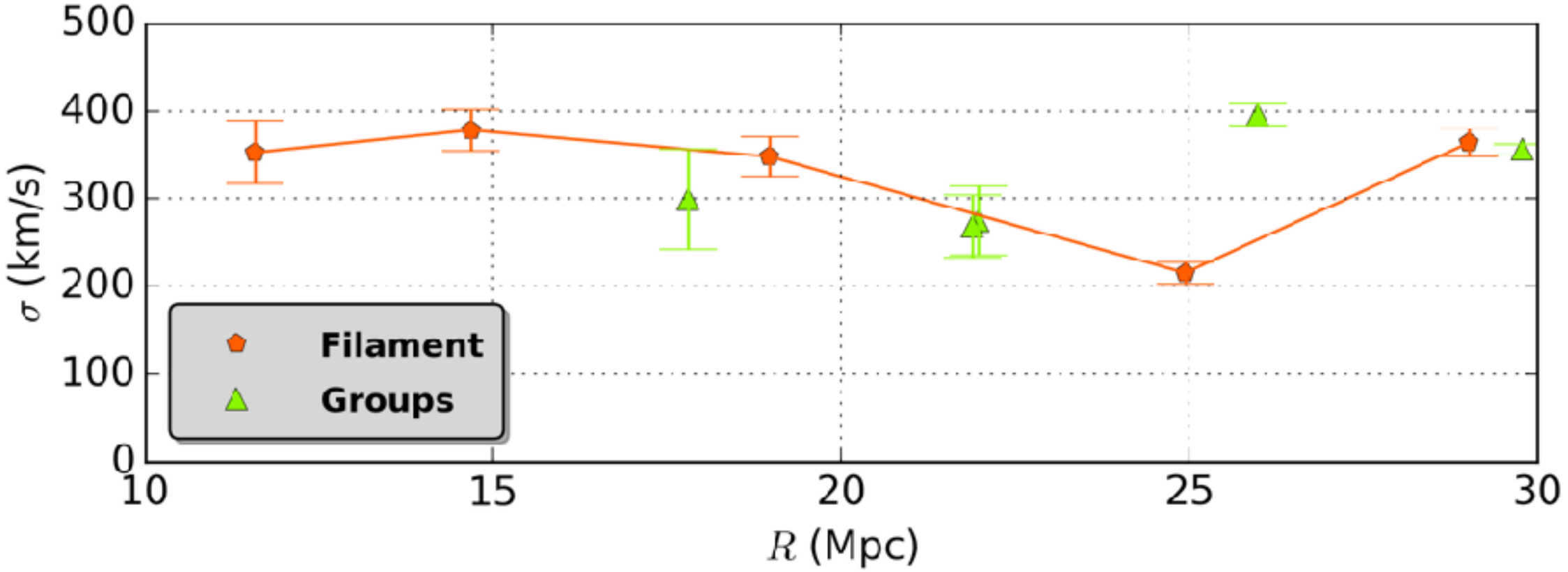
Coma


Filament
Groups
Pancake 1
Pancake 2
Pancakes
Dec [deg]
RA [deg]
20
15
10
5
0
−5
−10
−15
−20
−30
−20
−10
0
10
20
30

