Possible Imprints of the Overshoot Problem

Sunny Itzhaki

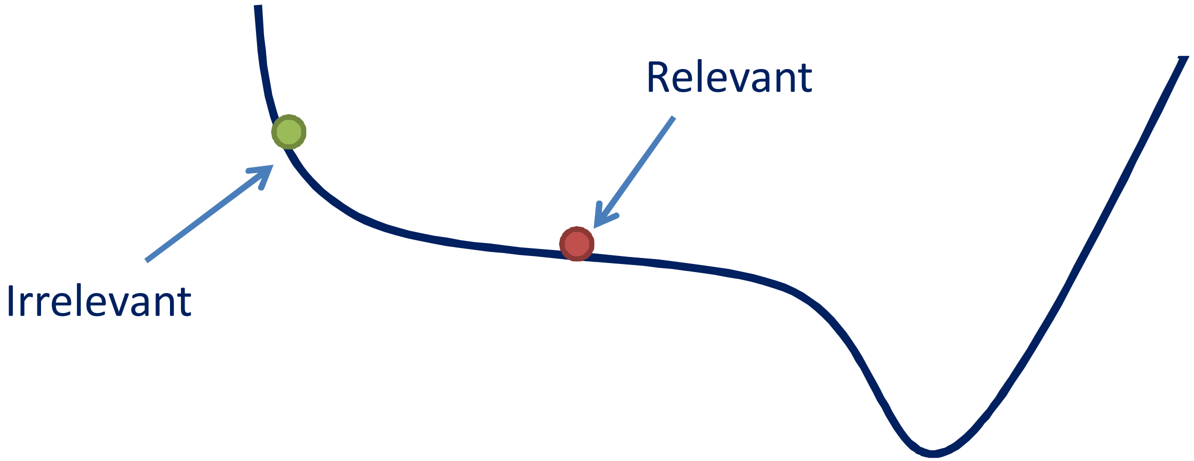
Based on:

0807.3216

A. Fialkov, N.I and E. Kovetz to appear

The basic feature of inflation is that it erases (exponentially fast) all details of the pre-inflationary period:

The basic feature of inflation is that it erases (exponentially fast) all details of the pre-inflationary period:



The attractor mechanism makes sure that  doesn't depend on  .

This is the main reason why precise predictions can be made despite the fact that we don't know the initial state  .

The parameter that controls how precise this statement is :

$$x = \exp(-\Delta N)$$

where

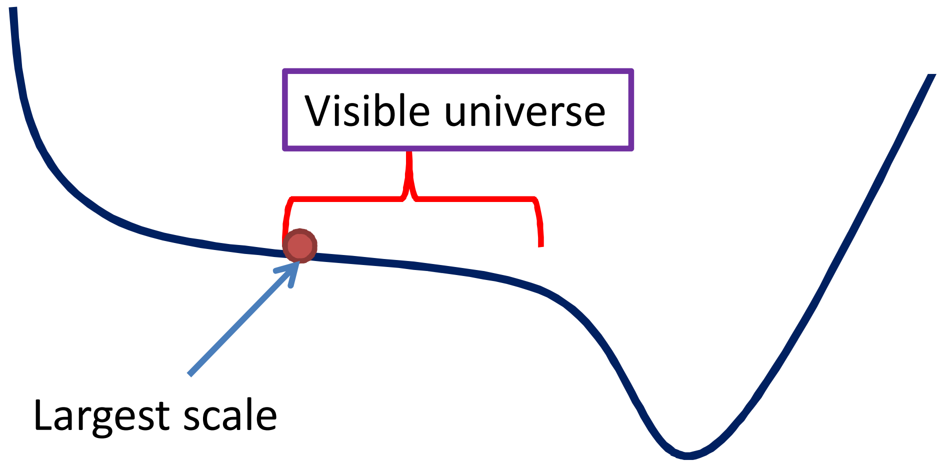
$$\Delta N = N^{total} - N^{visible}$$

The parameter that controls how precise this statement is :

$$x = \exp(-\Delta N)$$

where

$$\Delta N = N^{total} - N^{visible}$$

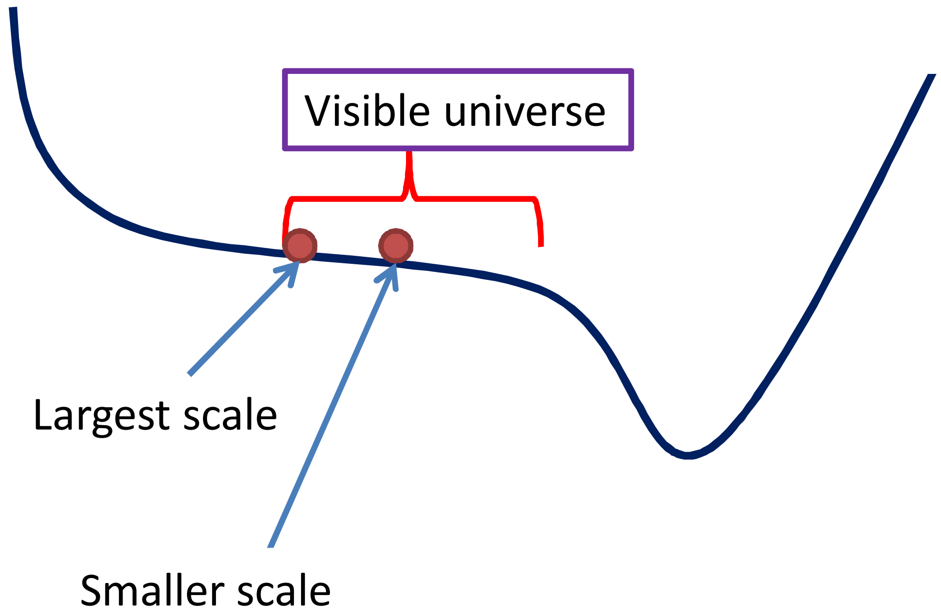


The parameter that controls how precise this statement is :

$$x = \exp(-\Delta N)$$

where

$$\Delta N = N^{total} \; - N^{visible}$$

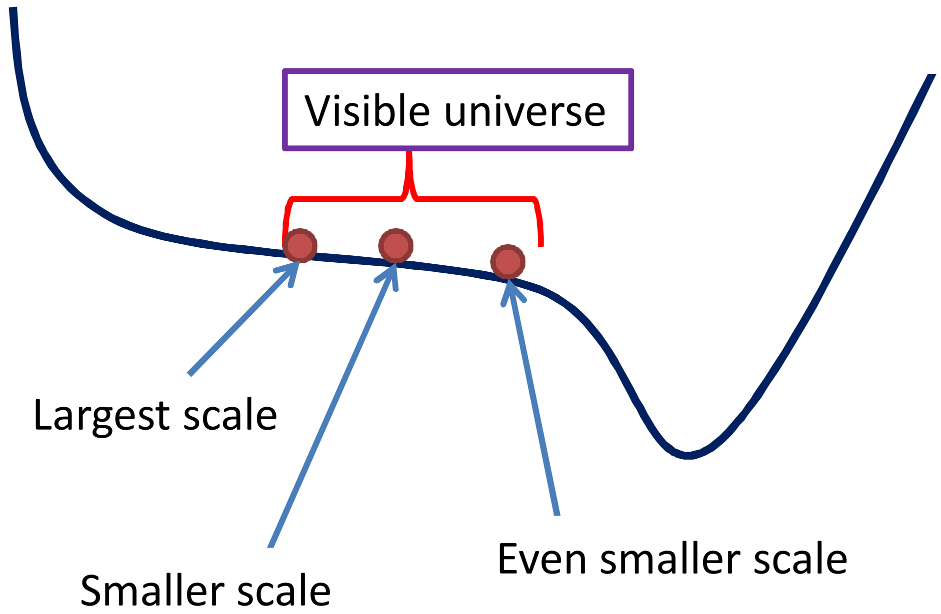


The parameter that controls how precise this statement is :

$$x = \exp(-\Delta N)$$

where

$$\Delta N = N^{total} - N^{visible}$$

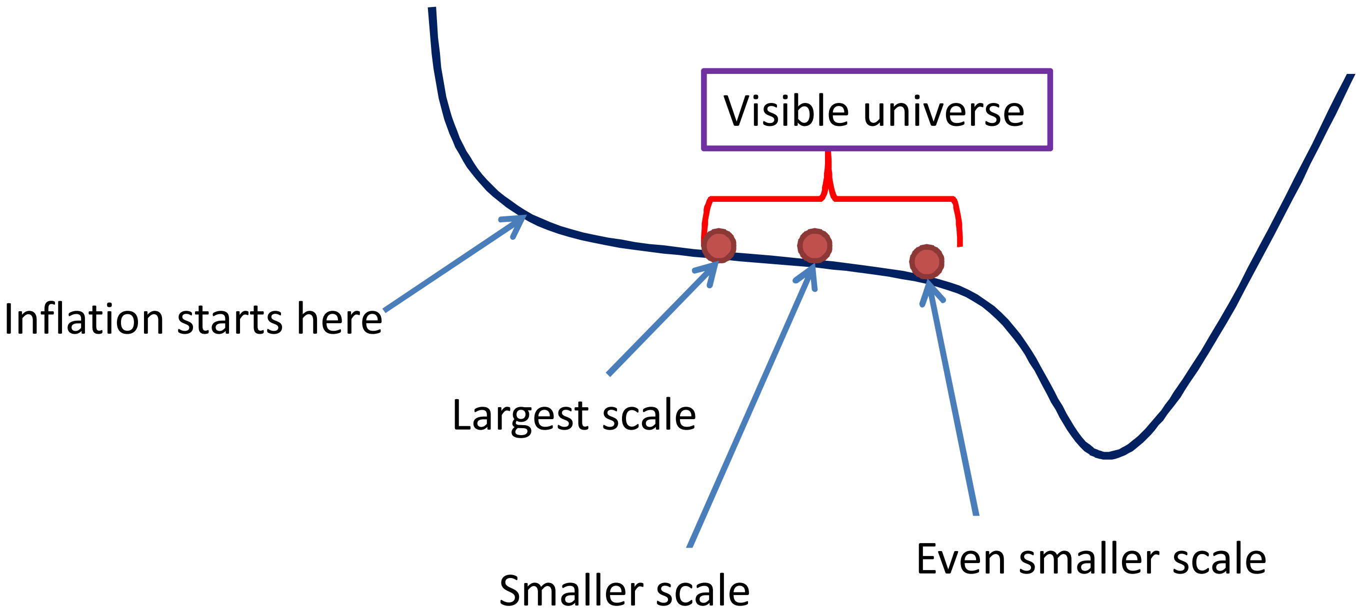


The parameter that controls how precise this statement is :

$$x = \exp(-\Delta N)$$

where

$$\Delta N = N^{total} - N^{visible}$$

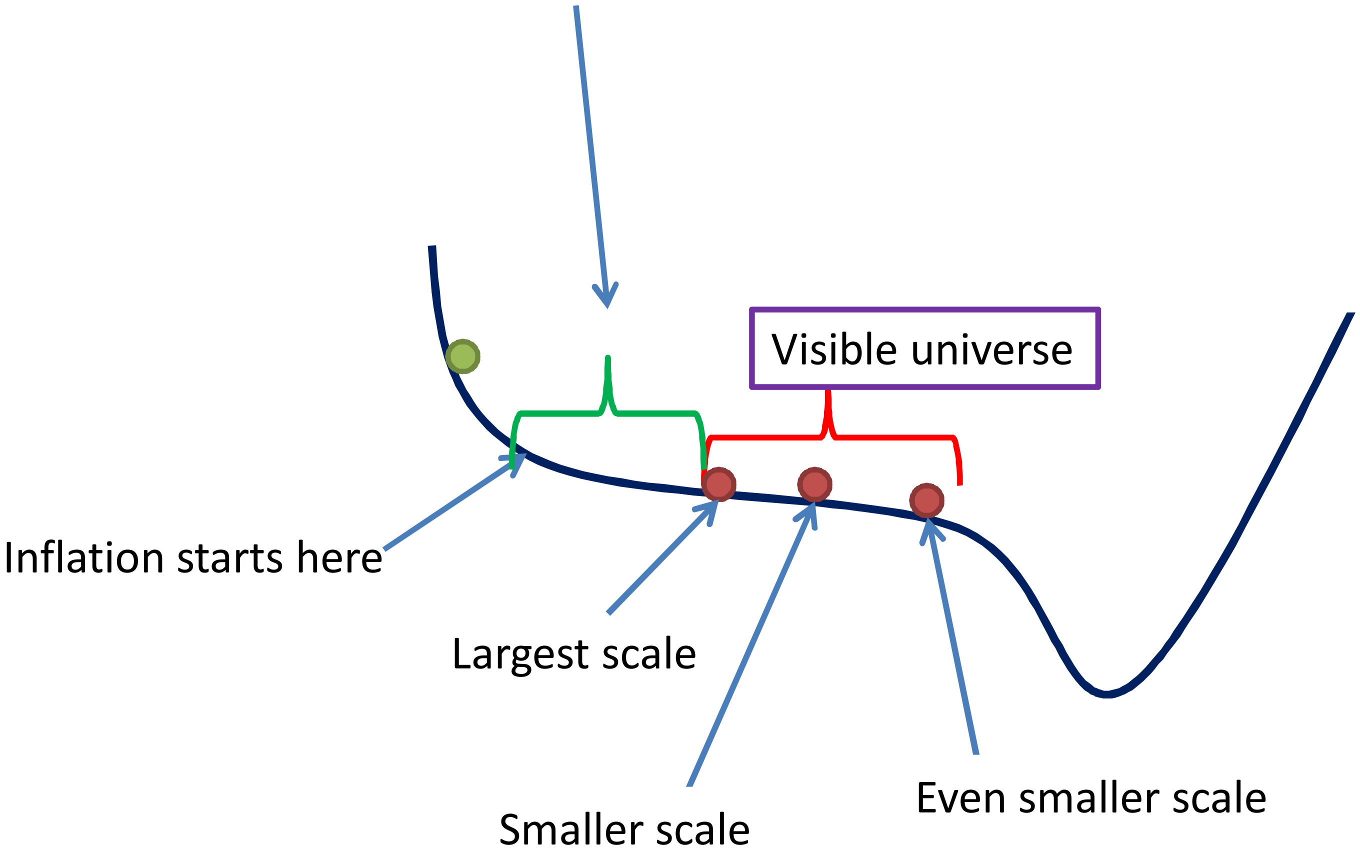


The parameter that controls how precise this statement is :

