Title: Recent works on holographic cosmology

Date: Jul 07, 2009 11:00 AM

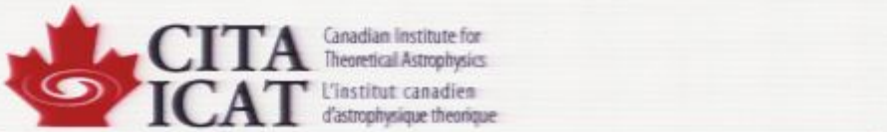
URL: http://pirsa.org/09070006

Abstract: My recent works were on new forms of non-gaussianity in CMB from inflationary physics.

Non-Gaussian Spikes from Chaotic Billiards in Inflation Preheating

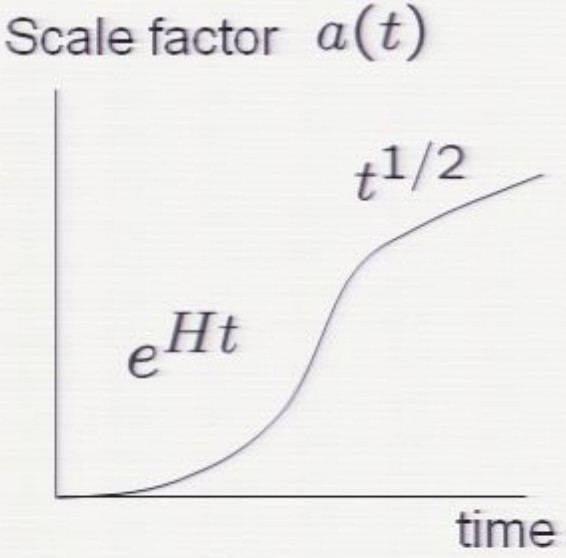
Lev Kofman

J.R.Bond, A.Frolov,Zh.Huang, LK, arXiv:0903.3407; Phys.Rev.Lett. 2009



Holographic Cosmology Workshop, PI July 7, 2009

Early Universe Inflation



Equation of State $t \leq 10^{-35}$ sec

$$p \approx -\epsilon$$

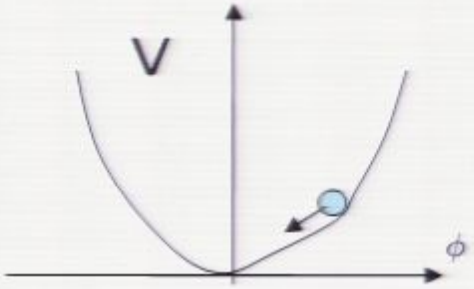
Inflation $a(t) \approx e^{Ht}$

Realization of Inflation

Scalar field

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

$$p = \frac{1}{2}\dot{\phi}^2 - V$$
$$\epsilon = \frac{1}{2}\dot{\phi}^2 + V$$



slow roll $\dot{\phi}^2 \ll V$

choise of $V(\phi)$

Generation of cosmological fluctuations

calar metric Fluctuations from Inflation

$s^2 = -(1-2\Phi)dt^2 + (1+2\Phi)a^2 d\vec{x}^2$

Initial conditions from Inflation ⟹

$$\Omega_{tot} = 1$$

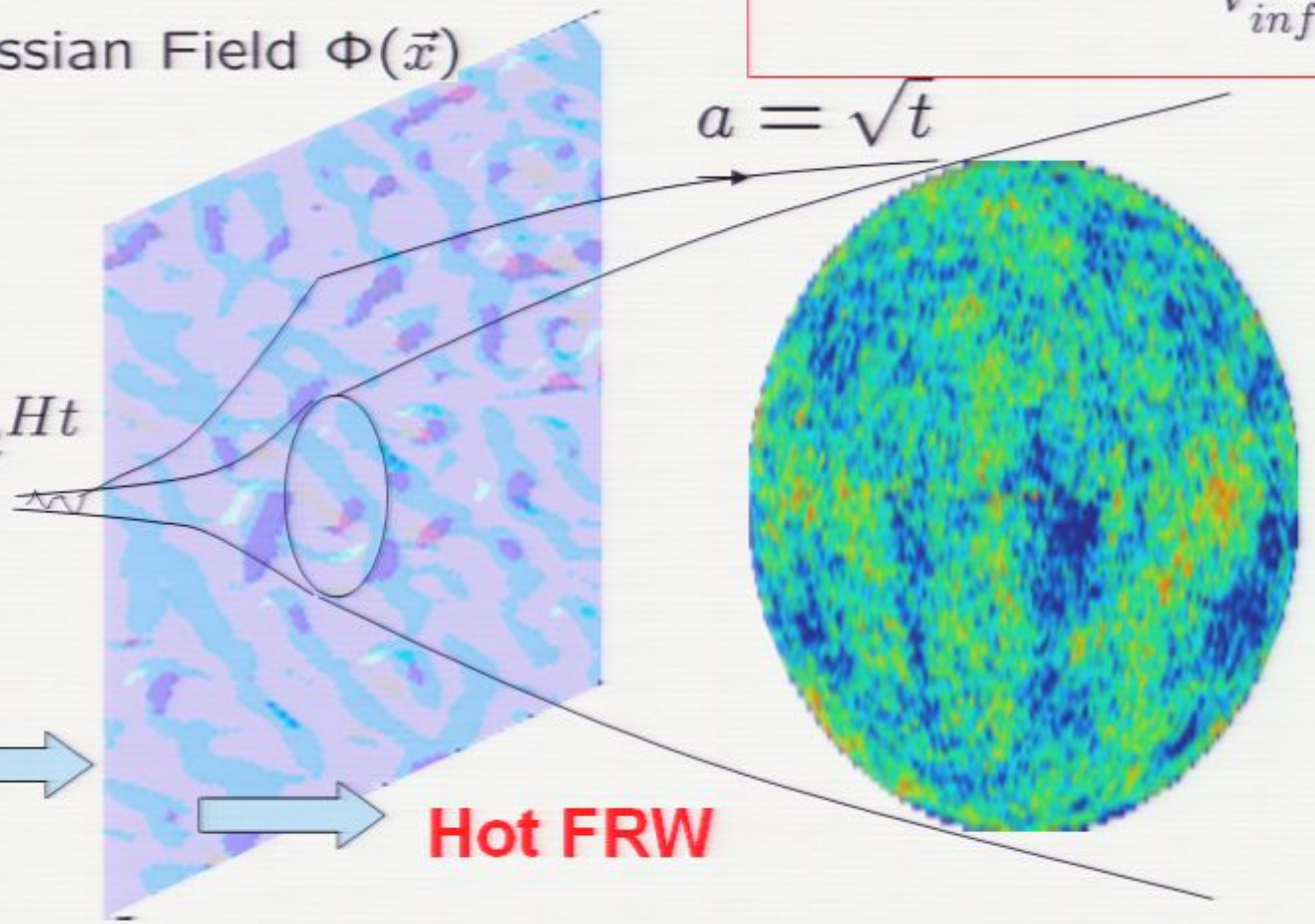
$$k^3 \Phi_k^2 \rightarrow P_s = A_s k^{n_s - 1}$$

$$P_T = \frac{H^2}{M_p^2} k^{n_T}$$

$$N = 62 - \ln \frac{10^{16} Gev}{V_{inf}^{1/4}}$$

⇓

Random Gaussian Field $\Phi(\vec{x})$



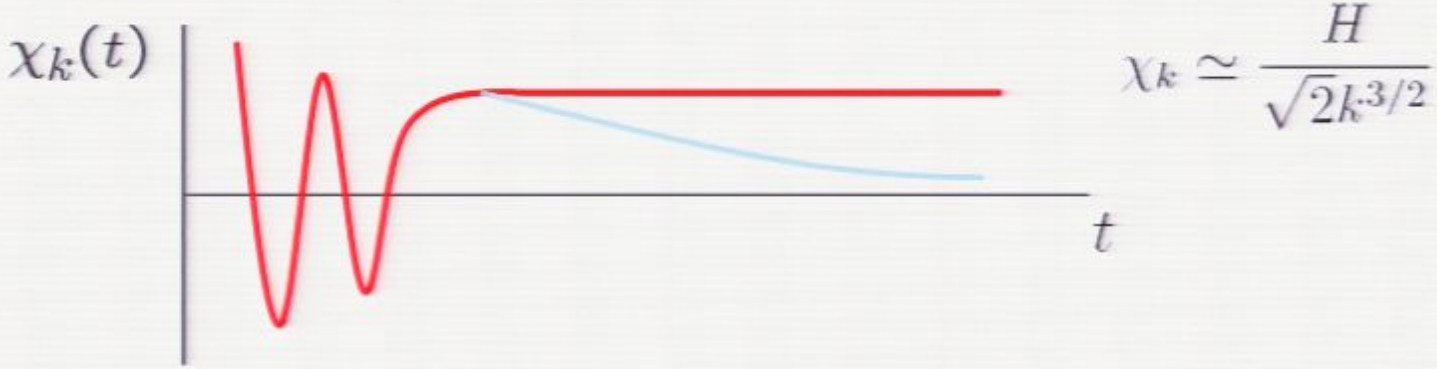
inflation ⟹

Hot FRW

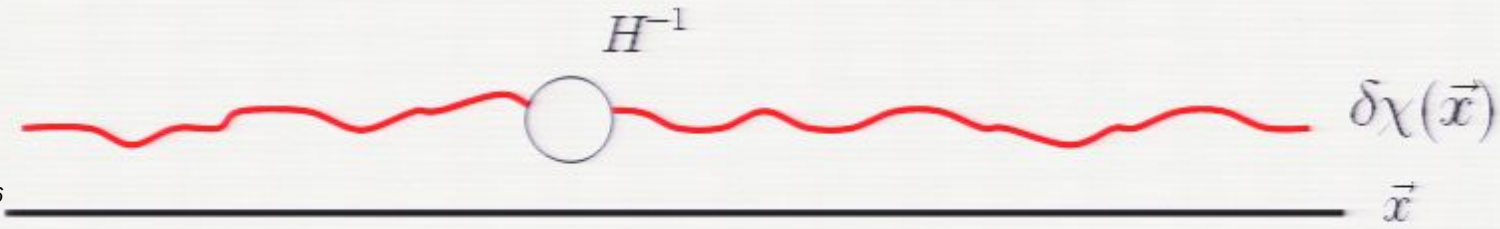
Light field at inflation

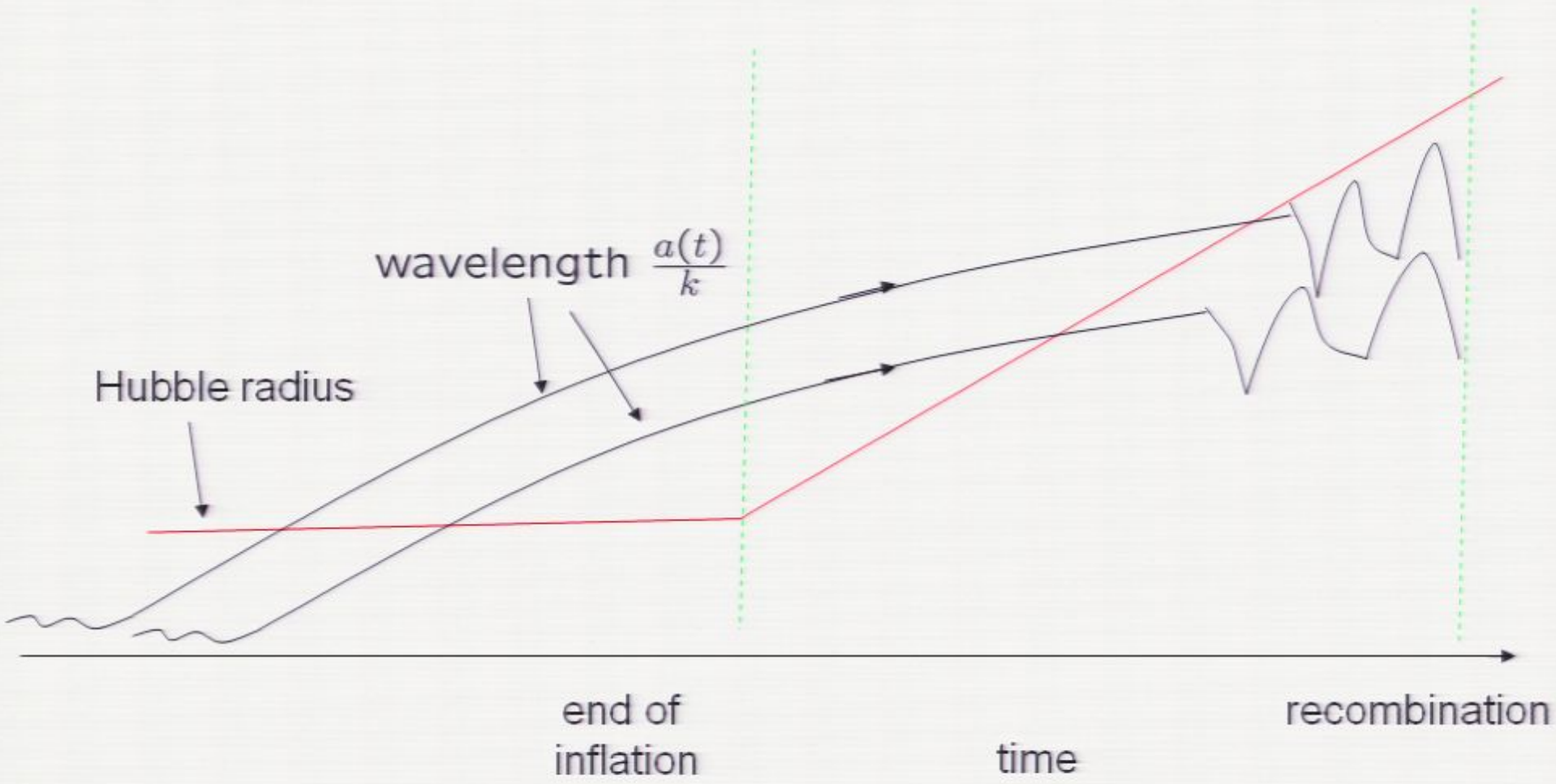
$$\delta\chi = \int d^3k (a_k \chi_k(t) e^{i\vec{k}\vec{x}} + h.c.)$$

$$\ddot{\chi}_k + 3H\dot{\chi}_k + \frac{k^2}{a^2}\chi_k = 0$$



$$\chi_k \simeq \frac{H}{\sqrt{2}k^{3/2}}$$




wavelength $\frac{a(t)}{k}$
Hubble radius
end of inflation
time
recombination

Light field at inflation

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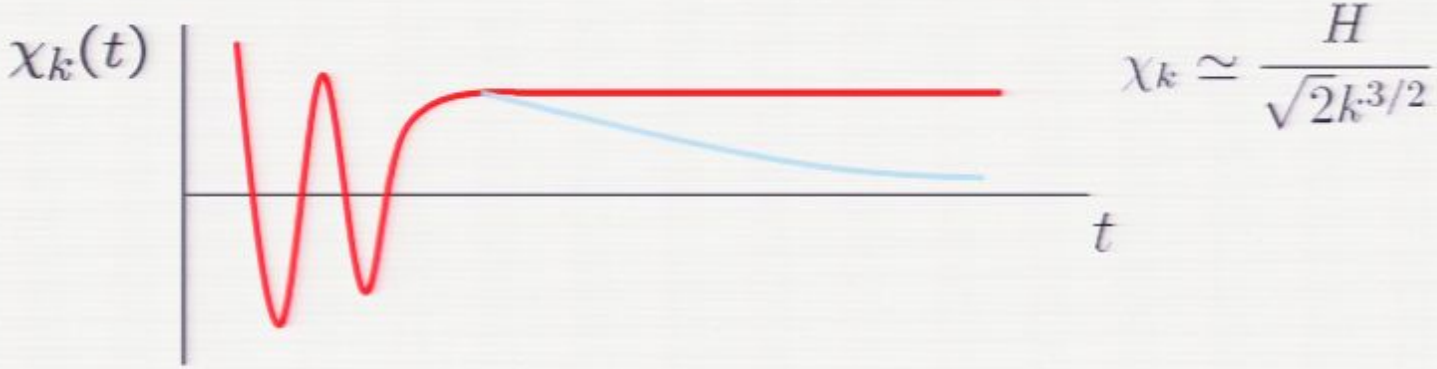

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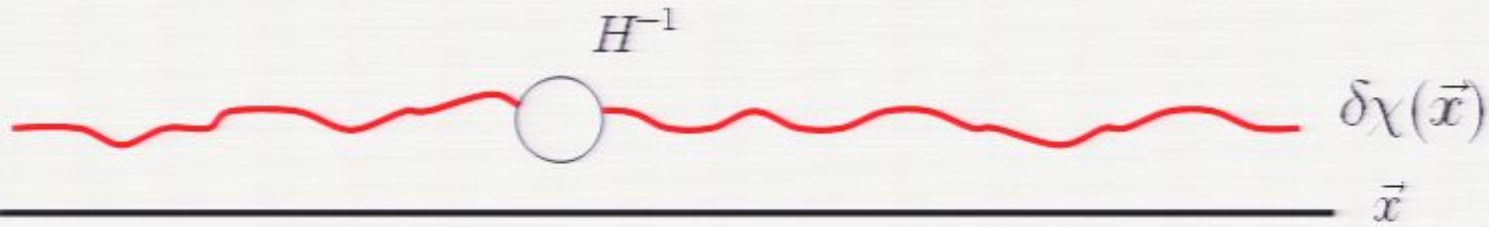

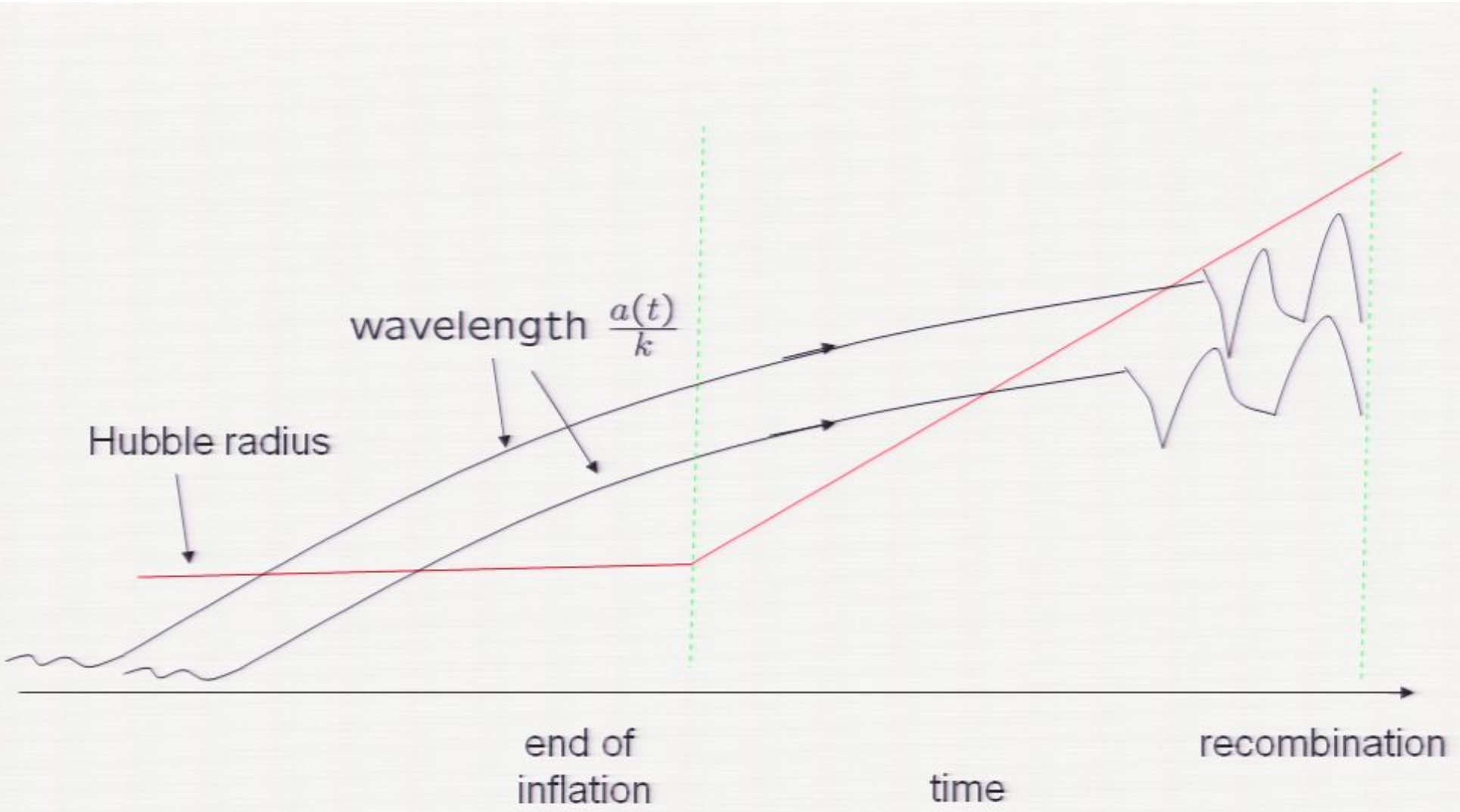
wavelength $\frac{a(t)}{k}$
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Scalar metric Fluctuations

$ds^2 = -(1-2\Phi)dt^2 + (1+2\Phi)a^2 d\vec{x}^2$

Scalar field fluctuations

$\phi(t,\vec{x}) = \phi(t) + \delta\phi(t,\vec{x})$

$\delta R^\mu_\nu = \frac{8\pi}{M_p^2}\delta T^\mu_\nu$

$u = a\delta\phi,\ z = \frac{a\dot{\phi}}{H},\ \eta = \int dt/a$

$$u_k'' + \left(k^2 - \frac{z''}{z}\right) u_k = 0$$

spectrum $P_s(k) = \frac{k^3}{2\pi^2}|\frac{u_k}{z}|^2 \sim \frac{V^3}{M_p^6 V_{,\phi}^2}$

$V(\phi) \sim \phi^n$

$k = aH$

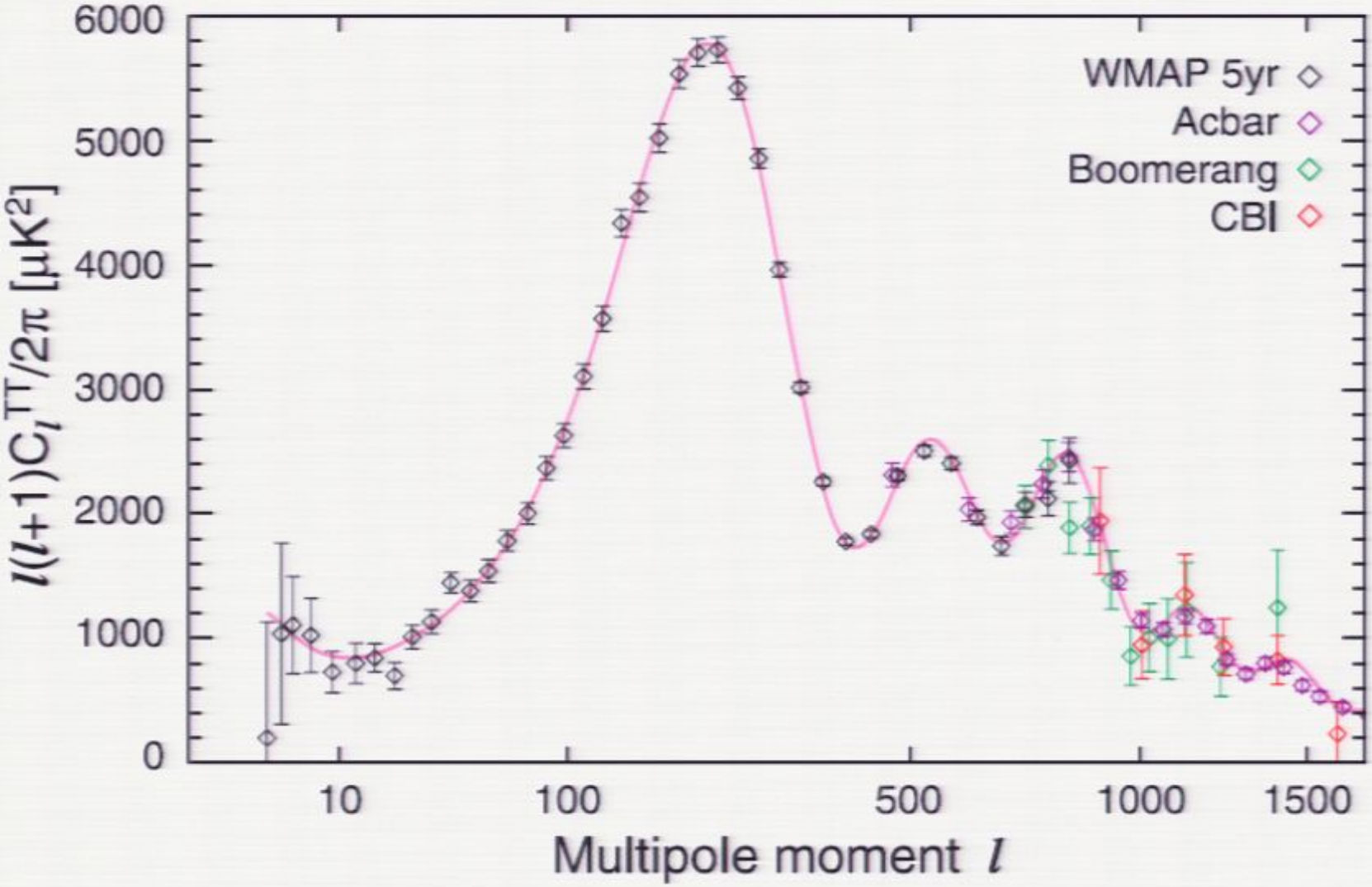
often $P_s(k) = A_s \left(\frac{k}{k_*}\right)^{n_s - 1}$