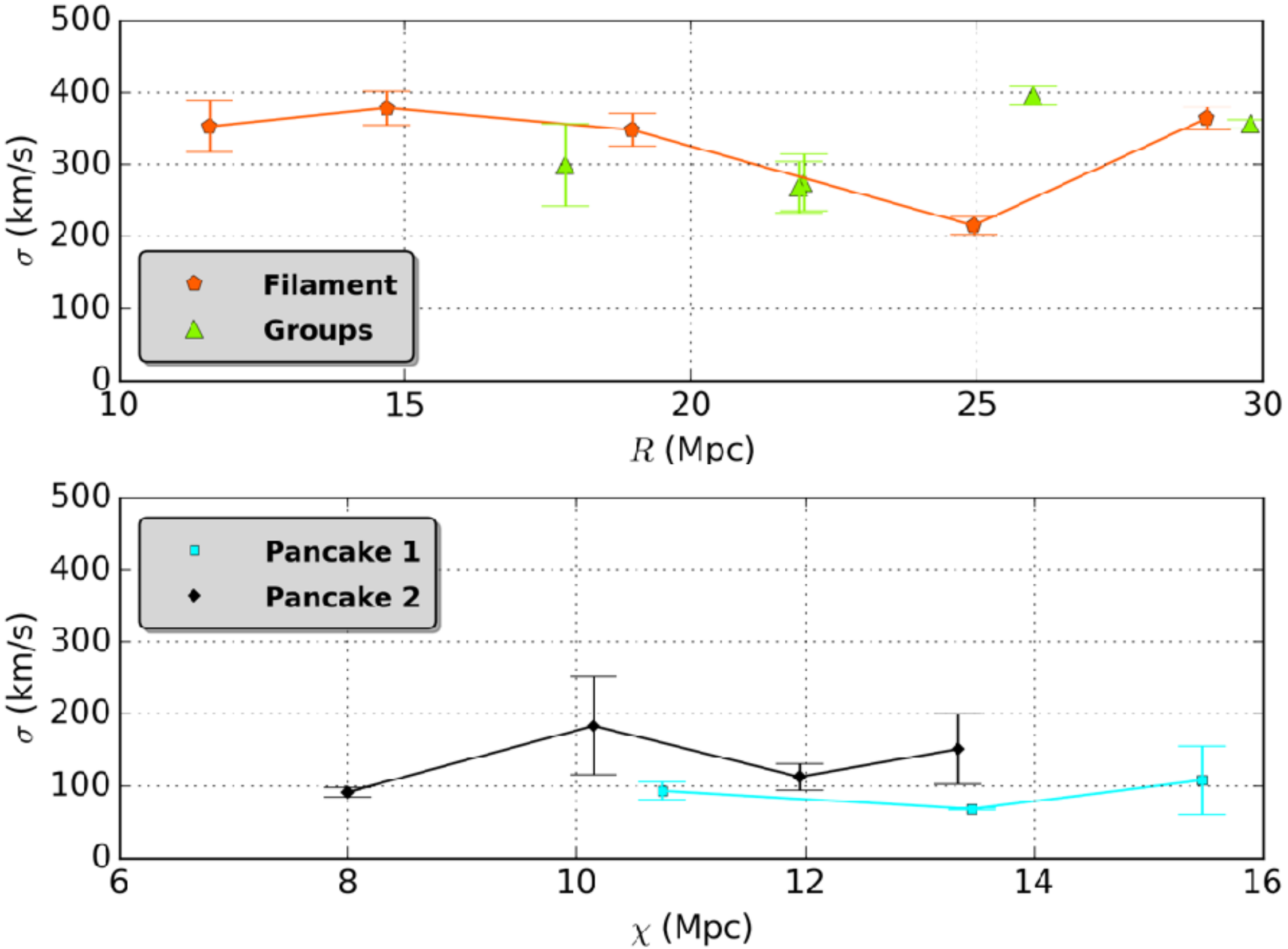

4000
3000
2000
1000
0
−1000
−2000
−3000
−4000
v_{los} [km/s]
0
5
10
15
20
25
30
R [Mpc]
Pancakes
Filament
Groups
Pancake 1
Pancake 2