$$x = \exp(-\Delta N)$$

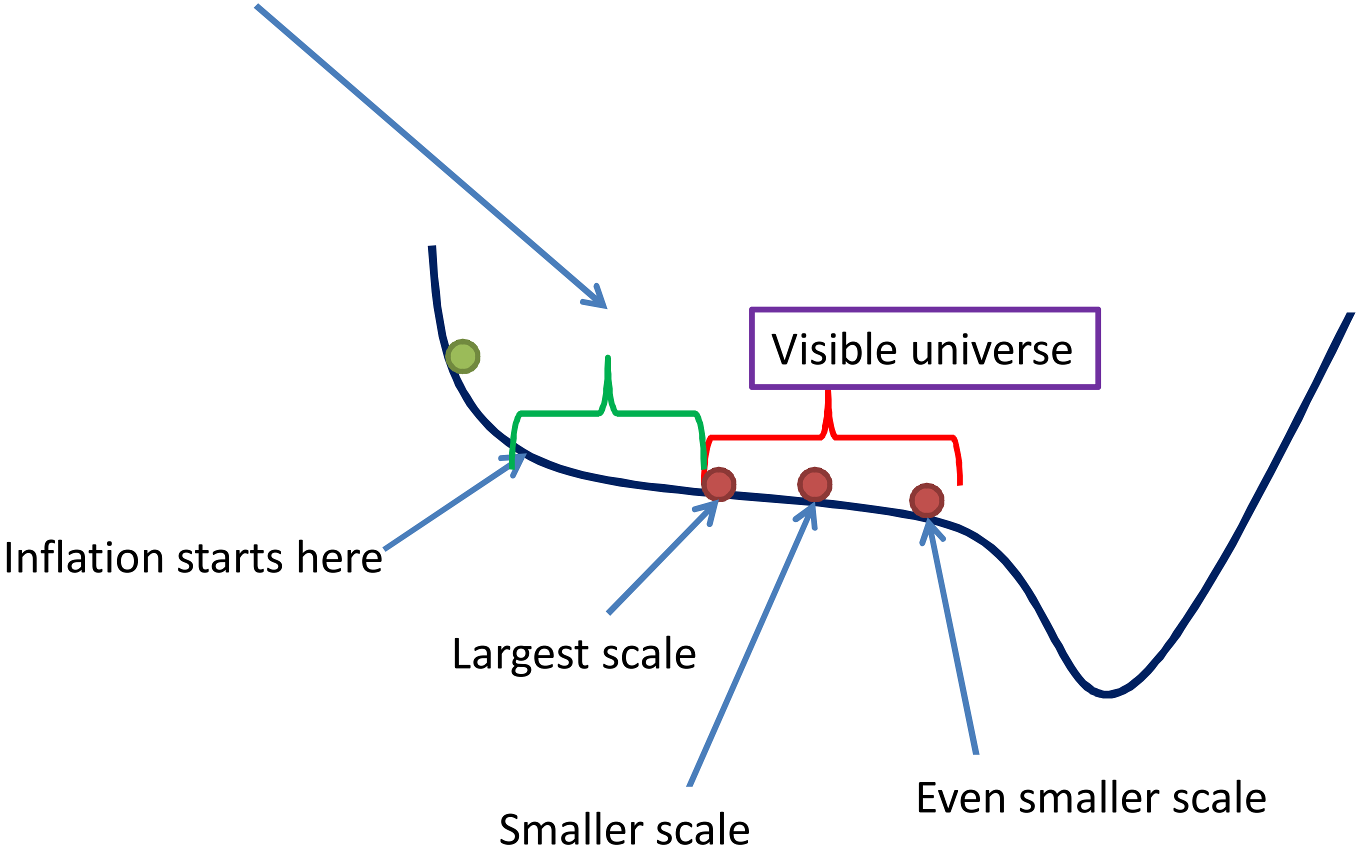
where

$$\Delta N = N^{total} - N^{visible}$$



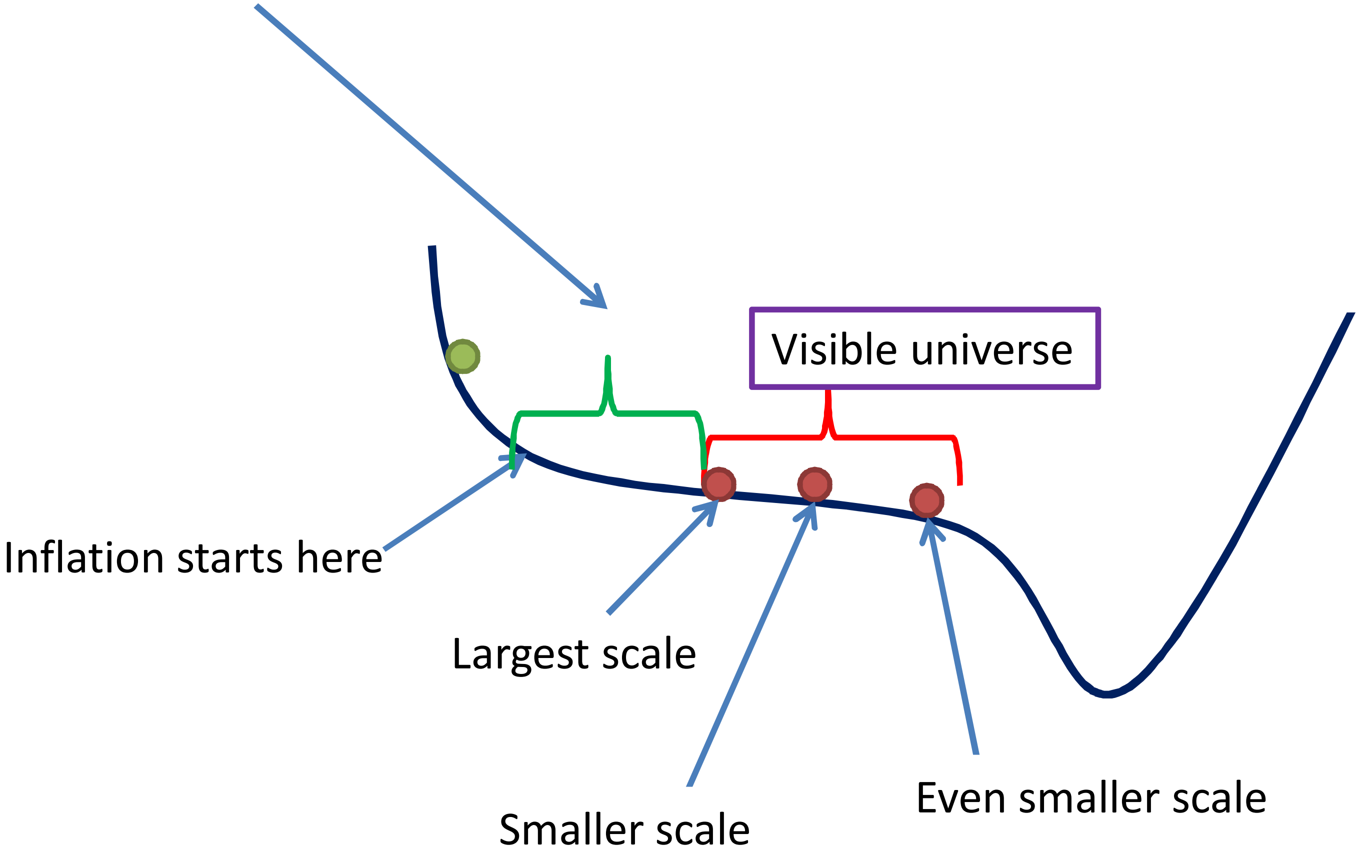
If ΔN is large then the visible universe is not sensitive to the initial condition ● .

$$\Delta N = N^{total} - N^{visible}$$



If ΔN is not that large then the largest scales in the visible universe depend on [green dot].

$$\Delta N = N^{total} - N^{visible}$$



I would like to argue that both experimentally and theoretically there are hints that ΔN is not too large.

Experimentally, there are some 2σ anomalies at the largest scales:

Large peculiar velocity

(Watkins, Feldman, Hudson, 0809.4041; Kashlinsky, Atrio-Barandela,Kocevski, Ebeling, 0809.3734; Lavaux, Tully, Mohayaee, Colombi, 0810.3658)

Theory :

1. For $\sim 100h^{-1}$ Mpc

   about ~ 110 km s^{-1}

2. Drops like $1/r$

Observation:

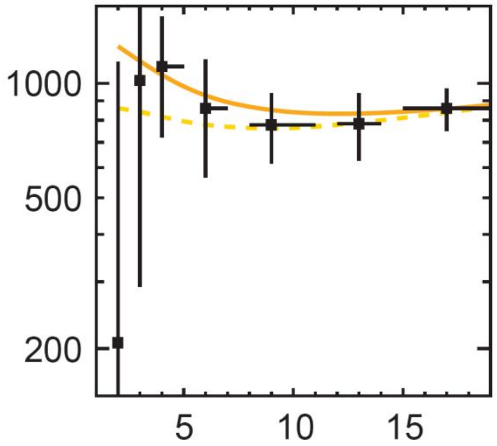
1. For $\sim 100h^{-1}$ Mpc

   about 407 ± 81 km s^{-1}

2. Does not drop with distance.

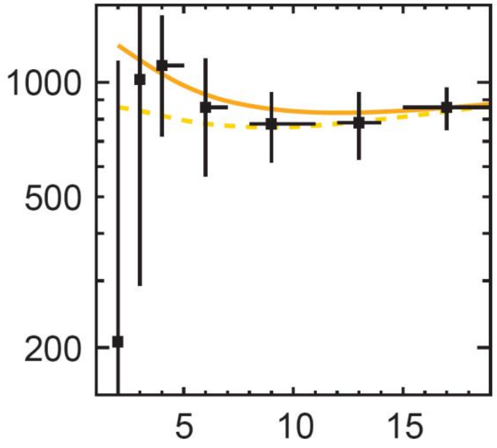
CMB is anomalously small at large distances

WMAP 3



CMB is anomalously small at large distances

WMAP 3

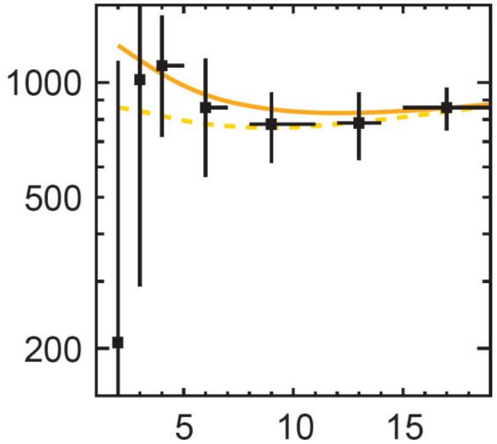


Might be viewed as evidence

for small ΔN .

CMB is anomalously small at large distances

WMAP 3



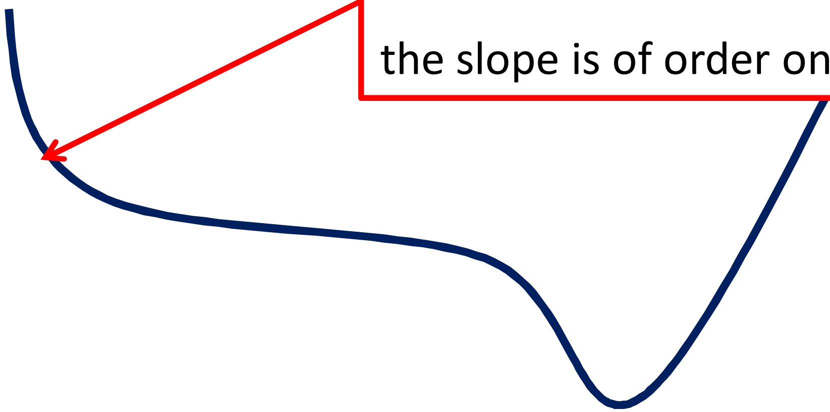
Might be viewed as evidence

for small ΔN .

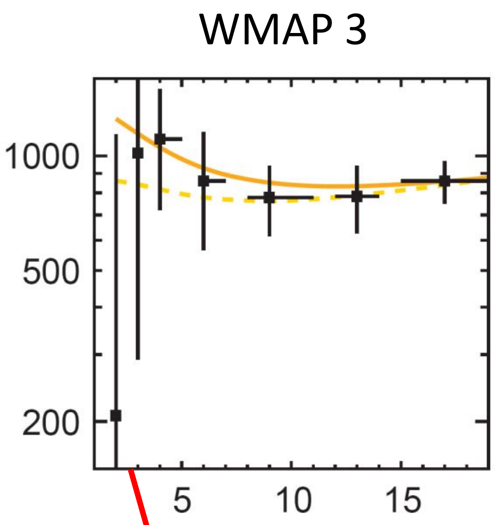
The reason is that $P \sim \frac{1}{V'}$

Inflation begins roughly were

the slope is of order one



CMB is anomalously small at large distances



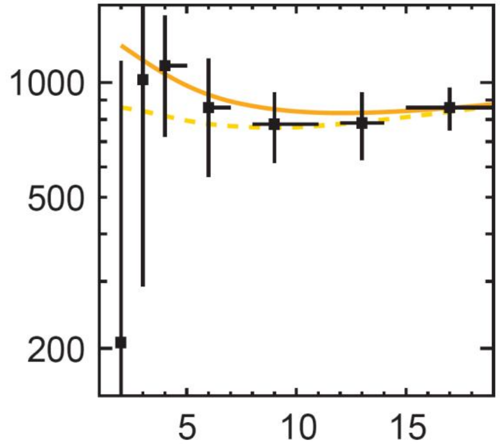
Might be viewed as evidence for small ΔN .

The reason is that $P \sim \frac{1}{V'}$

Inflation begins roughly were the slope is of order one

CMB is anomalously small at large distances

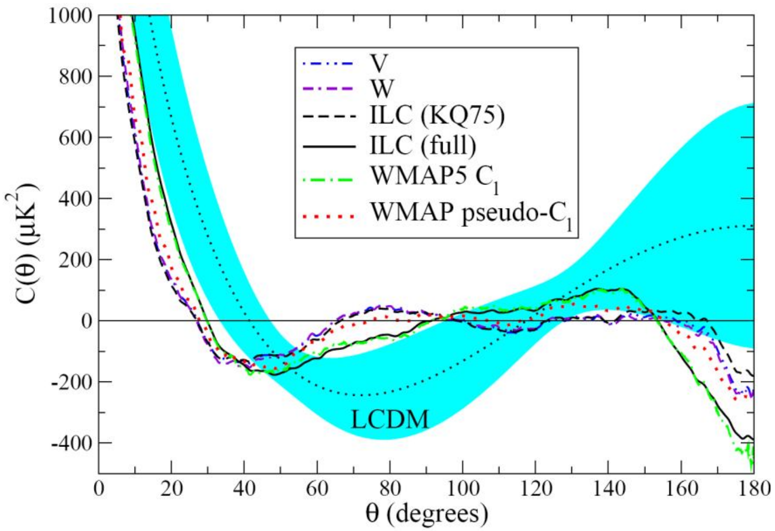
WMAP 3

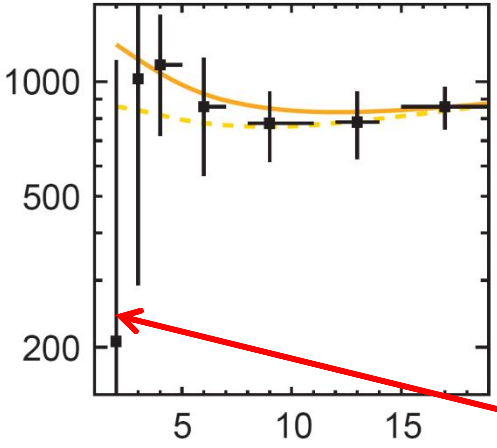


Might be viewed as evidence

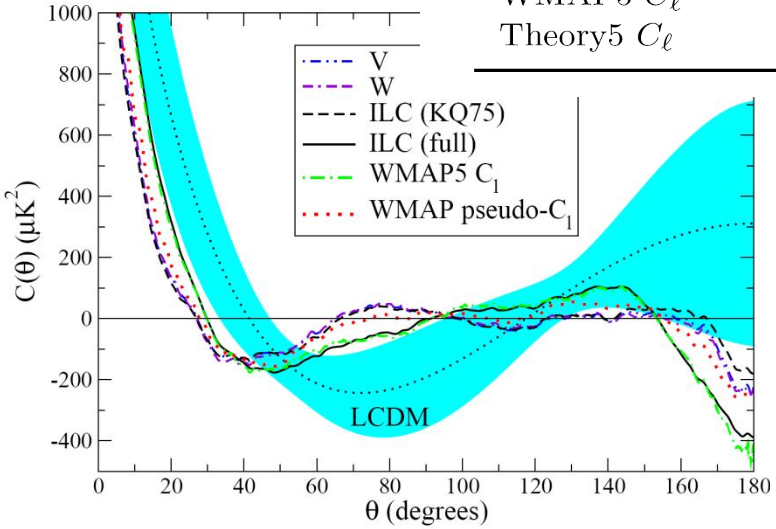
for small ΔN .

Copi et.al 0808.3767

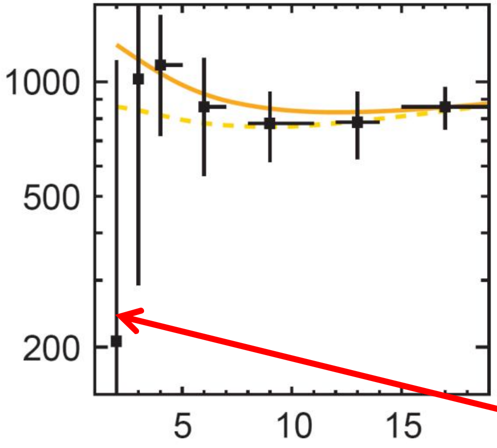




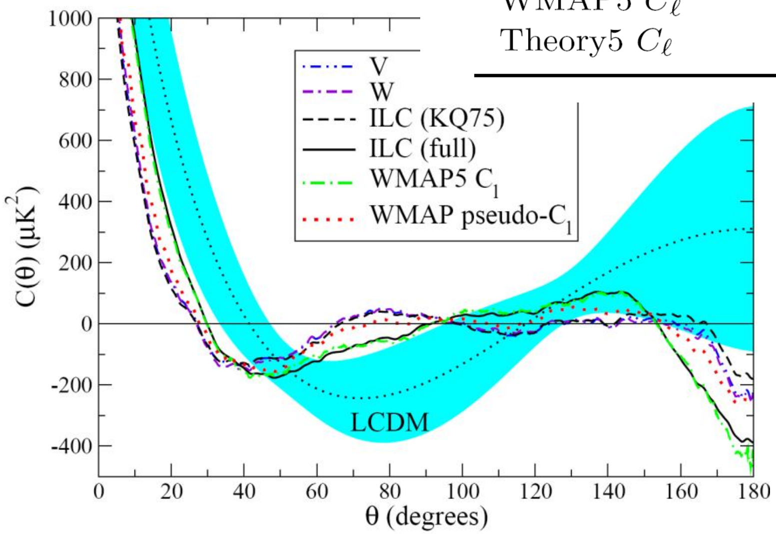
Data Source	$S_{1/2}$ $(\mu K)^4$	$P(S_{1/2})$ (per cent)	$6\mathcal{C}_2/2\pi$ $(\mu K)^2$	$12\mathcal{C}_3/2\pi$ $(\mu K)^2$	$20\mathcal{C}_4/2\pi$ $(\mu K)^2$	$30\mathcal{C}_5/2\pi$ $(\mu K)^2$
V3 (kp0, DQ)	1288	0.04	77	410	762	1254
W3 (kp0, DQ)	1322	0.04	68	450	771	1302
ILC3 (kp0, DQ)	1026	0.017	128	442	762	1180
ILC3 (kp0), $\mathcal{C}(> 60°) = 0$	0	—	84	394	875	1135
ILC3 (full, DQ)	8413	4.9	239	1051	756	1588
V5 (KQ75)	1346	0.042	60	339	745	1248
W5 (KQ75)	1330	0.038	47	379	752	1287
V5 (KQ75, DQ)	1304	0.037	77	340	746	1249
W5 (KQ75, DQ)	1284	0.034	59	379	753	1289
ILC5 (KQ75)	1146	0.025	81	320	769	1156
ILC5 (KQ75, DQ)	1152	0.025	95	320	768	1158
ILC5 (full, DQ)	8583	5.1	253	1052	730	1590
WMAP3 pseudo-C_ℓ	2093	0.18	120	602	701	1346
WMAP3 MLE C_ℓ	8334	4.2	211	1041	731	1521
Theory3 C_ℓ	52857	43	1250	1143	1051	981
WMAP5 C_ℓ	8833	4.6	213	1039	674	1527
Theory5 C_ℓ	49096	41	1207	1114	1031	968