$$n_s - 1 \approx -\frac{n+2}{2N}$$

$V = \frac{1}{2}m^2\phi^2$

$V = \frac{1}{4}\lambda\phi^4$

number of efolding $N = \ln \frac{k_0}{}$



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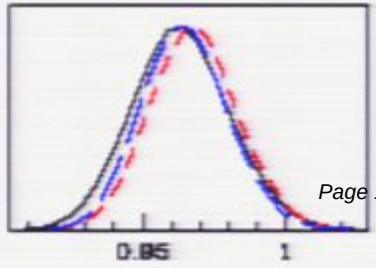
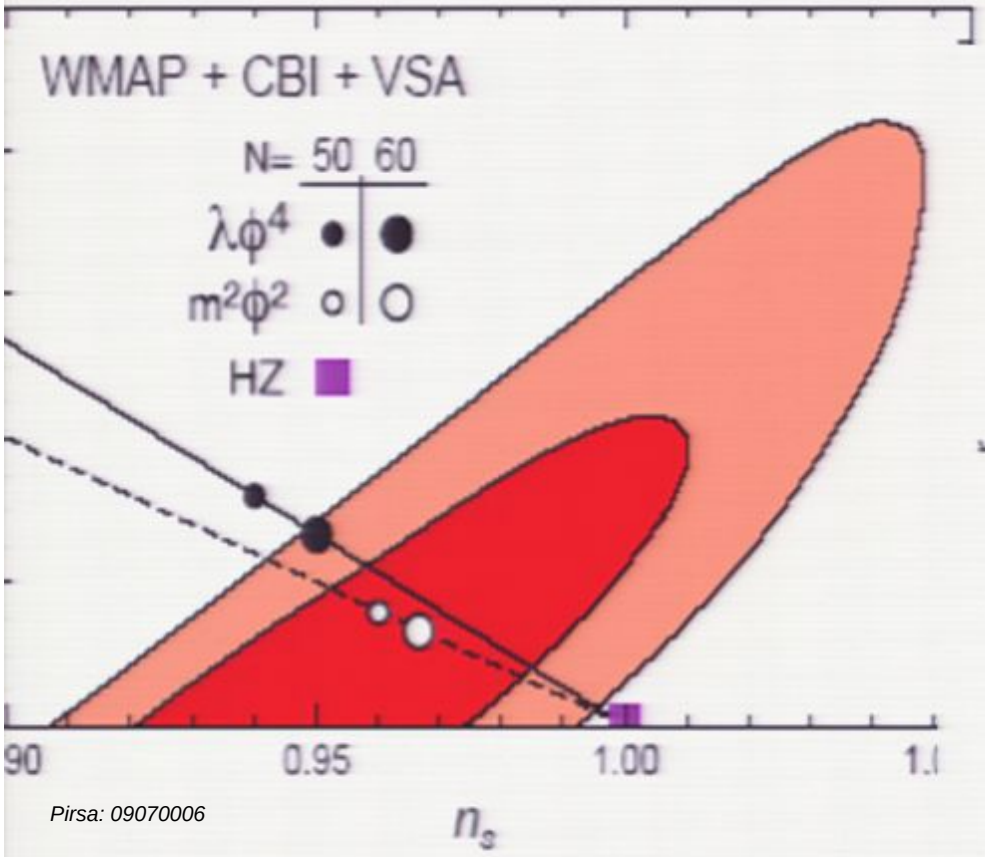
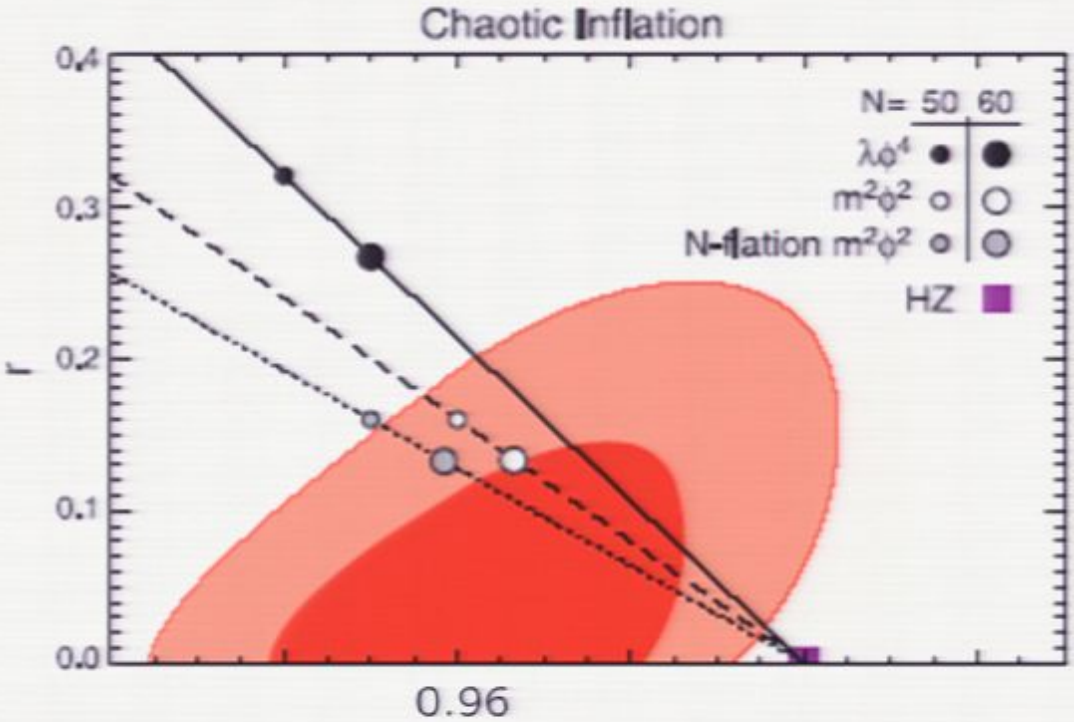


March 2008

Large field models

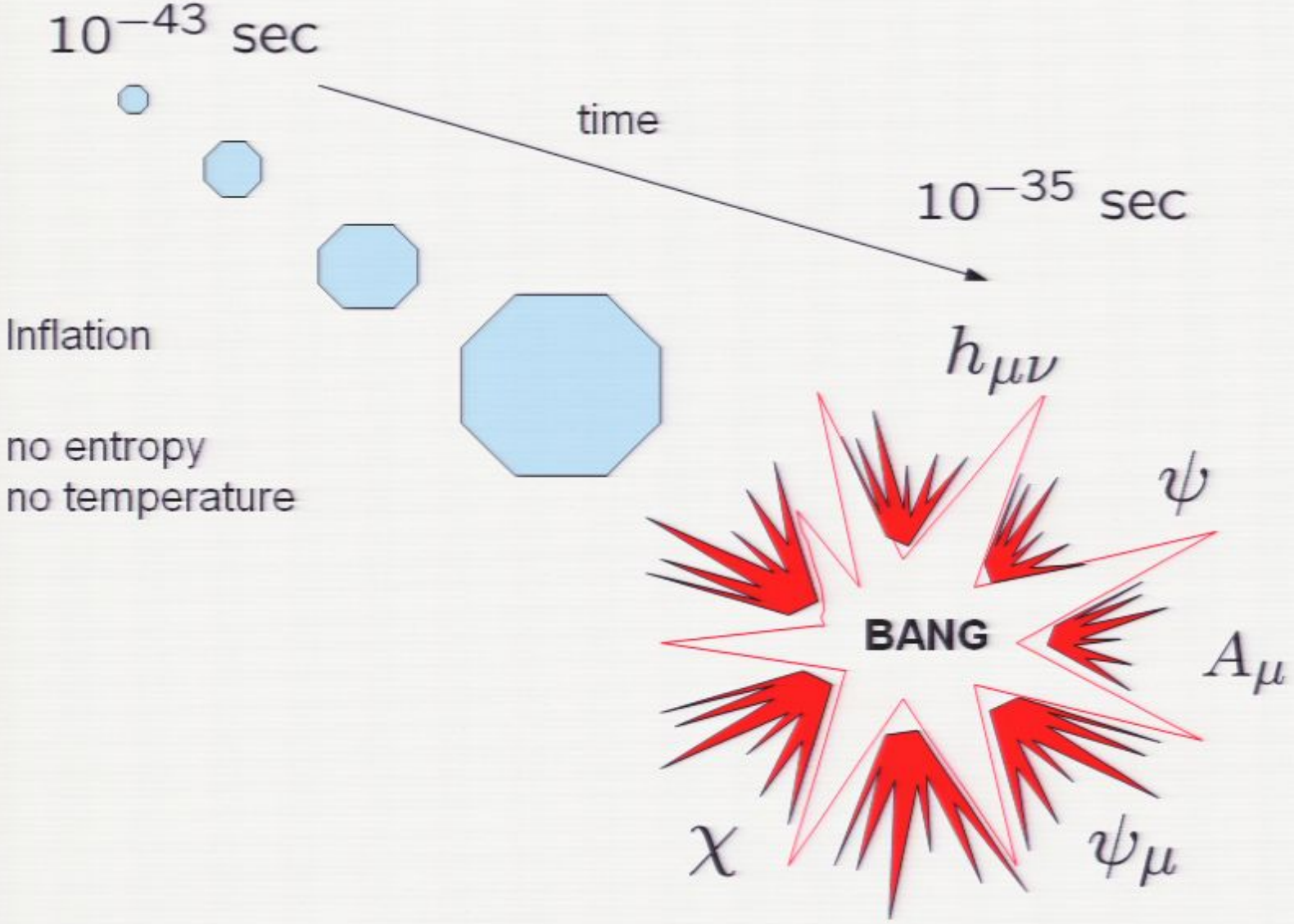
$$V = \phi^n \qquad n_s - 1 = -\frac{2+n}{2N} \qquad r = \frac{4n}{N}$$





WMAP3 WMAP5

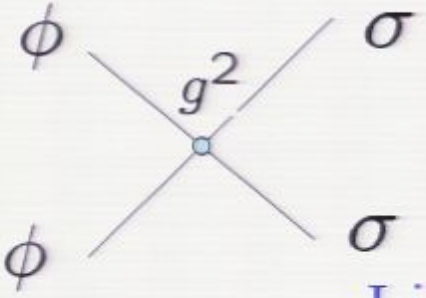
Particlegenesis

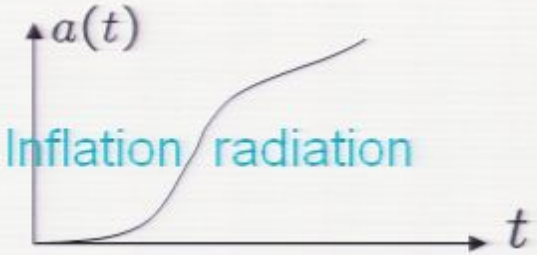


$$\mathcal{L}(\phi, \chi, \psi, A_\mu, \psi_\mu, h_{\mu\nu})$$

Modulated Fluctuations

$g^2\phi^2\sigma^2$

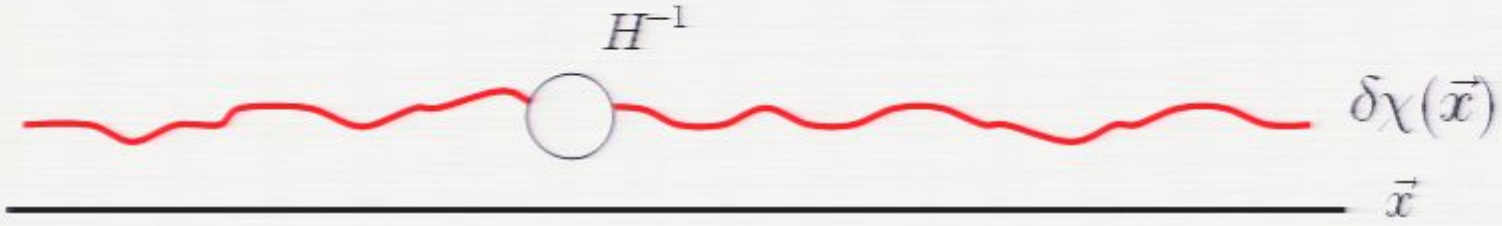


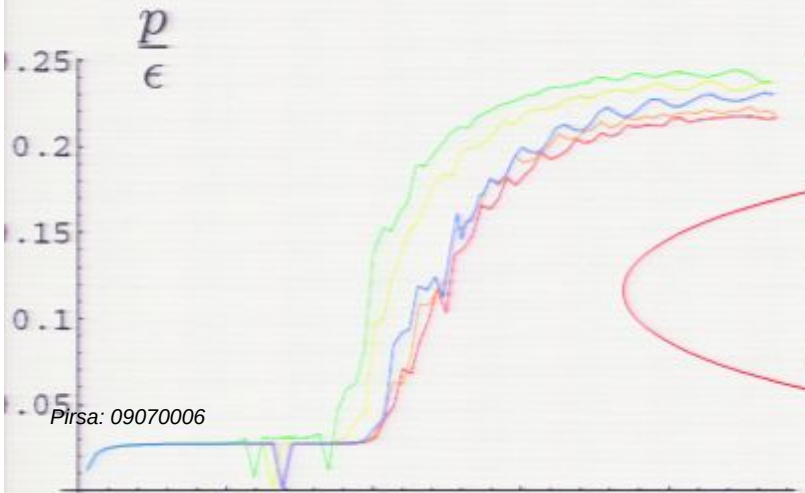


coupling depends on moduli $g^2 = g^2(\chi)$

Light field at inflation develops fluctuations $\chi_k \simeq \frac{H}{\sqrt{2}k^{3/2}}$

spacial variations $\delta g^2 = \frac{\partial g^2}{\partial \chi}\delta\chi$





varying $g^2 = 10^{-7}$ by 5%

Generation of metric fluctuations

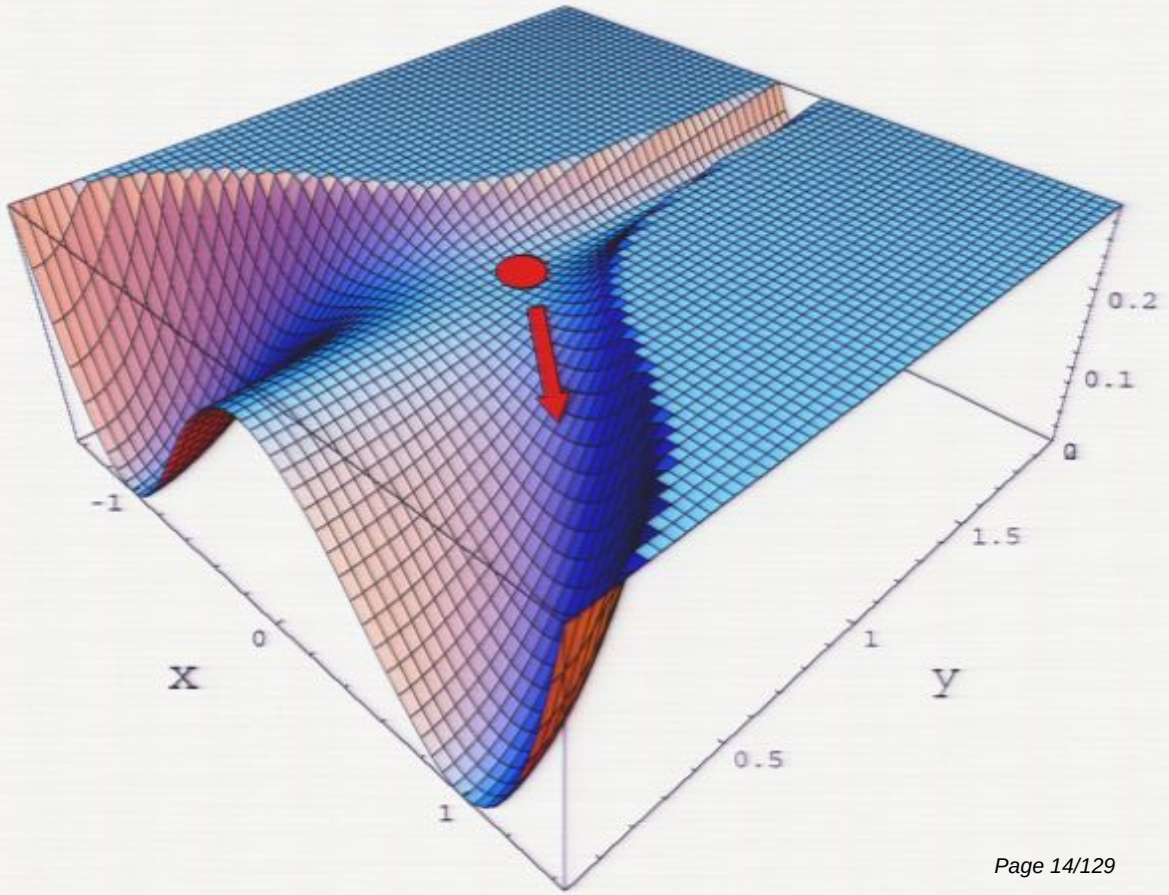
$\delta\chi_k \rightarrow \delta g^2 \rightarrow \Phi_k$

Modulated fluctuations in Hybrid Inflation

$$V(\phi,\sigma) = \frac{\lambda}{4}(\sigma^2 - v^2)^2 + \frac{g^2}{2}\phi^2\sigma^2$$

bifurcation point $\phi_c = \frac{\sqrt{\lambda}v}{g}$

$\phi_c(\chi_0 + \delta\chi)$



inhomogeneous waterfall

Bernardeau, LK, Uzan 03

Non-Gaussianity theory

$$\Phi = \Phi_G + f_{NG}^{local}\left(\Phi_G^2 - <\Phi^2>\right)$$

single field $f_{NL} = \frac{1}{4}(n_s - 1) \quad \sim 0.01$

modulated/curvaton $f_{NL} \simeq 1$

multiple fields/non-canonical kinetic f_{NL} any

Modulated fluctuations in Hybrid Inflation

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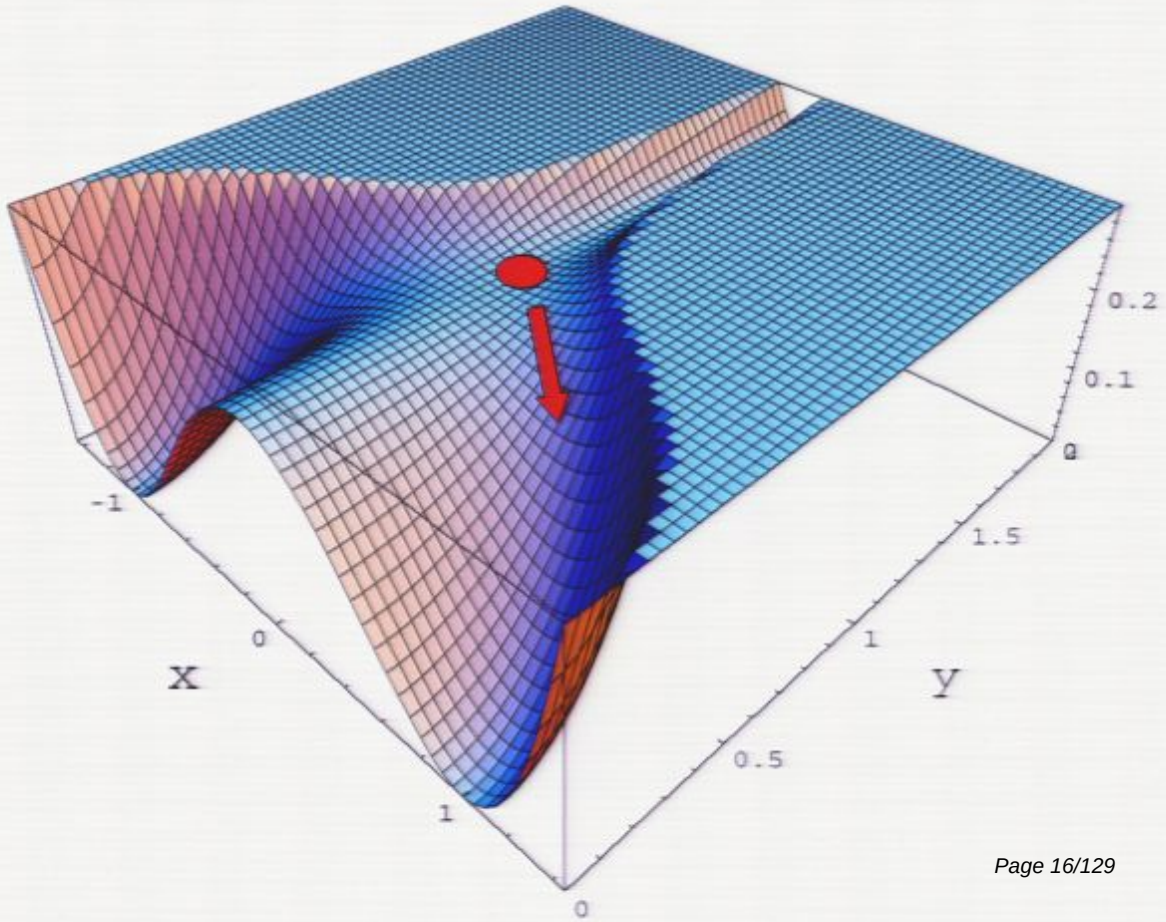

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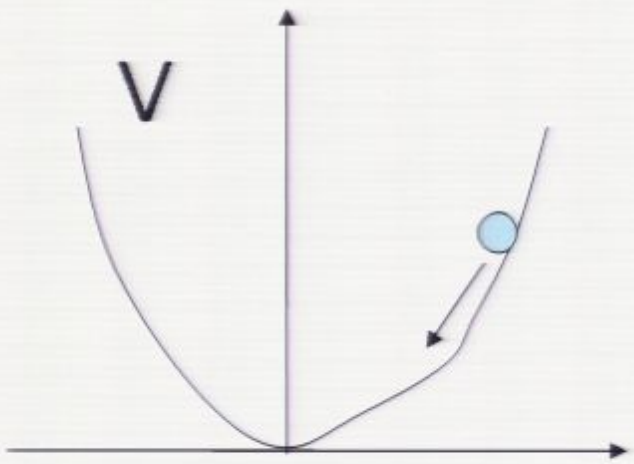
Non-Gaussianity data

$$\Phi = \Phi_G + f_{NG}^{local}\left(\Phi_G^2 - <\Phi^2>\right)$$

WMAP5	$-9 < f_{\rm NL}^{\rm local} < 111$ at 95% C.L.
WMAP5+SDSS	$-1 < f_{\rm NL}^{\rm local} < 70$ at 95% C.L.
Planck	$\Delta f_{\rm NL}^{\rm local} \simeq 4$
CMBPol	$\Delta f_{\rm NL}^{\rm local} \sim 2-3$
LSS	$\Delta f_{\rm NL}^{\rm local} \sim 1$
EUCLID(SPACE+DUNE)	$\Delta f_{\rm NL}^{\rm local} \sim 0.2$



$$V(\phi) = \frac{1}{4}\lambda\phi^4$$

New Type of Modulated Fluctuations from Preheating

$$\frac{1}{4}\lambda\phi^4 + \frac{1}{2}g^2\phi^2\chi^2$$

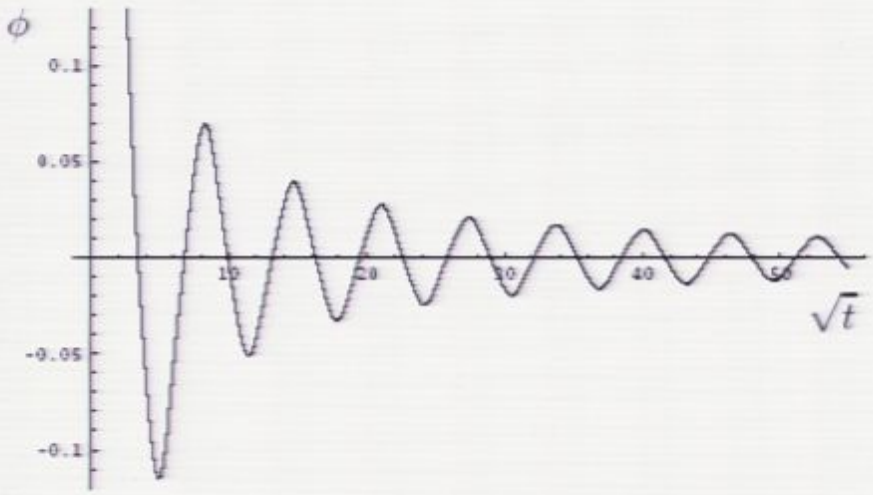
iso-inflaton field is light if

$$g^2/\lambda \sim \mathcal{O}(1)$$

A. Chambers, A. Rajantie arXiv:0805.4795

$$\tfrac{1}{4}\lambda\phi^4 + \tfrac{1}{2}g^2\phi^2\chi^2$$

$$H^2 = \frac{8\pi}{3M_p^2}\left(\frac{1}{2}\dot{\phi}^2 + \frac{\lambda\phi^4}{4}\right)$$



$$\ddot{\phi} + 3H\,\dot{\phi} + \lambda\phi^3 = 0\ .$$

$$\eta = \int \frac{dt}{a(t)} \qquad \varphi = a\phi$$

$$\varphi'' + \lambda\varphi^3 - \frac{a''}{a}\varphi = 0$$

$$\varphi'' + \lambda\varphi^3 = 0$$

$$\varphi \equiv a\phi = \tilde{\varphi} f(x) \qquad f(x) = cn\left(x - x_0, \frac{1}{\sqrt{2}}\right)$$

$$x \equiv \sqrt{\lambda}\tilde{\varphi}\eta = \left(\frac{6\lambda M_p^2}{\pi}\right)^{1/4}\sqrt{t}$$

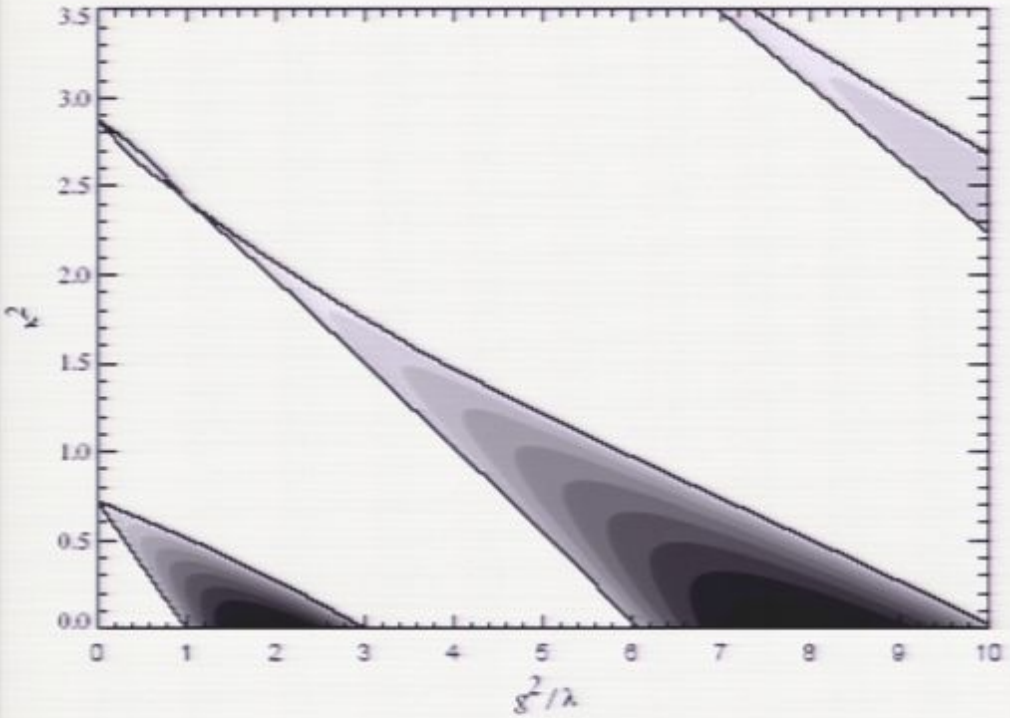
$$\hat{\chi}(t,\mathbf{x}) = \frac{1}{(2\pi)^{3/2}} \int d^3k \left(\hat{a}_k \chi_k(t)\, e^{-i\mathbf{k}\mathbf{x}} + \hat{a}_k^+ \chi_k^*(t)\, e^{i\mathbf{k}\mathbf{x}} \right)$$

$$\ddot{\chi}_k + 3\frac{\dot{a}}{a}\dot{\chi}_k + \left(\frac{k^2}{a^2} + g^2\phi^2 \right) \chi_k = 0$$

$$X_k(t) = a(t)\chi_k(t)$$

$$X_k'' + \left(\kappa^2 + \frac{g^2}{\lambda} cn^2\left(x, \frac{1}{\sqrt{2}} \right) \right) X_k = 0$$

$$\kappa^2 = \frac{k^2}{\lambda \tilde{\varphi}^2} \qquad \chi_k(t) = P_k(t) e^{\mu_k t}$$