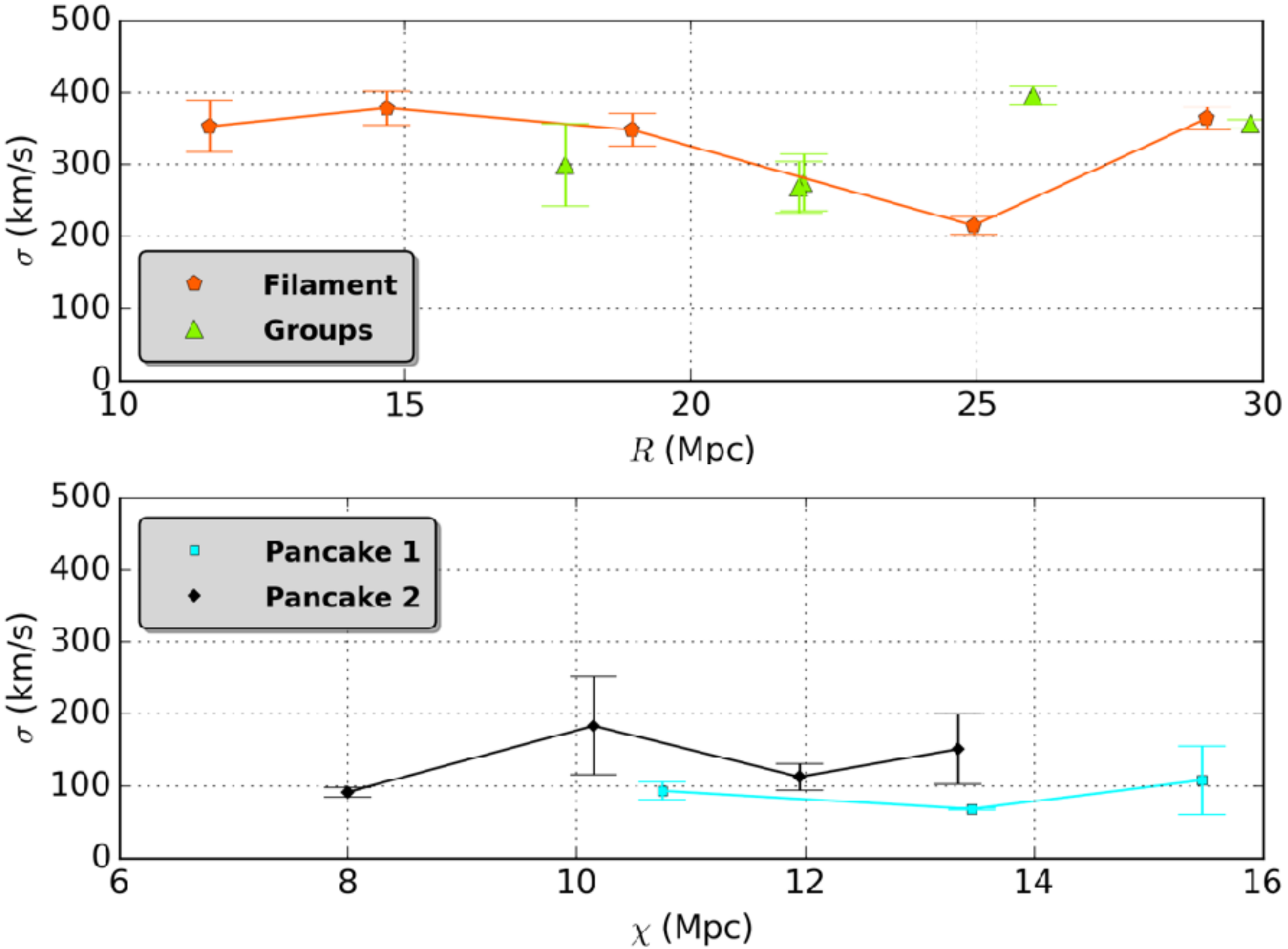
Numerical simulations





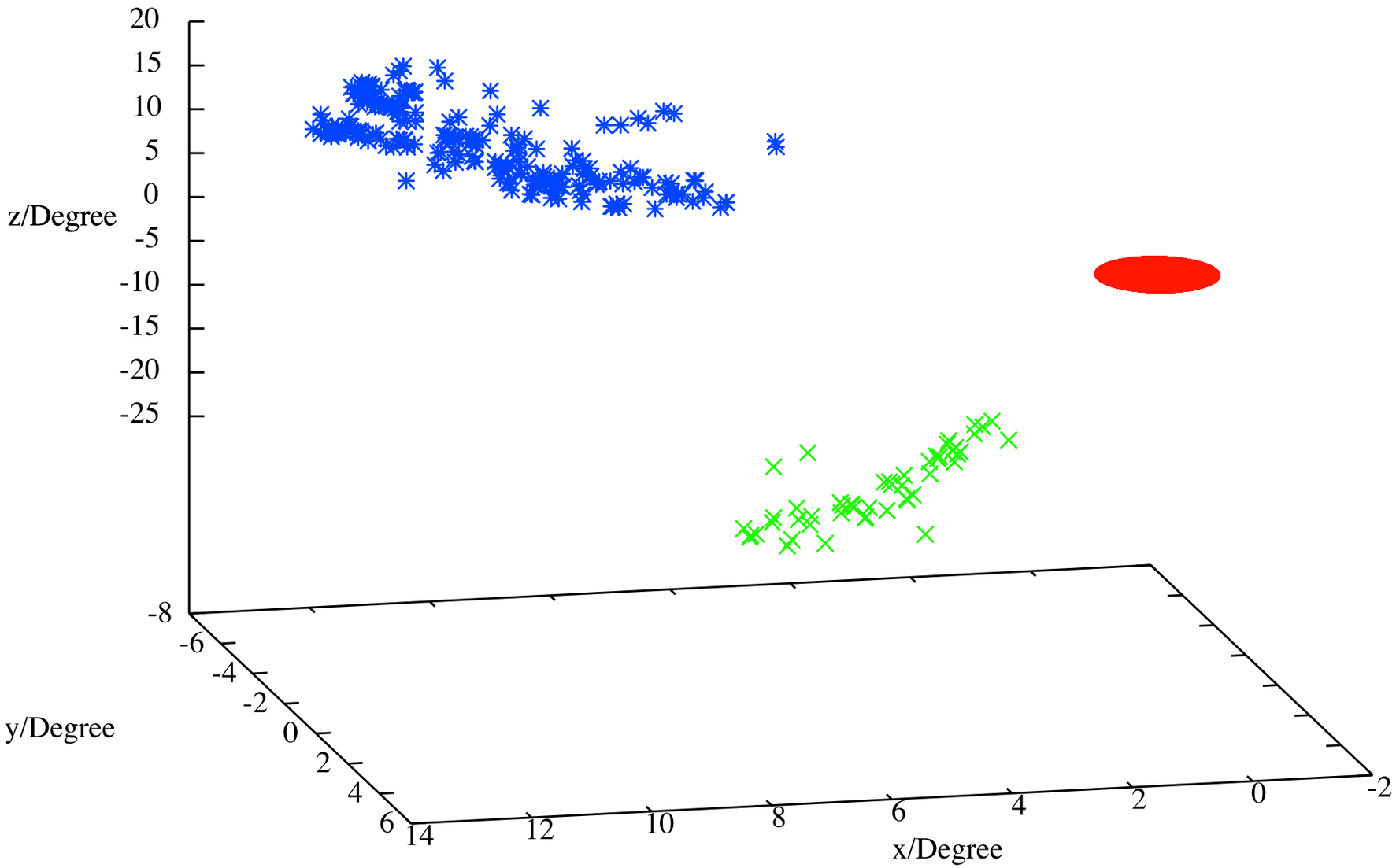
Known groups and filaments near Coma


500
400
300
200
100
0
σ (km/s)
Filament
Groups
10
15
20
25
30
R (Mpc)
Pancake 1
Pancake 2
6
8
10
12
14
16
χ (Mpc)

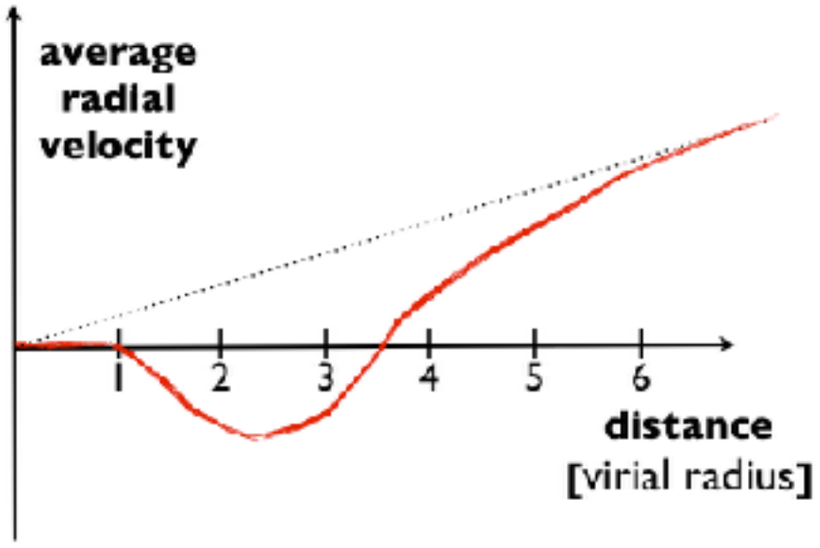


Pancakes are cold !!

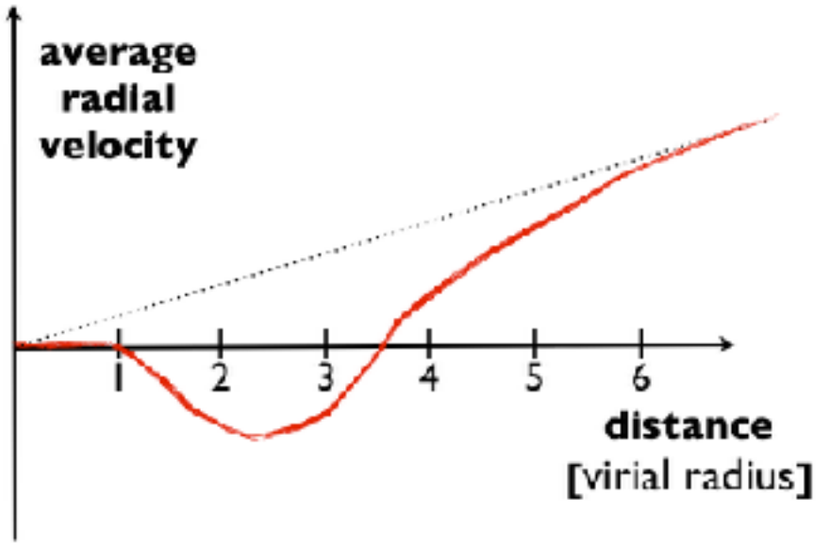
What are pancakes useful for?