Copi et.al 0808.3767



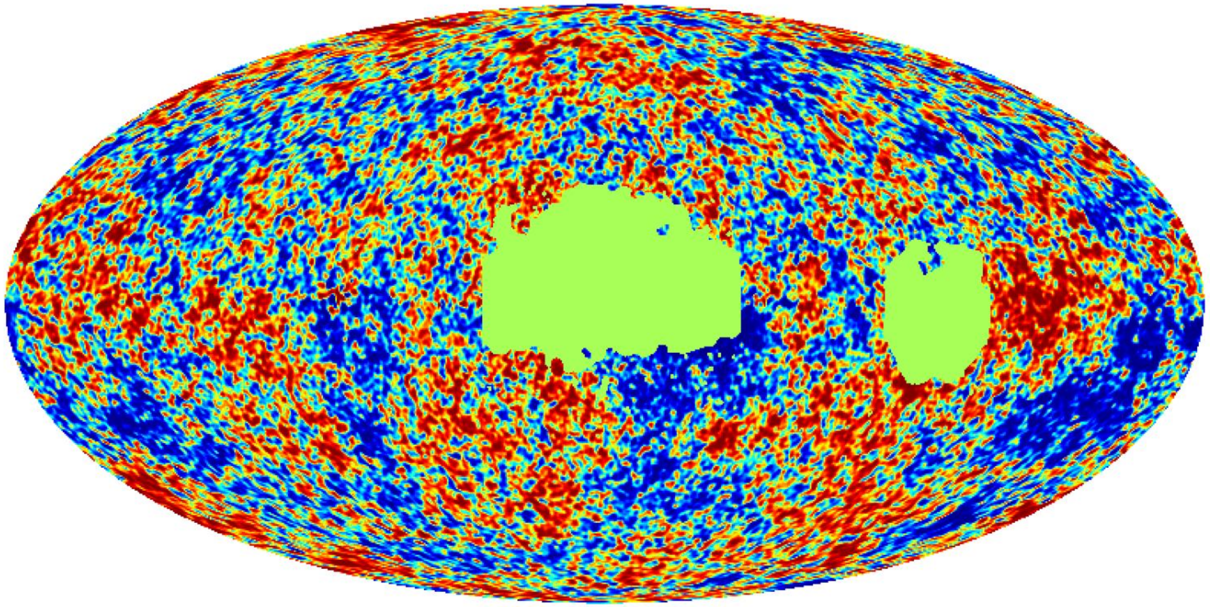
Data Source	$S_{1/2}$ $(\mu K)^4$	$P(S_{1/2})$ (per cent)	$6\mathcal{C}_2/2\pi$ $(\mu K)^2$	$12\mathcal{C}_3/2\pi$ $(\mu K)^2$	$20\mathcal{C}_4/2\pi$ $(\mu K)^2$	$30\mathcal{C}_5/2\pi$ $(\mu K)^2$
V3 (kp0, DQ)	1288	0.04	77	410	762	1254
W3 (kp0, DQ)	1322	0.04	68	450	771	1302
ILC3 (kp0, DQ)	1026	0.017	128	442	762	1180
ILC3 (kp0), $\mathcal{C}(>60^\circ)=0$	0	—	84	394	875	1135
ILC3 (full, DQ)	8413	4.9	239	1051	756	1588
V5 (KQ75)	1346	0.042	60	339	745	1248
W5 (KQ75)	1330	0.038	47	379	752	1287
V5 (KQ75, DQ)	1304	0.037	77	340	746	1249
W5 (KQ75, DQ)	1284	0.034	59	379	753	1289
ILC5 (KQ75)	1146	0.025	81	320	769	1156
ILC5 (KQ75, DQ)	1152	0.025	95	320	768	1158
ILC5 (full, DQ)	8583	5.1	253	1052	730	1590
WMAP3 pseudo-C_ℓ	2093	0.18	120	602	701	1346
WMAP3 MLE C_ℓ	8334	4.2	211	1041	731	1521
Theory3 C_ℓ	52857	43	1250	1143	1051	981
WMAP5 C_ℓ	8833	4.6	213	1039	674	1527
Theory5 C_ℓ	49096	41	1207	1114	1031	968



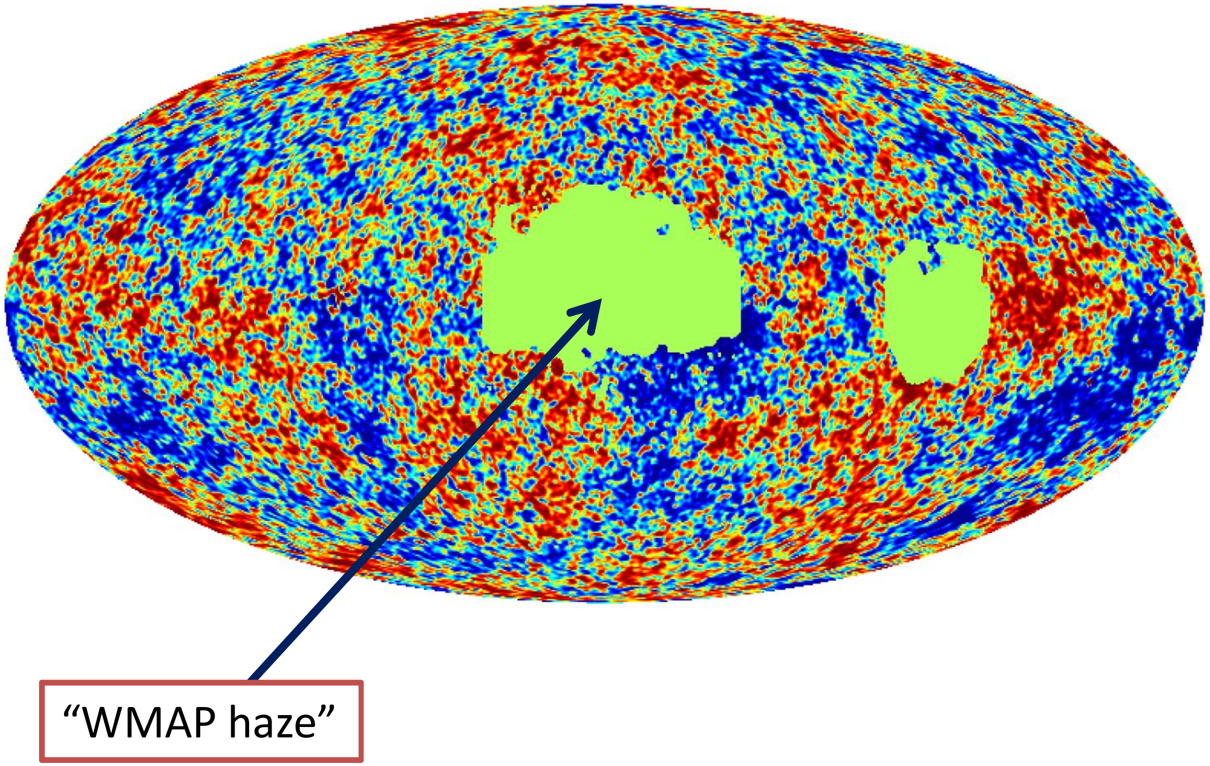
Become much less probable when masking the galactic plane

Copi et.al 0808.3767

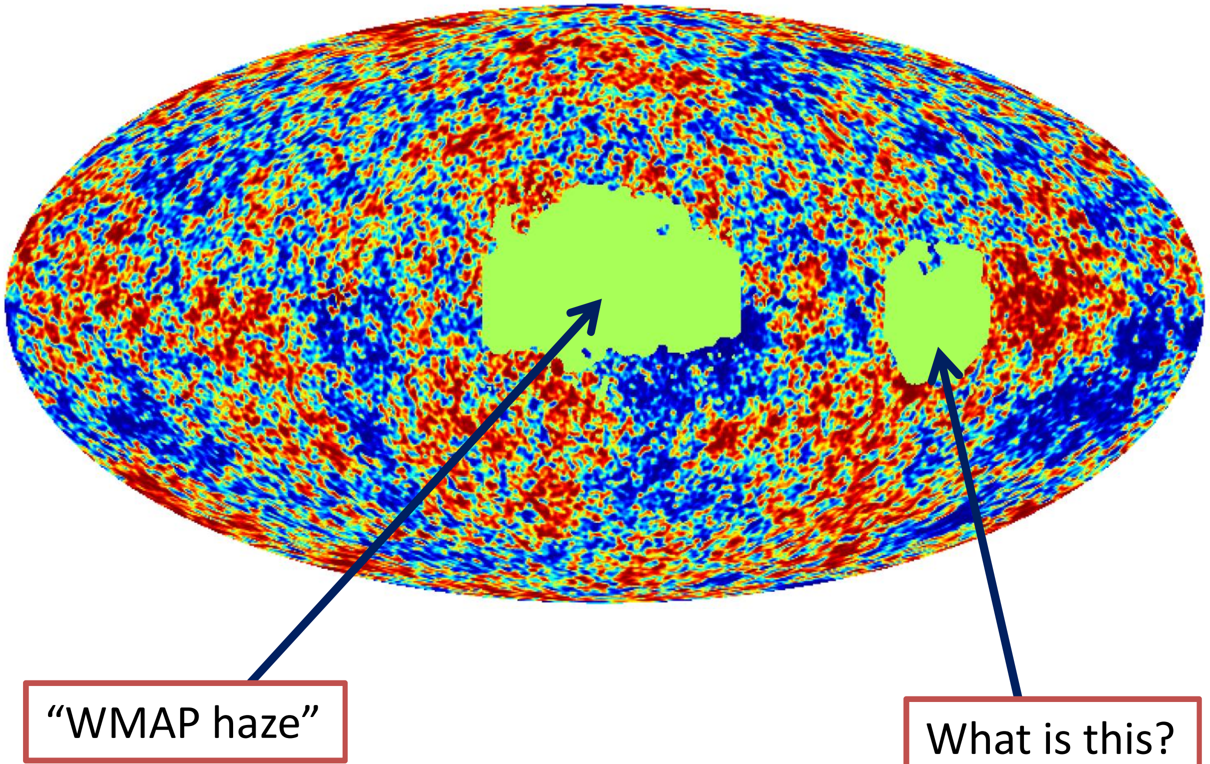
In fact even within the galactic plane it is localized (Hajian 0702723)



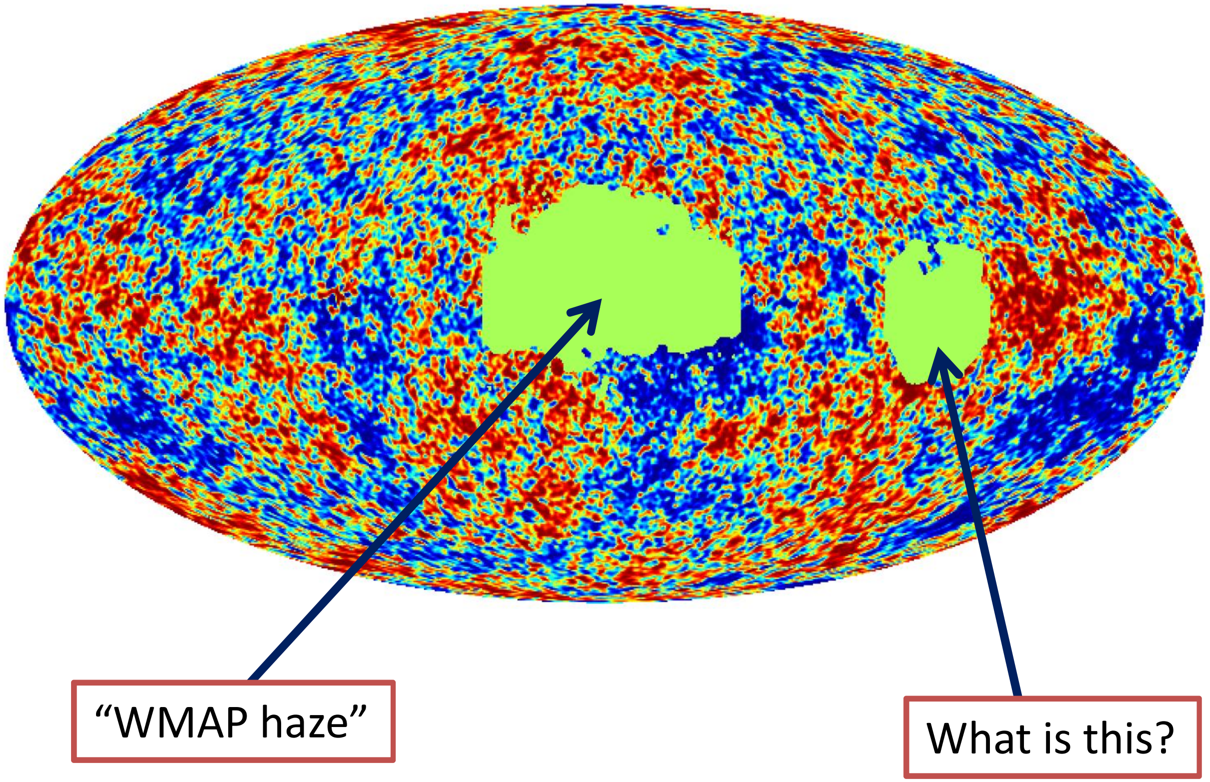
In fact even within the galactic plane it is localized (Hajian 0702723)



In fact even within the galactic plane it is localized (Hajian 0702723)



In fact even within the galactic plane it is localized (Hajian 0702723)



Don't know.

But it is interesting that roughly it is in the same direction as the peculiar velocity.

Theoretically, it is not easy to construct in string theory large field models of inflation.

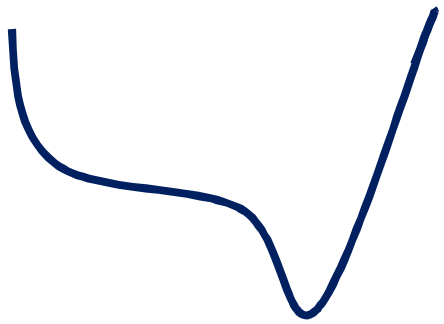
Where ΔN is always large.

Theoretically, it is not easy to construct in string theory large field models of inflation.

Where ΔN is always large.