Stability/instability chart Of the Lame equation

$$X_k'' + \left(\kappa^2 + \frac{g^2}{\lambda} cn^2\left(x, \frac{1}{\sqrt{2}}\right)\right) X_k = 0$$

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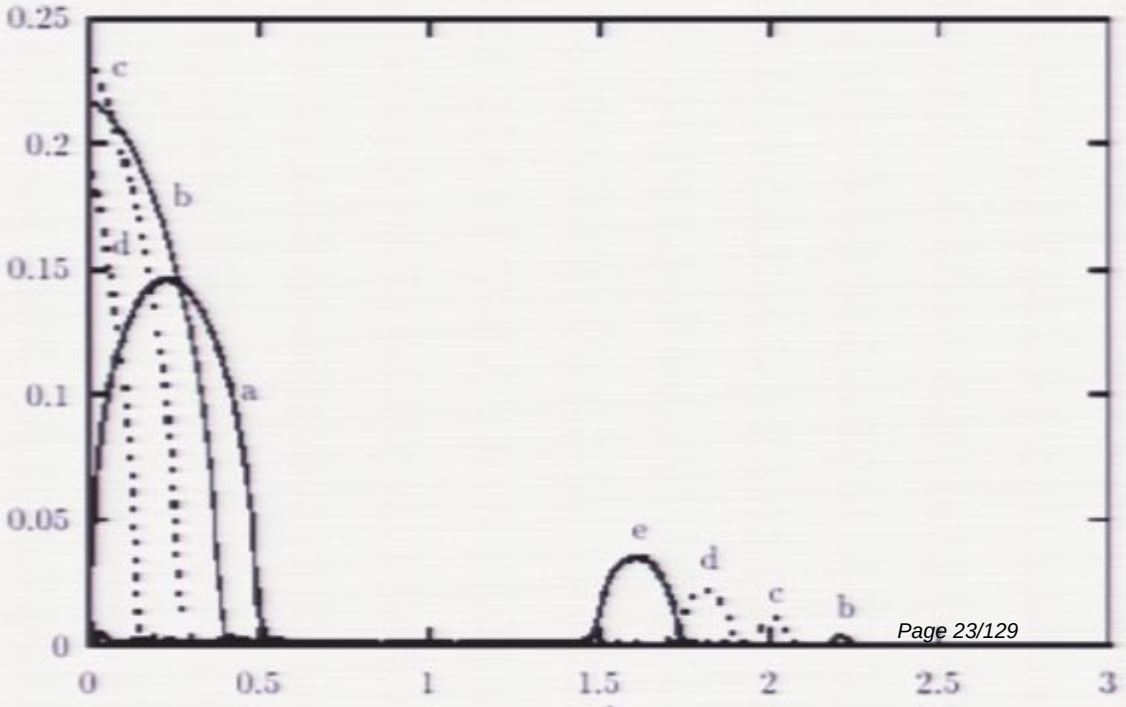
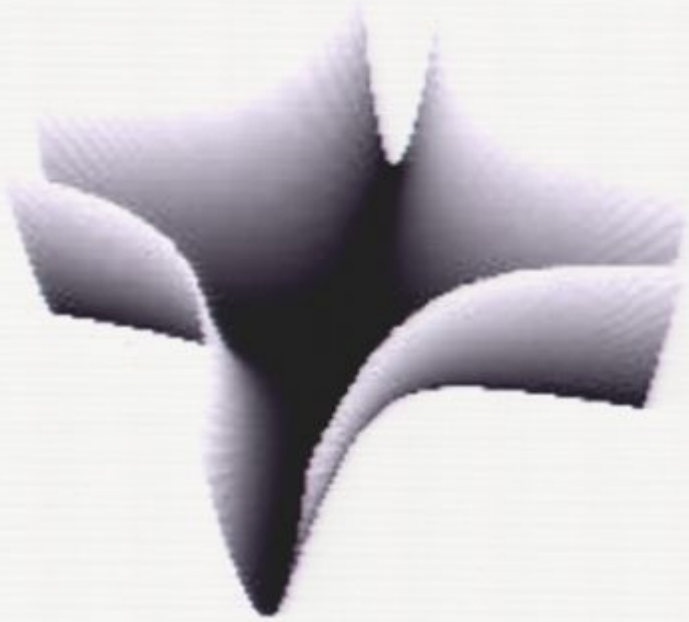
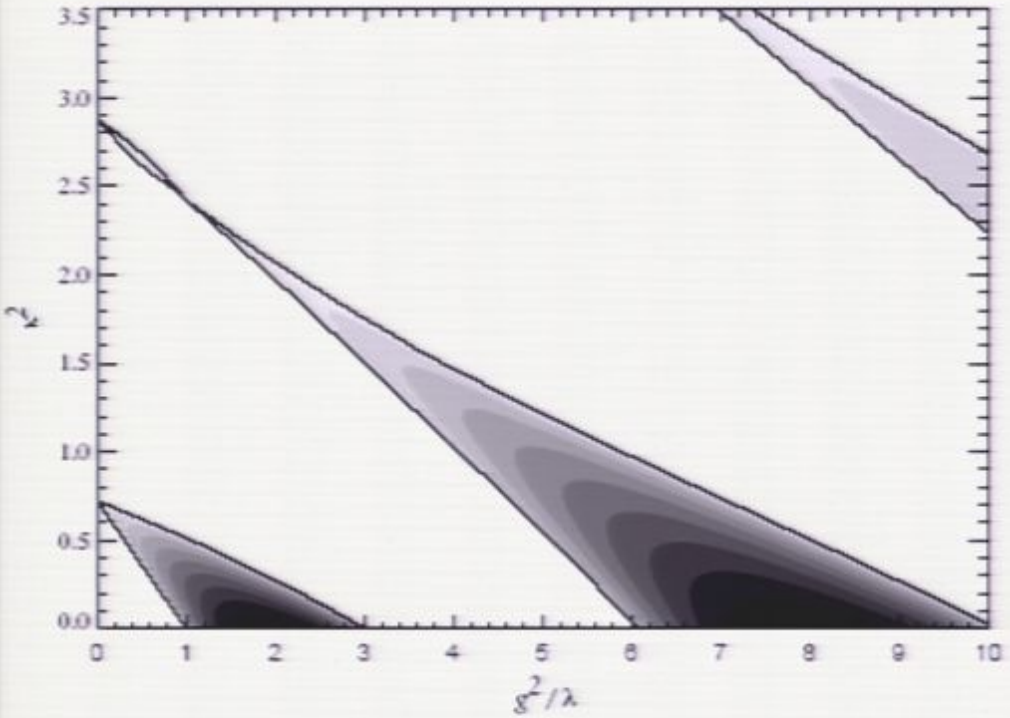


Chaotic Billiards

$$\frac{1}{2}\dot{\phi}^2 + \frac{1}{2}\dot{\chi}^2 + \frac{1}{2}g^2\phi^2\chi^2$$





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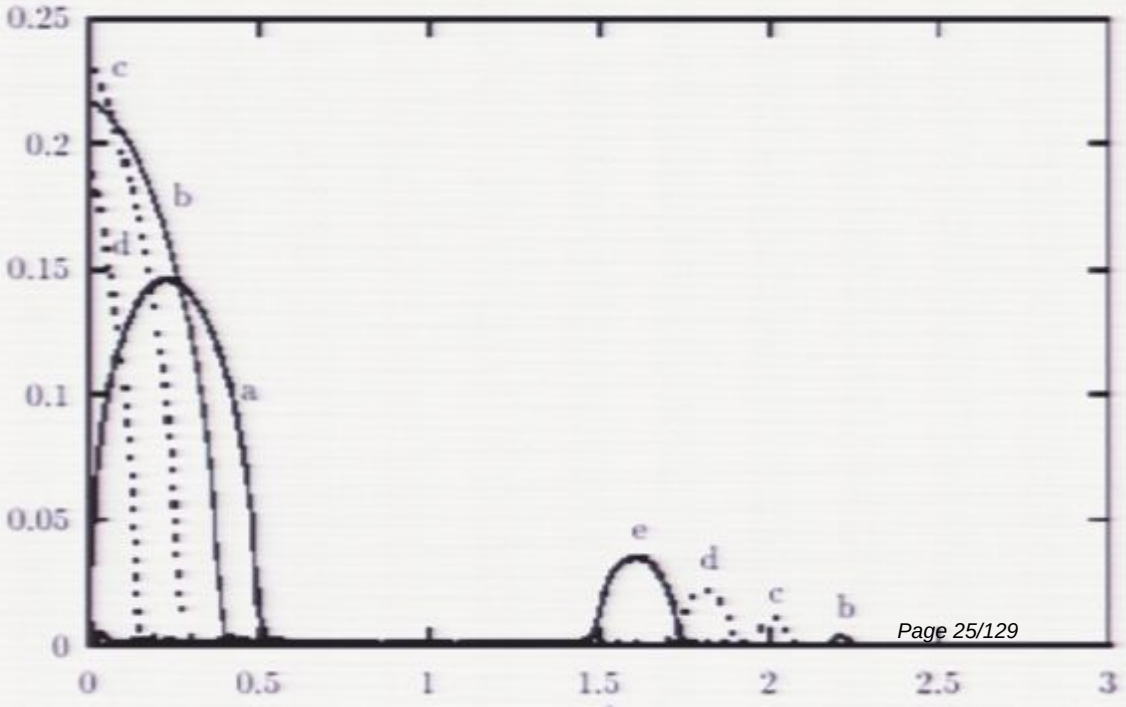

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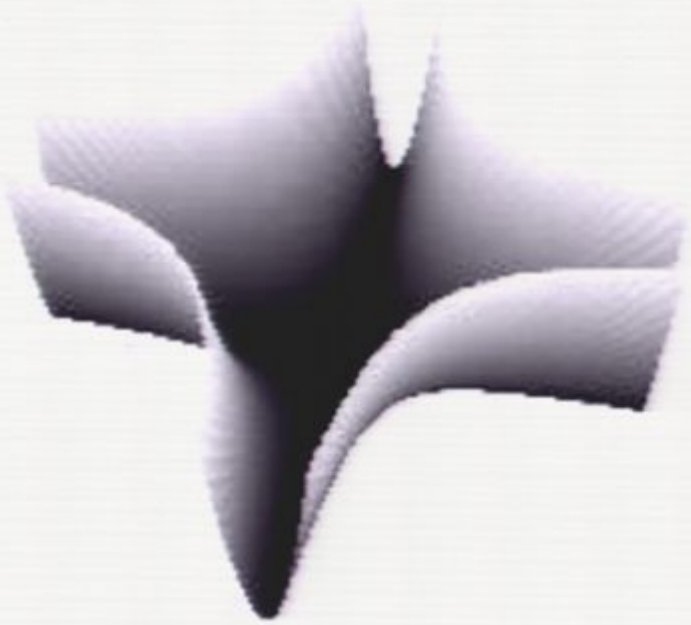

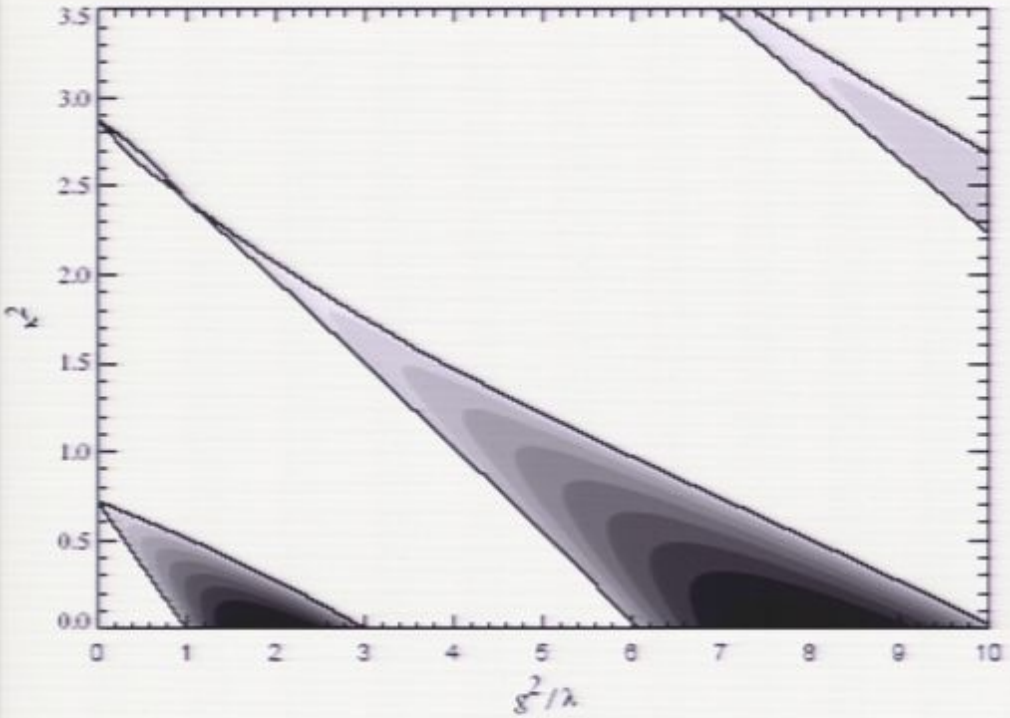

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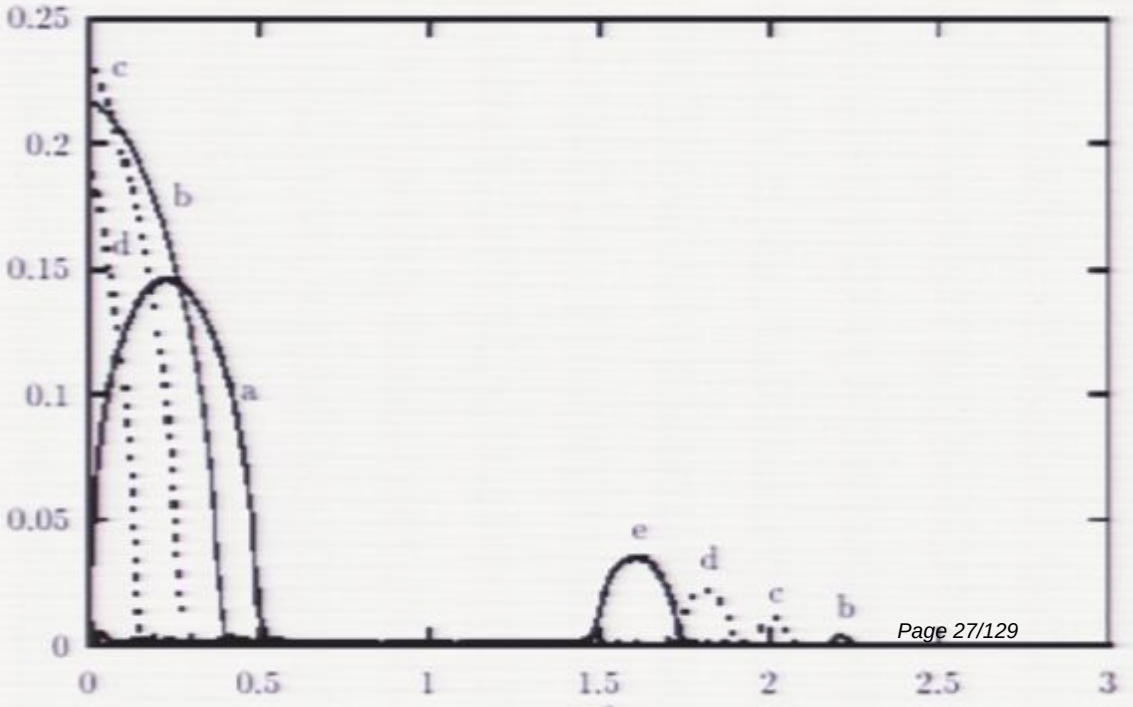

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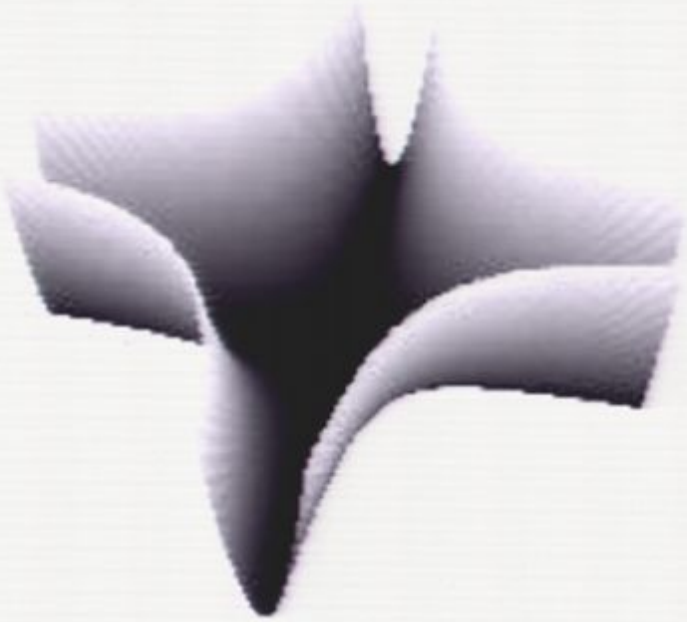


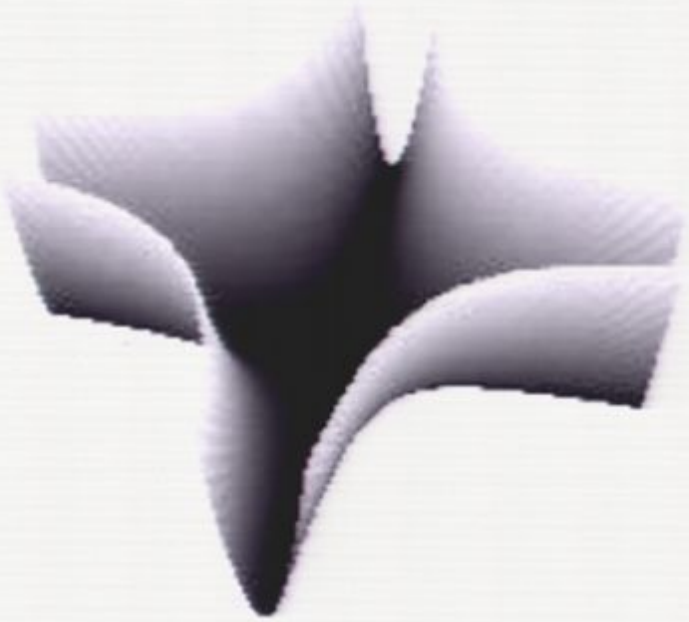
from parametric resonance $\chi_k = P_k(t)\, e^{\mu_k t}$

from billiard $\chi_0 \sim e^{\Lambda t}$

$$\Lambda = \mu_0$$

Chaotic Billiards

$$\frac{1}{2}\dot{\phi}^2 + \frac{1}{2}\dot{\chi}^2 + \frac{1}{2}g^2\phi^2\chi^2$$



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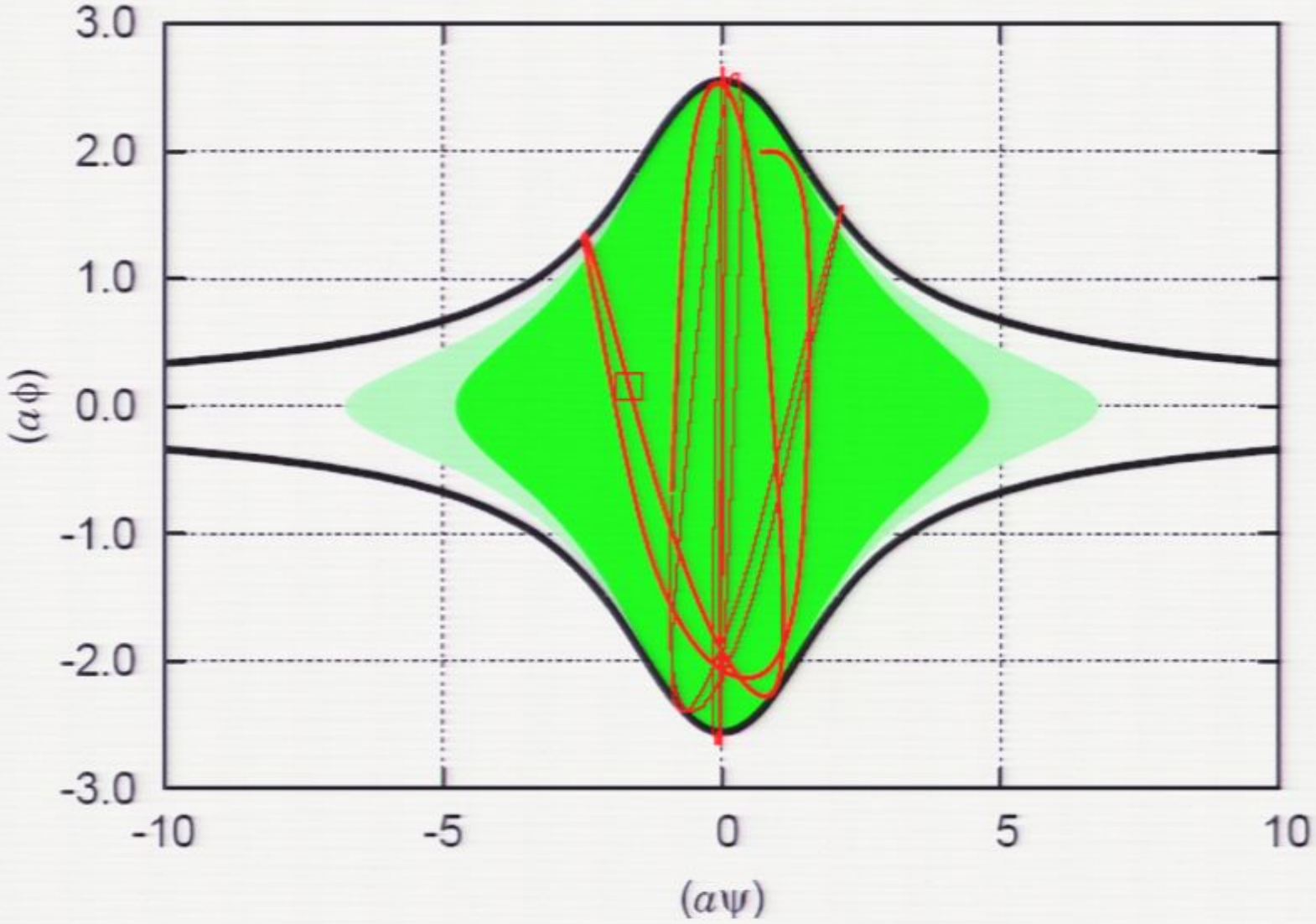
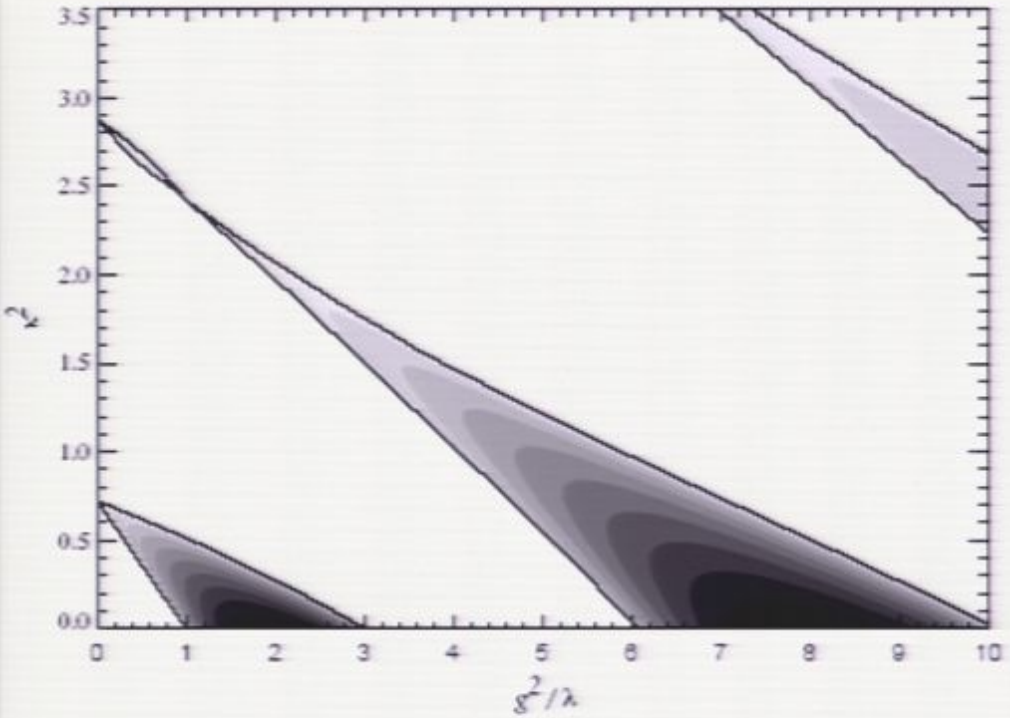
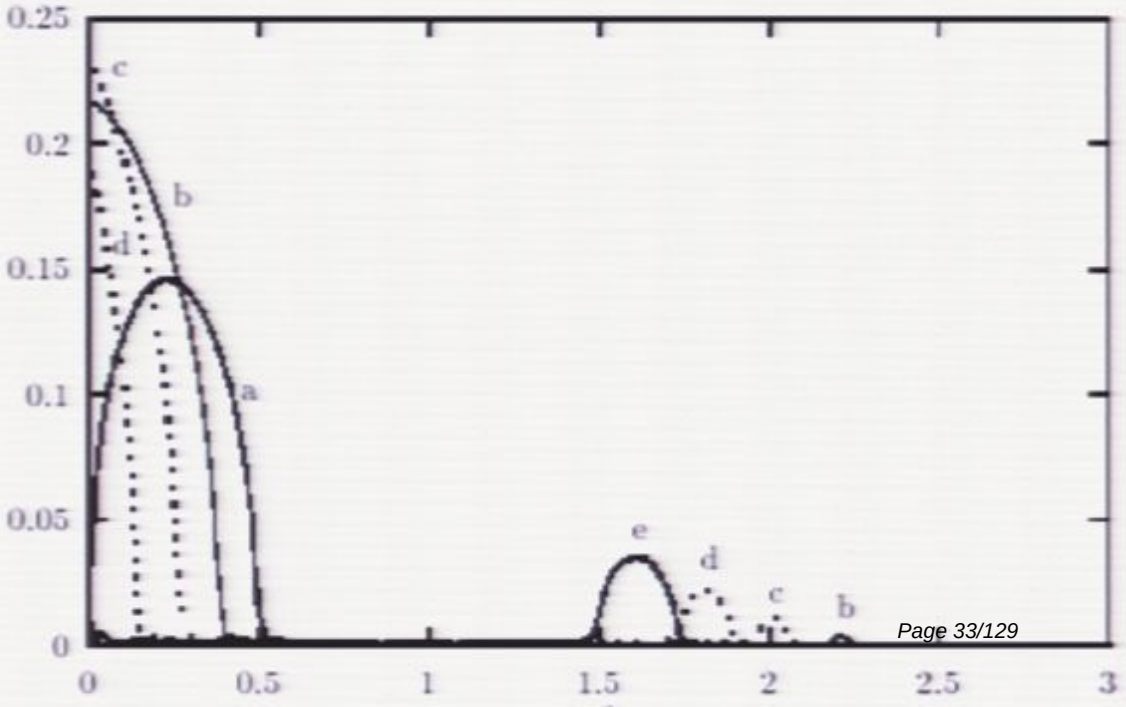