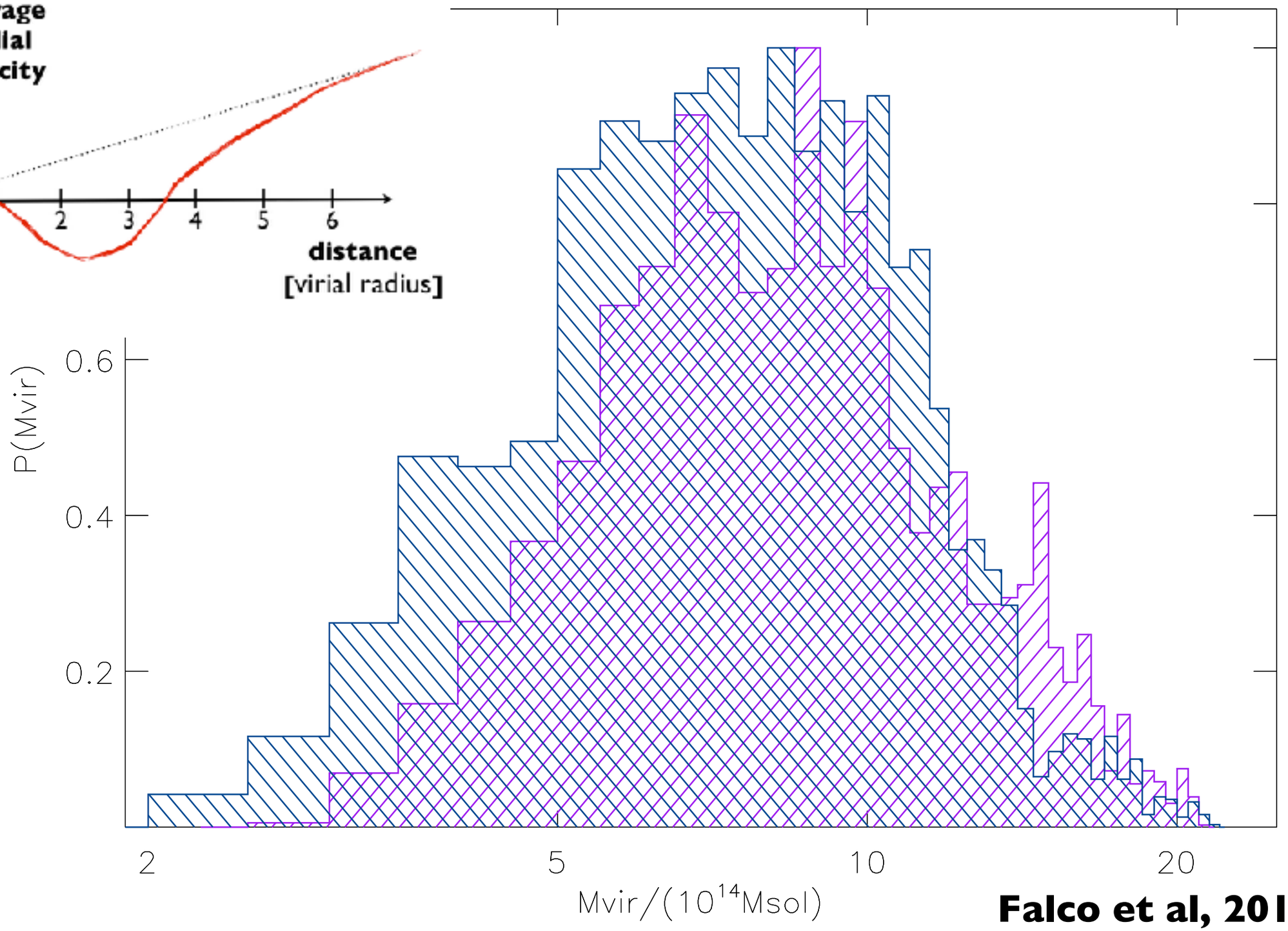


Get the mass of Coma

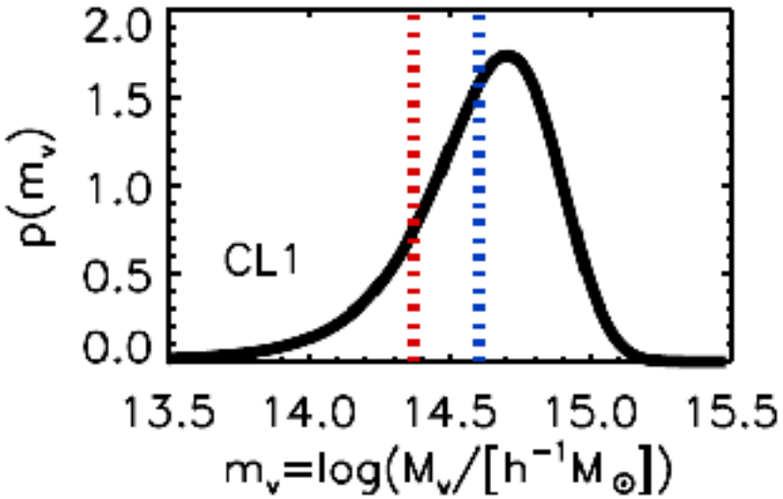


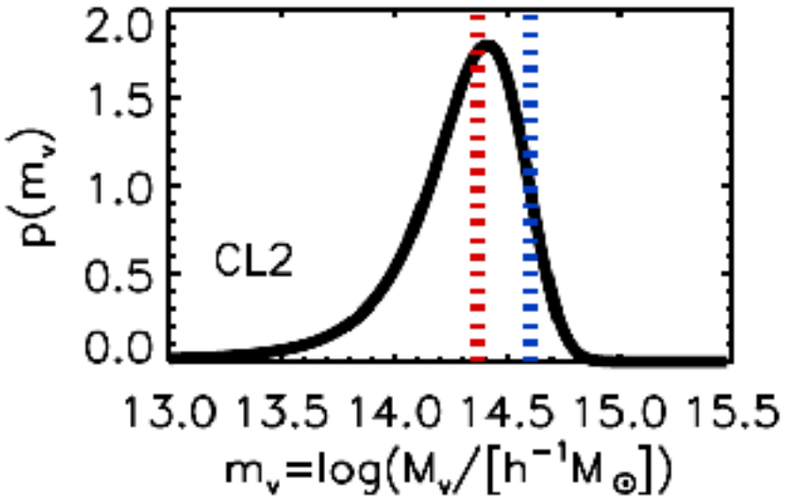
Get the mass of Coma

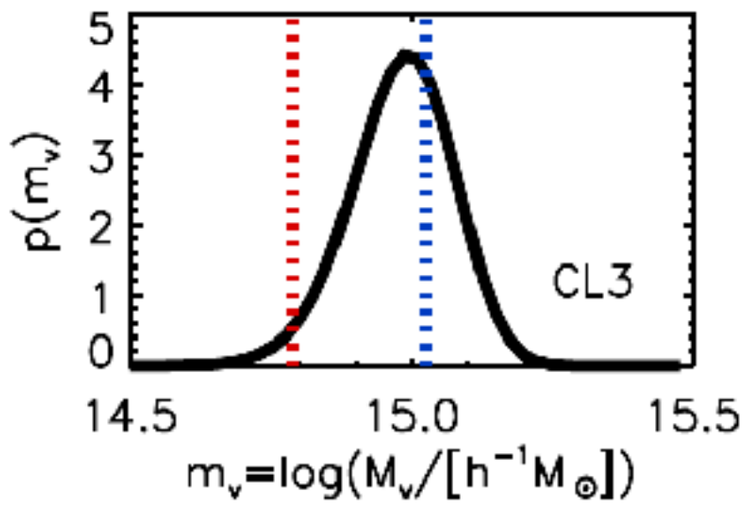


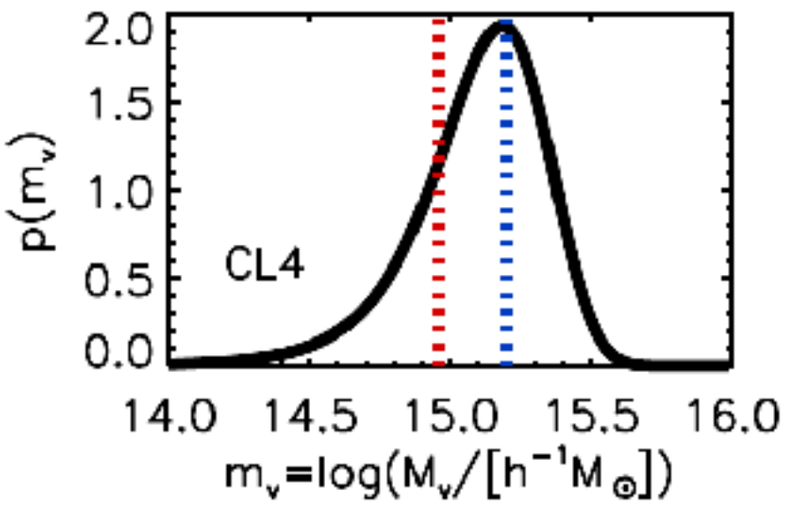