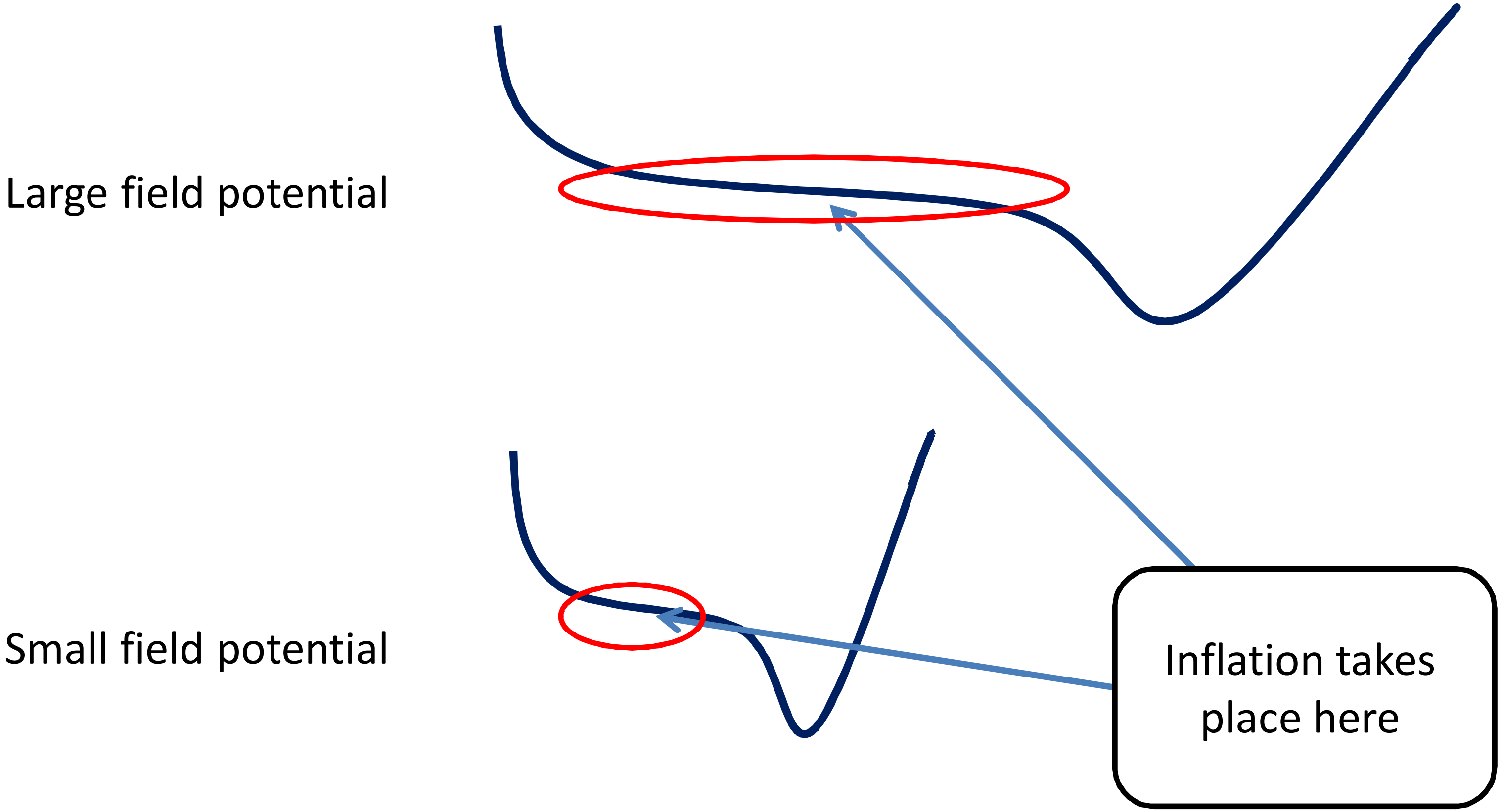
Large field potential

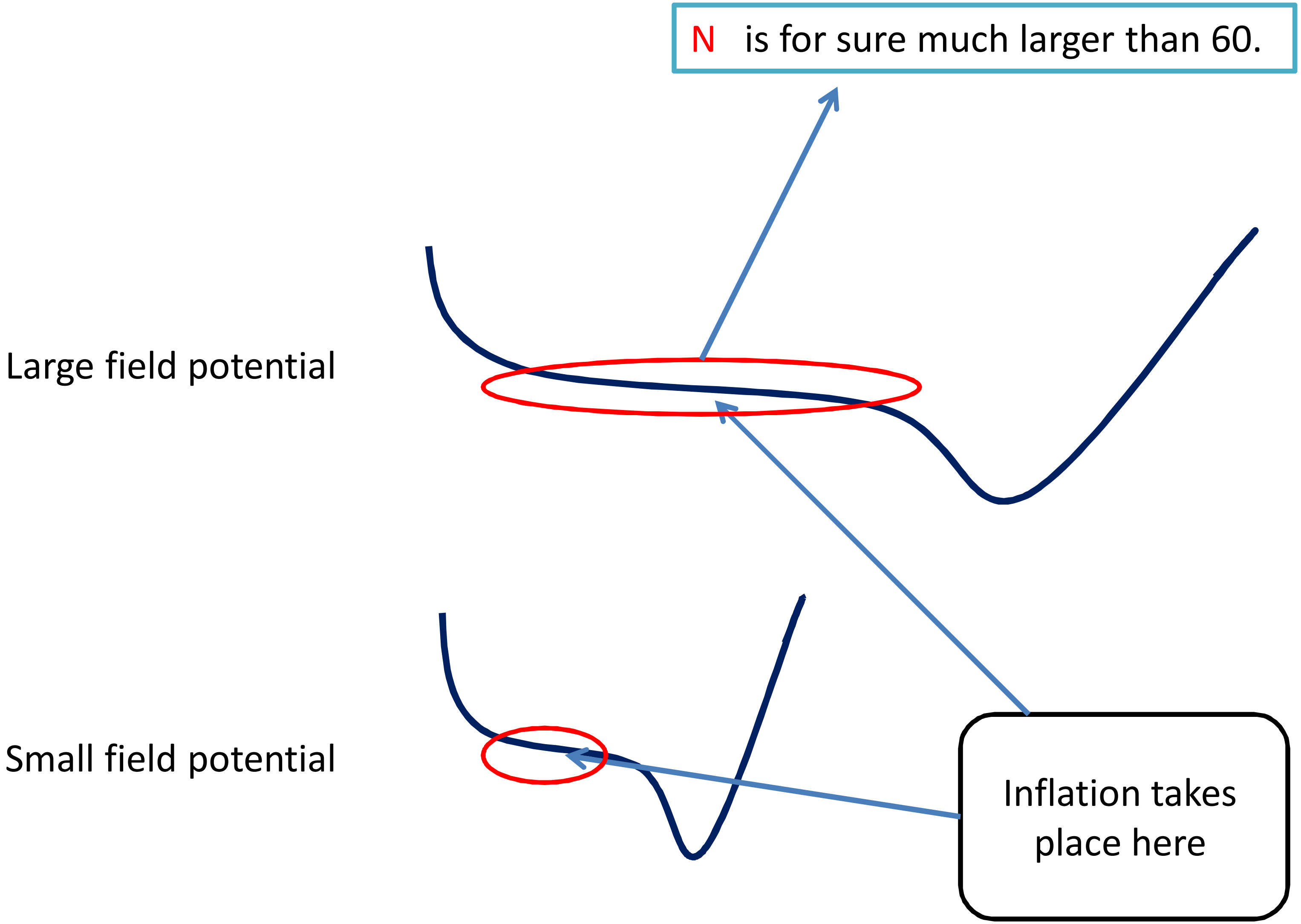
Small field potential

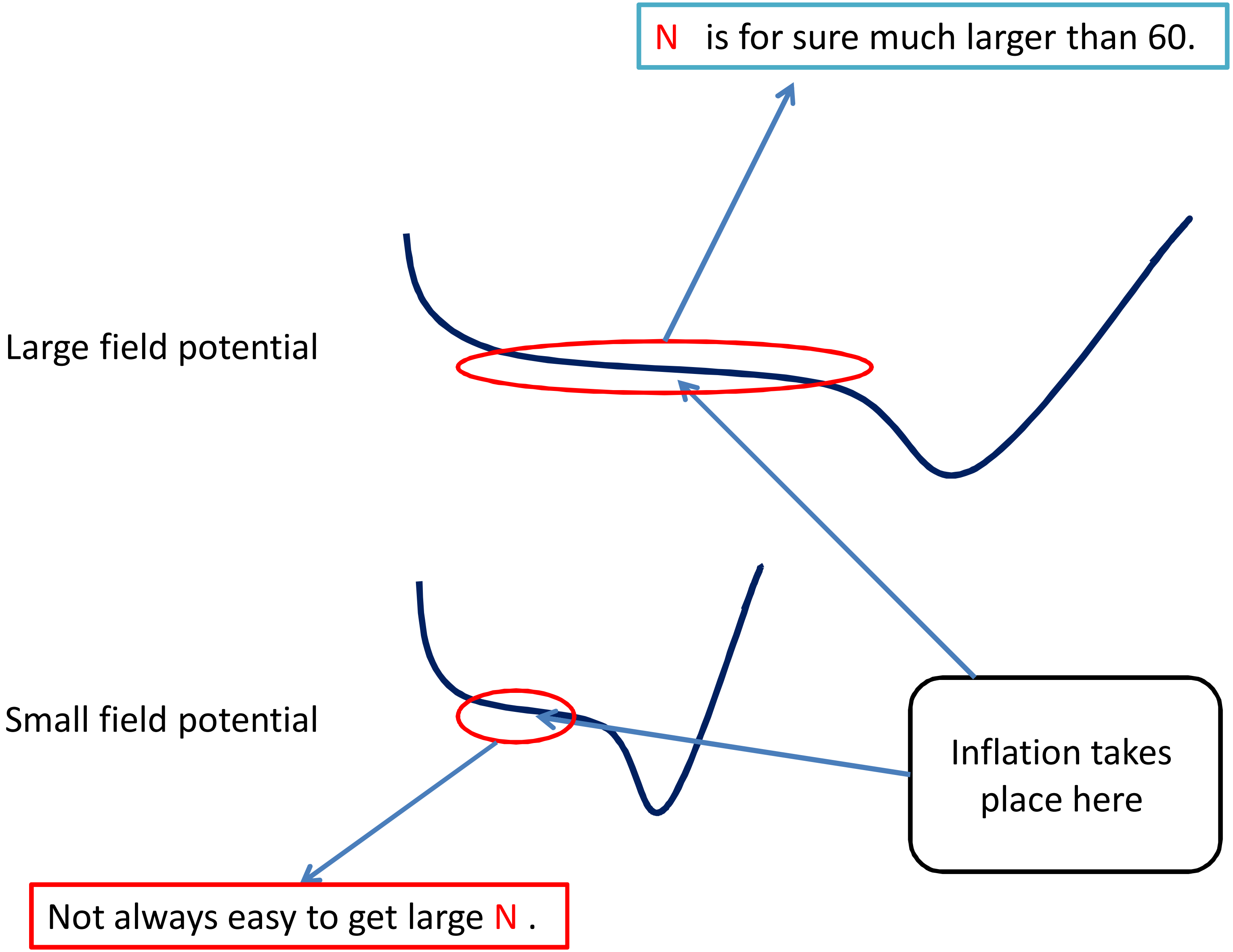


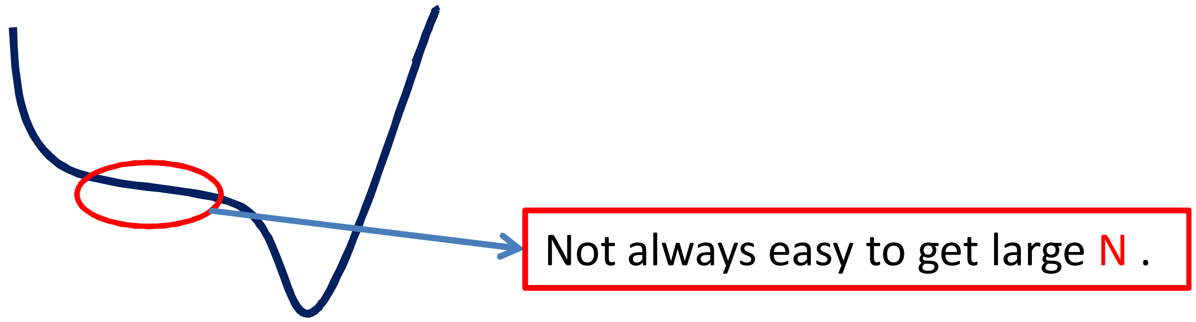
Theoretically, it is not easy to construct in string theory large field models of inflation.

Where ΔN is always large.




N is for sure much larger than 60.
Large field potential
Small field potential
Inflation takes place here


N is for sure much larger than 60.
Large field potential
Small field potential
Inflation takes place here
Not always easy to get large N .



Moreover, often encounter the overshoot problem (Brustein, Steinhardt 92) :

The inflaton overshoots the slow roll region (where the universe inflates).

In the rest of the talk:

1. Discuss ways to over come the overshoot problem.

In the rest of the talk:

1. Discuss ways to over come the overshoot problem.

2. Show that in some cases the resolution has an experimental signatures.

In the rest of the talk:

1. Discuss ways to over come the overshoot problem.

2. Show that in some cases the resolution has an experimental signatures.

3. Possible connection with the 2σ anomalies at the largest scales.

There aren't too many ways to address the overshoot problem.

The basic equation is

$$\ddot{\phi} + 3H\dot{\phi} + V_{,\phi} = 0$$

There aren't too many ways one can address the overshoot problem.

The basic equation is

$$\ddot{\phi} + 3H\dot{\phi} + V_{,\phi} = 0$$

N. Kaloper and K. A. Olive; A. A. Tseytlin and C. Vafa;
T. Barreiro, B. de Carlos and E. J. Copeland; M. Dine;
G. Huey, P. J. Steinhardt, B. A. Ovrut and D. Waldram;
R. Brustein, S. P. de Alwis and P. Martens, B. Freivogel; M. Kleban, M. Rodriguez Martinez and L. Susskind.

A - Increase H in a time dependent

fashion by adding particles.

There aren't too many ways one can address the overshoot problem.

The basic equation is

$$\ddot{\phi} + 3H\dot{\phi} + V_{,\phi} = 0$$

N. Kaloper and K. A. Olive, A. A. Tseytlin and C. Vafa, T. Barreiro, B. de Carlos and E. J. Copeland, M. Dine, G. Huey, P. J. Steinhardt, B. A. Ovrut and D. Waldram, R. Brustein, S. P. de Alwis and P. Martens, B. Freivogel, M. Kleban, M. Rodriguez Martinez and L. Susskind.

N. Kaloper, J. Rahmfeld, L. Sorbo; A.Berndsen, T. Biswas and J. M. Cline; S.Cremonini, S.Watson; N.I, E.Kovetz

A - Increase H in a time dependent fashion by adding particles.

B- Modify V in a time dependent fashion by adding particles with mass that depend on the inflaton.

There aren't too many ways one can address the overshoot problem.

The basic equation is

$$\ddot{\phi} + 3H\dot{\phi} + V_{,\phi} = 0$$

No simple imprint for moduli stabilization.

For the inflaton stabilization there is a distinct imprint

A - Increase H in a time dependent fashion by adding particles.

B- Modify V in a time dependent fashion by adding particles with mass that depend on the inflaton.

There aren't too many ways one can address the overshoot problem.

The basic equation is

$$\ddot{\phi} + 3H\dot{\phi} + V_{,\phi} = 0$$

No simple imprint for moduli stabilization.

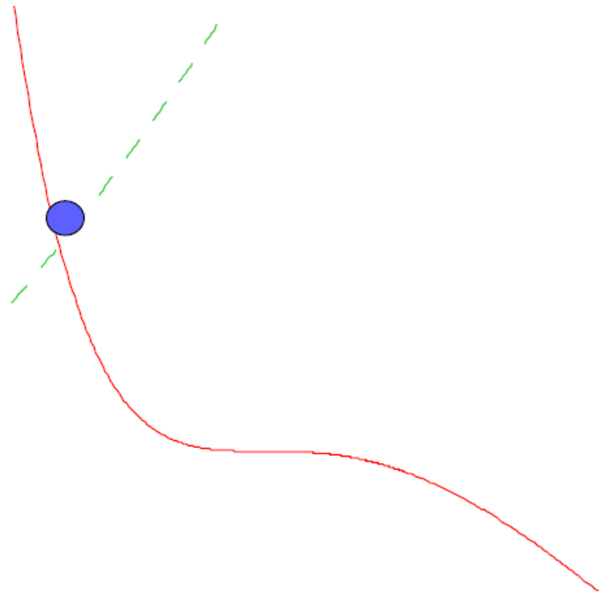
For the inflaton stabilization there is a distinct imprint

A - Increase H in a time dependent fashion by adding particles.

B- Modify V in a time dependent fashion by adding particles with mass that depend on the inflaton.

B is more efficient than A (by a factor of the slow-roll parameter) and has a stronger imprint (by a factor of the slow-roll parameter) .

A resolution to the overshoot problem (N.I, E. Kovetz 0708.2798)

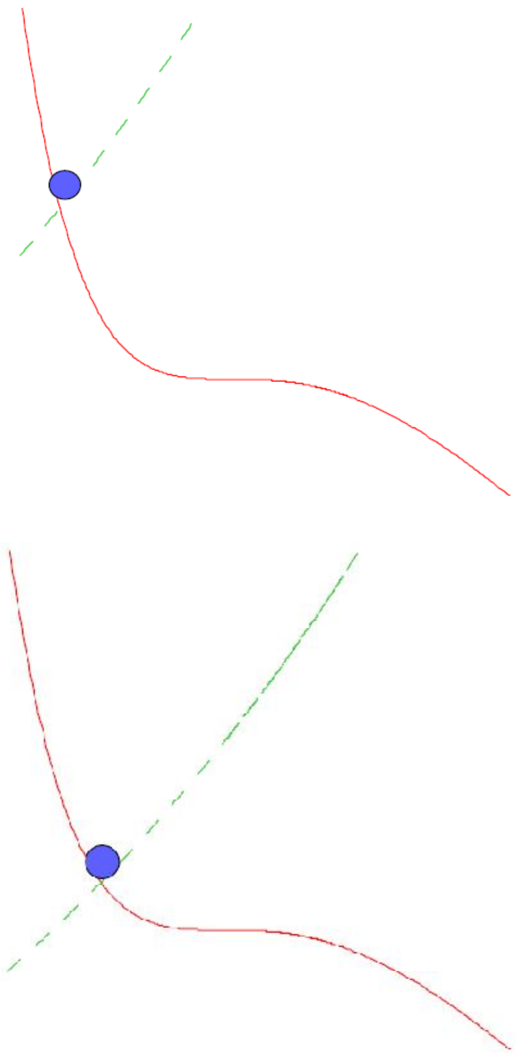


There are particles in the theory

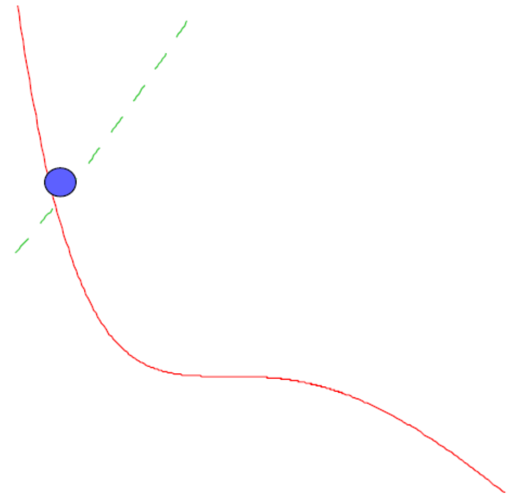
with mass that grows with the inflaton.

These particles induce a time-dependent

potential for the inflaton (green line).



As the universe expands their density becomes smaller and the induced potential grows weaker.

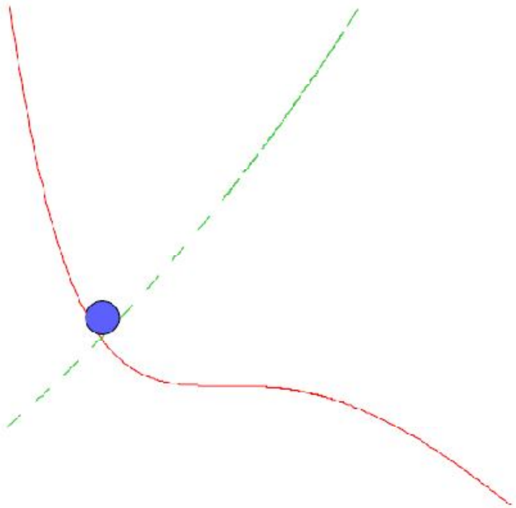


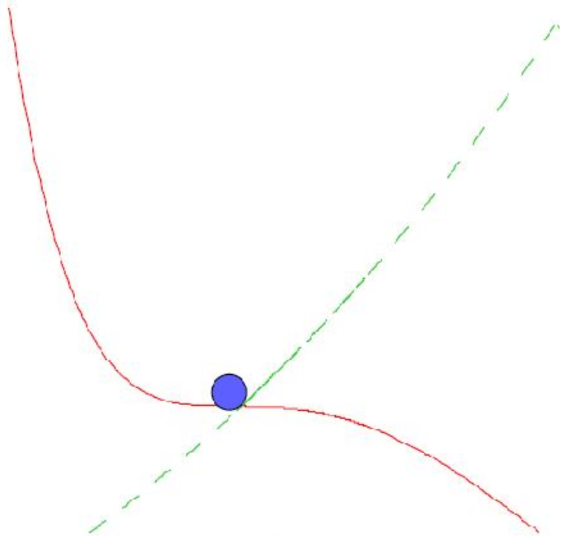
As the universe expands their density

becomes smaller and the induced

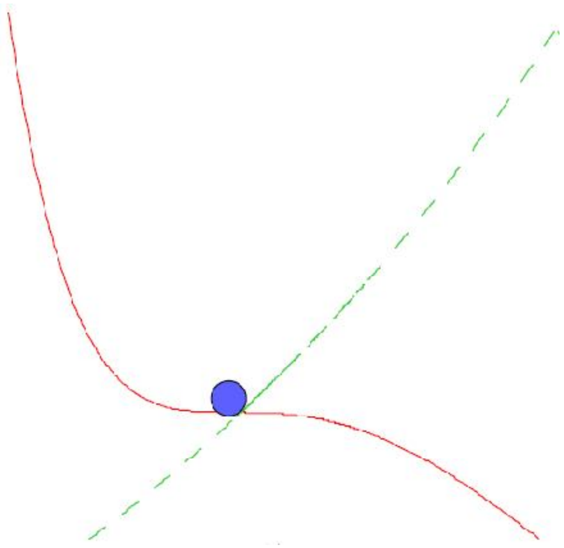
potential grows weaker.

And weaker.



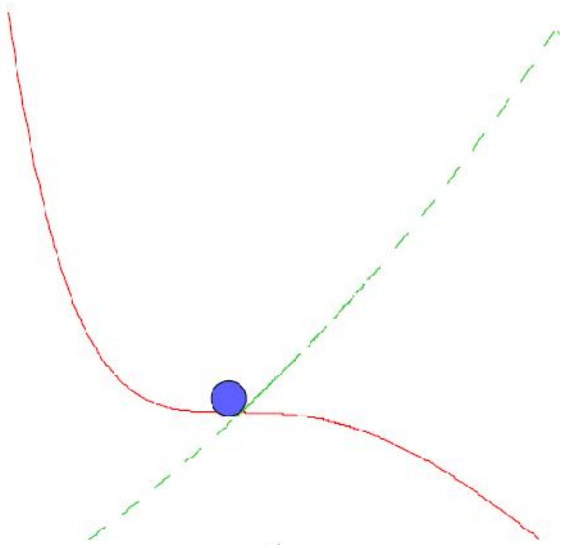


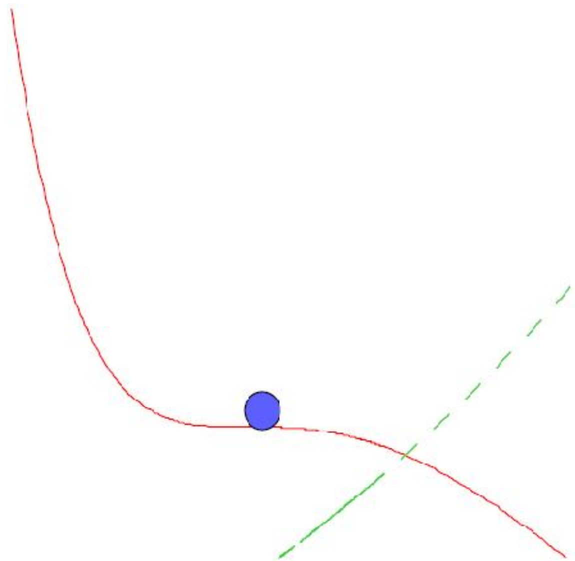
At this stage the particles are not “needed” to balance the inflaton.