3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
10
$(\alpha\phi)$
$(\alpha\psi)$



Stability/instability chart Of the Lame equation

$$X_k'' + \left(\kappa^2 + \frac{g^2}{\lambda} cn^2\left(x, \frac{1}{\sqrt{2}}\right)\right) X_k = 0$$

$$\chi_k(t) = P_k(t) e^{\mu_k t}$$



Chaotic Billiards

from parametric resonance $\chi_k = P_k(t)\, e^{\mu_k t}$

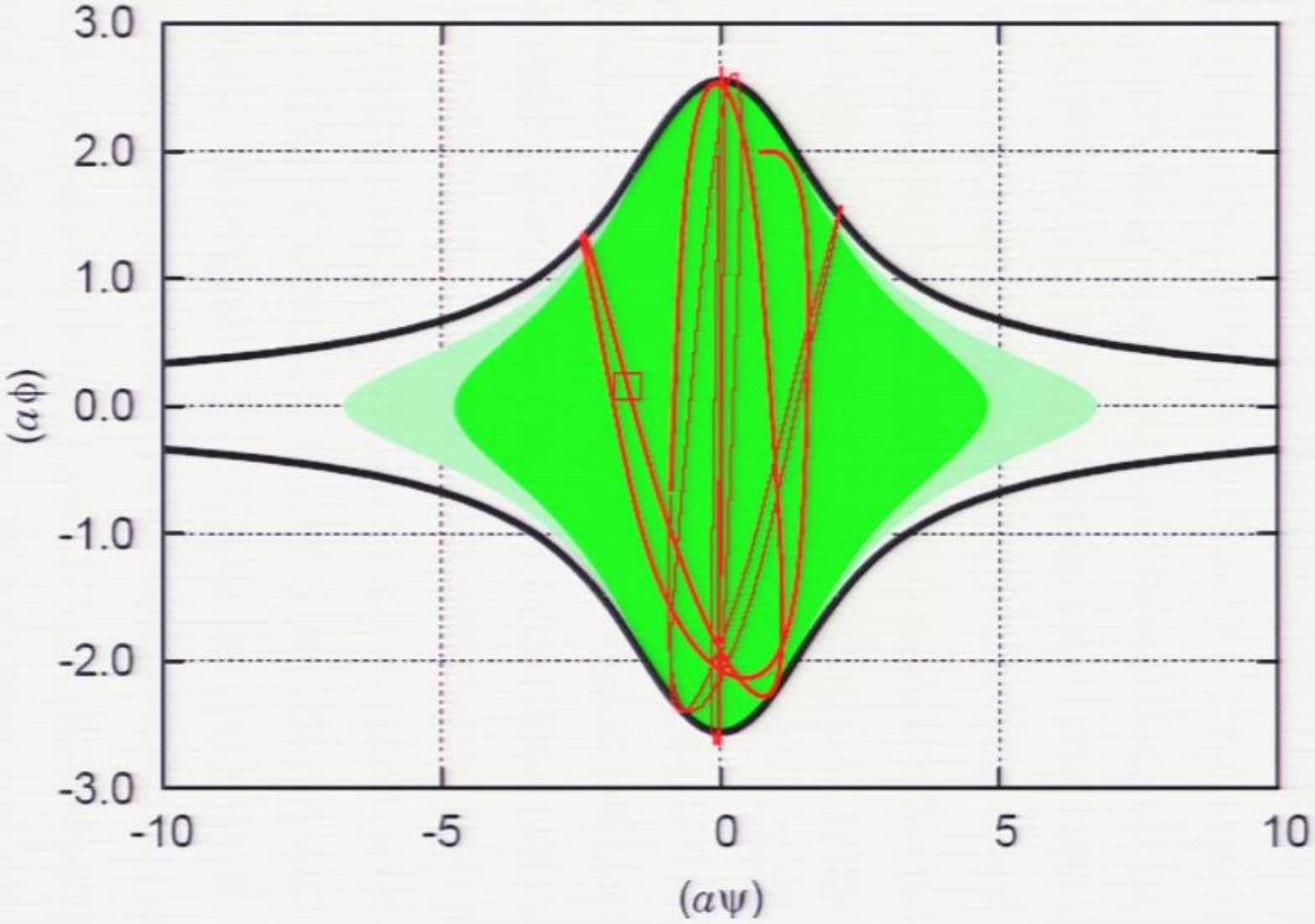
from billiard $\chi_0 \sim e^{\Lambda t}$

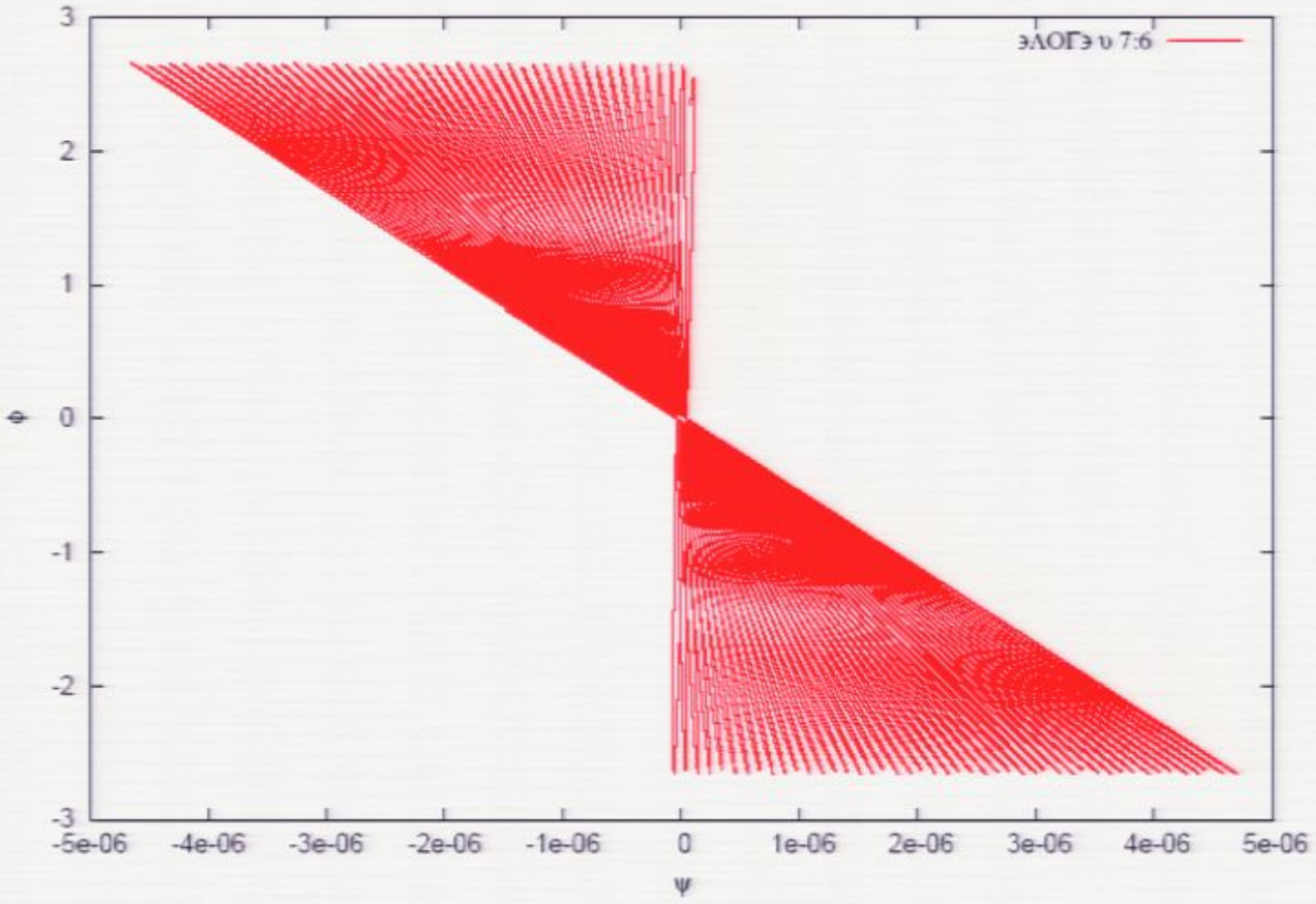
$$\Lambda = \mu_0$$

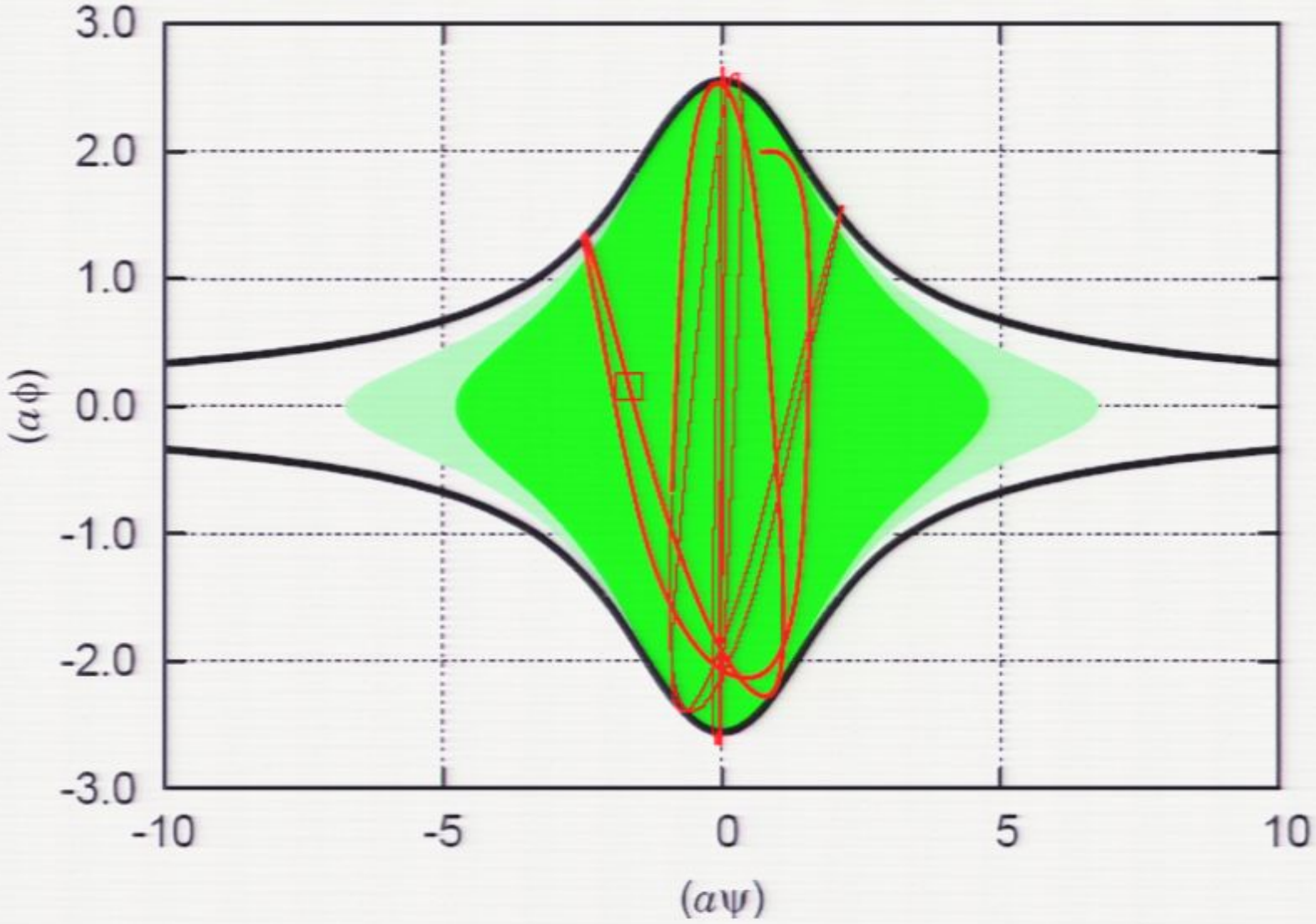
from parametric resonance $\chi_k = P_k(t)\, e^{\mu_k t}$

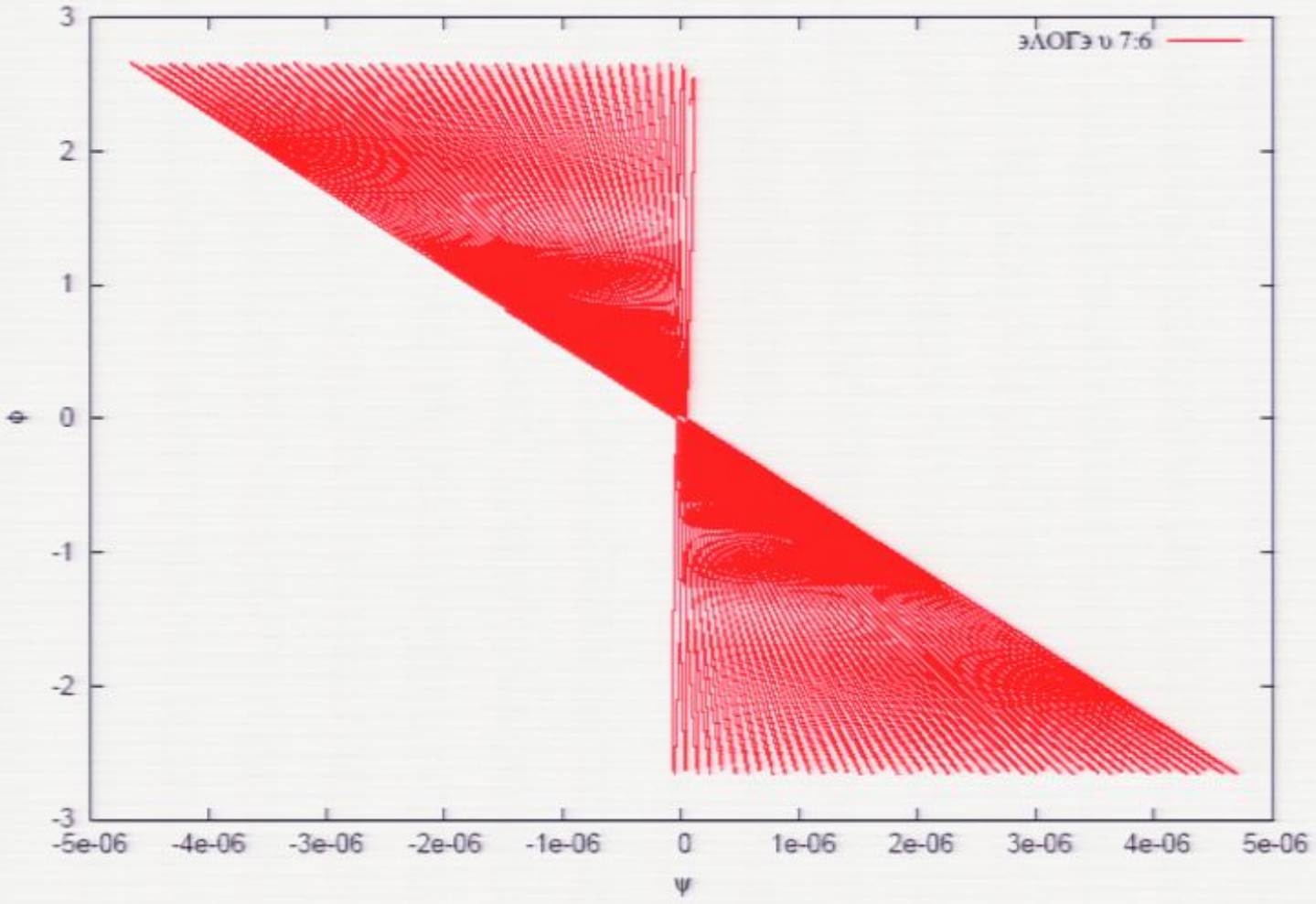
from billiard $\chi_0 \sim e^{\Lambda t}$

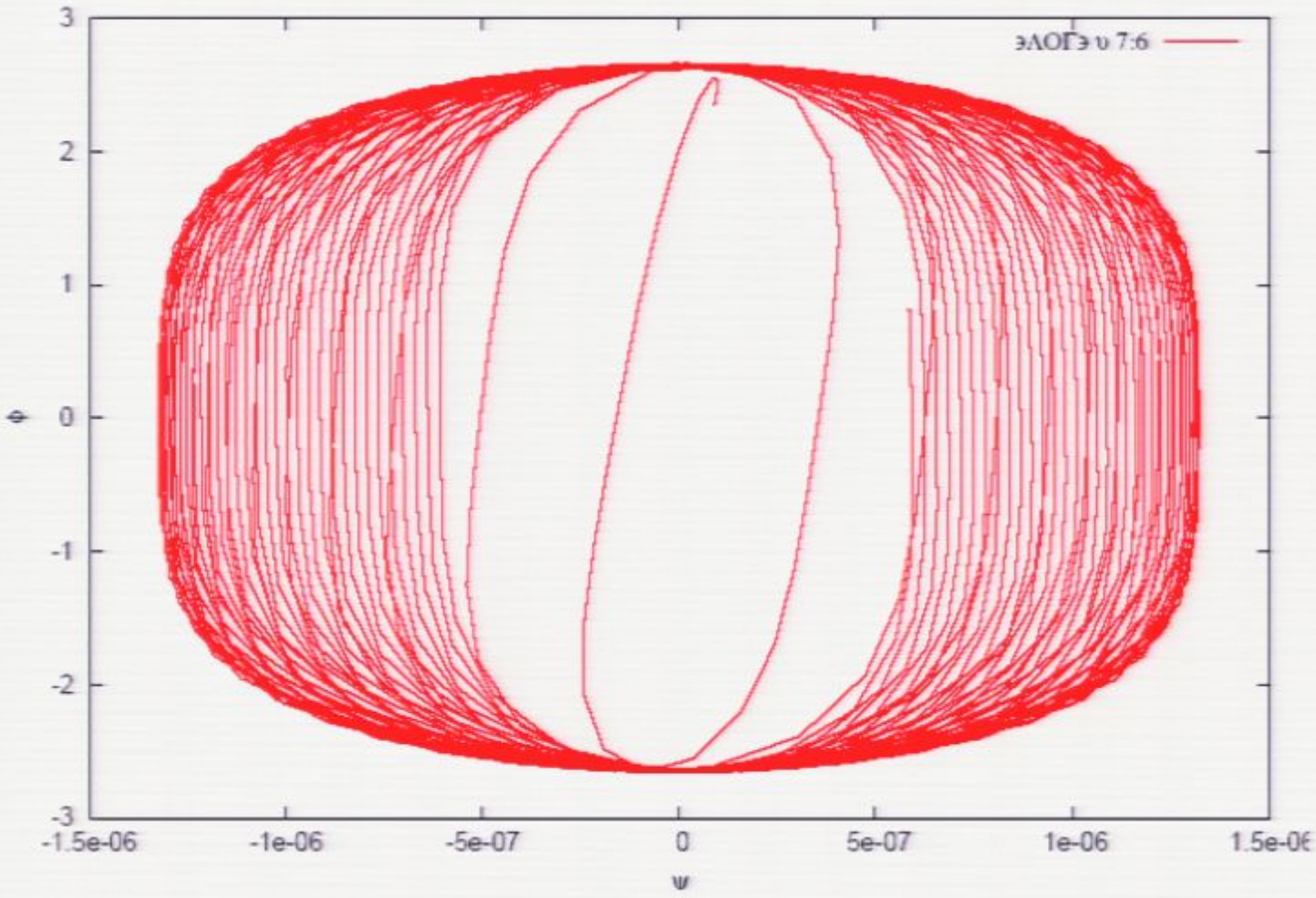
$$\Lambda = \mu_0$$


3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
10
$(\alpha\phi)$
$(\alpha\psi)$


3
2
1
0
-1
-2
-3
-5e-06
-4e-06
-3e-06
-2e-06
-1e-06
0
1e-06
2e-06
3e-06
4e-06
5e-06
ψ


3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
$(a\phi)$
-10
-5
0
5
10
$(a\psi)$

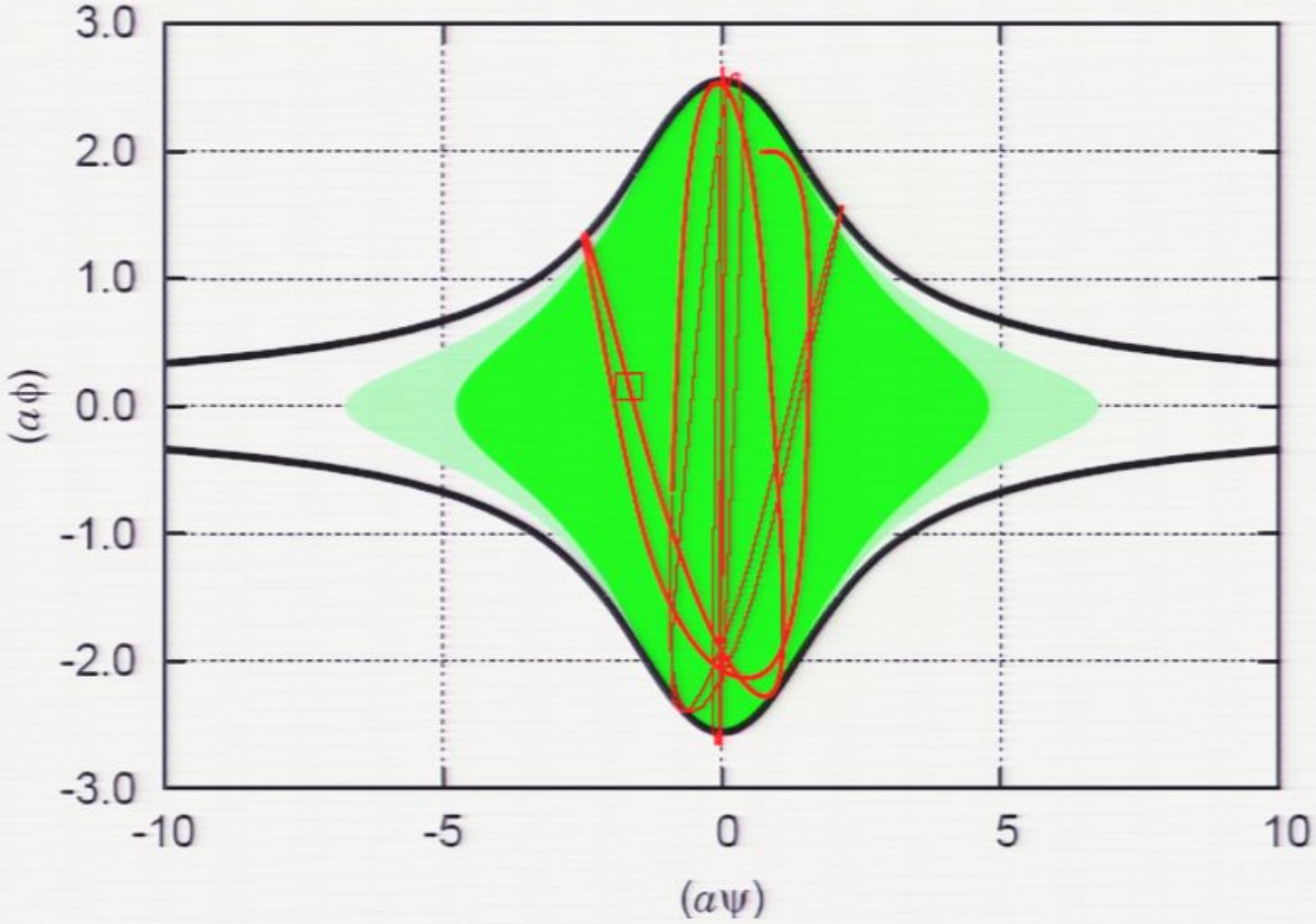

3
2
1
0
-1
-2
-3
-5e-06
-4e-06
-3e-06
-2e-06
-1e-06
0
1e-06
2e-06
3e-06
4e-06
5e-06
ψ


3
2
1
0
-1
-2
-3
-1.5e-06
-1e-06
-5e-07
0
5e-07
1e-06
1.5e-06
ψ

from parametric resonance $\chi_k = P_k(t)\, e^{\mu_k t}$

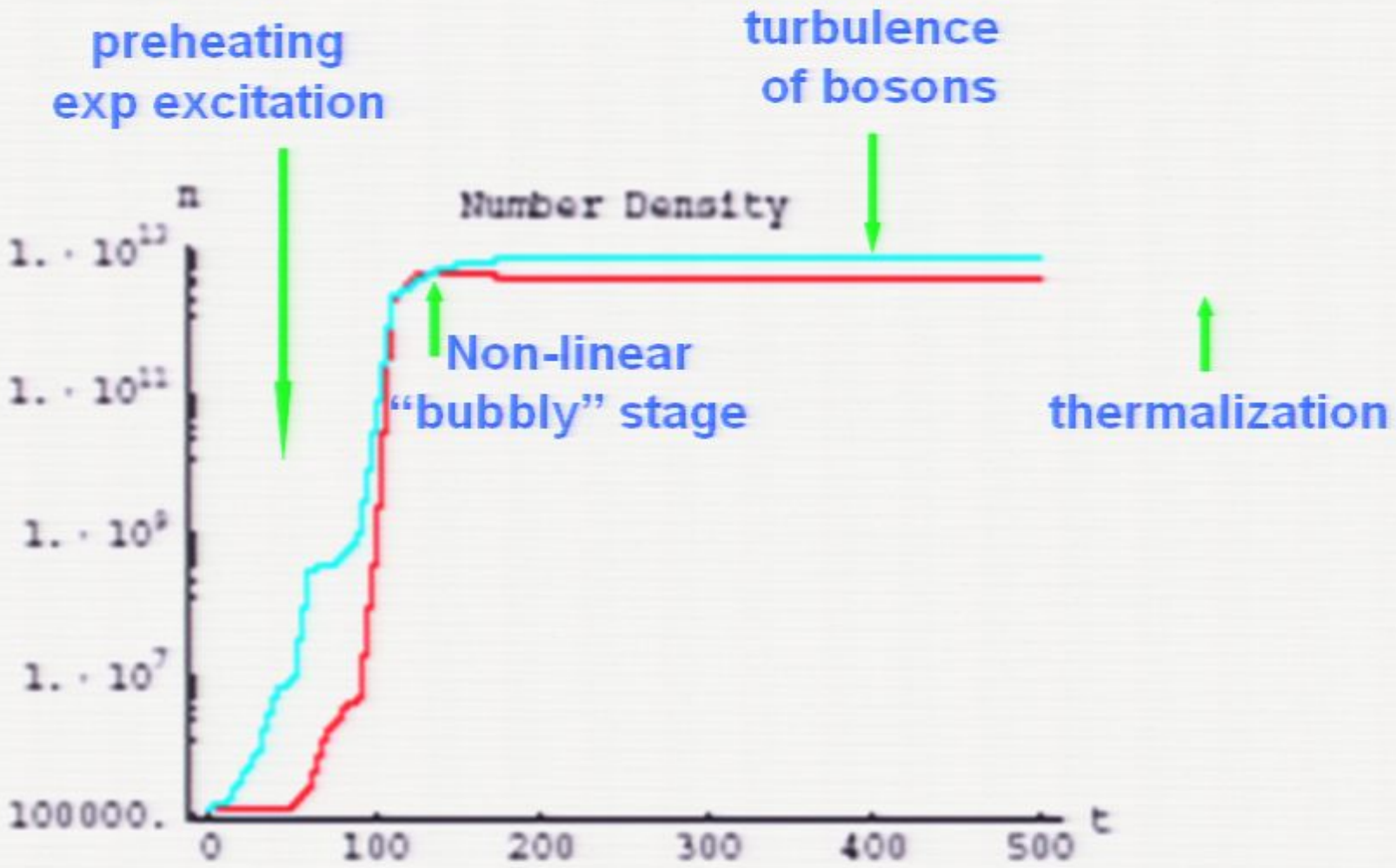
from billiard $\chi_0 \sim e^{\Lambda t}$

$$\Lambda = \mu_0$$


3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
10
$(\alpha\phi)$
$(\alpha\psi)$