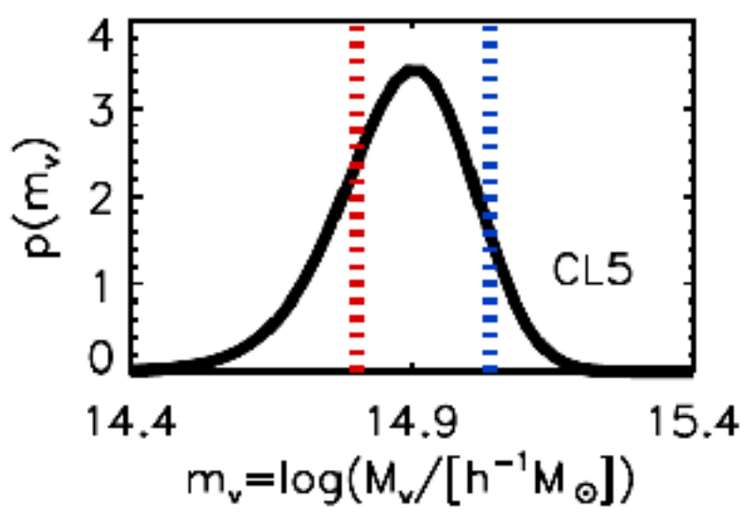
Falco et al, 2014

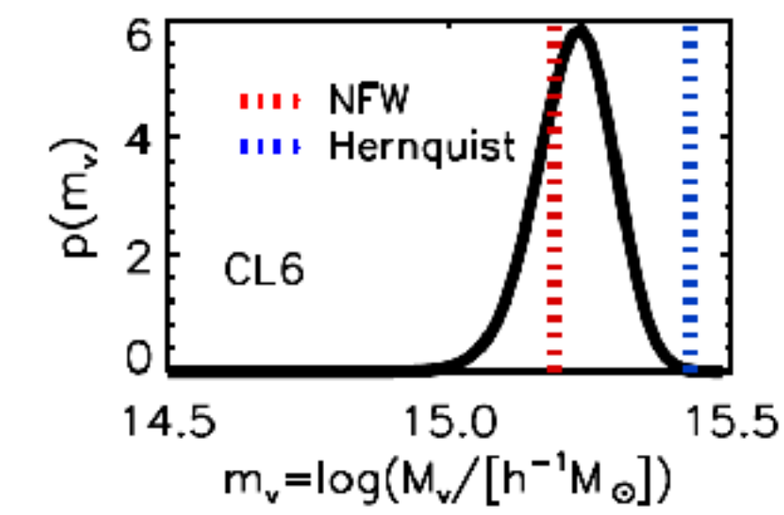












Jounghun Lee, arXiv:1702.05559

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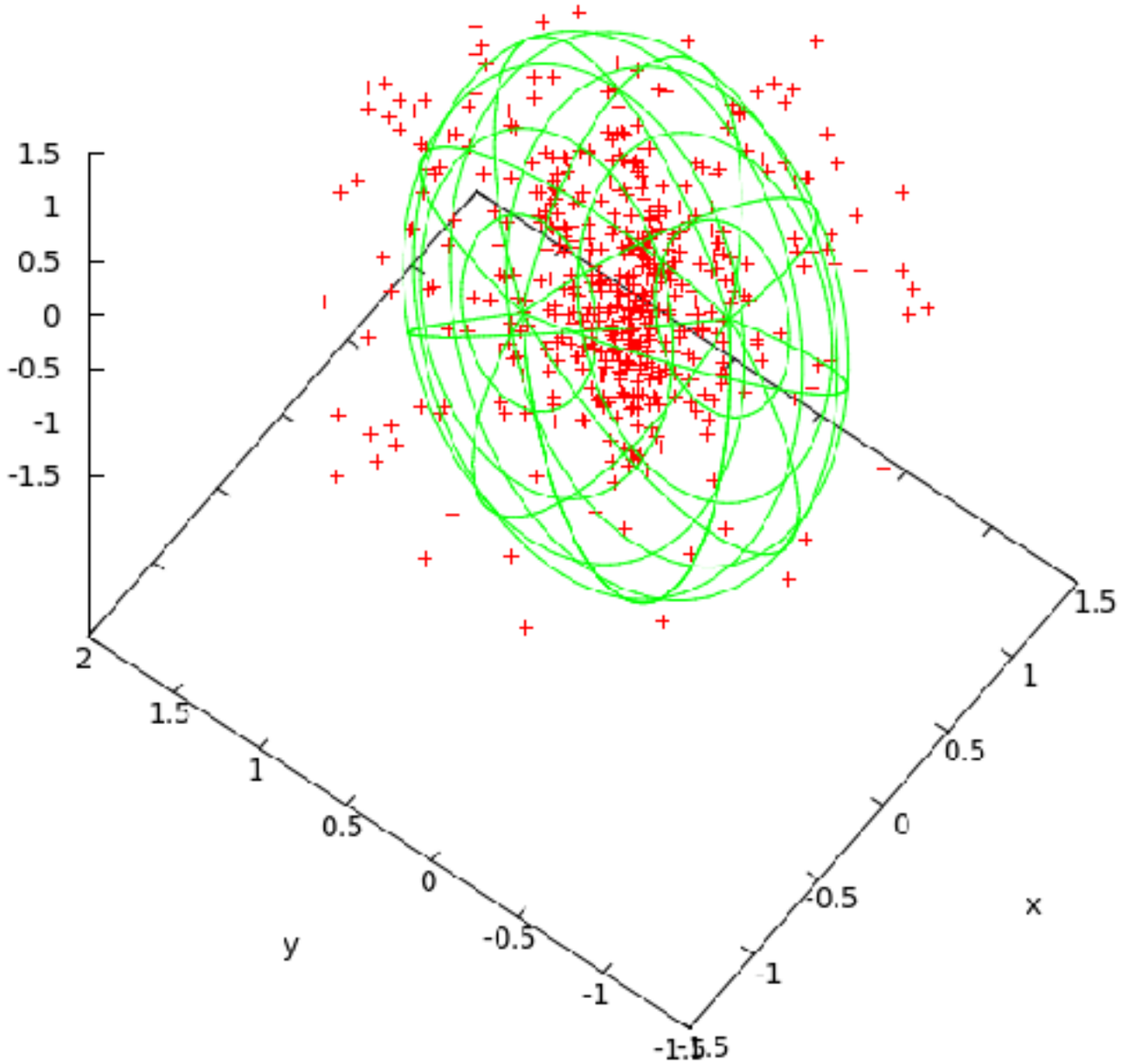
Clusters are not spherical