At this stage the particles are not “needed” to balance the inflaton.

And they get diluted while the inflaton remains at the slow-roll region

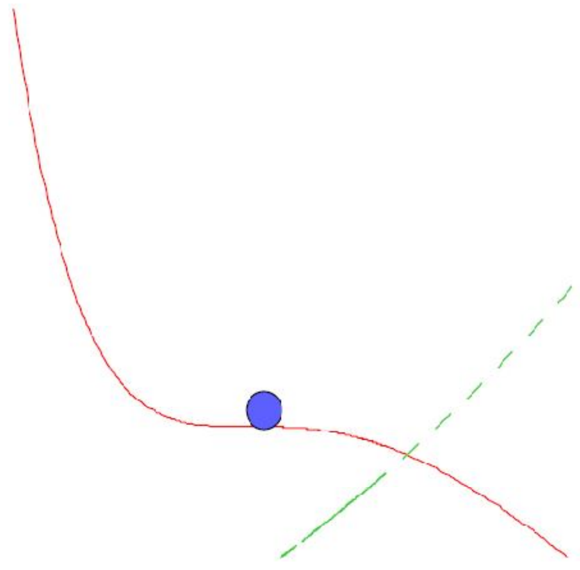




Regardless of the initial condition

we end up at the slow roll region.

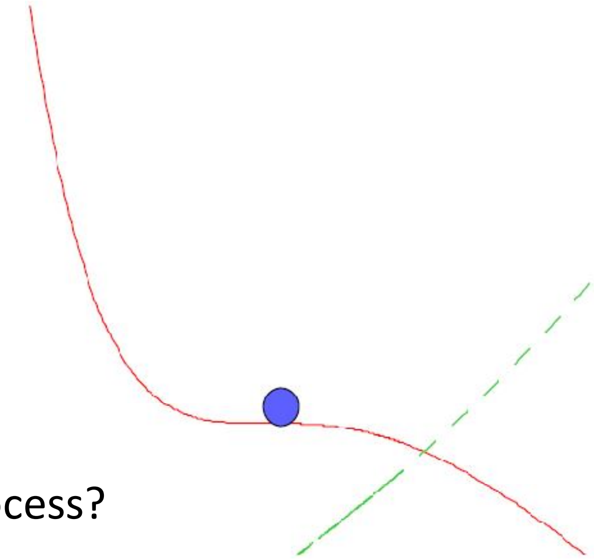
And inflation can begin.



Regardless of the initial condition

we end up at the slow roll region.

And inflation can begin.



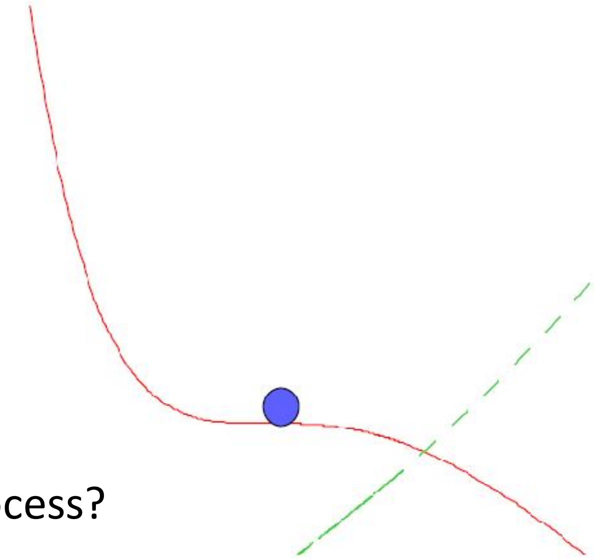
Q: Is there any experimental signature to this process?

(any remnant of these particles?)

Regardless of the initial condition

we end up at the slow roll region.

And inflation can begin.



Q: Is there any experimental signature to this process?

(any remnant of these particles?)

A : Yes.

Each particle creates a spherically symmetric giant structure.

If ΔN is not too large some of them are in the visible universe.

We know that the shape of the inflaton during inflation is the seed for structure formation.

We know that the shape of the inflaton during inflation is the seed for structure formation.

A particle during inflation will have the following effect on the inflaton

$$\delta\ddot{\phi} + 3H\delta\dot{\phi} - \frac{1}{a(t)^2}\nabla^2\delta\phi + \frac{\delta^3(x)}{a^3}m_{eff} = 0$$

where

$$m_{eff} = \frac{\partial m}{\partial\phi} - \frac{1}{2}\frac{V'}{V}m$$

We know that the shape of the inflaton during inflation is the seed for structure formation.

A particle during inflation will have the following effect on the inflaton

$$\delta\ddot{\phi} + 3H\delta\dot{\phi} - \frac{1}{a(t)^2}\nabla^2\delta\phi + \frac{\delta^3(x)}{a^3}m_{eff} = 0$$

where

$$m_{eff} = \frac{\partial m}{\partial \phi} - \frac{1}{2}\frac{V'}{V}m$$

The imprint of ordinary particles is suppress

by the slow roll parameter

We know that the shape of the inflaton during inflation is the seed for structure formation.

A particle during inflation will have the following effect on the inflaton

$$\delta\ddot{\phi} + 3H\delta\dot{\phi} - \frac{1}{a(t)^2}\nabla^2\delta\phi + \frac{\delta^3(x)}{a^3}m_{eff} = 0$$

where

$$m_{eff} = \frac{\partial m}{\partial \phi} - \frac{1}{2}\frac{V'}{V}m$$

The homogeneous solutions generate the usual quantum fluctuation which lead to the usual power spectrum.

On top we have the inhomogeneous solution which depends on the location of the particle(s).

$$\delta\ddot{\phi} + 3H\delta\dot{\phi} - \frac{1}{a(t)^2}\nabla^2\delta\phi + \frac{\delta^3(x)}{a^3}m_{eff} = 0$$

On top we have the inhomogeneous solution which depends on the location of the particle(s).

$$\delta\ddot{\phi} + 3H\delta\dot{\phi} - \frac{1}{a(t)^2}\nabla^2\delta\phi + \frac{\delta^3(x)}{a^3}m_{eff} = 0$$

The particles push in

the opposite direction

Each particle provide the seed

for an overdense region

On top we have the inhomogeneous solution which depends on the location of the particle(s).

$$\delta\ddot{\phi} + 3H\delta\dot{\phi} - \frac{1}{a(t)^2}\nabla^2\delta\phi + \frac{\delta^3(x)}{a^3}m_{eff} = 0$$

The particles push in

the opposite direction

Each particle provide the seed

for an overdense region

The shape of the overdense region is fixed by the inhomogeneous

solution. In momentum space we find

$$\delta\phi_k = -\frac{Hm_{eff}}{\sqrt{32\pi}k^3}$$

$$\delta\phi_k = -\frac{H m_{eff}}{\sqrt{32\pi k^3}}$$

1. Scales like H (like the usual quantum effect)

→ m_{eff} should be large to be noticed.

The signal to noise ration is roughly m_{eff}

$$\delta\phi_k = -\frac{H m_{eff}}{\sqrt{32\pi}k^3}$$

1. Scales like H (like the usual quantum effect)

   ↳ m_{eff} should be large to be noticed.

2. Goes like $1/k^3$ (usual quantum effect $\sim 1/k^{3/2}$)

   ↳ more important at small k

   ↕

   giant structure

$$\delta\phi_k = -\frac{H m_{eff}}{\sqrt{32\pi k^3}}$$

1. Scales like H (like the usual quantum effect)

→ m_{eff} should be large to be noticed.

2. Goes like $1/k^3$ (usual quantum effect $\sim 1/k^{3/2}$)

→ more important at small k

↕

giant structure

Let's study the properties of this giant structure.

In 0807.3216 I considered the simplest

approximation to the transfer function:

$$T(k) = \begin{cases} 1 & \text{for} \quad k < k_{eq} \\ k_{eq}^2/k^2 & \text{for} \quad k > k_{eq}, \end{cases}$$

In 0807.3216 I considered the simplest

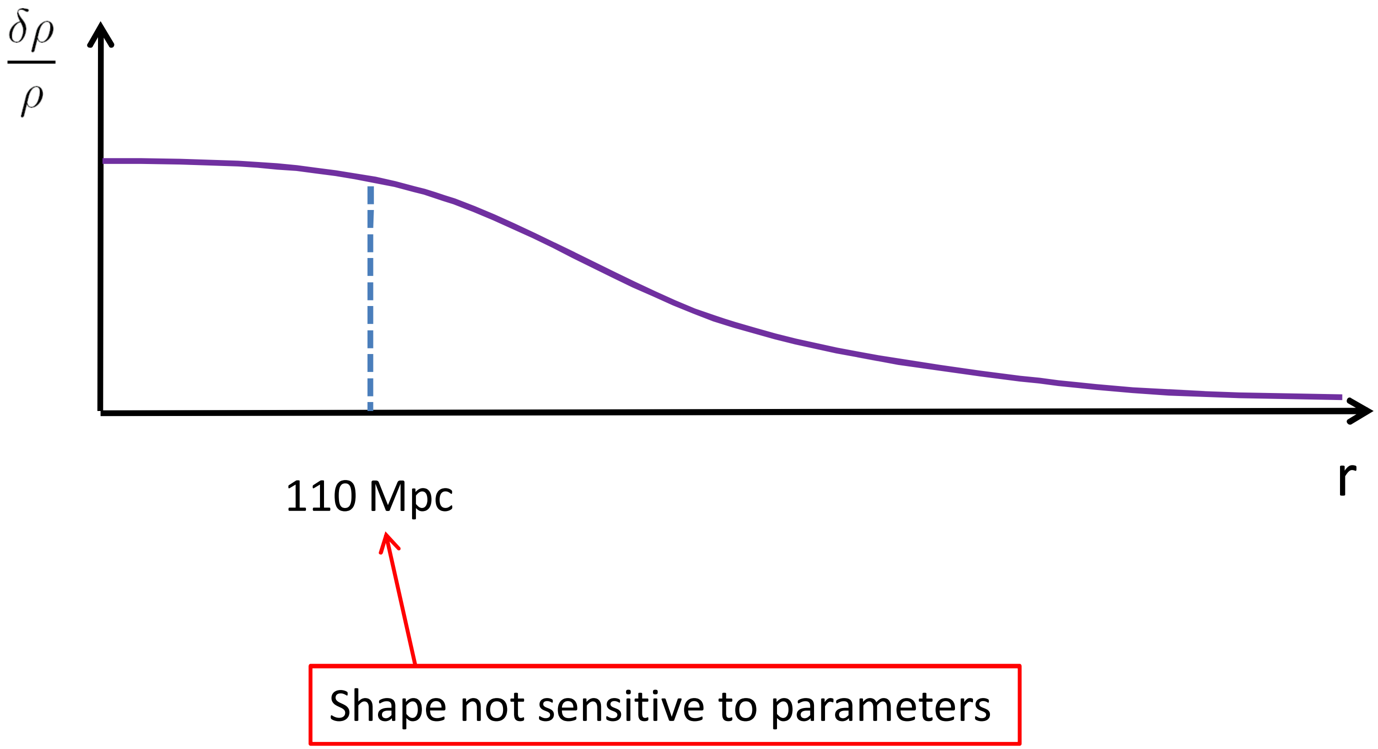
approximation to the transfer function:

$$T(k) = \begin{cases} 1 & \text{for} \quad k < k_{eq} \\ k_{eq}^2/k^2 & \text{for} \quad k > k_{eq}, \end{cases}$$

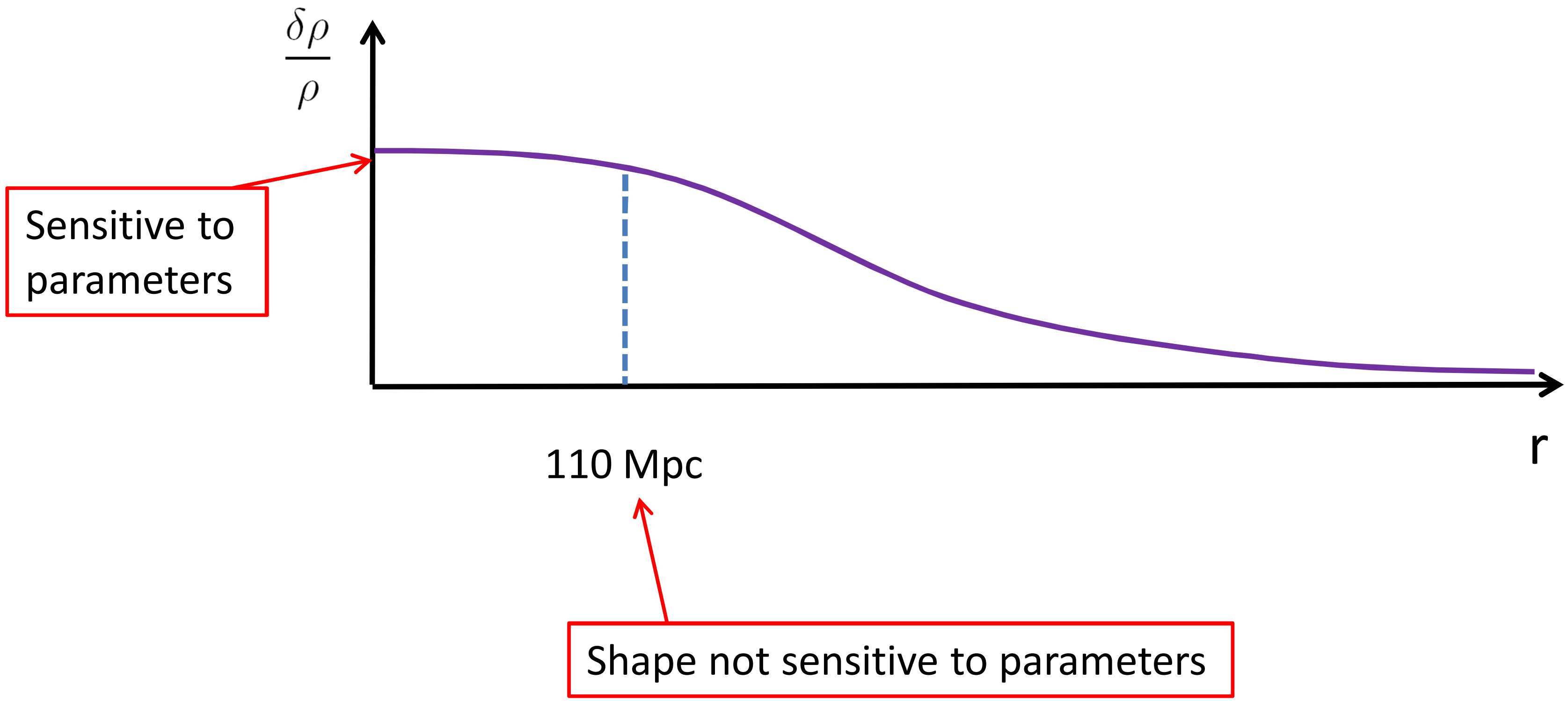
Linear with the scale factor during matter domination

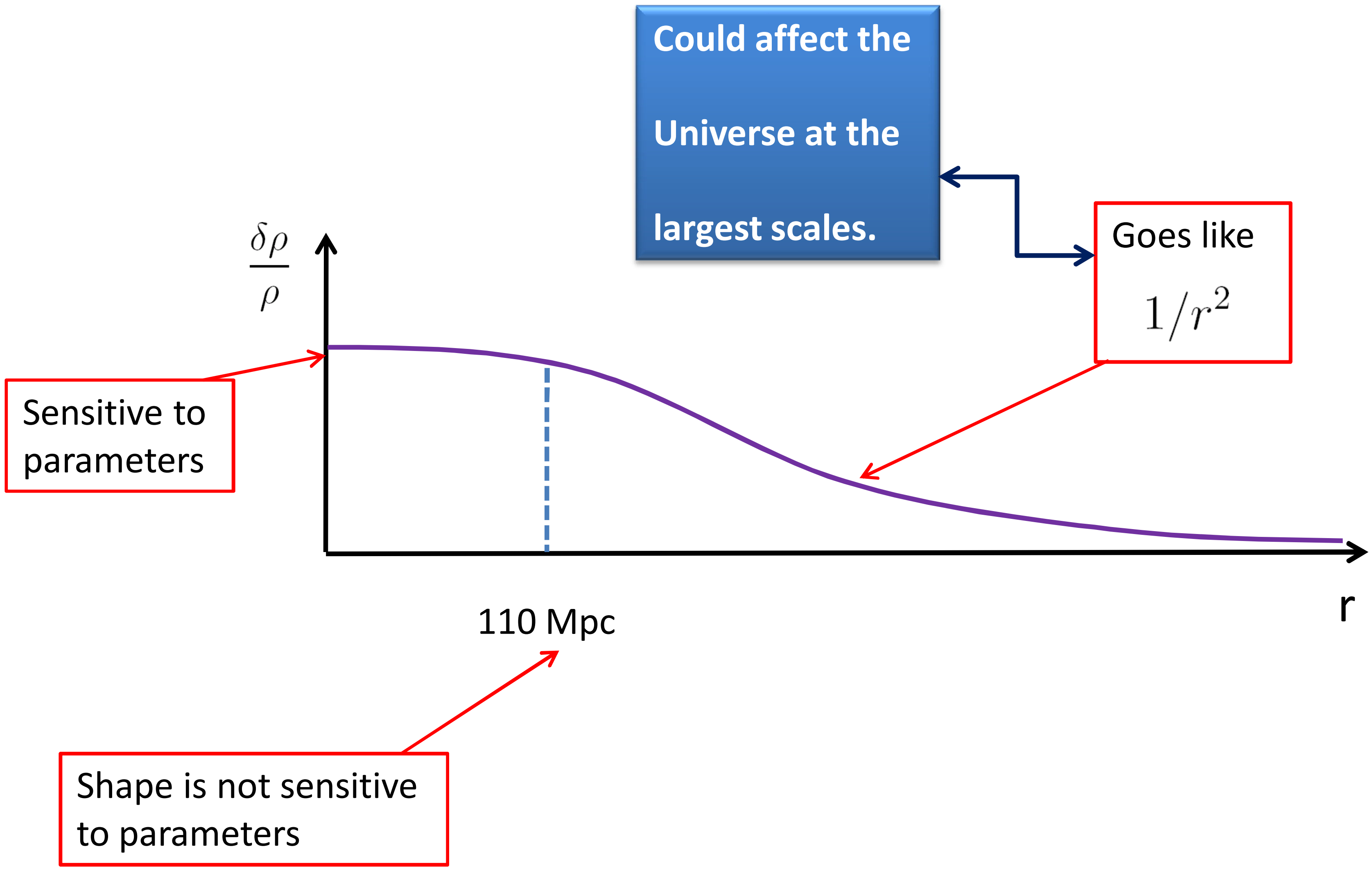
No growth at all during radiation domination

In this approximation



In this approximation




Could affect the Universe at the largest scales.
$\frac{\delta\rho}{\rho}$
Goes like $1/r^2$
Sensitive to parameters
110 Mpc
r
Shape is not sensitive to parameters

Right now with A. Fialkov and E. Kovetz we are looking in more detail into this option.