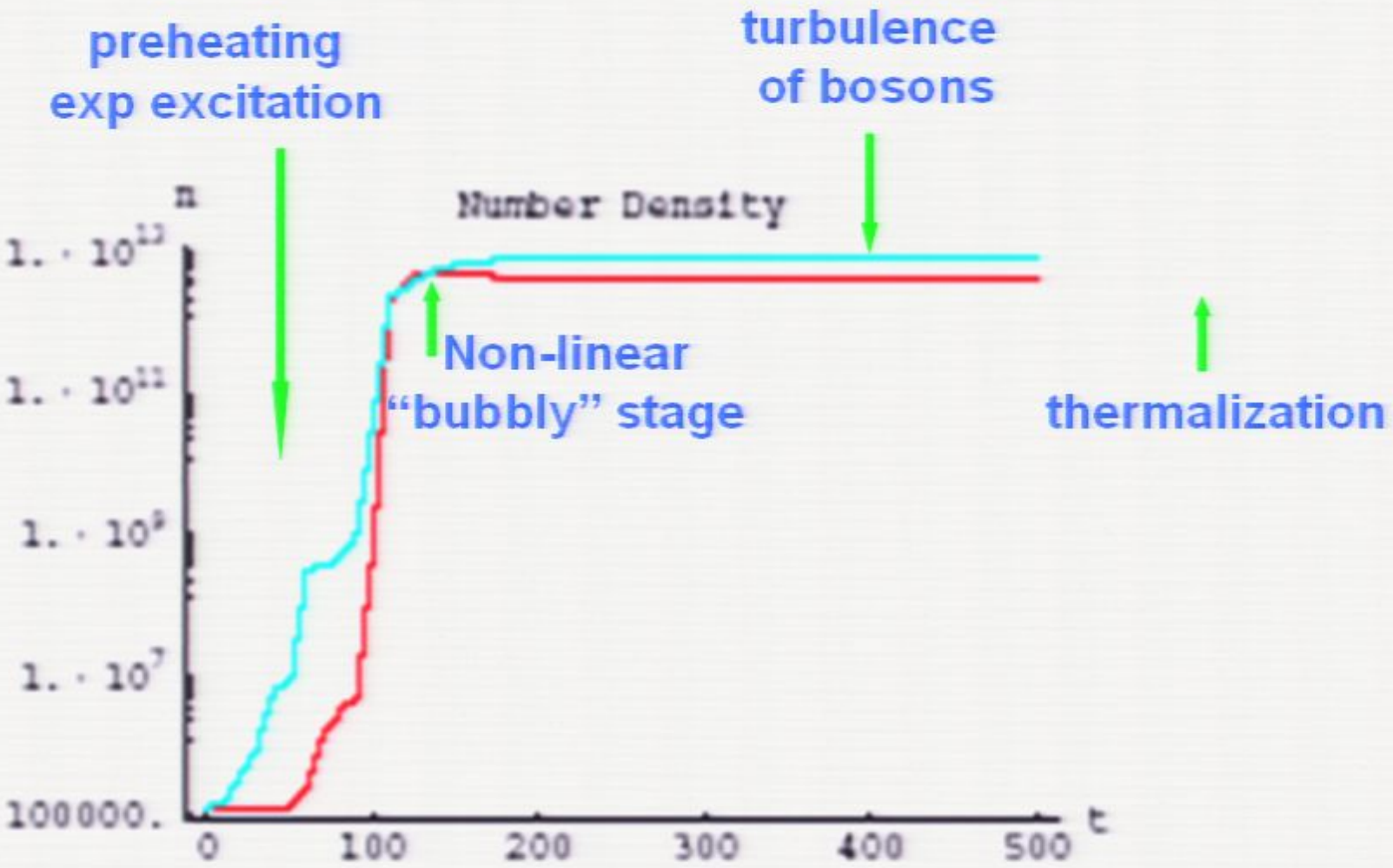
Evolution of total energy density

$g^2\phi^2\chi^2$ up to $t = 256/m$


preheating
exp excitation
turbulence
of bosons
Number Density
n
1. · 10^13
1. · 10^11
1. · 10^9
1. · 10^7
100000.
Non-linear
"bubbly" stage
thermalization
0
100
200
300
400
500
t

Evolution of total energy density

$g^2\phi^2\chi^2$ up to $t = 256/m$

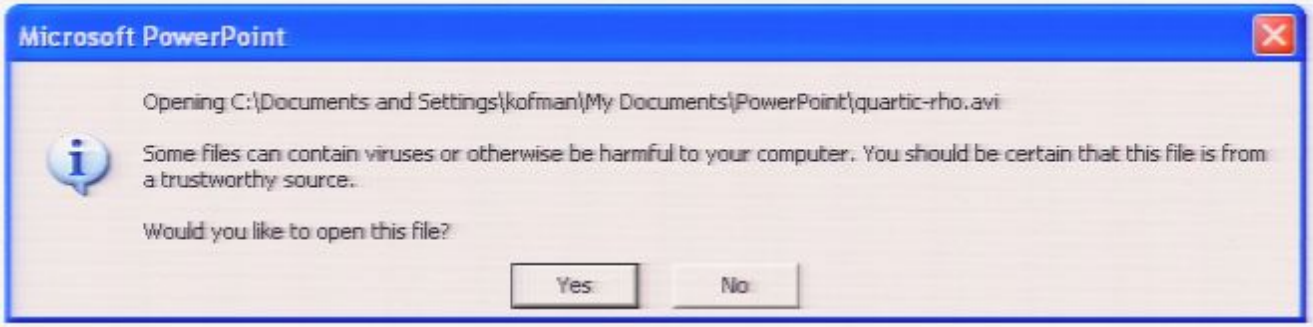

preheating
exp excitation
turbulence
of bosons
Number Density
n
1. · 10^13
1. · 10^11
1. · 10^9
1. · 10^7
100000.
Non-linear
"bubbly" stage
thermalization
0
100
200
300
400
500
t

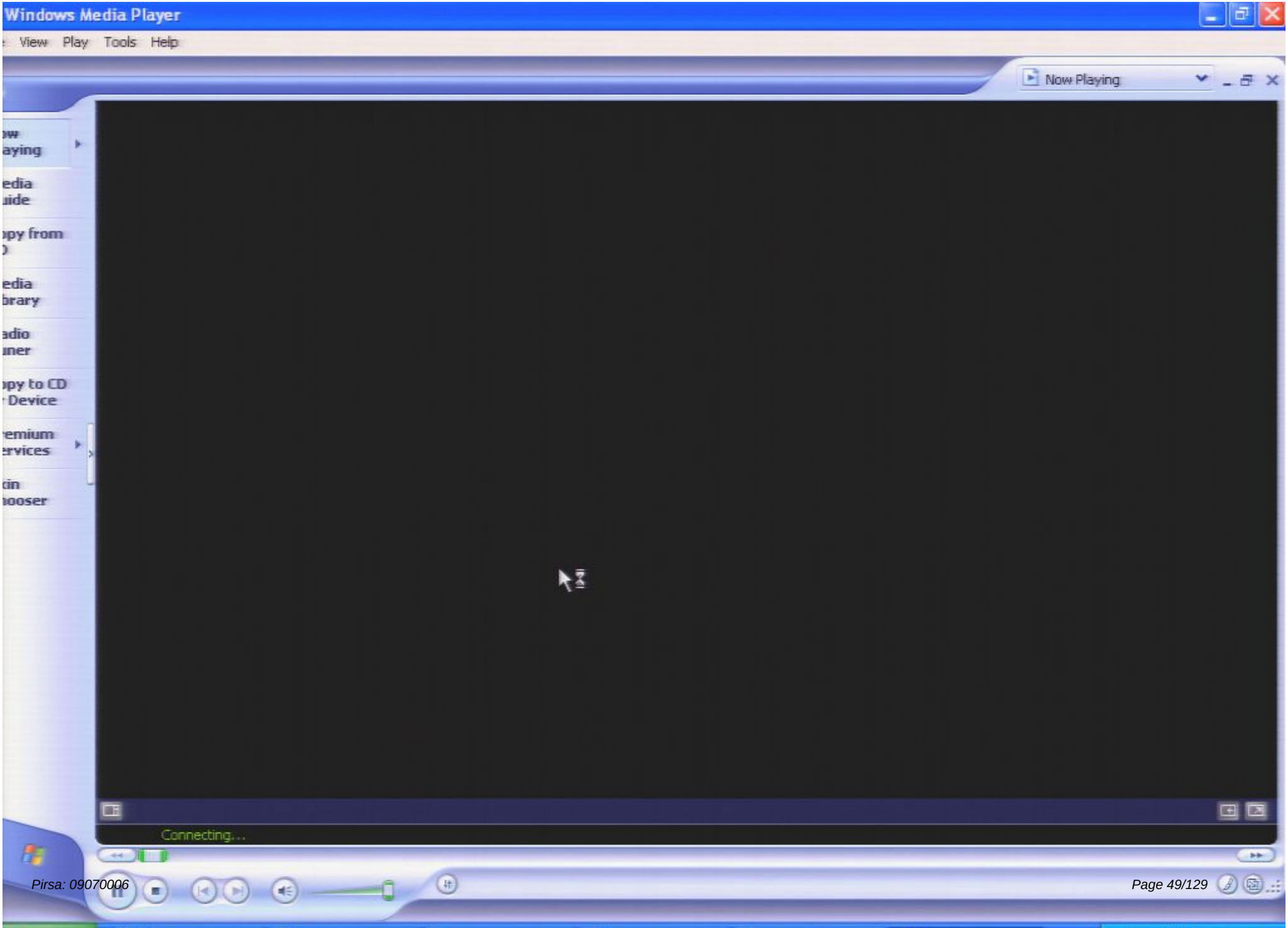
Evolution of total energy density

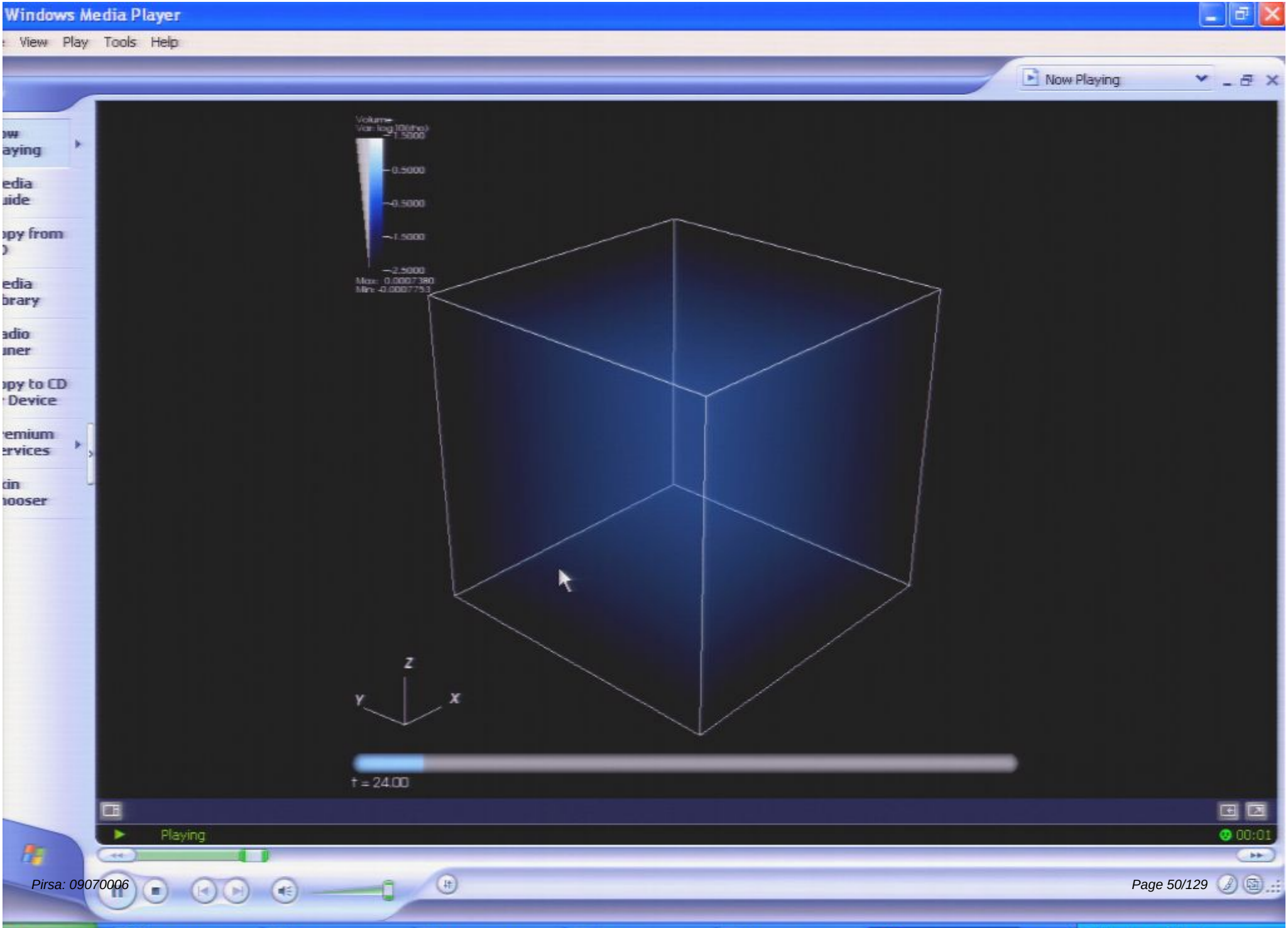
$g^2\phi^2\chi^2$ up to $t = 256/m$

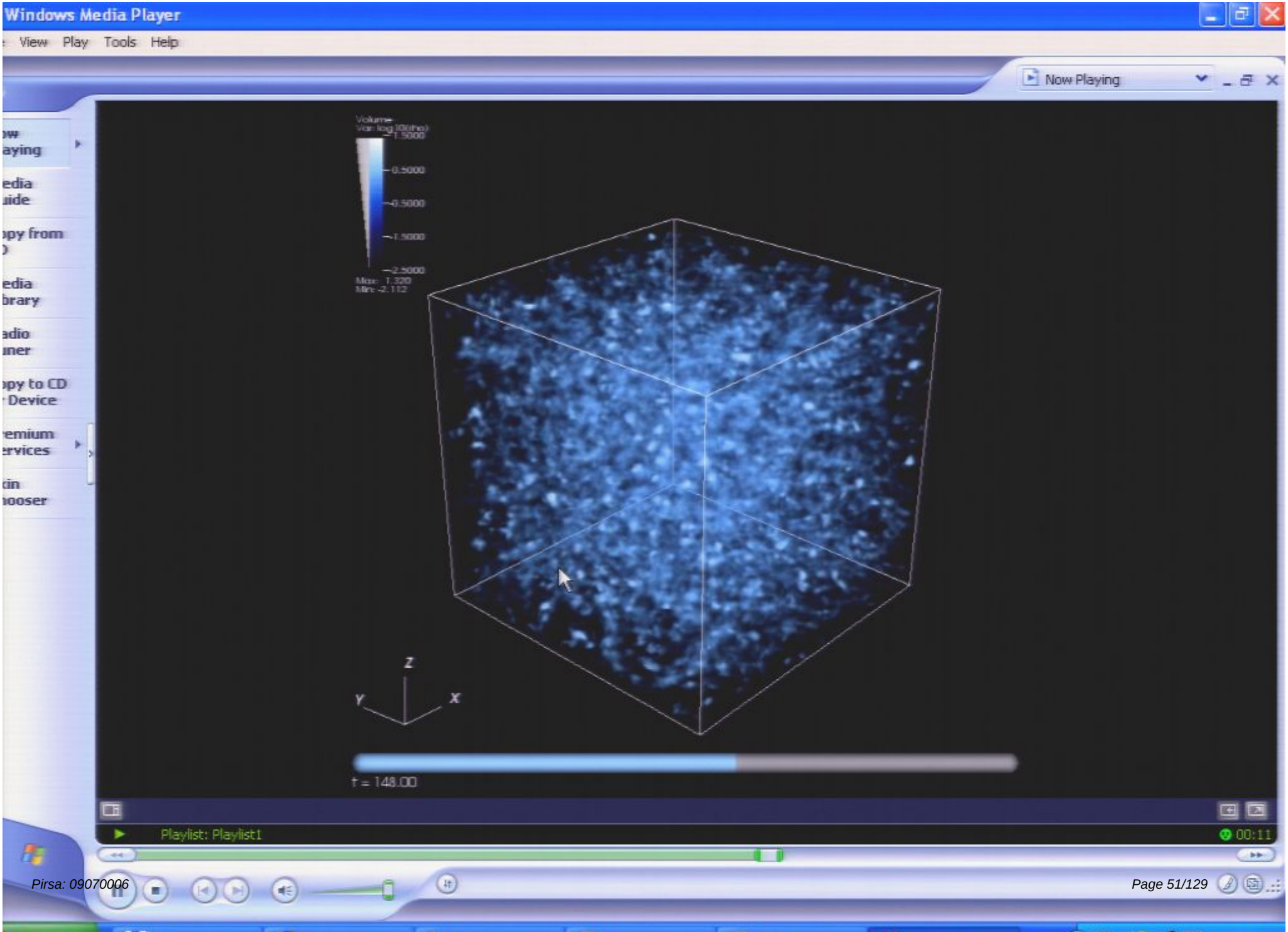
Evolution of total energy density

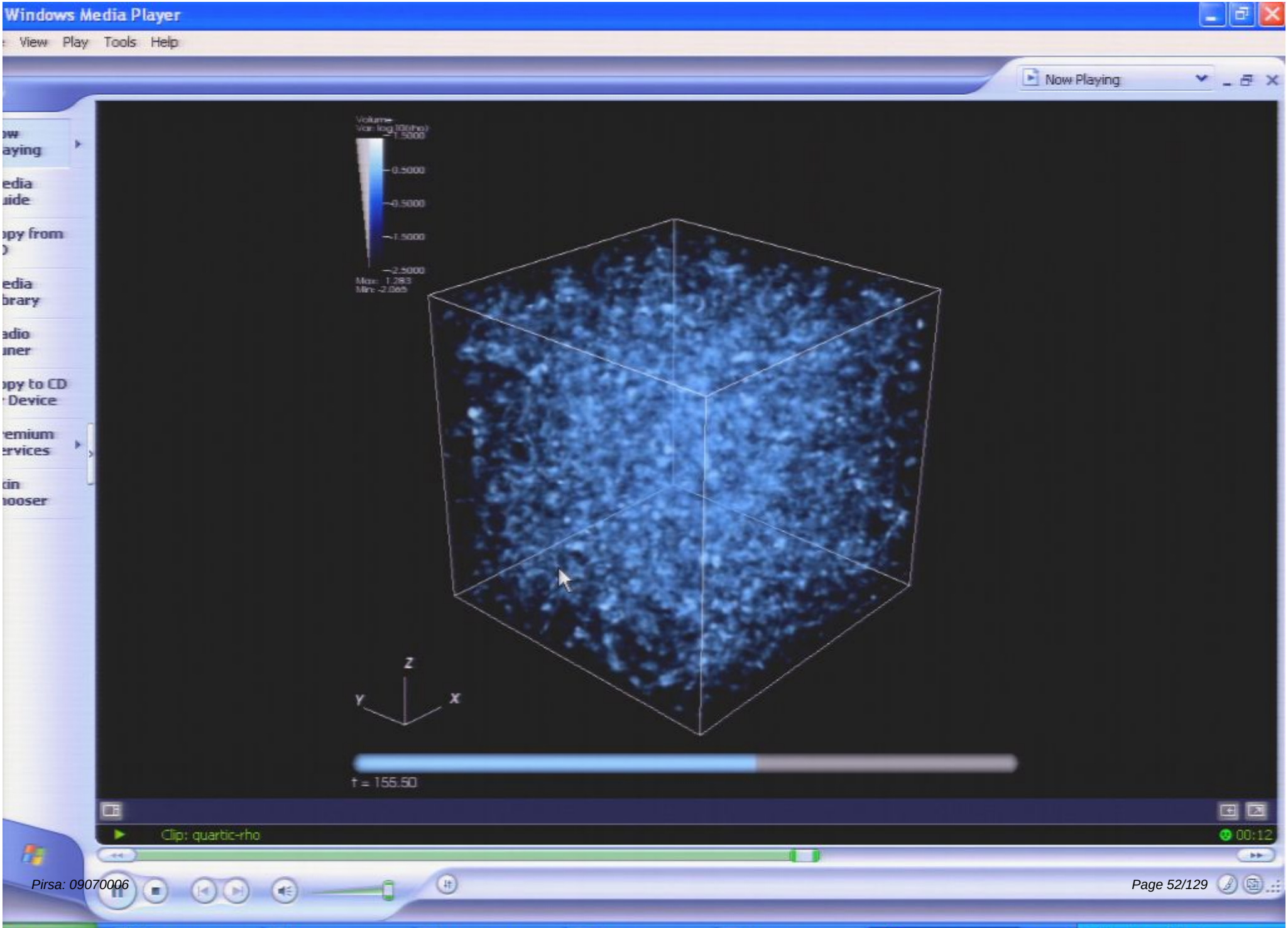
$$g^2\phi^2\chi^2 \text{ up to } t = 256/m$$

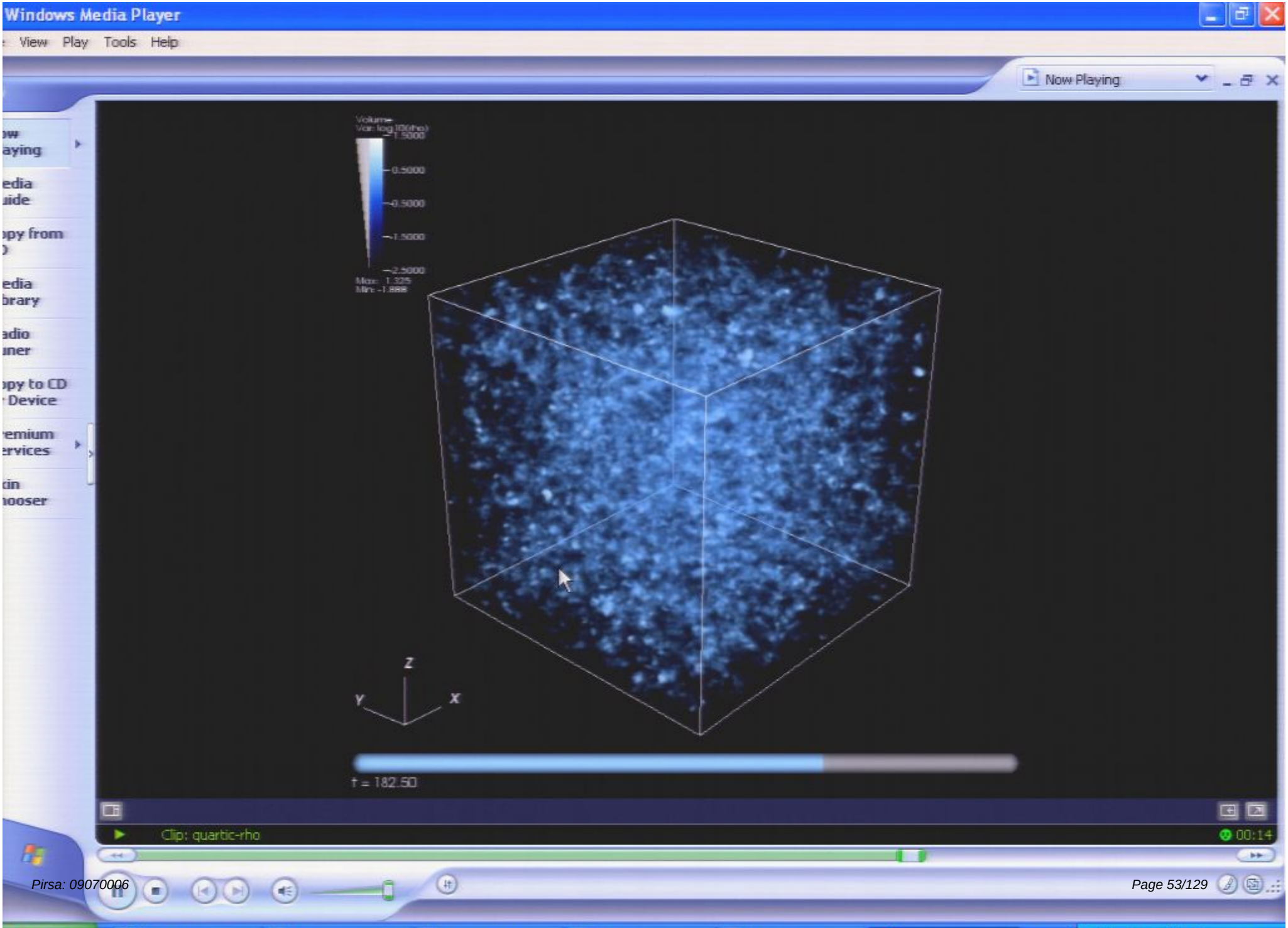


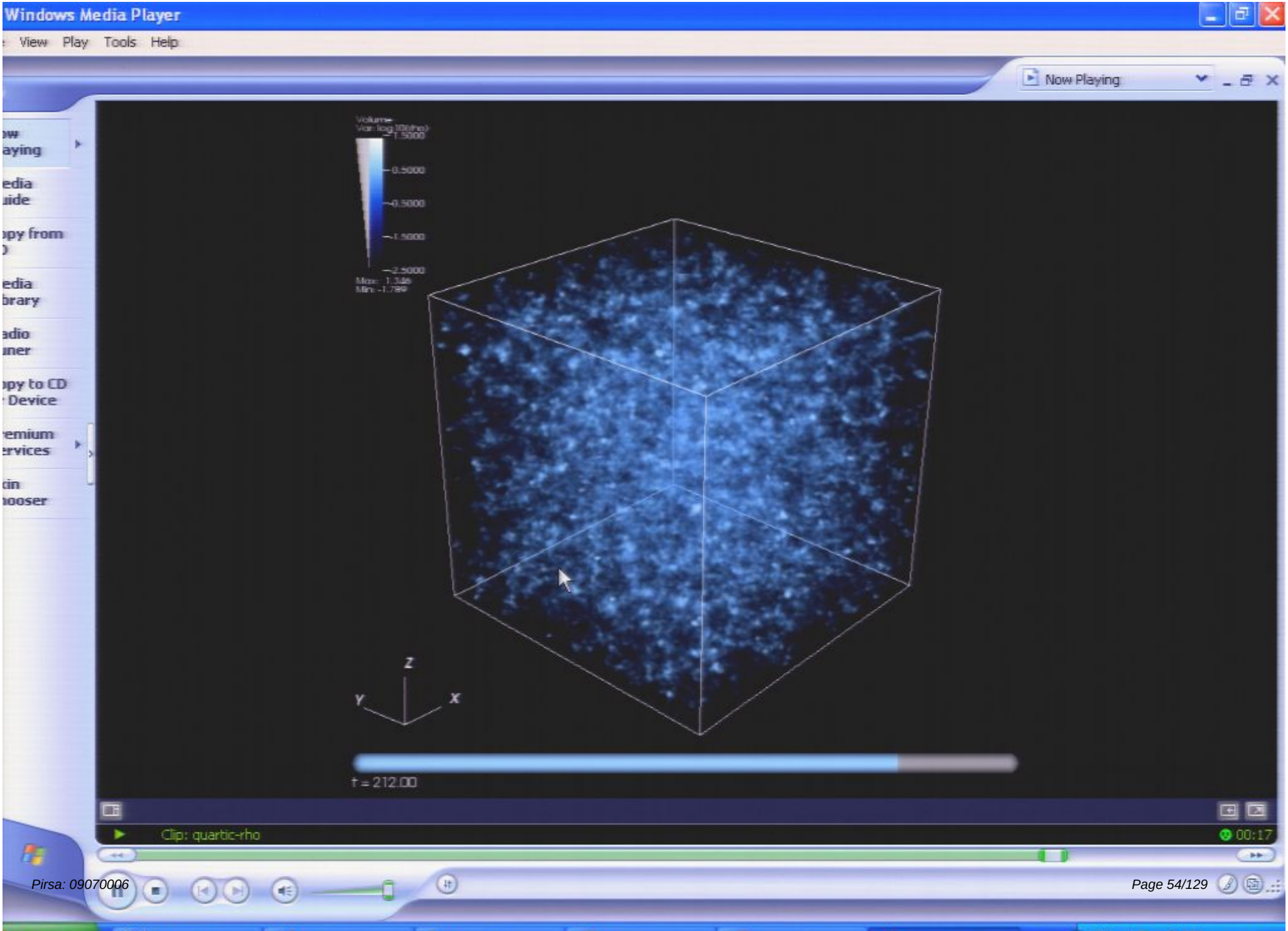

Windows Media Player
View
Play
Tools
Help
Now Playing
Connecting...