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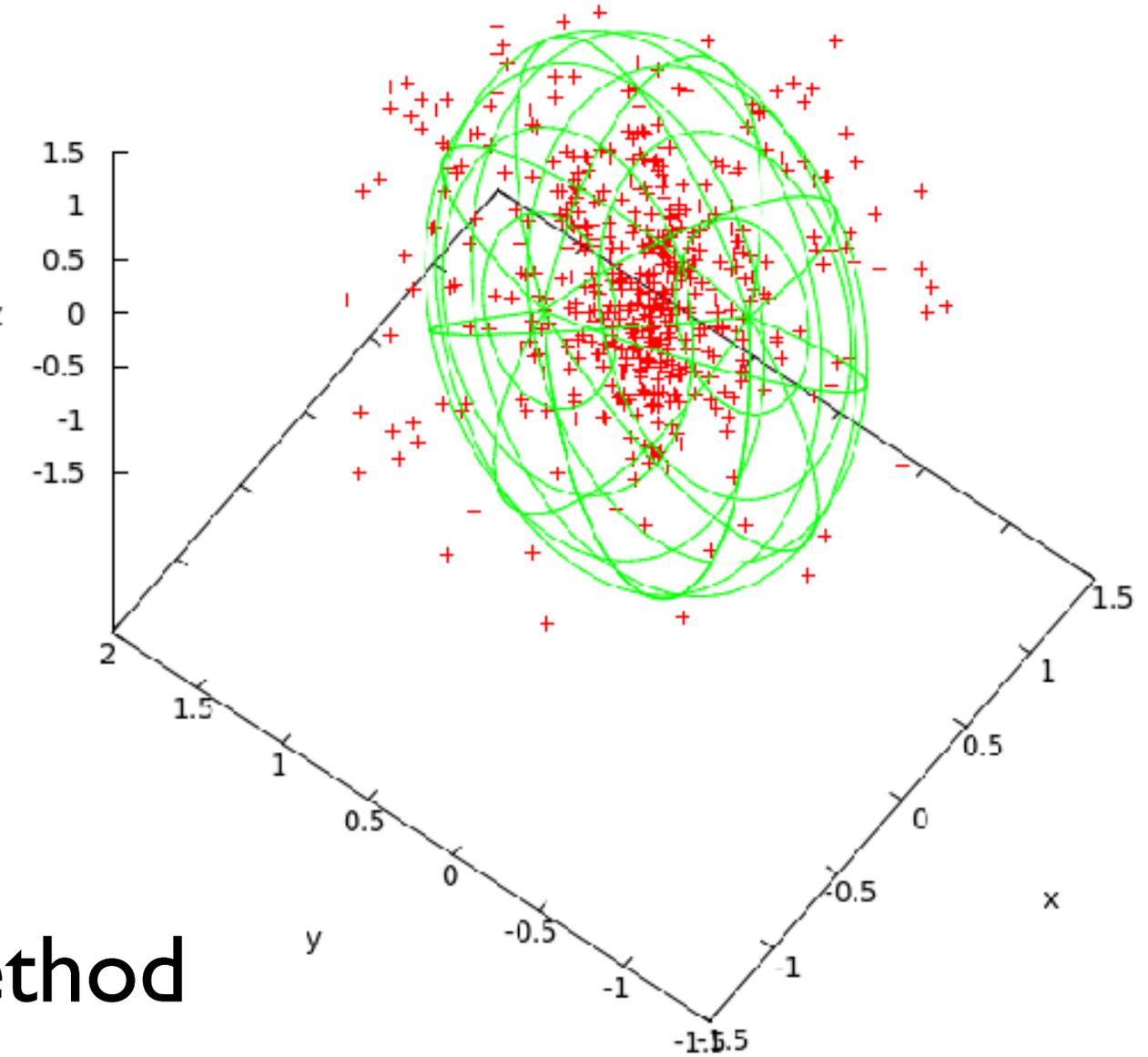