Right now with A. Fialkov and E. Kovetz we are looking in more detail into this option.

We used CMBFAST and CAMB to calculate the shape of the giant structure .

Turns out that

$$\ln^2(1 + \frac{c}{r})$$ with c=47 MpC/h

is a great approximation.

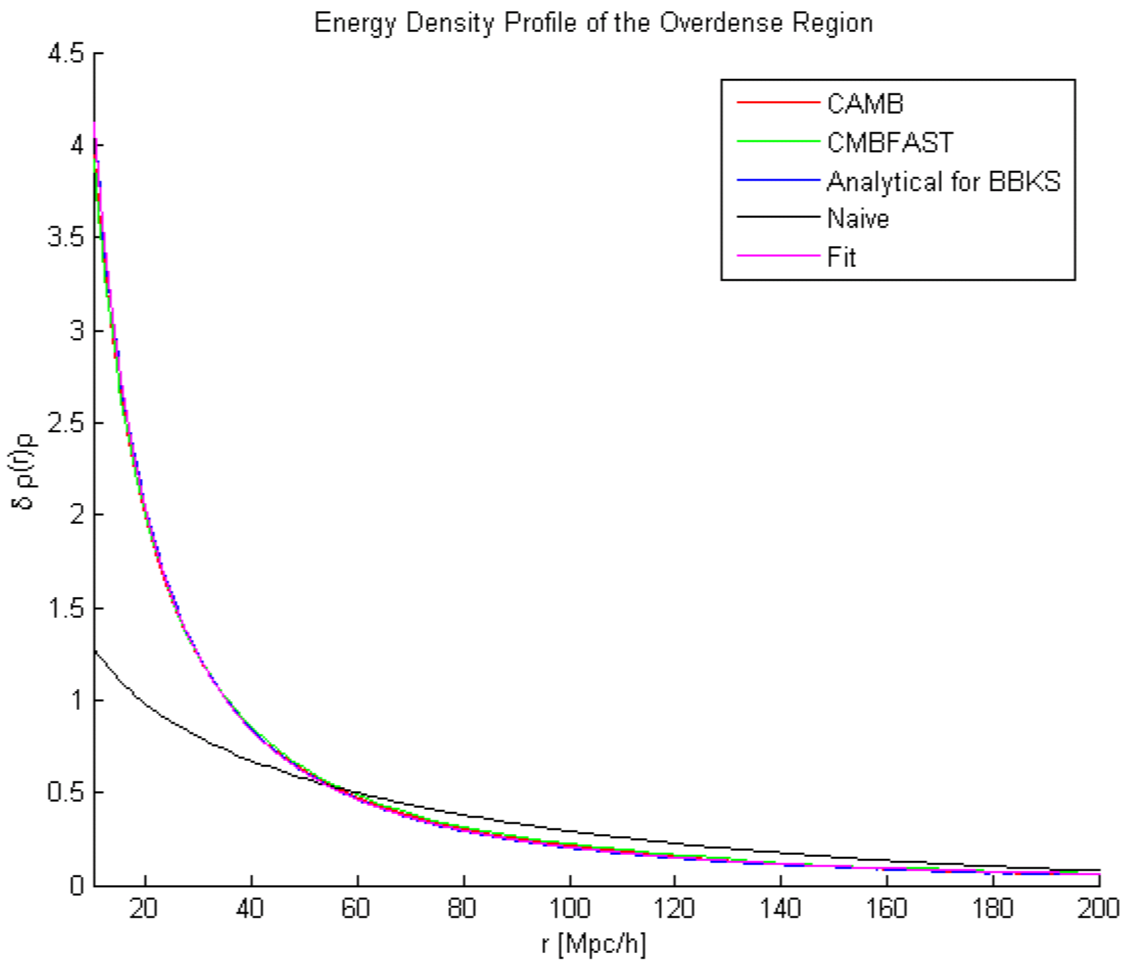
We used CMBFAST and CAMB to calculate the shape of the giant structure .

Turns out that

$$\ln^2(1 + \frac{c}{r})$$

with c=47 Mpc/h

is a great approximation.



We used CMBFAST and CAMB to calculate the shape of the giant structure .

Turns out that

for r > c we get $1/r^2$

$$\ln^2(1+\frac{c}{r})$$

We used CMBFAST and CAMB to calculate the shape of the giant structure .

Turns out that

$$\ln^2(1 + \frac{c}{r})$$

- for $r > c$ we get $1/r^2$
- for $r < c$ we have $\log^2 r$

We used CMBFAST and CAMB to calculate the shape of the giant structure .

Turns out that

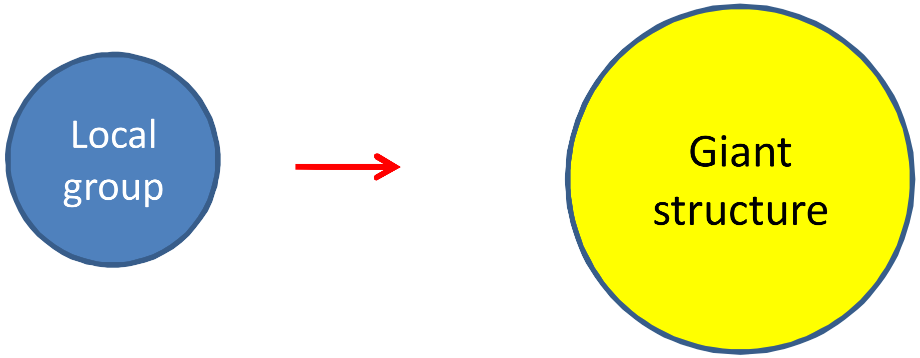
$$\ln^2(1+\frac{c}{r})$$ with c=47 Mpc/h

is a great approximation.

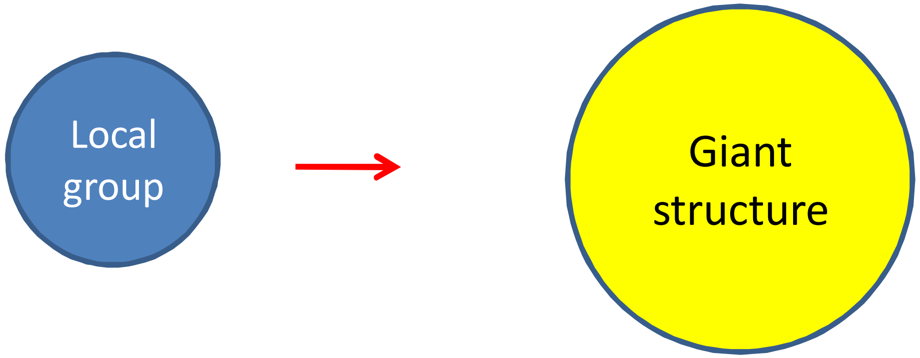
If you know of a giant structure that roughly

looks like that please let me know…

Such a structure could easily explain the large peculiar velocity:



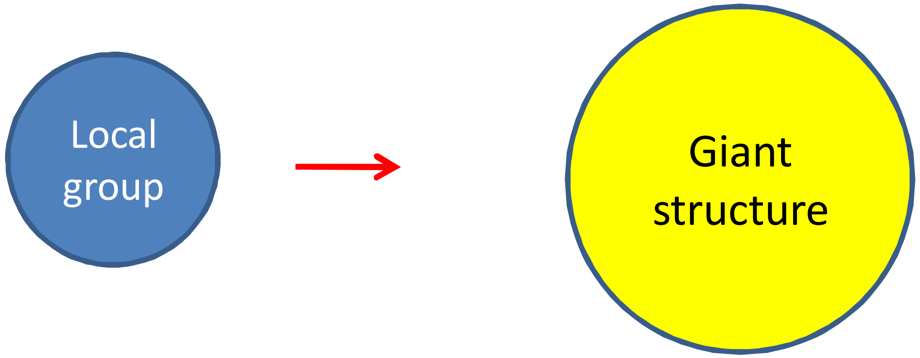
Such a structure could easily explain the large peculiar velocity:



The real question is whether we can get a large enough

peculiar velocity without messing up other things (e.g. CMB)

Such a structure could easily explain the large peculiar velocity:



The real question is whether we can get a large enough peculiar velocity without messing up other things (e.g. CMB)

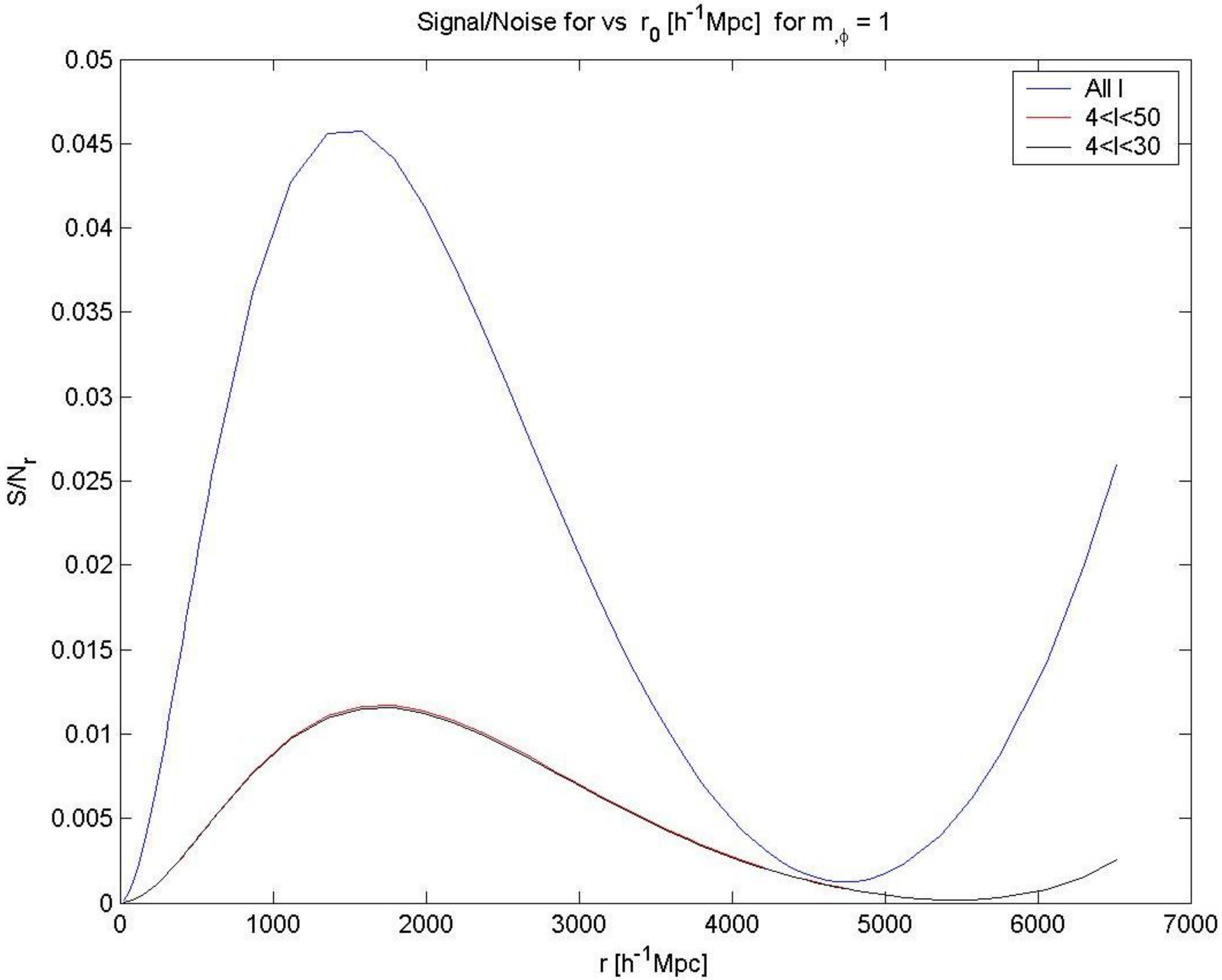
To address this question we calculated the effect such a giant structure will have on the CMB.

As expected it affects mainly the low-l modes.

To address this question we calculated the effect such

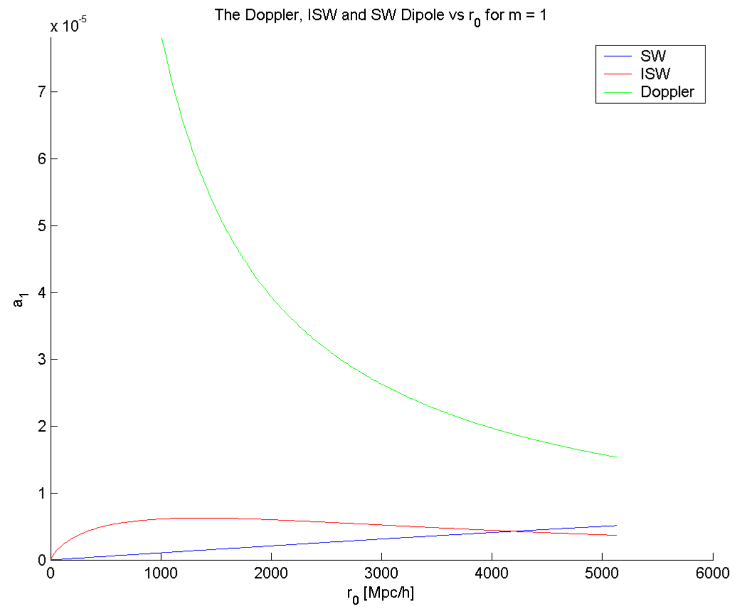
a giant structure will have on the CMB.

As expected it affects mainly the low-l modes.



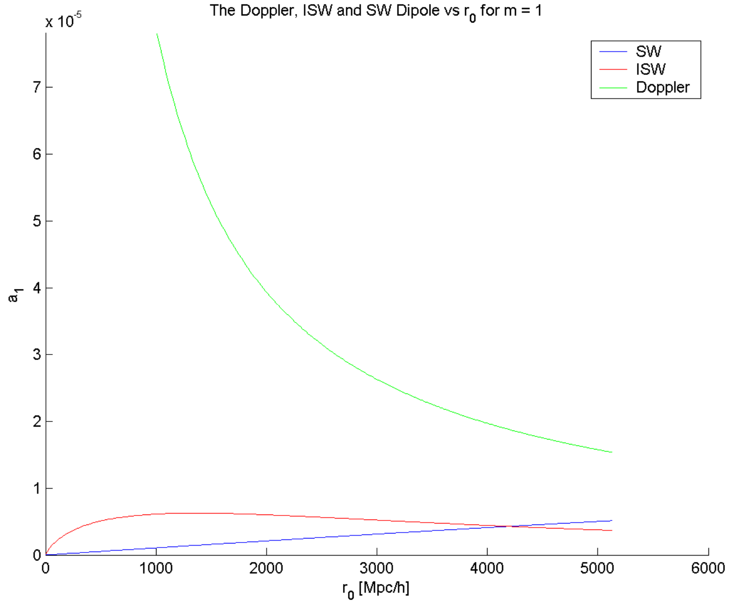
There are three contributions

to the dipole (or peculiar velocity):

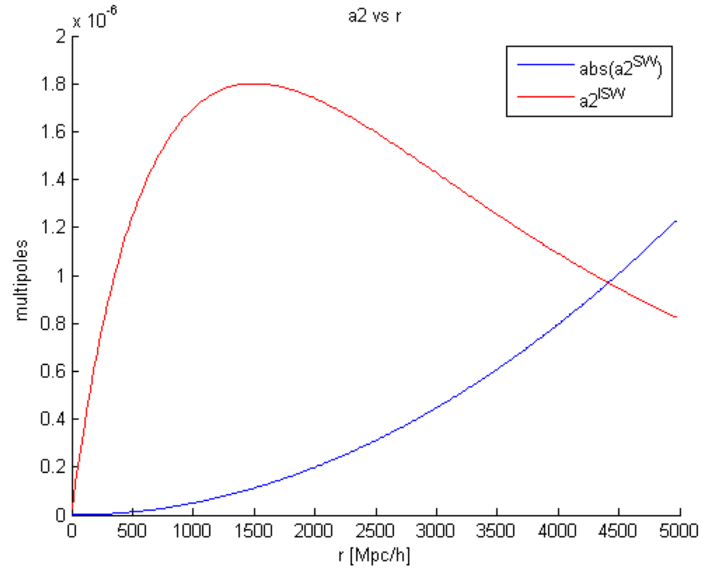


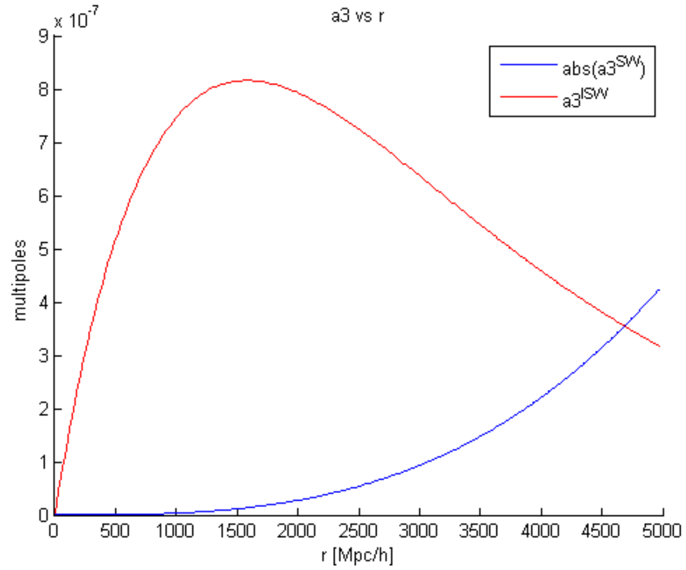
There are three contributions

to the dipole (or peculiar velocity):



And two contributions to the rest (e.g. quadrupole & octopole):