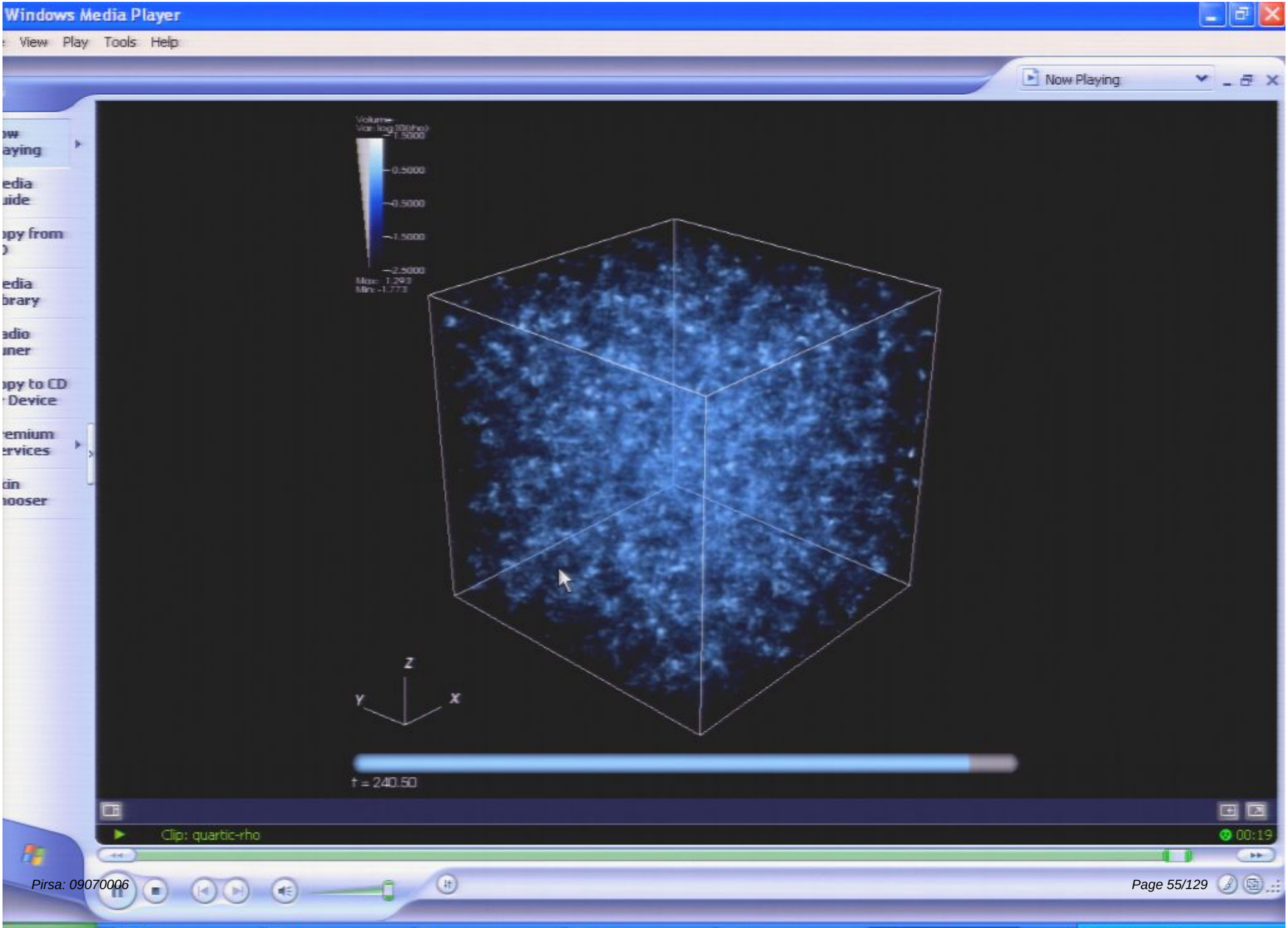

Windows Media Player
View Play Tools Help
Now Playing
Volume
1.5000
0.5000
-0.5000
-1.5000
-2.5000
Max: 0.0007380
Min: -0.0007753
Z
Y
X
t = 24.00
Playing
00:01

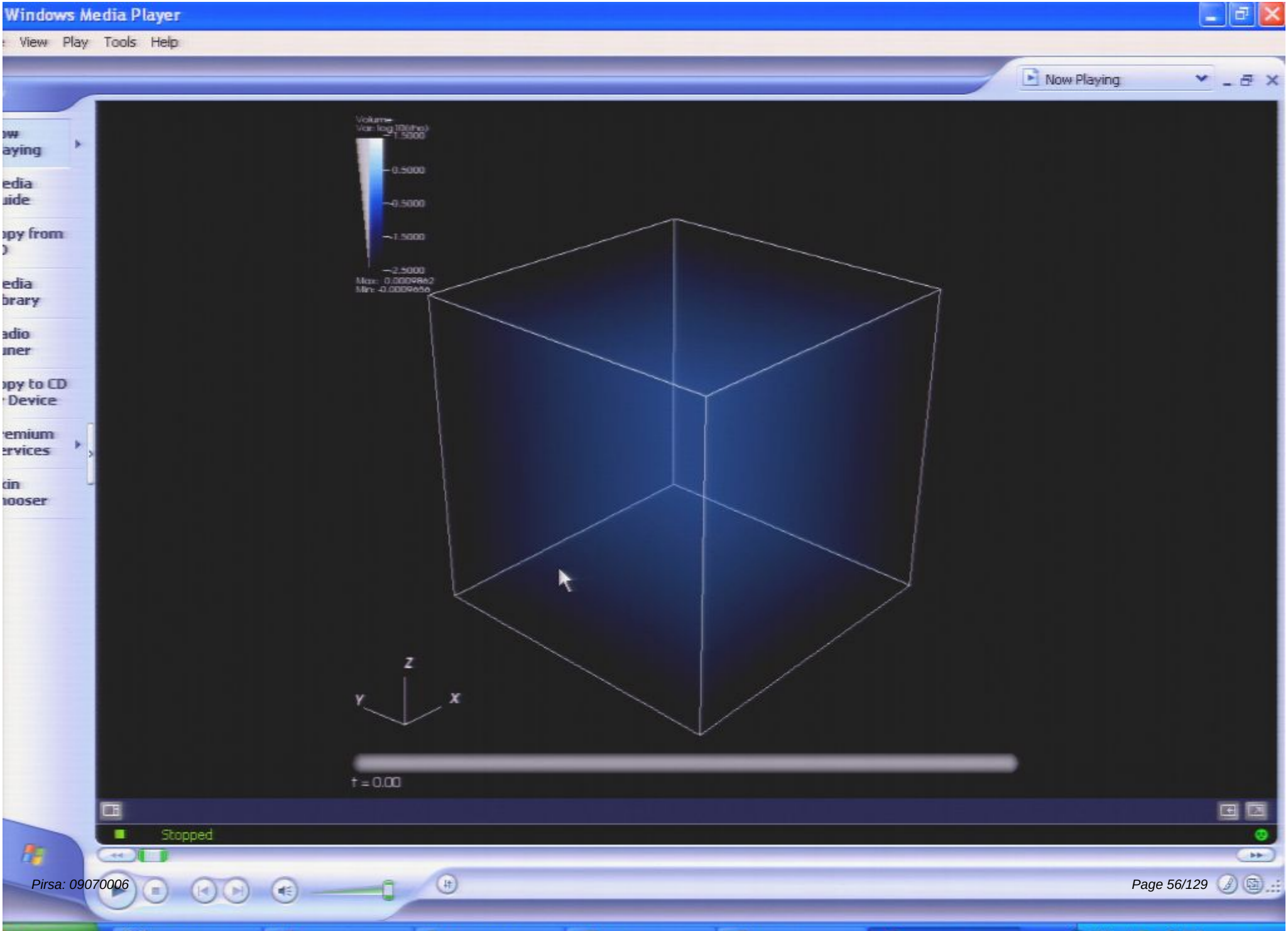

Windows Media Player
View Play Tools Help
Now Playing
Volume:
Var: log10(rho)
1.5000
0.5000
-0.5000
-1.5000
-2.5000
Max: 1.320
Min: -2.112
Z
Y
X
t = 148.00
Playlist: Playlist1
00:11

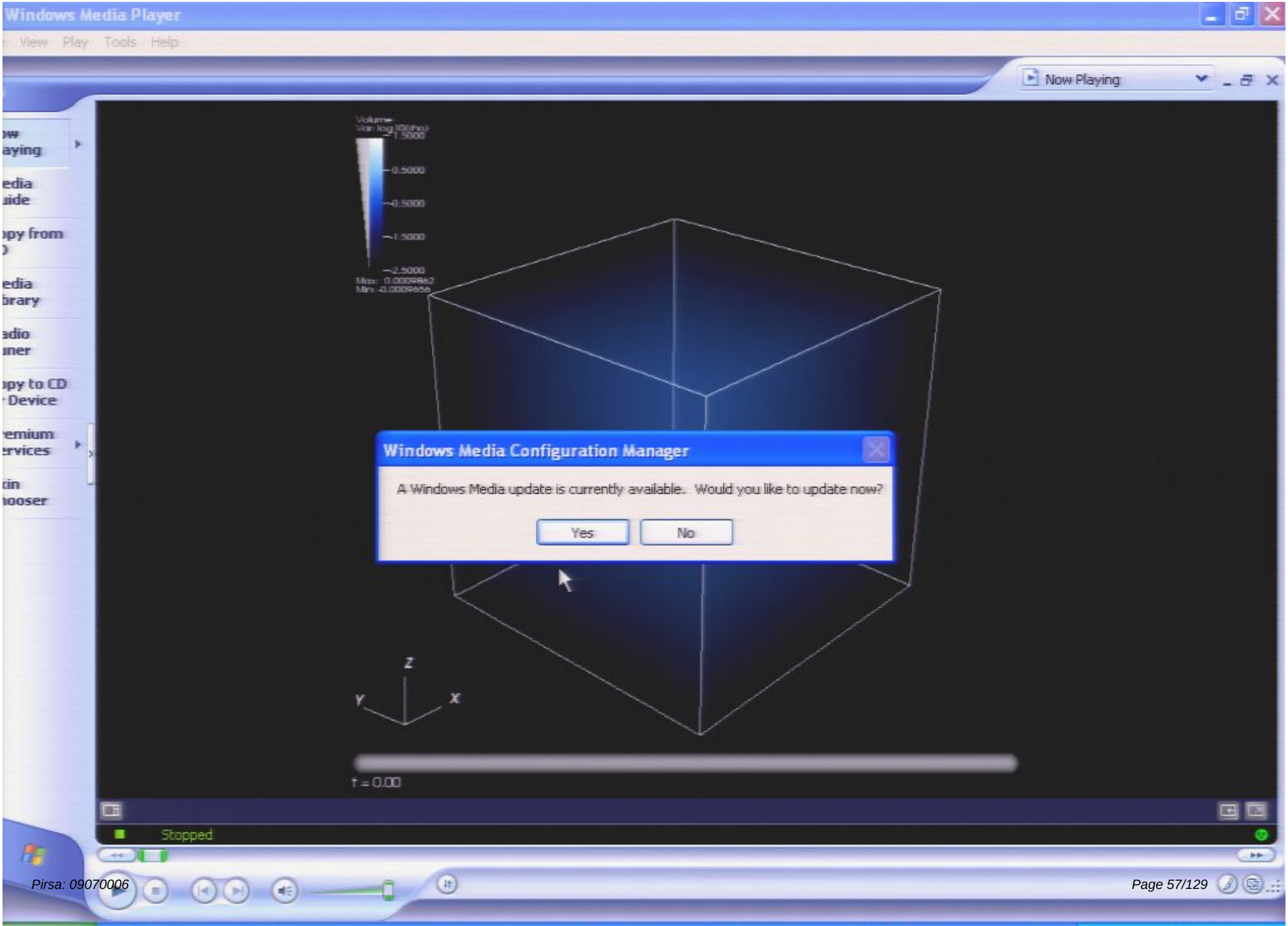

Windows Media Player
View Play Tools Help
Now Playing
1.5000
0.5000
-0.5000
-1.5000
-2.5000
Max: 1.283
Min: -2.065
Z
Y
X
t = 155.50
Clip: quartic-rho
00:12

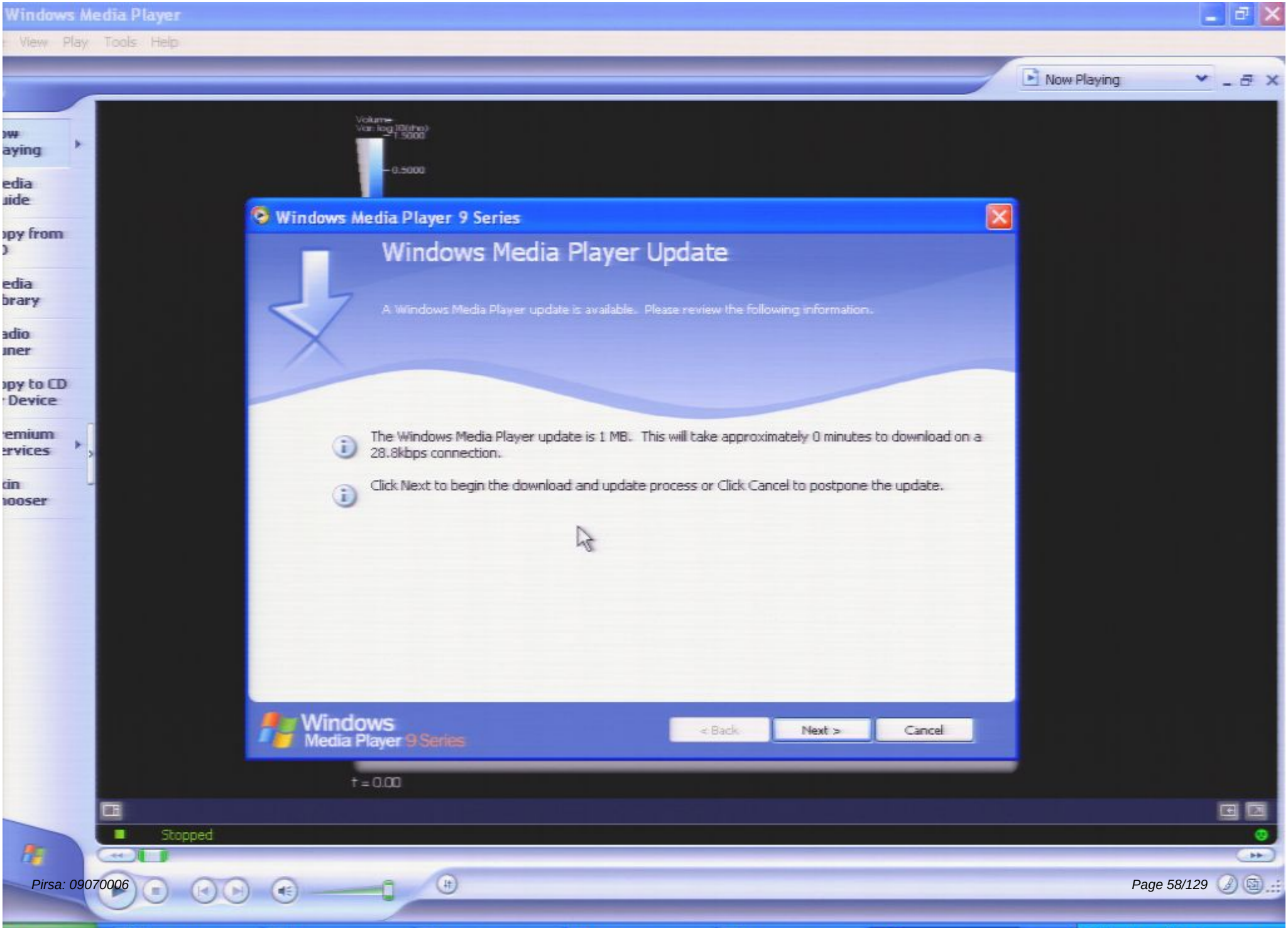

Windows Media Player
View
Play
Tools
Help
Now Playing
Volume
Var: log10(rho)
1.5000
0.5000
-0.5000
-1.5000
-2.5000
Max: 1.325
Min: -1.888
Z
Y
X
t = 182.50
Clip: quartic-rho
00:14

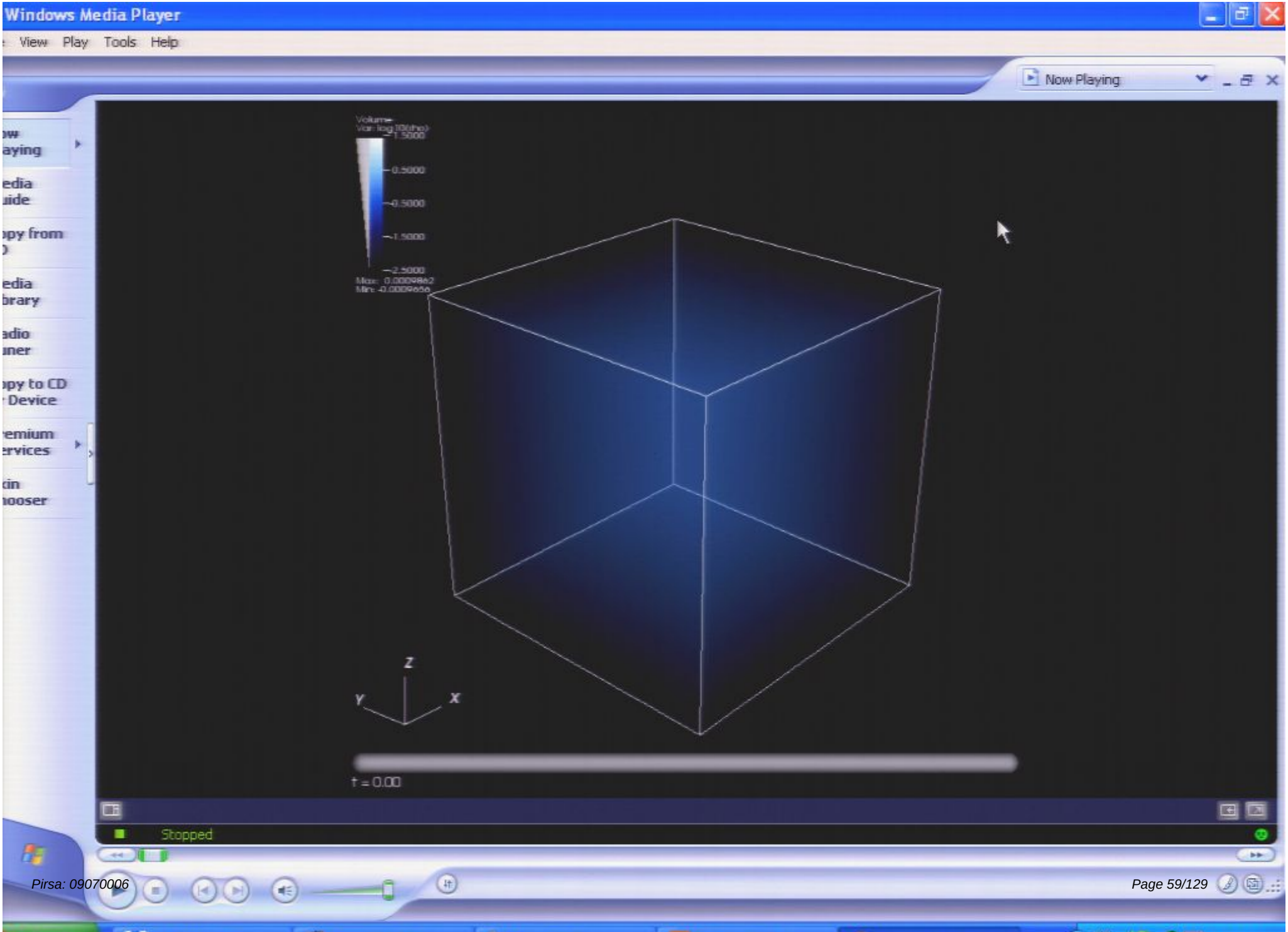

Windows Media Player
View
Play
Tools
Help
Now Playing
Volume:
Var: log10(rho)
1.5000
0.5000
-0.5000
-1.5000
-2.5000
Max: 1.346
Min: -1.789
Z
Y
X
t = 212.00
Clip: quartic-rho
00:17


Windows Media Player
View Play Tools Help
Now Playing
1.5000
0.5000
-0.5000
-1.5000
-2.5000
Z
Y
X
t = 240.50
Clip: quartic-rho
00:19


Windows Media Player
View
Play
Tools
Help
Now Playing
Volume
1.5000
0.5000
-0.5000
-1.5000
-2.5000
Max: 0.0009862
Min: -0.0009656
Z
Y
X
t = 0.00
Stopped

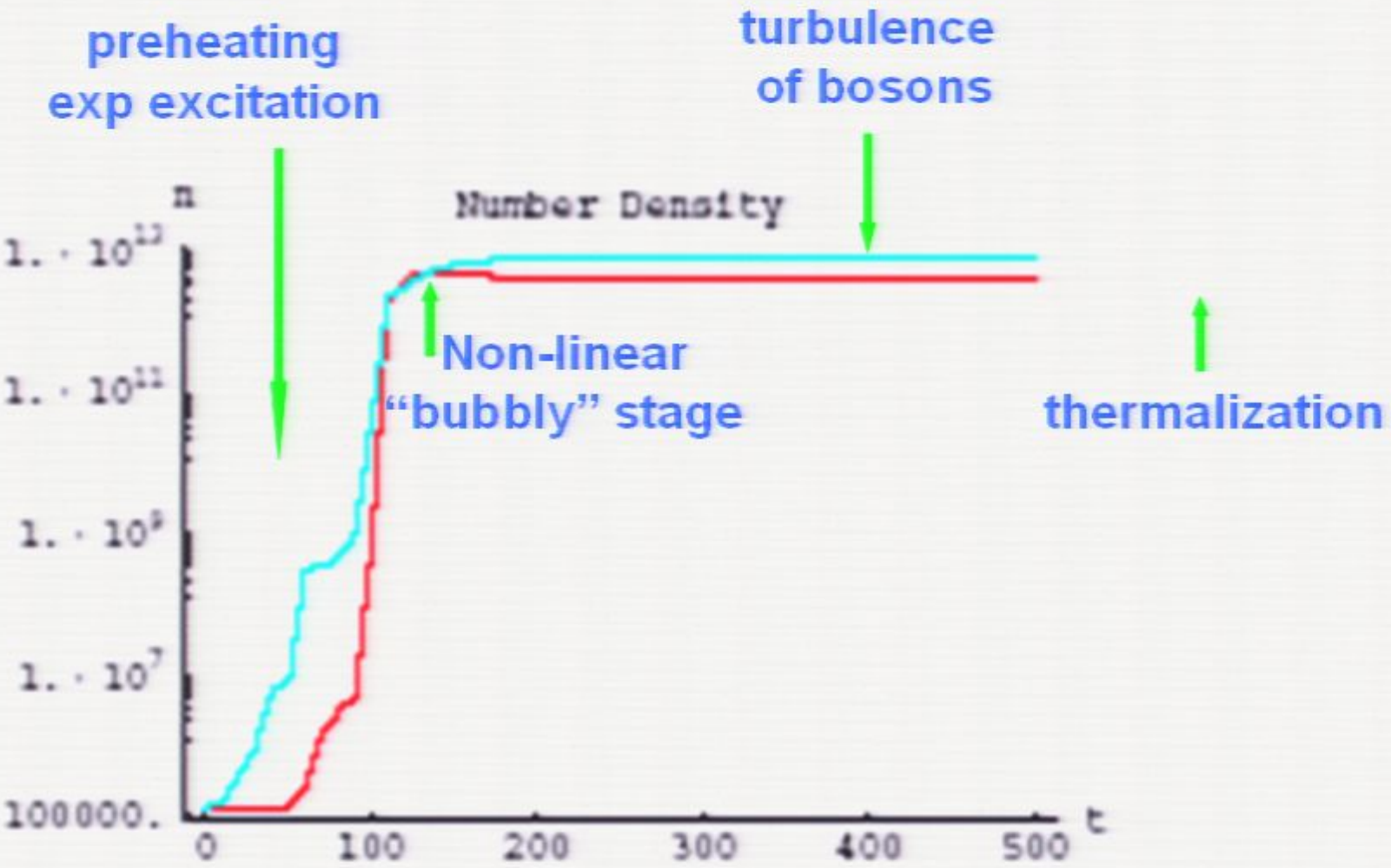

Windows Media Player
View Play Tools Help
Now Playing
Windows Media Configuration Manager
A Windows Media update is currently available. Would you like to update now?
Yes
No
Z
Y
X
t = 0.00
Stopped


Windows Media Player
View Play Tools Help
Now Playing
Windows Media Player 9 Series
Windows Media Player Update
A Windows Media Player update is available. Please review the following information.
The Windows Media Player update is 1 MB. This will take approximately 0 minutes to download on a 28.8kbps connection.
Click Next to begin the download and update process or Click Cancel to postpone the update.
Windows Media Player 9 Series
< Back
Next >
Cancel
Stopped


Windows Media Player
View
Play
Tools
Help
Now Playing
Volume
1.5000
0.5000
-0.5000
-1.5000
-2.5000
Z
Y
X
t = 0.00
Stopped