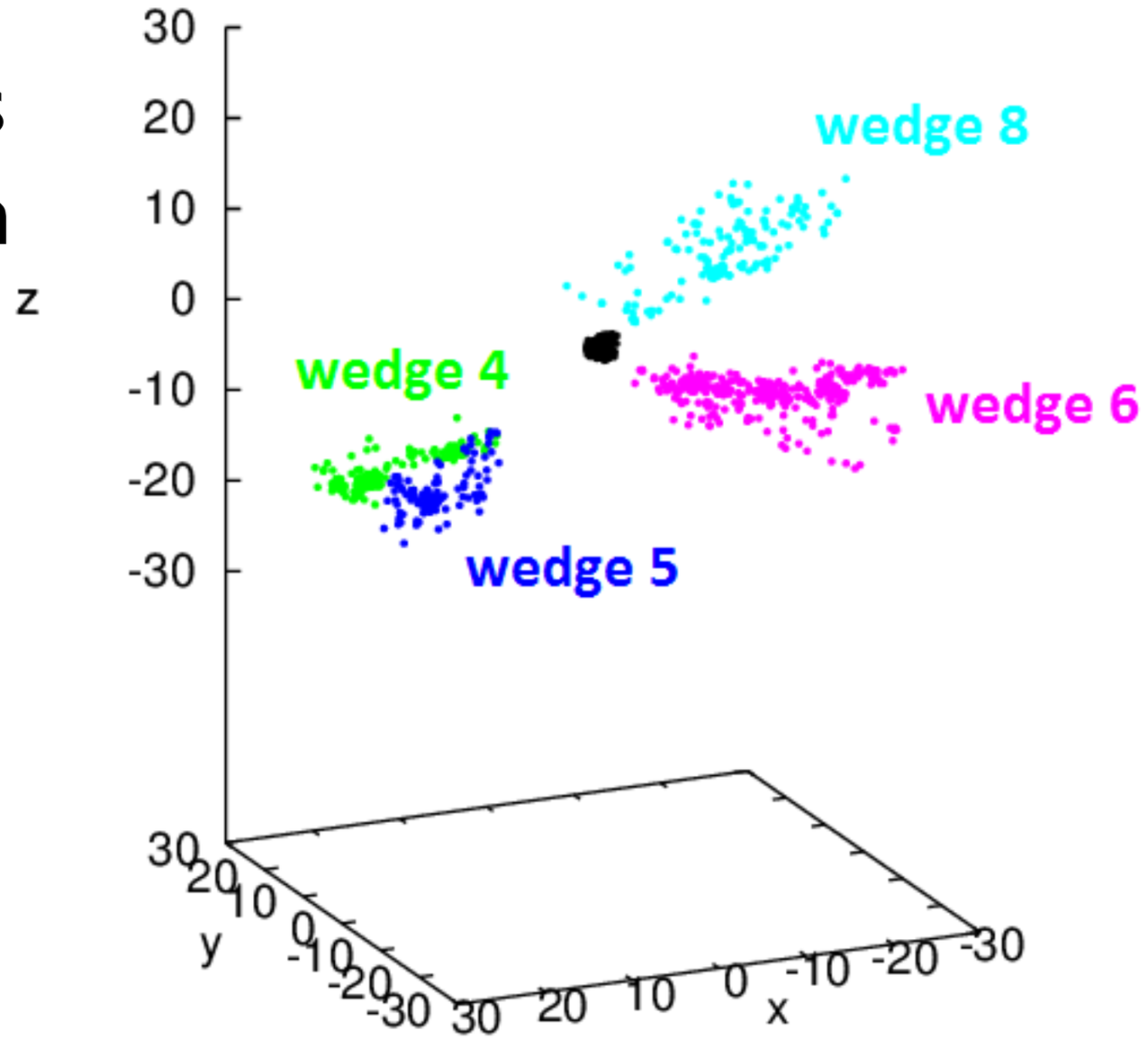
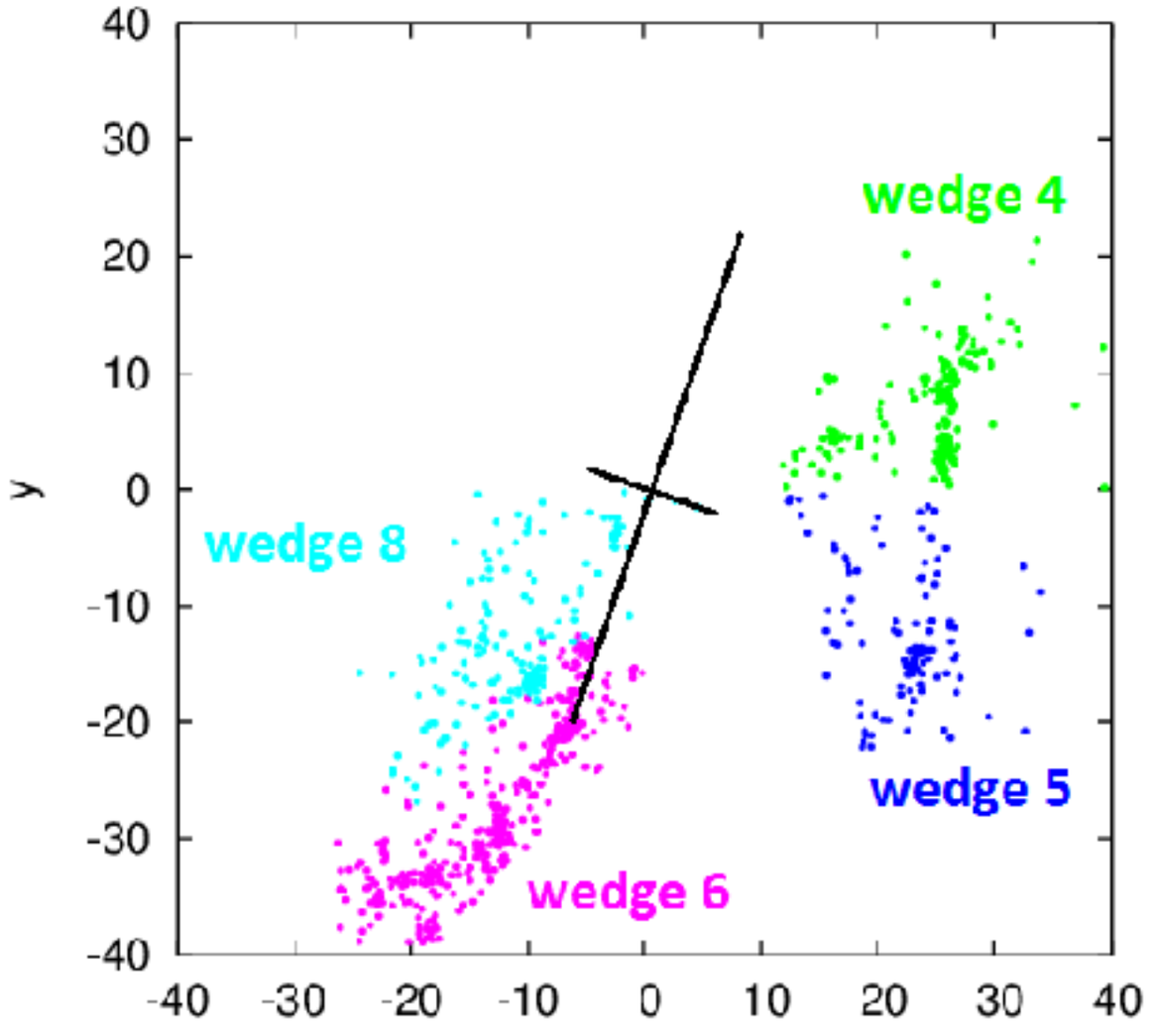