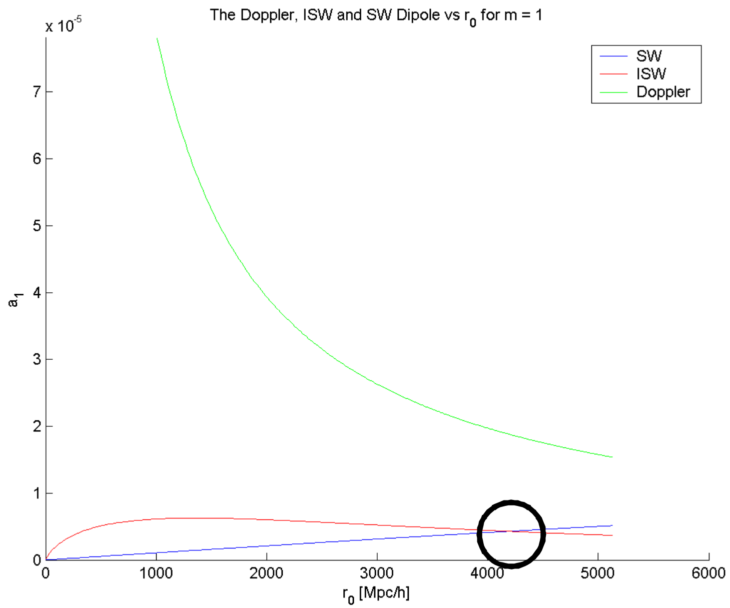


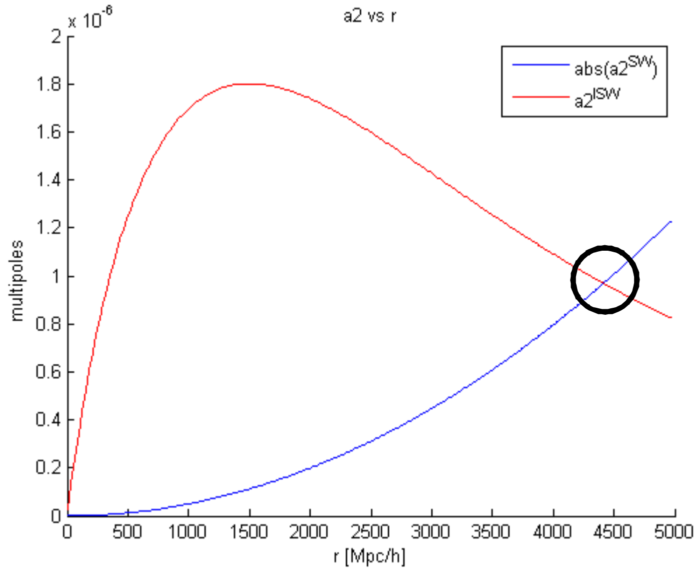


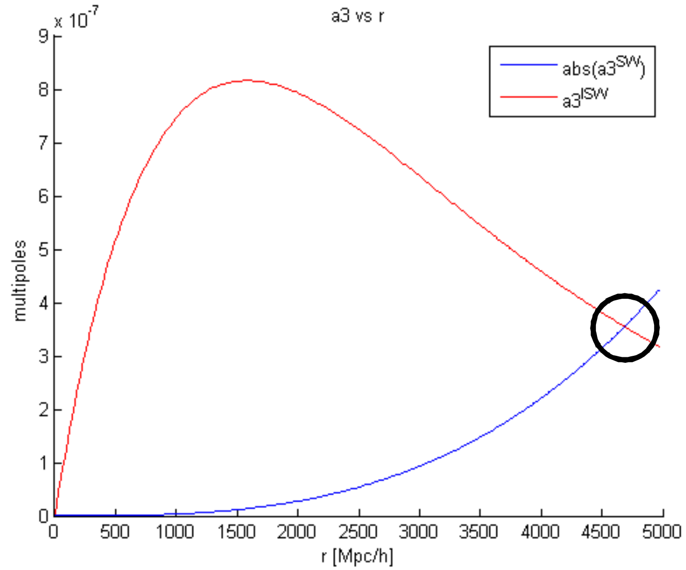
Notice that for

r ~ 4500/h Mpc

SW cancels ISW





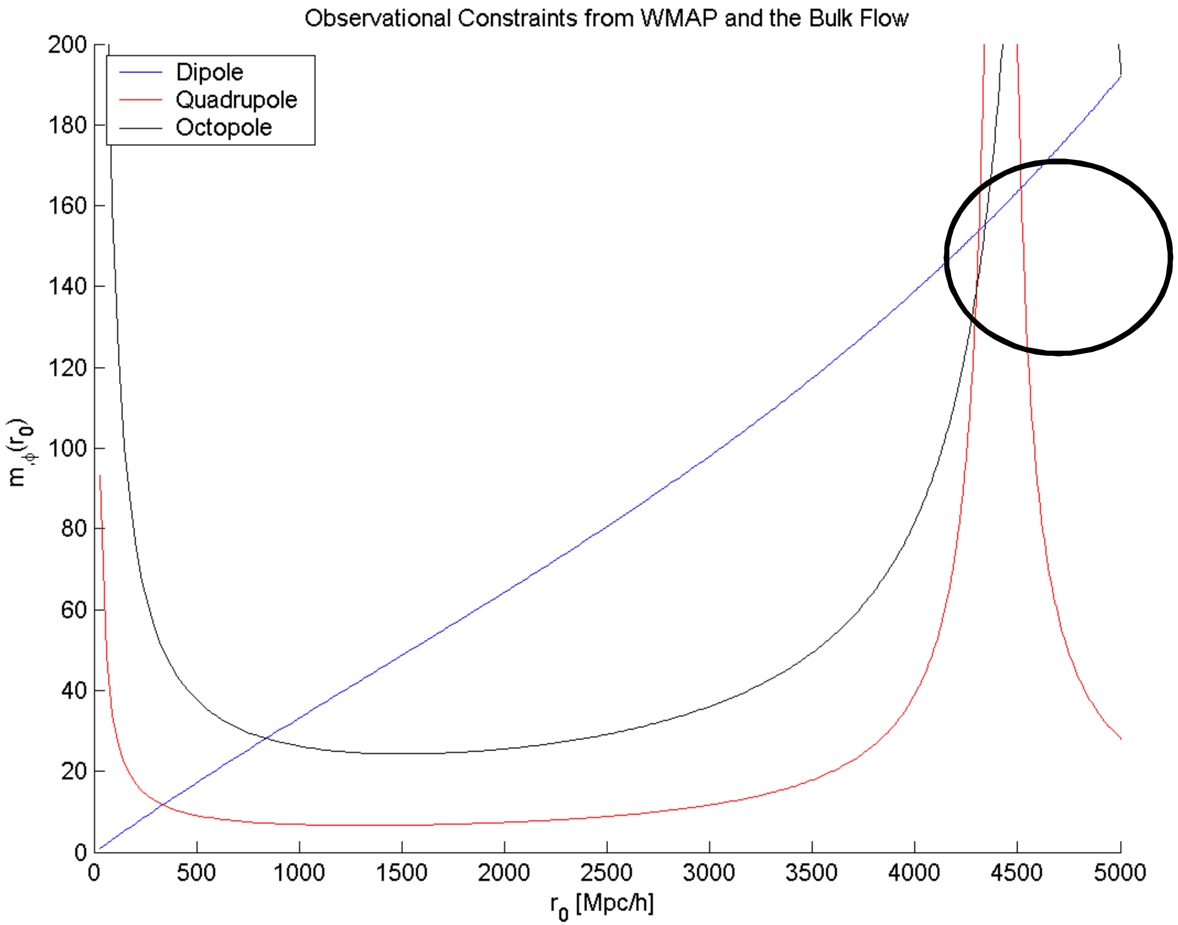


There is a region around 4500/h Mpc where we get a large peculiar velocity

without affecting the CMB.

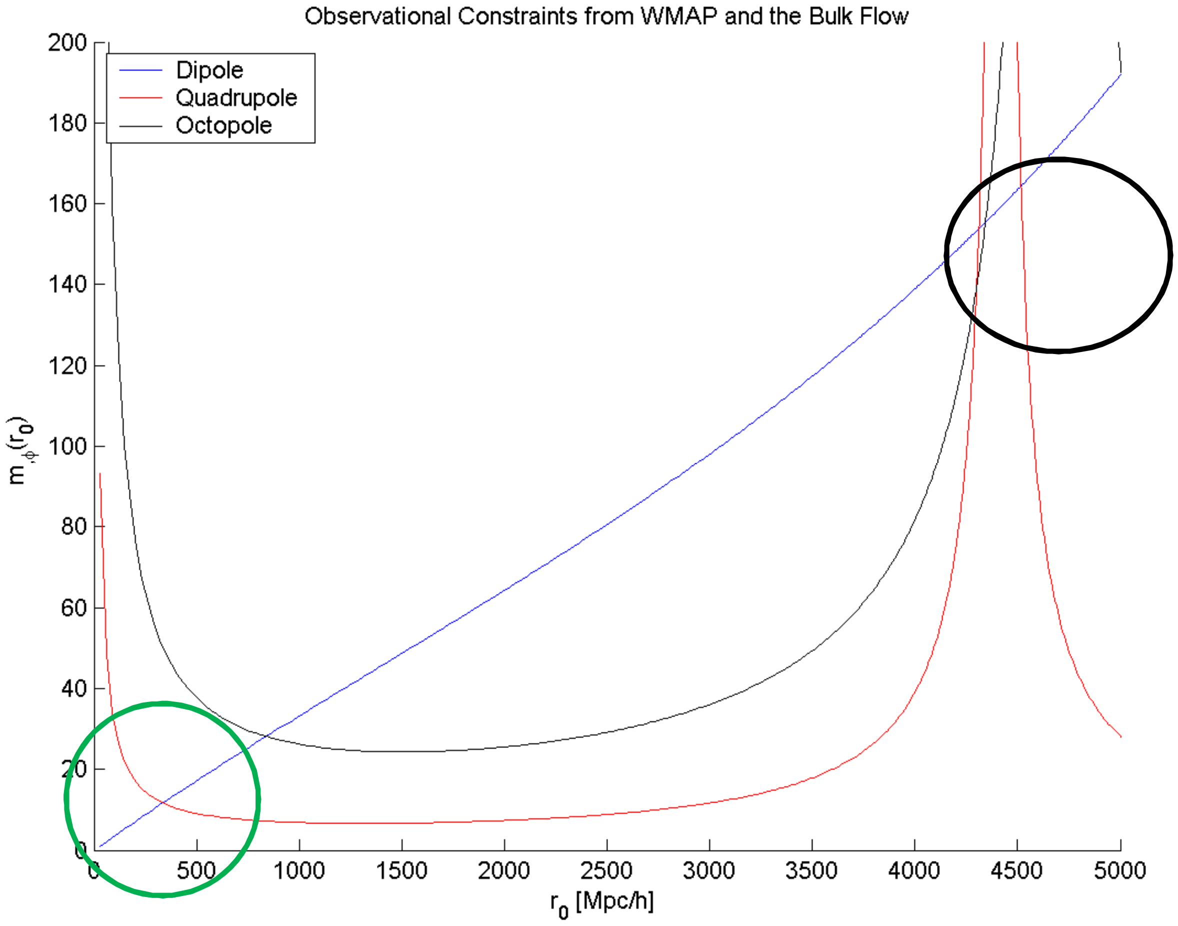
There is a region around 4500/h Mpc where we get a large peculiar velocity

without affecting the CMB.

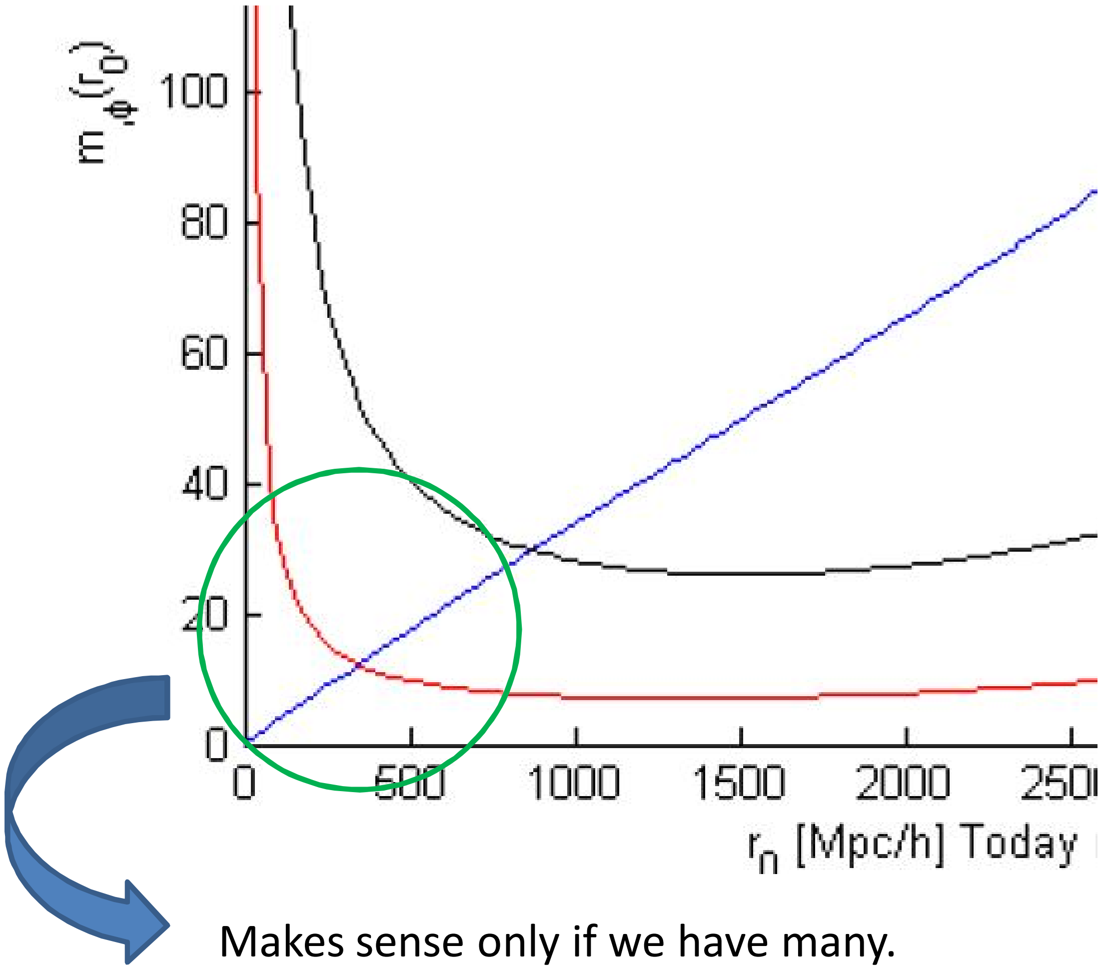


There is a region around 4500/h Mpc where we get a large peculiar velocity without affecting the CMB.

The other possibility is that it is located near by (r < 800/h Mpc)



The other possibility is that it is located near by (r < 800/h Mpc)



Makes sense only if we have many.

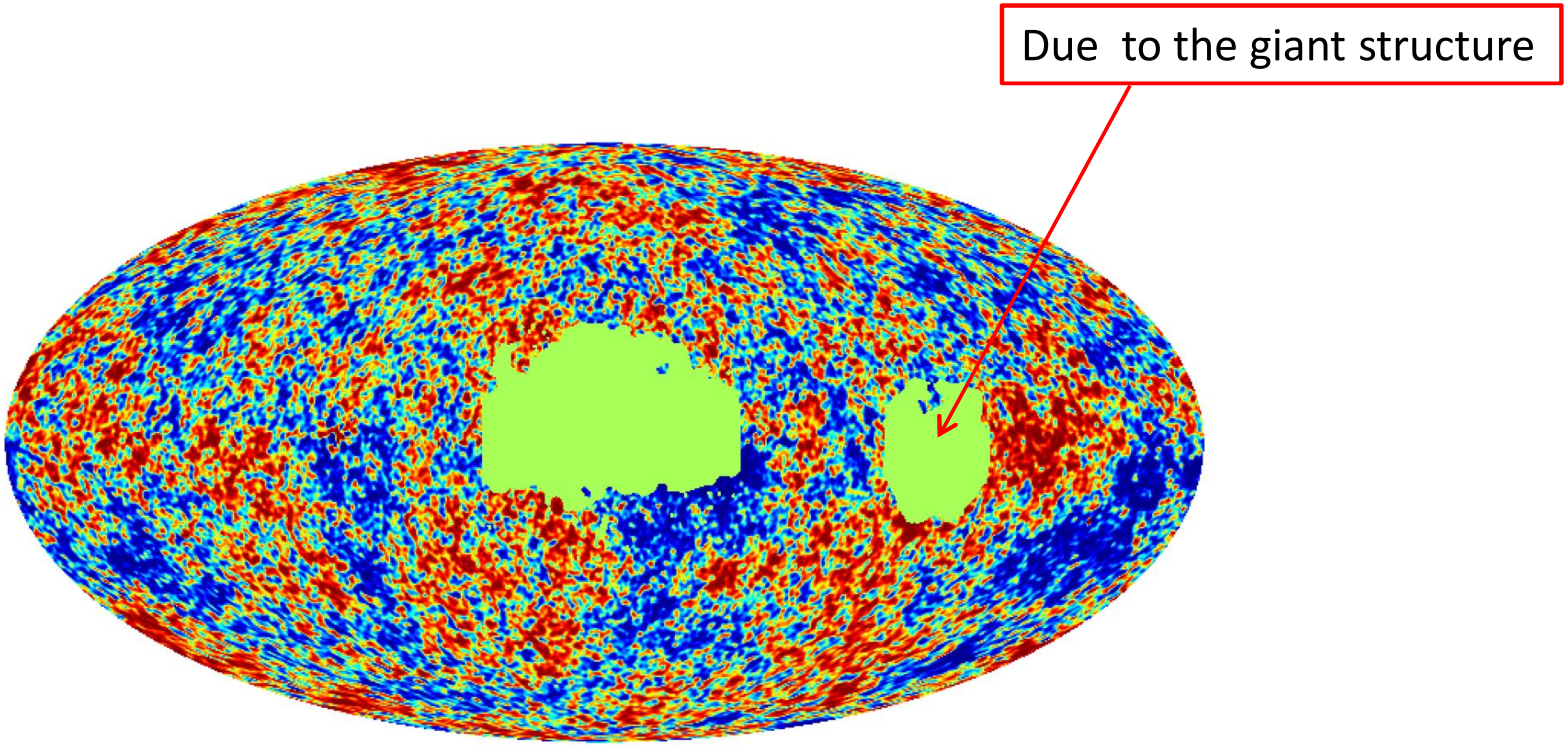
$$P_\Phi = \frac{H^2}{9\epsilon k^3}\left(1 + \frac{n\bar{m}^2}{16\pi k^3}\right)$$

Important at the IR

Currently we are checking whether the low-l CMB anomalies can be explained via this giant structure.