Evolution of total energy density

$g^2\phi^2\chi^2$ up to $t = 256/m$

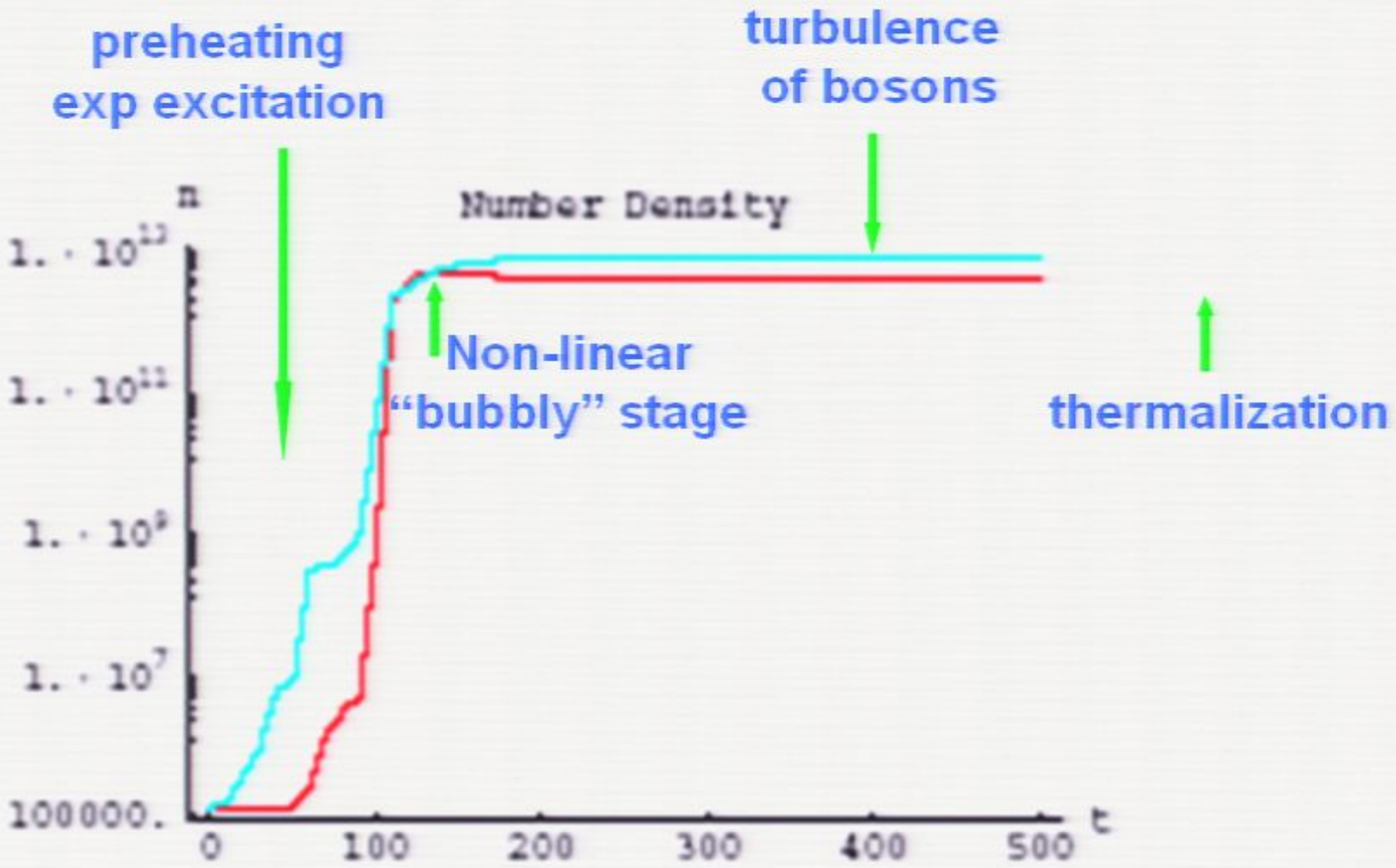

preheating
exp excitation
turbulence
of bosons
Number Density
n
1. · 10^12
1. · 10^11
1. · 10^9
1. · 10^7
100000.
Non-linear
"bubbly" stage
thermalization
0
100
200
300
400
500
t

$$V(\phi,\chi) = \tfrac{1}{4}\lambda\phi^4 + \tfrac{1}{2}g^2\phi^2\chi^2$$

$$\ddot{\phi} - \nabla^2\phi + g^2\chi^2\phi = 0$$

$$\ddot{\chi} - \nabla^2\chi + g^2\phi^2\chi = 0$$

$$3H^2 = \frac{8\pi}{M_p^2}\left(\tfrac{1}{2}\dot{\phi}^2 + \tfrac{1}{2}\dot{\chi}^2 + + \tfrac{1}{2a^2}\nabla\phi^2 + \tfrac{1}{2a^2}\nabla\chi^2 + V(\phi,\chi)\right)$$

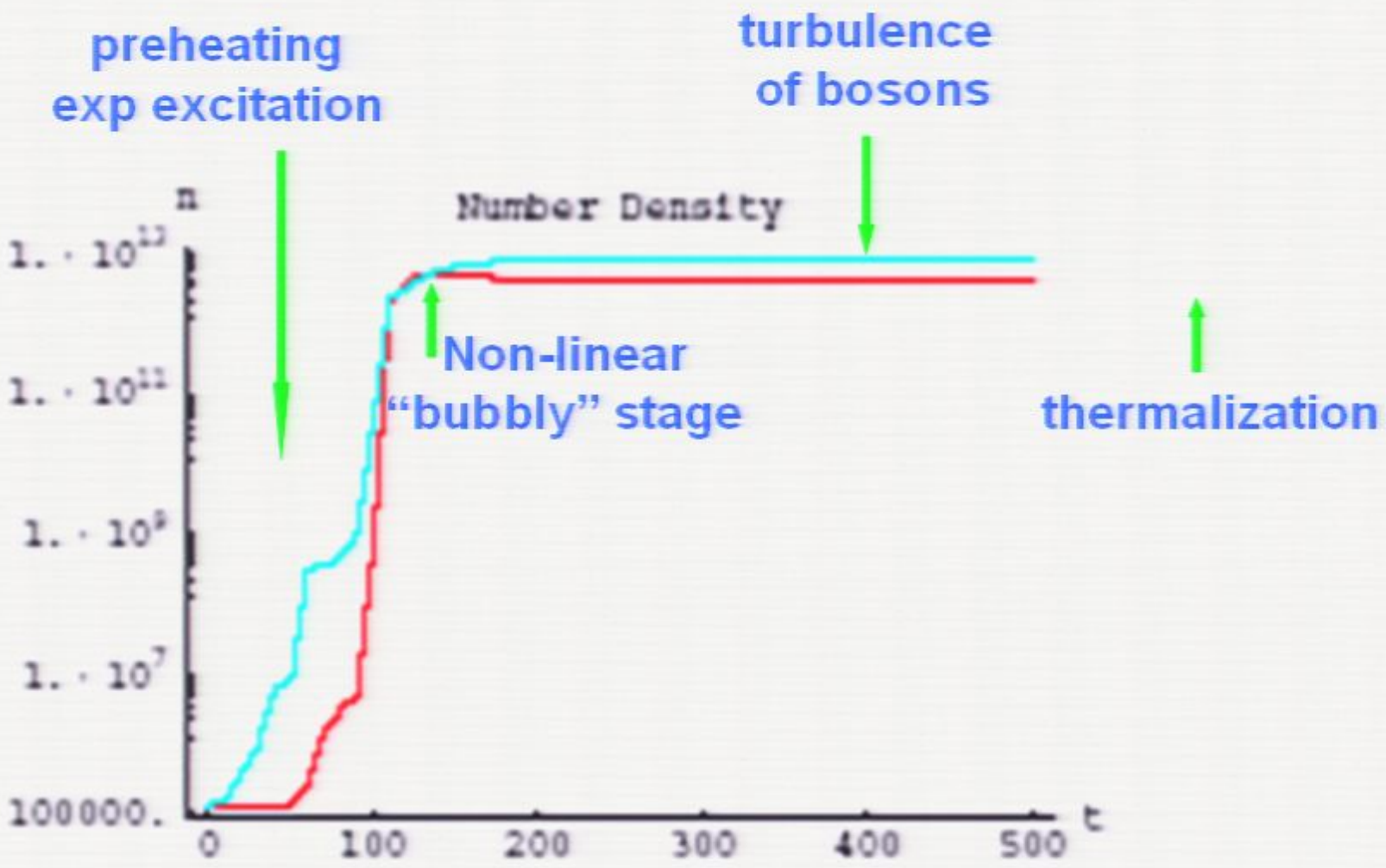

preheating
exp excitation
turbulence
of bosons
Number Density
n
1. · 10^13
1. · 10^11
1. · 10^9
1. · 10^7
100000.
Non-linear
"bubbly" stage
thermalization
0
100
200
300
400
500
t

$$V(\phi,\chi) = \tfrac{1}{4}\lambda\phi^4 + \tfrac{1}{2}g^2\phi^2\chi^2$$

$$\ddot{\phi} - \nabla^2\phi + g^2\chi^2\phi = 0$$

$$\ddot{\chi} - \nabla^2\chi + g^2\phi^2\chi = 0$$

$$3H^2 = \frac{8\pi}{M_p^2}\left(\tfrac{1}{2}\dot{\phi}^2 + \tfrac{1}{2}\dot{\chi}^2 + + \tfrac{1}{2a^2}\nabla\phi^2 + \tfrac{1}{2a^2}\nabla\chi^2 + V(\phi,\chi)\right)$$

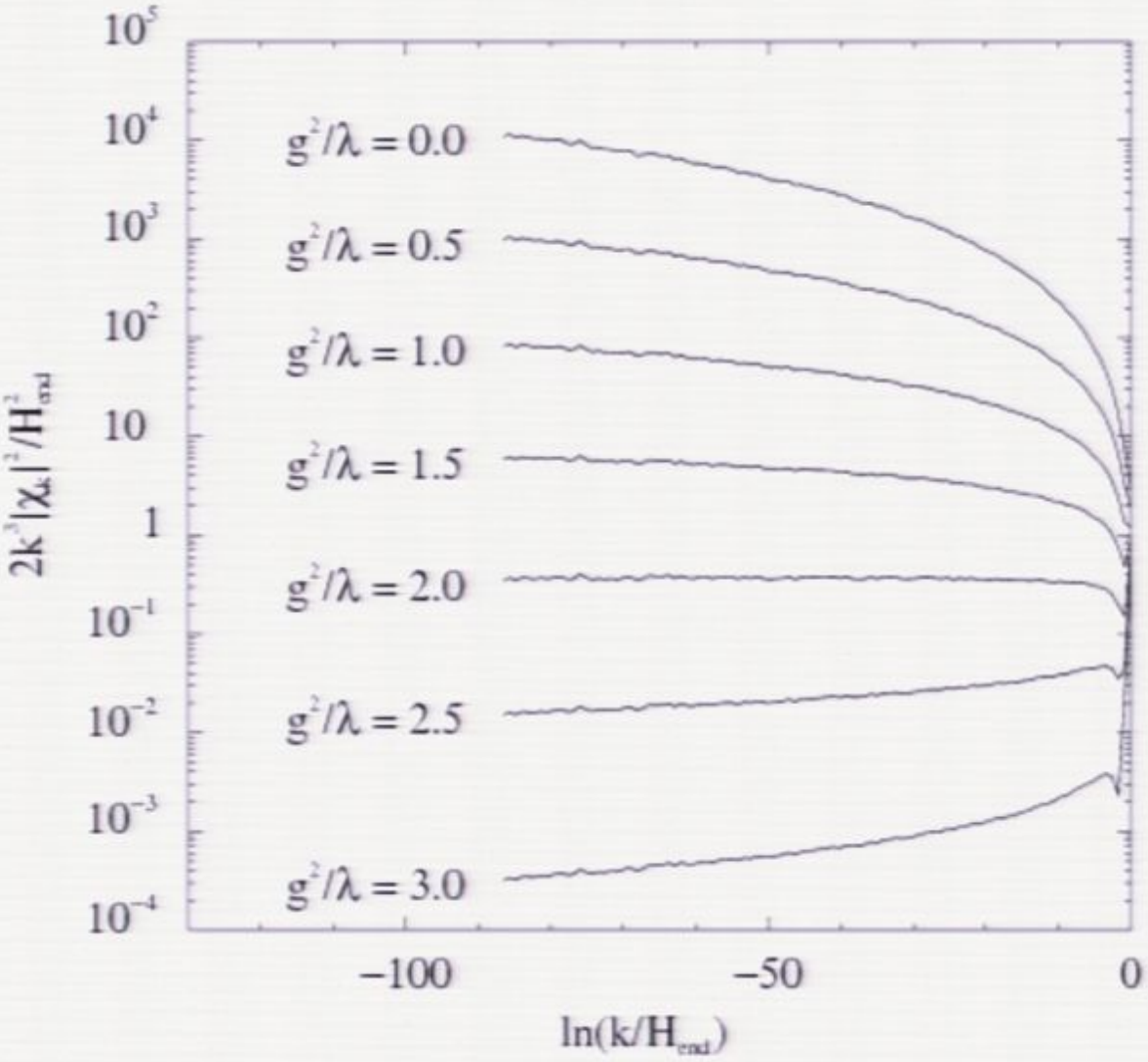

preheating
exp excitation
turbulence
of bosons
Number Density
n
1. · 10^13
1. · 10^11
1. · 10^9
1. · 10^7
100000.
0
100
200
300
400
500
t
Non-linear
"bubbly" stage
thermalization

$$V(\phi,\chi) = \tfrac{1}{4}\lambda\phi^4 + \tfrac{1}{2}g^2\phi^2\chi^2$$

$$\ddot{\phi} - \nabla^2\phi + g^2\chi^2\phi = 0$$

$$\ddot{\chi} - \nabla^2\chi + g^2\phi^2\chi = 0$$

$$3H^2 = \frac{8\pi}{M_p^2}\left(\tfrac{1}{2}\dot{\phi}^2 + \tfrac{1}{2}\dot{\chi}^2 + + \tfrac{1}{2a^2}\nabla\phi^2 + \tfrac{1}{2a^2}\nabla\chi^2 + V(\phi,\chi)\right)$$


10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$2k^3|\chi_k|^2/H_{end}^2$
$g^2/\lambda = 0.0$
$g^2/\lambda = 0.5$
$g^2/\lambda = 1.0$
$g^2/\lambda = 1.5$
$g^2/\lambda = 2.0$
$g^2/\lambda = 2.5$
$g^2/\lambda = 3.0$
−100
−50
0
$\ln(k/H_{end})$

$$V(\phi,\chi) = \tfrac{1}{4}\lambda\phi^4 + \tfrac{1}{2}g^2\phi^2\chi^2$$

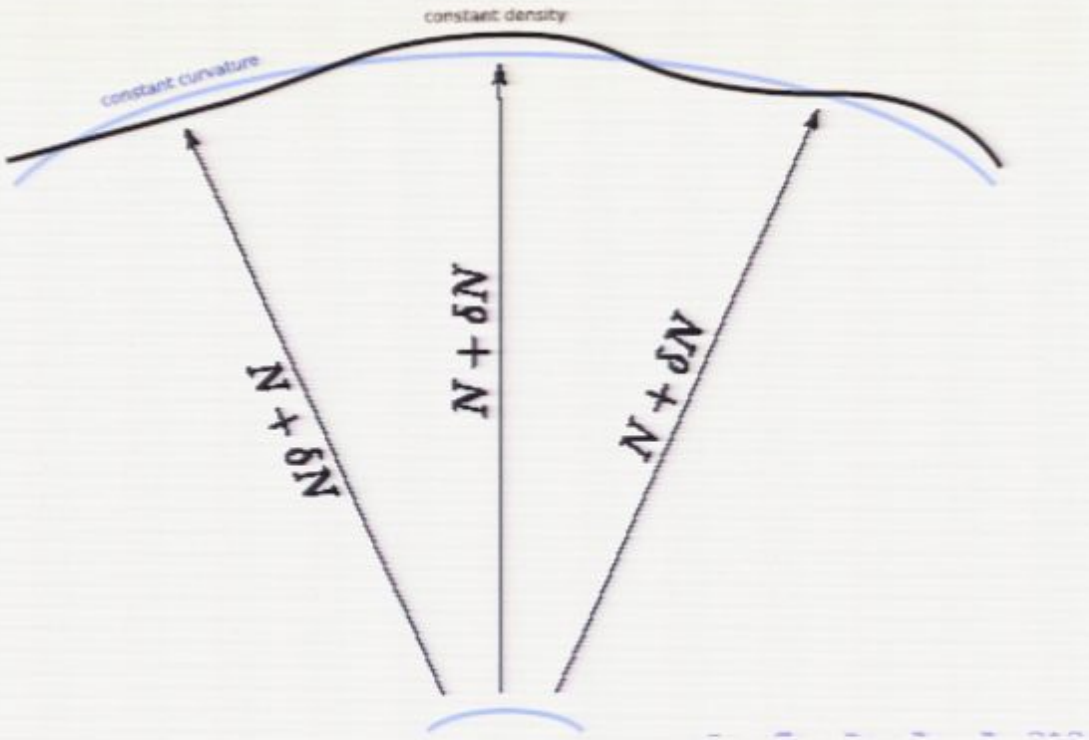
$$\ddot{\phi} - \nabla^2\phi + g^2\chi^2\phi = 0$$

$$\ddot{\chi} - \nabla^2\chi + g^2\phi^2\chi = 0$$

$$3H^2 = \frac{8\pi}{M_p^2}\left(\tfrac{1}{2}\dot{\phi}^2 + \tfrac{1}{2}\dot{\chi}^2 + + \tfrac{1}{2a^2}\nabla\phi^2 + \tfrac{1}{2a^2}\nabla\chi^2 + V(\phi,\chi)\right)$$

"separated universes" approximation

$$\zeta = \delta \ln a|_H = \delta N(\chi_i)$$



$$V(\phi,\chi) = \tfrac{1}{4}\lambda\phi^4 + \tfrac{1}{2}g^2\phi^2\chi^2$$

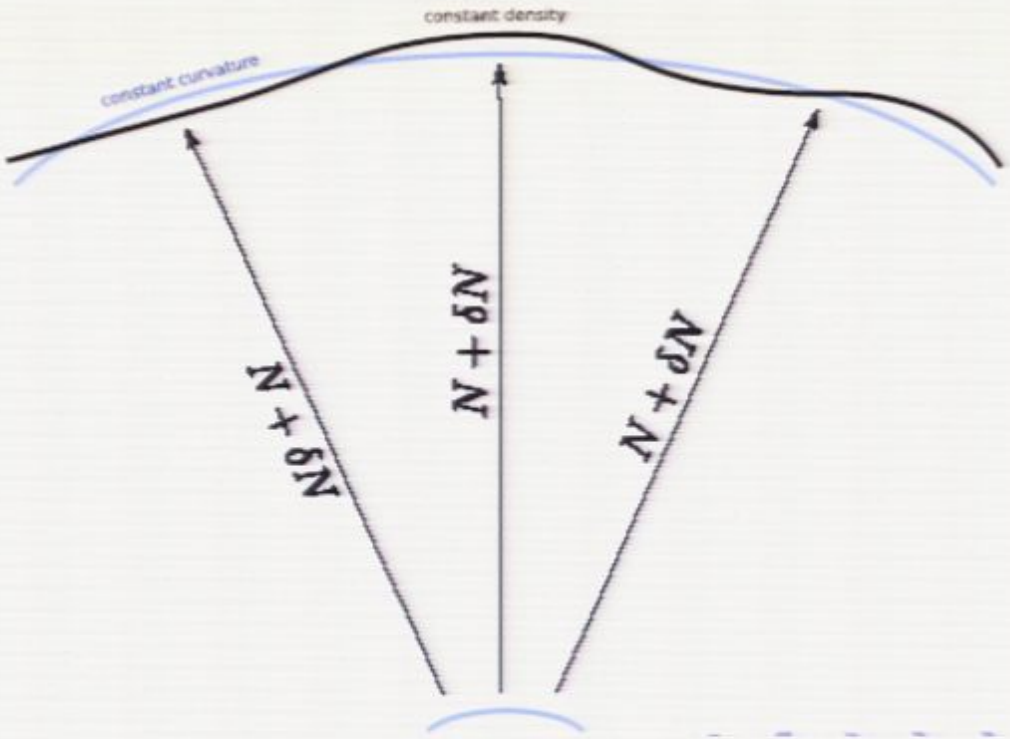
$$\ddot{\phi} - \nabla^2\phi + g^2\chi^2\phi = 0$$

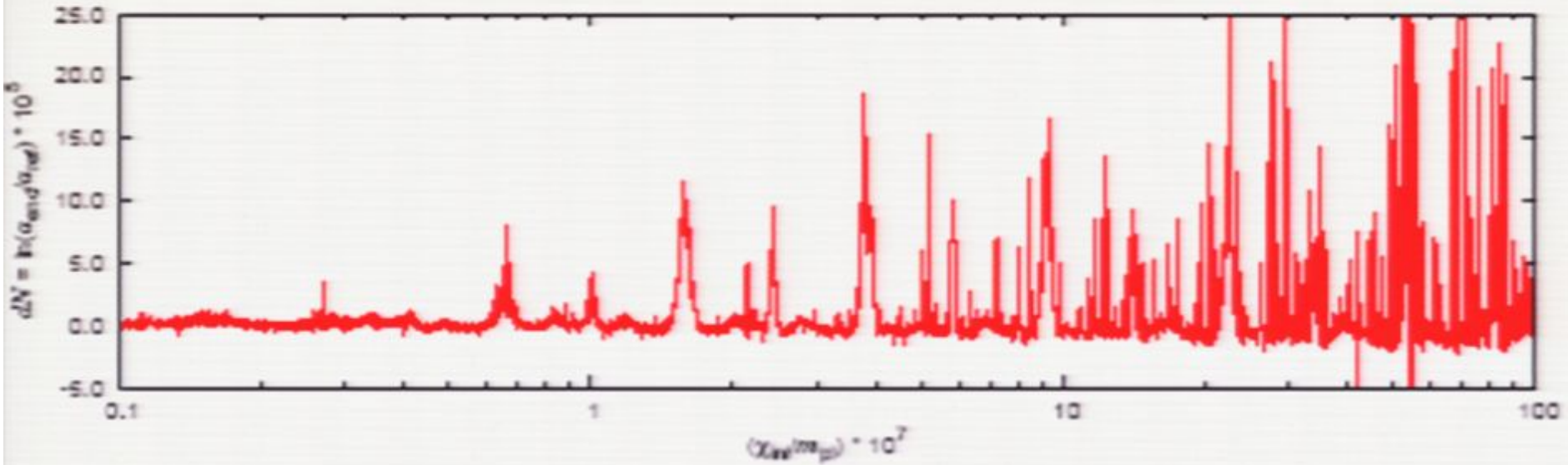
$$\ddot{\chi} - \nabla^2\chi + g^2\phi^2\chi = 0$$

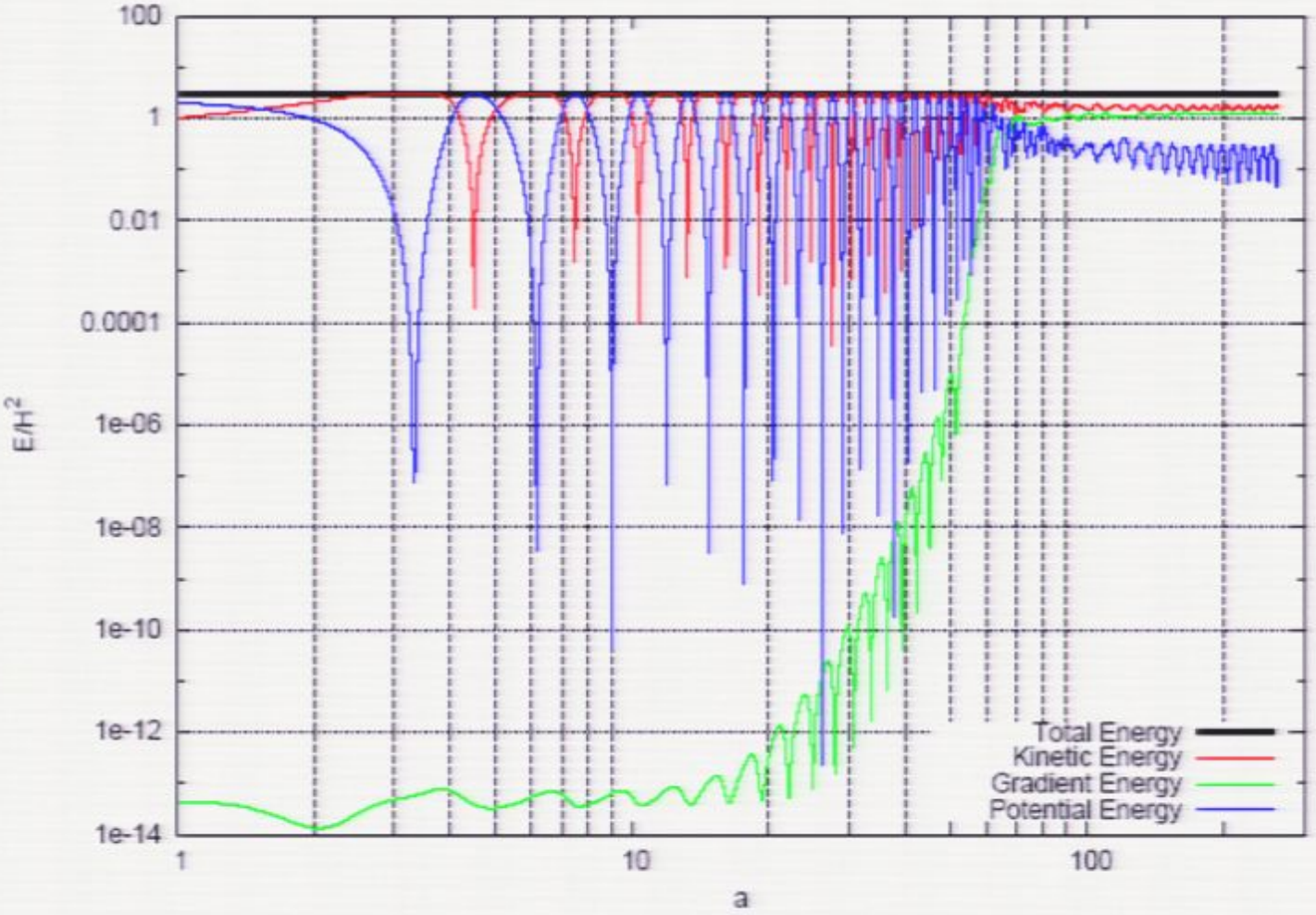
$$3H^2 = \frac{8\pi}{M_p^2}\left(\tfrac{1}{2}\dot{\phi}^2 + \tfrac{1}{2}\dot{\chi}^2 + + \tfrac{1}{2a^2}\nabla\phi^2 + \tfrac{1}{2a^2}\nabla\chi^2 + V(\phi,\chi)\right)$$

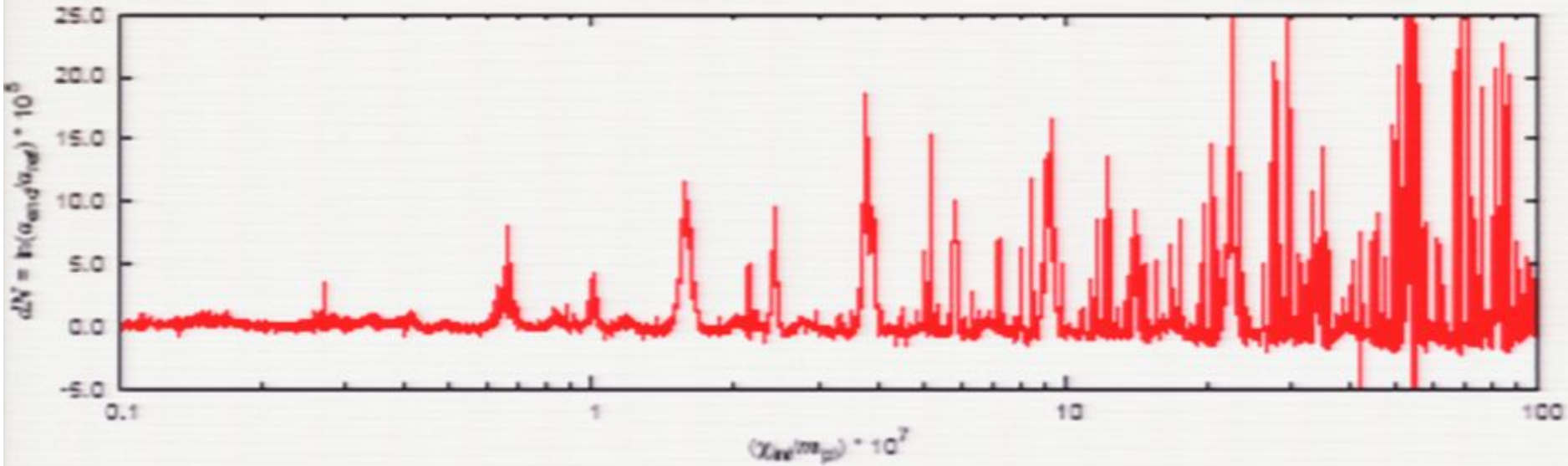
"separated universes" approximation

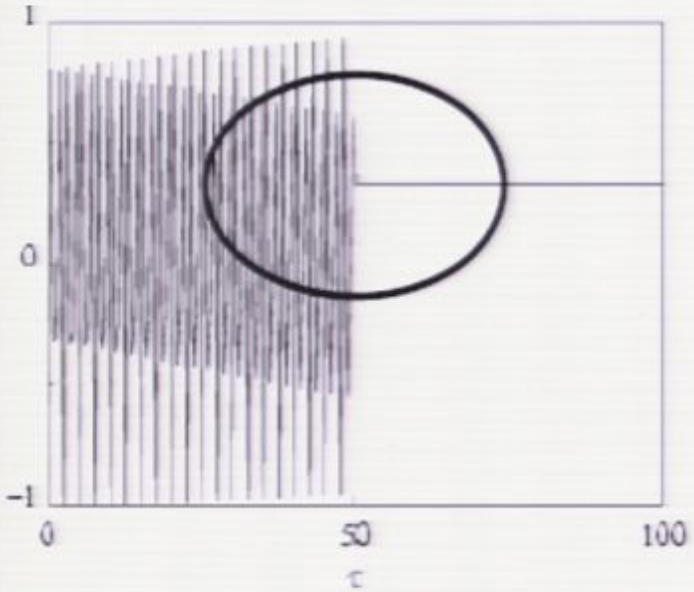
$$\zeta = \delta \ln a|_H = \delta N(\dot{\chi}_i)$$




25.0
20.0
15.0
10.0
5.0
0.0
-5.0
0.1
1
10
100


100
1
0.01
0.0001
1e-06
1e-08
1e-10
1e-12
1e-14
E/H²
1
10
100
a
Total Energy
Kinetic Energy
Gradient Energy
Potential Energy


25.0
20.0
15.0
10.0
5.0
0.0
-5.0
0.1
1
10
100



a

We search for ppm effects

⇒ Symplectic DEFROST:

energy conservation ~10^{-13} level!!