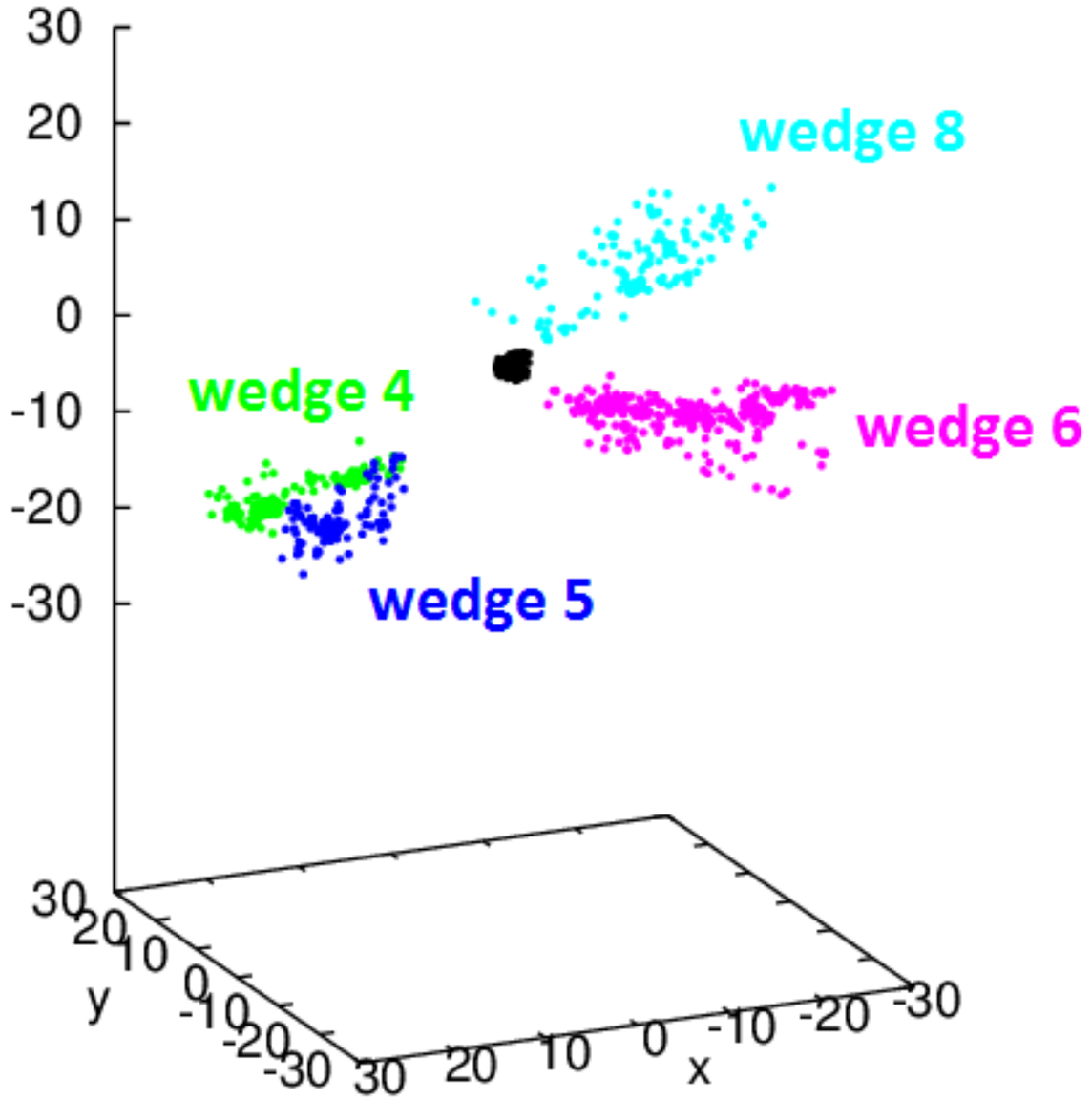
Our new mass-measurement-method depends on orientation

If we find several pancakes near a cluster, then we can measure its orientation



If we find several pancakes near a cluster, then we can measure its orientation





A master student et al, in prep

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The end