Currently we are checking whether the low-l CMB anomalies can be explained via this giant structure.

Basic idea is simple:



Weak Lensing

It turns out that this giant structure has also a distinct signature in weak lensing.

The density goes like $1/r^2$ at large distances (r > 100 Mpc).

⇕

A cosmological "Isothermal sphere" model.

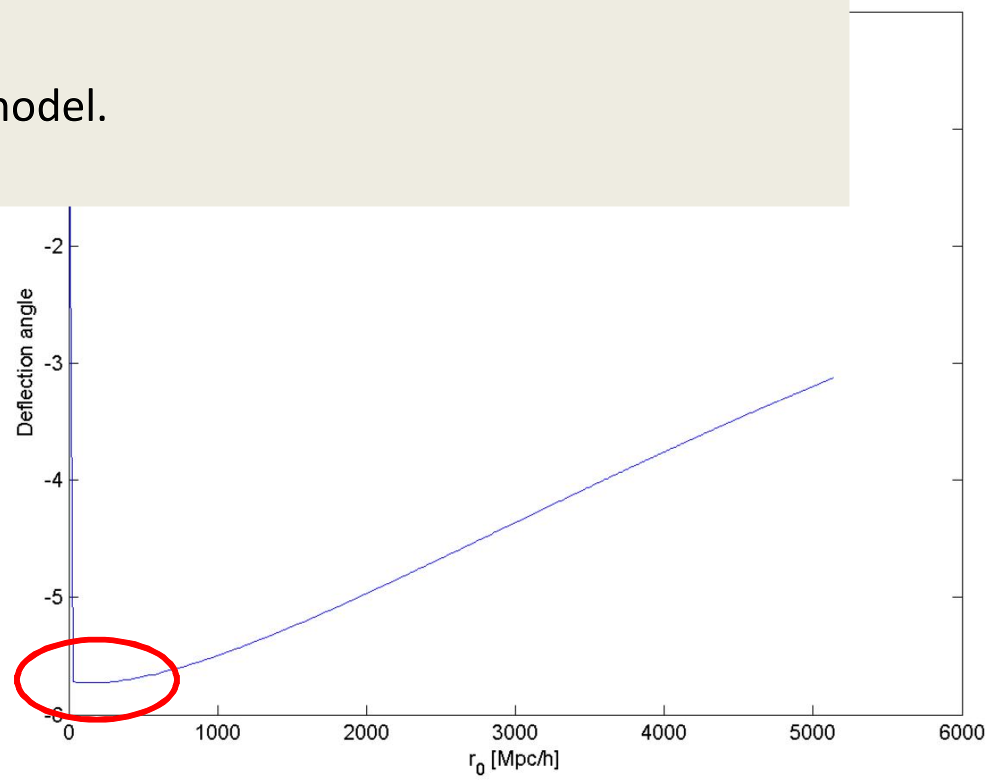
Weak Lensing

It turns out that this giant structure has also a distinct signature in weak lensing.

The density goes like $1/r^2$ at large distances (r > 100 Mpc).

⇕

A cosmological "Isothermal sphere" model.



Weak Lensing

It turns out that this giant structure has also a distinct signature in weak lensing.

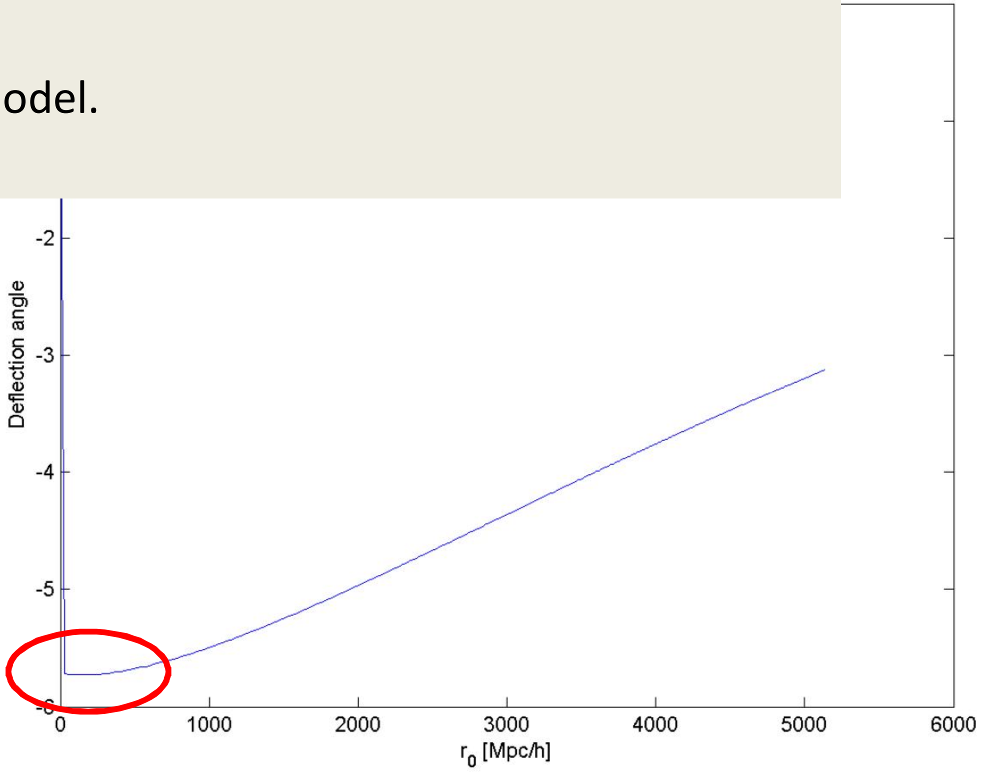
The density goes like $1/r^2$ at large distances (r > 100 Mpc).

⇕

A cosmological "Isothermal sphere" model.

Should have simple effects on CMB:

1. Polarization at low – l .
2. Mixing between low- l due to relative motion.



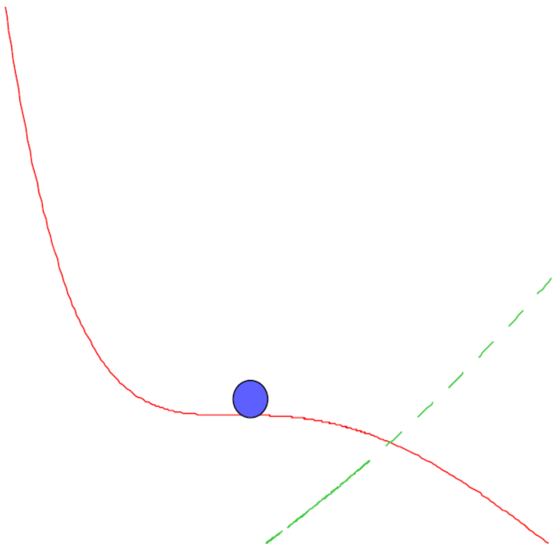
Summary :

1. We proposed a concrete pre-inflationary remnant that is motivated by string theory.

2. We study some of its affects on the largest scale in the universe.

3. Argue that might be the way to explain some of the anomalies.

The particles become irrelevant



0807.3216:

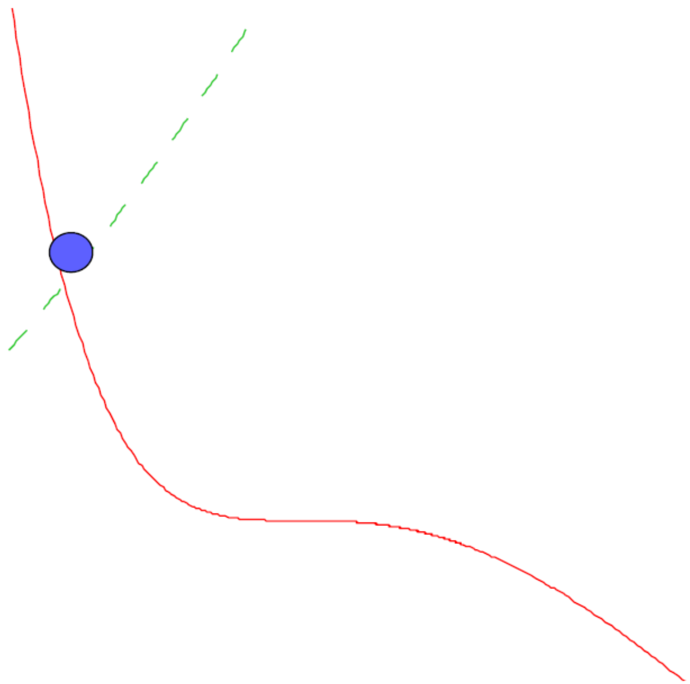
Not quite irrelevant.

There is a possible distinct imprint in structure formation:

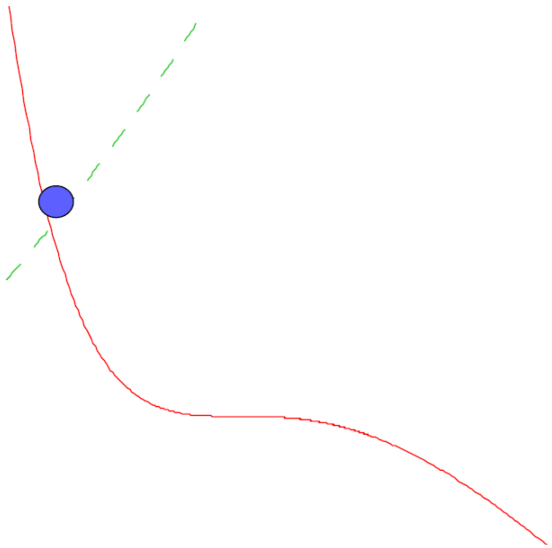
Creation of spherically symmetric overdense region(s) with radius of about 110 Mpc.

A resolution to the overshoot problem (N.I, E. Kovetz 0708.2798)

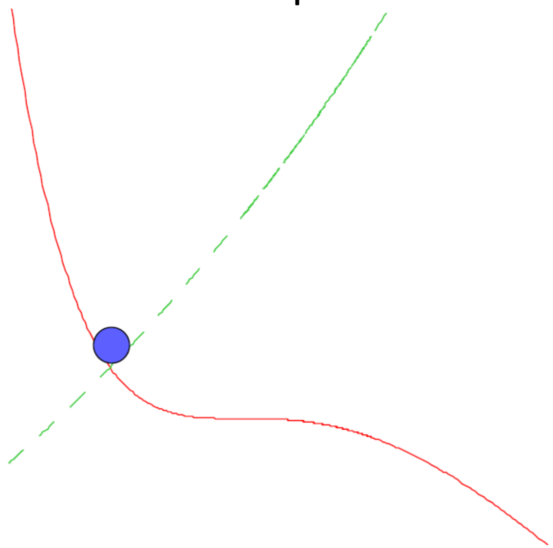
String theory often has non-pertubative particles with mass that grow with the value of the inflanton.



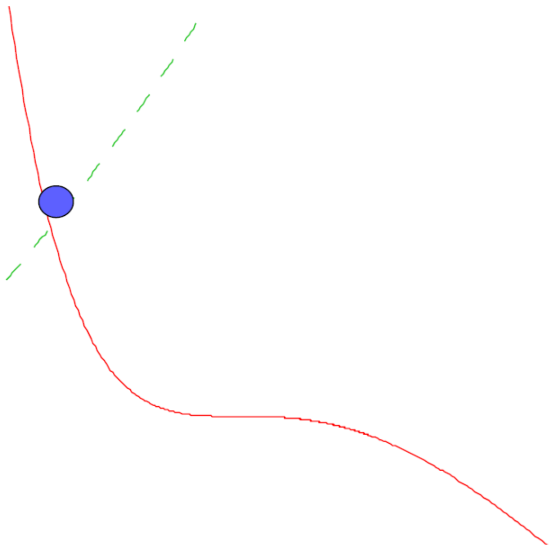
Minor effect at the beginning



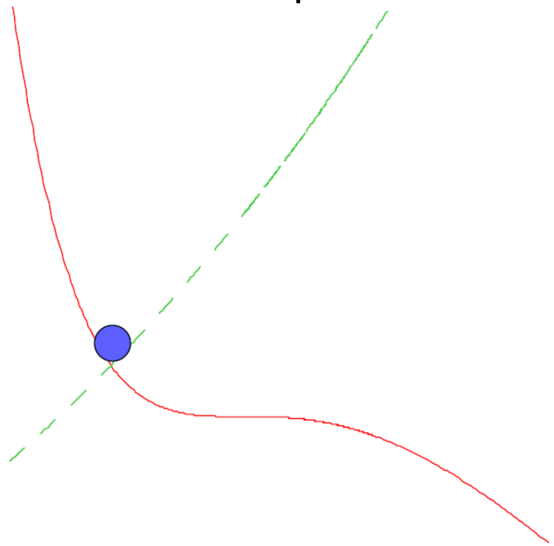
The inflaton follows the minimum
of the combined potential



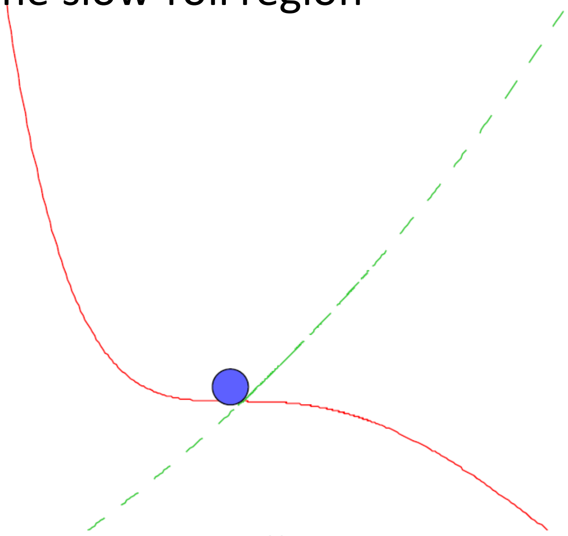
Minor effect at the beginning



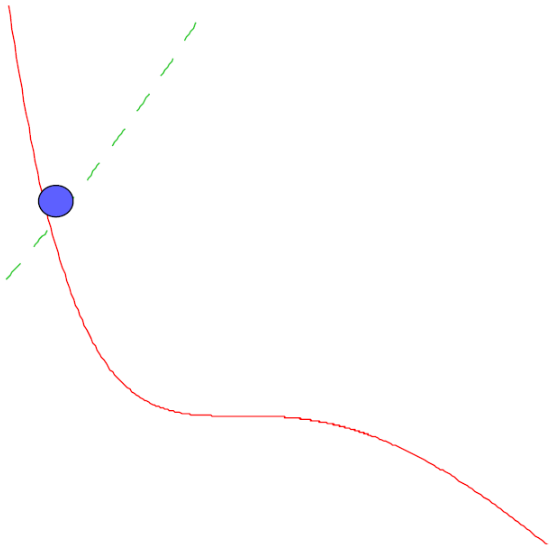
The inflaton follows the minimum of the combined potential



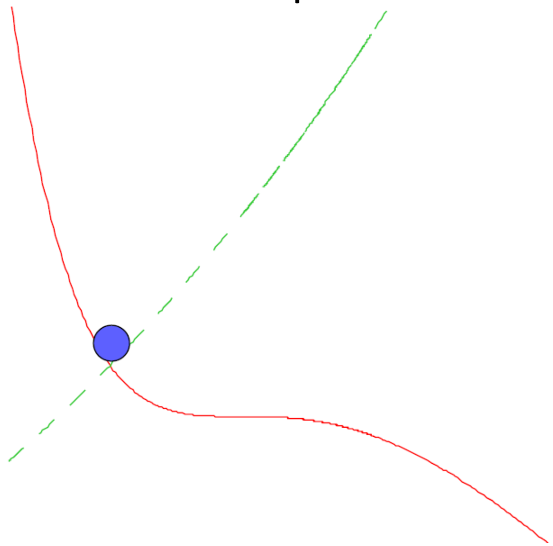
Inflaton moves slows down at the slow-roll region



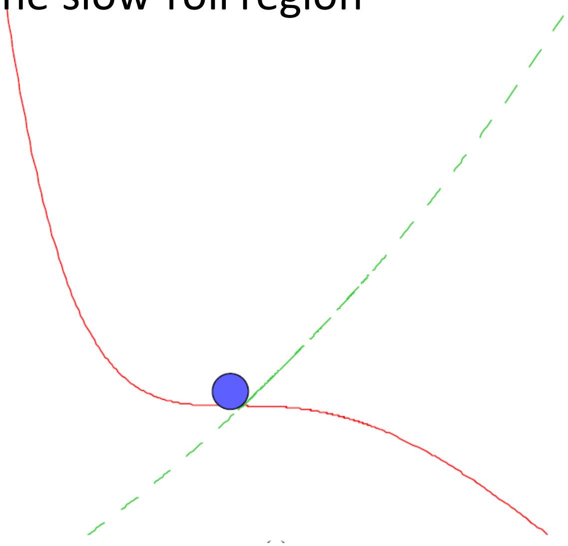
Minor effect at the beginning



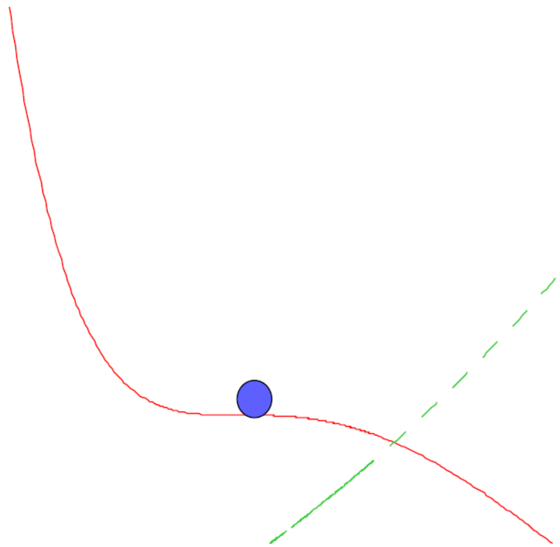
The inflaton follows the minimum of the combined potential



Inflaton moves slows down at the slow-roll region



The particles become irrelevant



Right now with A. Fialkov and E. Kovetz I'm looking in greater details into this option.

We used CMBFAST and CAMB to calculate the shape of the giant structure .

Turns out that

$$\ln^2(1+\frac{c}{r})$$

with c=47 Mpc/h

is a great approximation.

Shapely looks like a good nearby candidate

If you know of a giant structure that roughly looks like that please let me know…