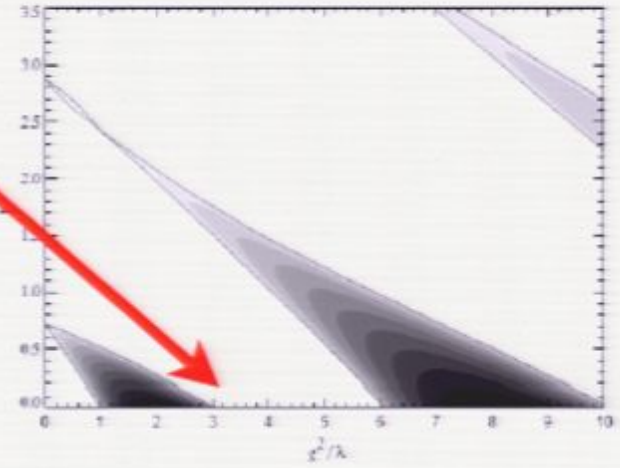
cf. DEFROST ~10^{-5} level & Felder's LatticeEasy ~10^{-4} level.

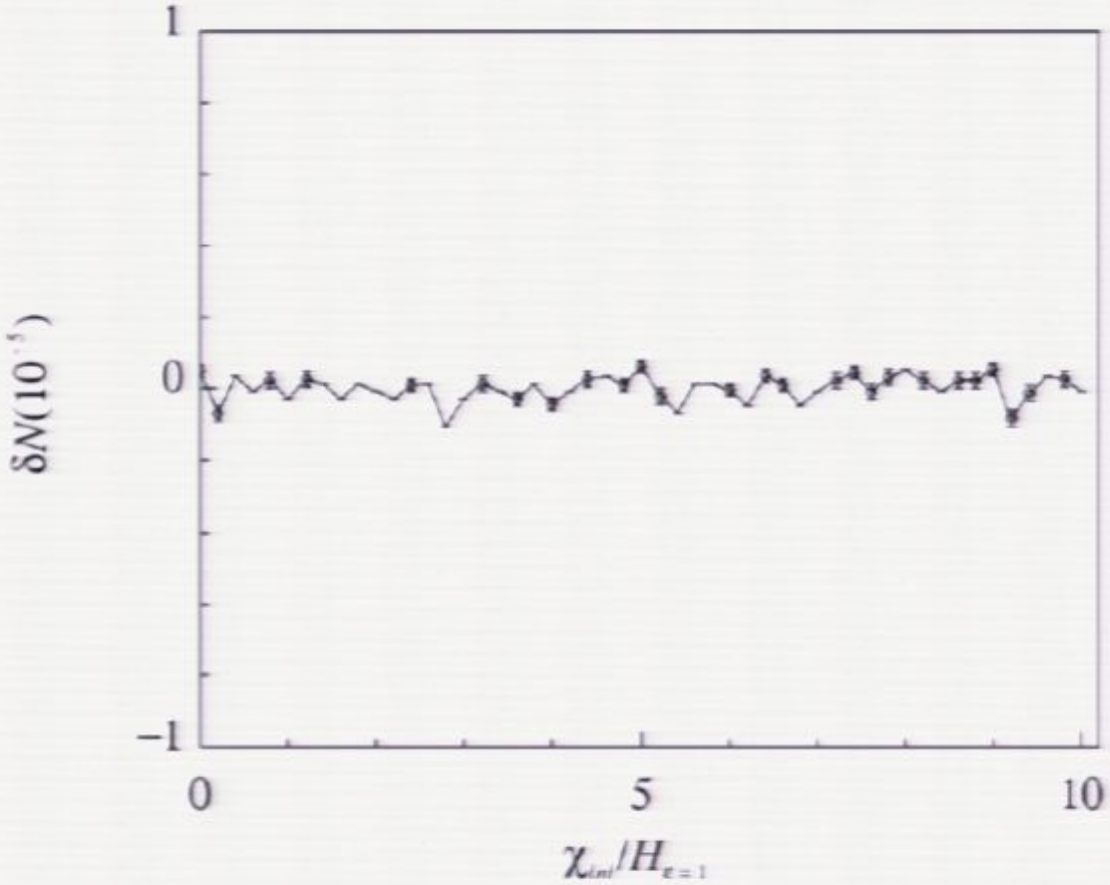
Lattice simulation codes

- Good publicly available codes:
  LatticeEasy (G. Felder), 2^{nd} order PDE solver;
  DEFROST (A. Frolov), 2^{nd} order PDE solver;
- Our new lattice simulation code:

➢ Higher (optional 2^{nd},4^{th},6^{th},8^{th}) order Symplectic PDE integrator
➢ Energy conservation ~ 10^{-13} level!!
➢ MPI parallelized for large size simulation
➢ initialization in configuration space (DEFROST algorithm) or momentum space (LatticeEasy algorithm).
➢ Numerically calculate initial super-horizon mode functions
➢ More recent updates (non-canonical scalar fields simulation; a module for GW spectrum calculation…)

if the k=0 mode is not in the parametric resonance bands (g^2/λ=3 example) then $\delta ln\ a$ is not modulated by χ_b

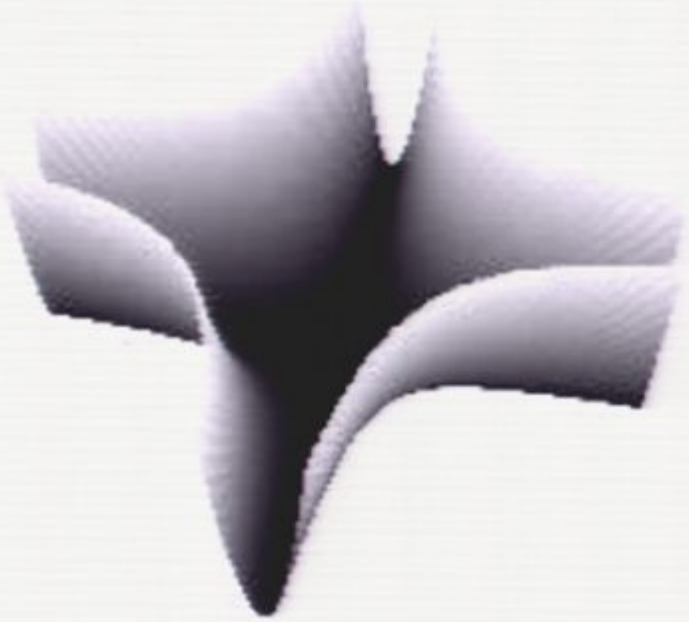


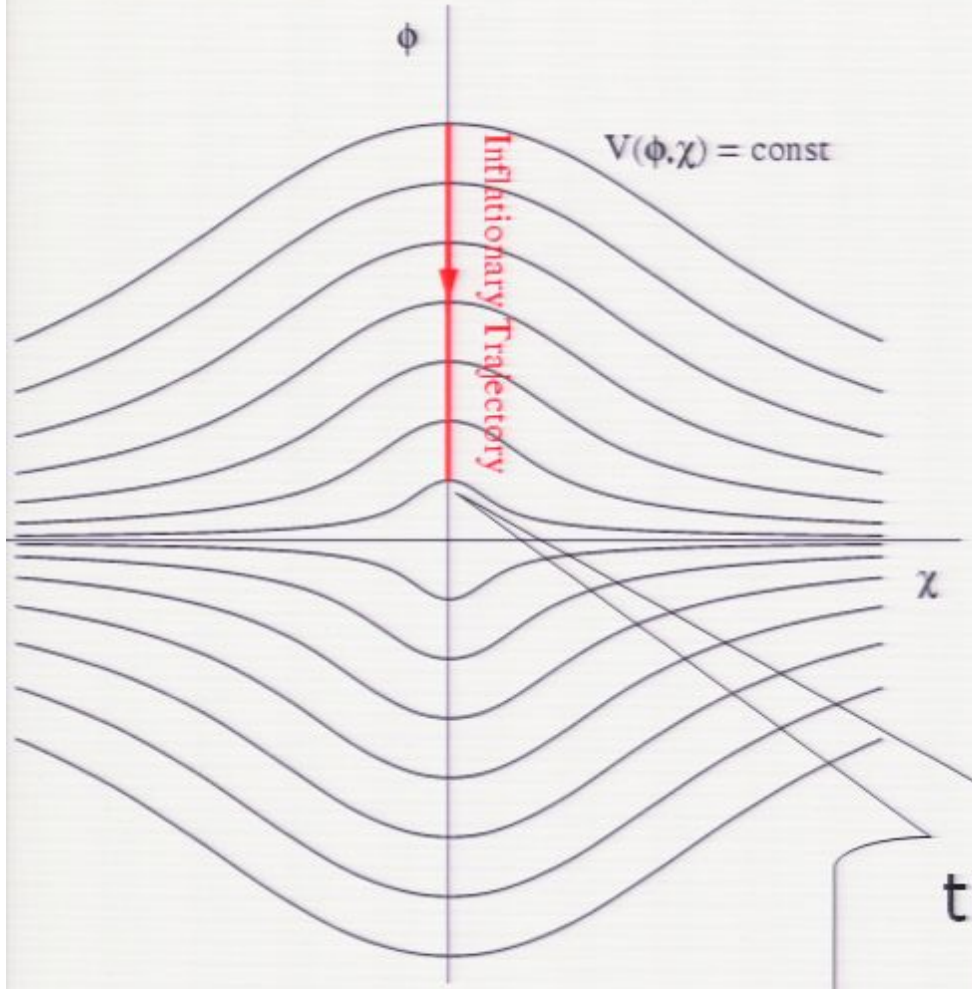


Other tests: UV and IR cutoffs ok ➔

Chaotic Billiards

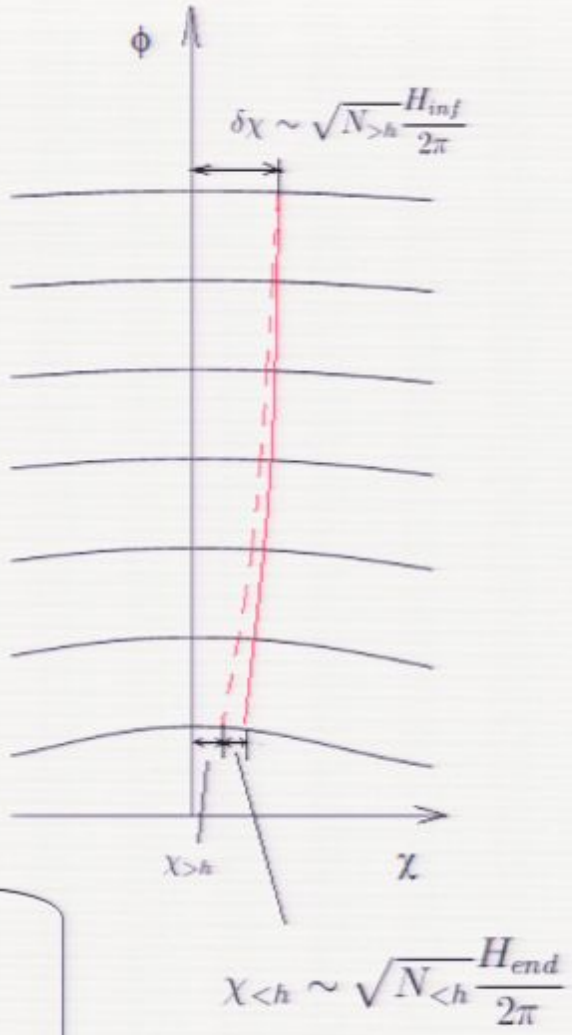
$$\frac{1}{2}\dot{\phi}^2 + \frac{1}{2}\dot{\chi}^2 + \frac{1}{2}g^2\phi^2\chi^2$$





zoom in

exagerating $\delta\chi$ ➔

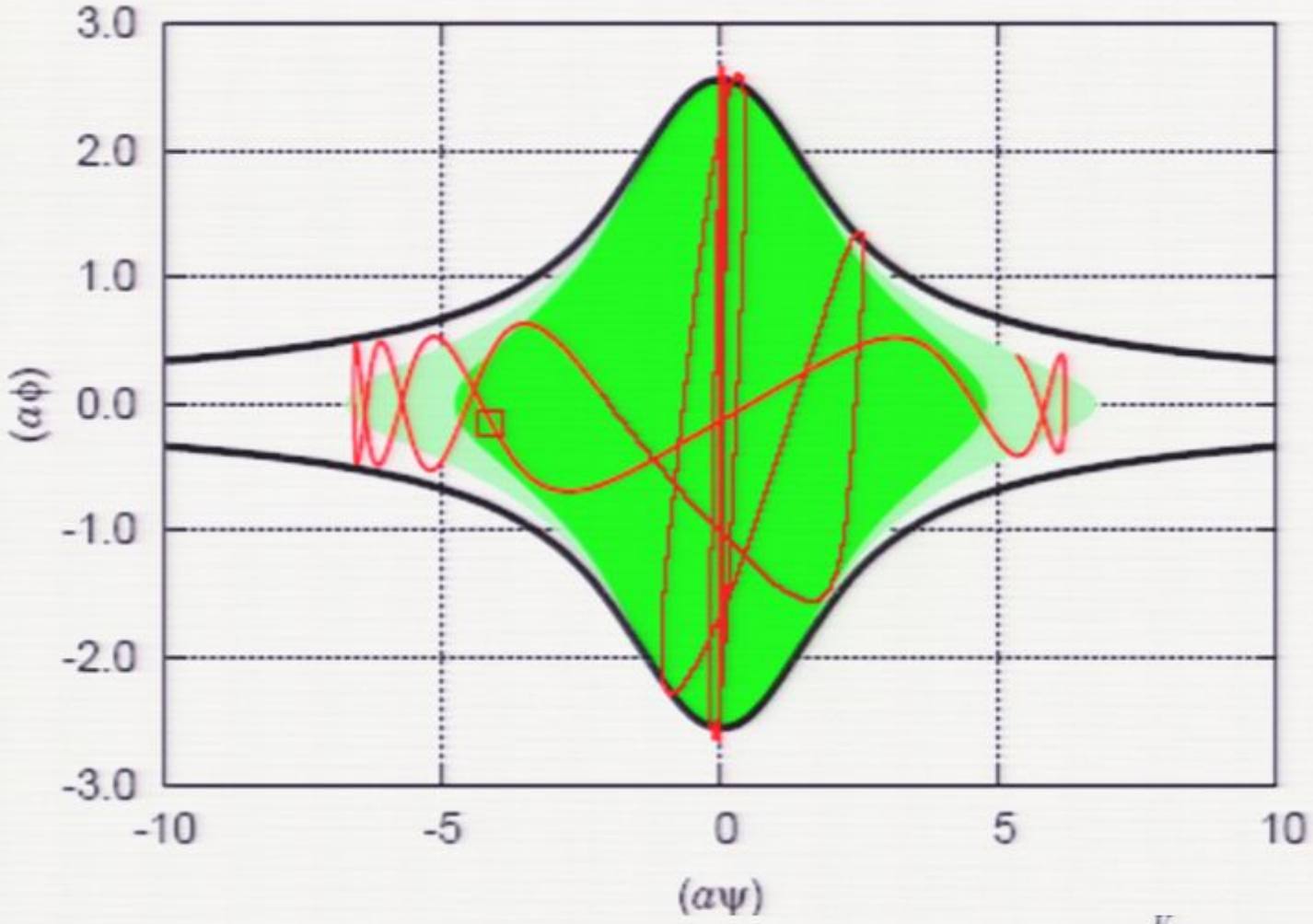


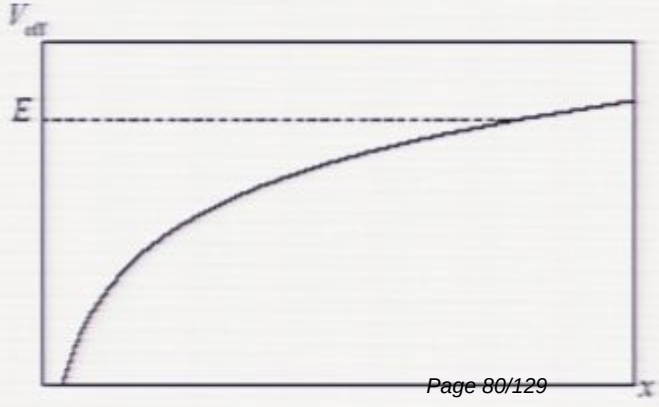
the end of inflation

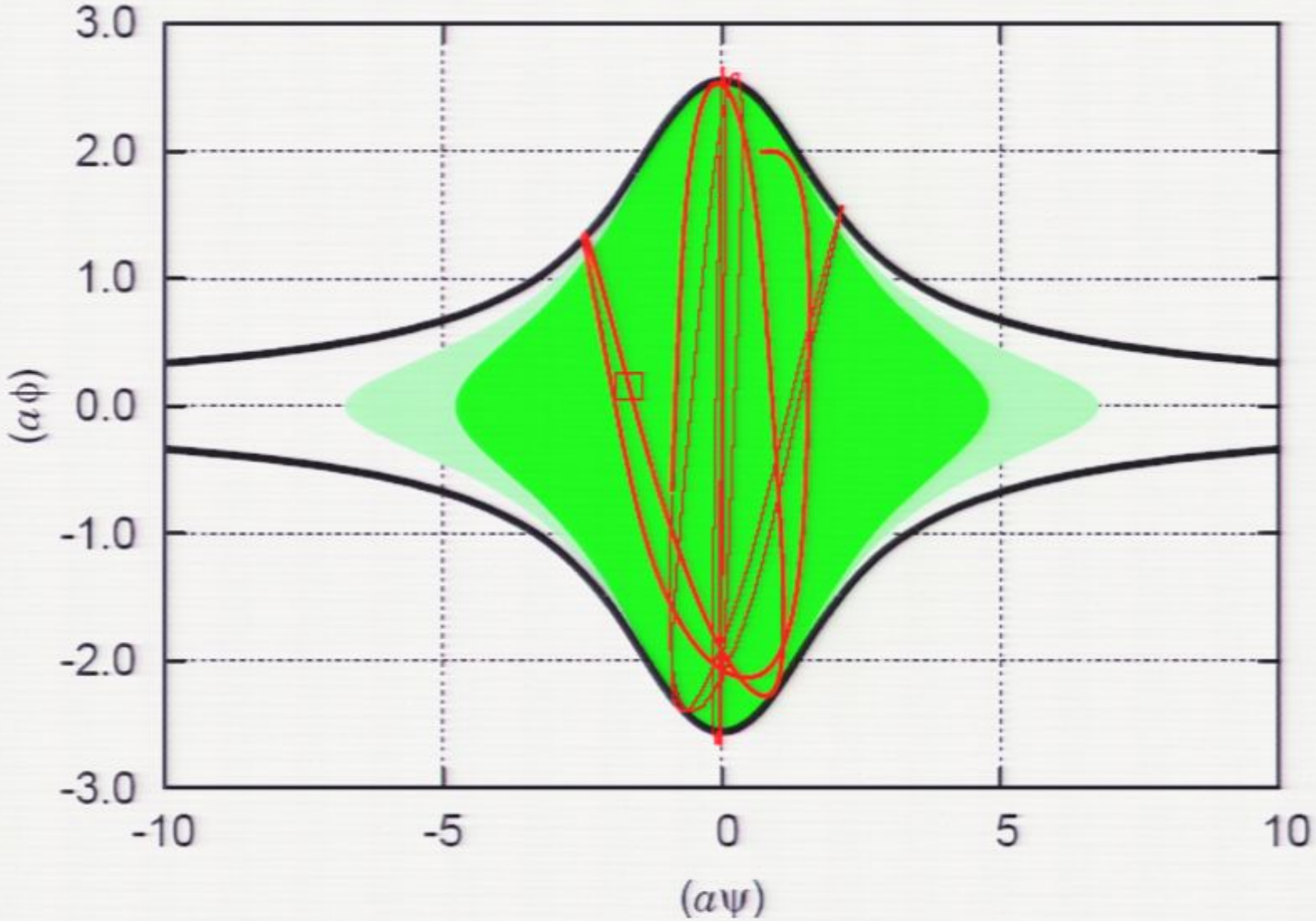
$\chi_i = \chi_{>h} + \chi_{<h}$

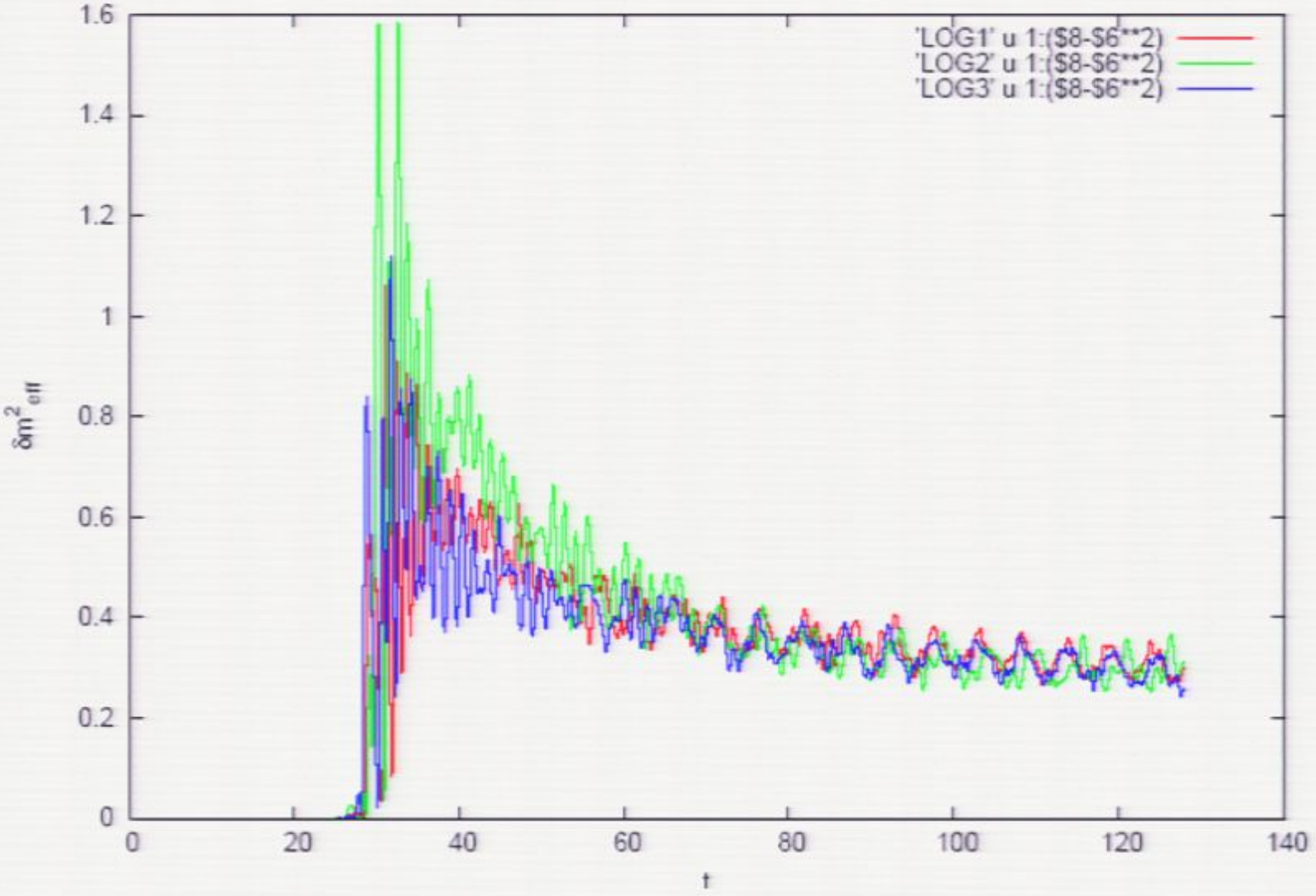
$N_{>h}$ (? efolds)➔ # of efolds before current horizon scale (10^4 Mpc) exits the horizon

$N_{<h}$ (~65 efolds) ➔ # of efolds – from when current horizon scale exits

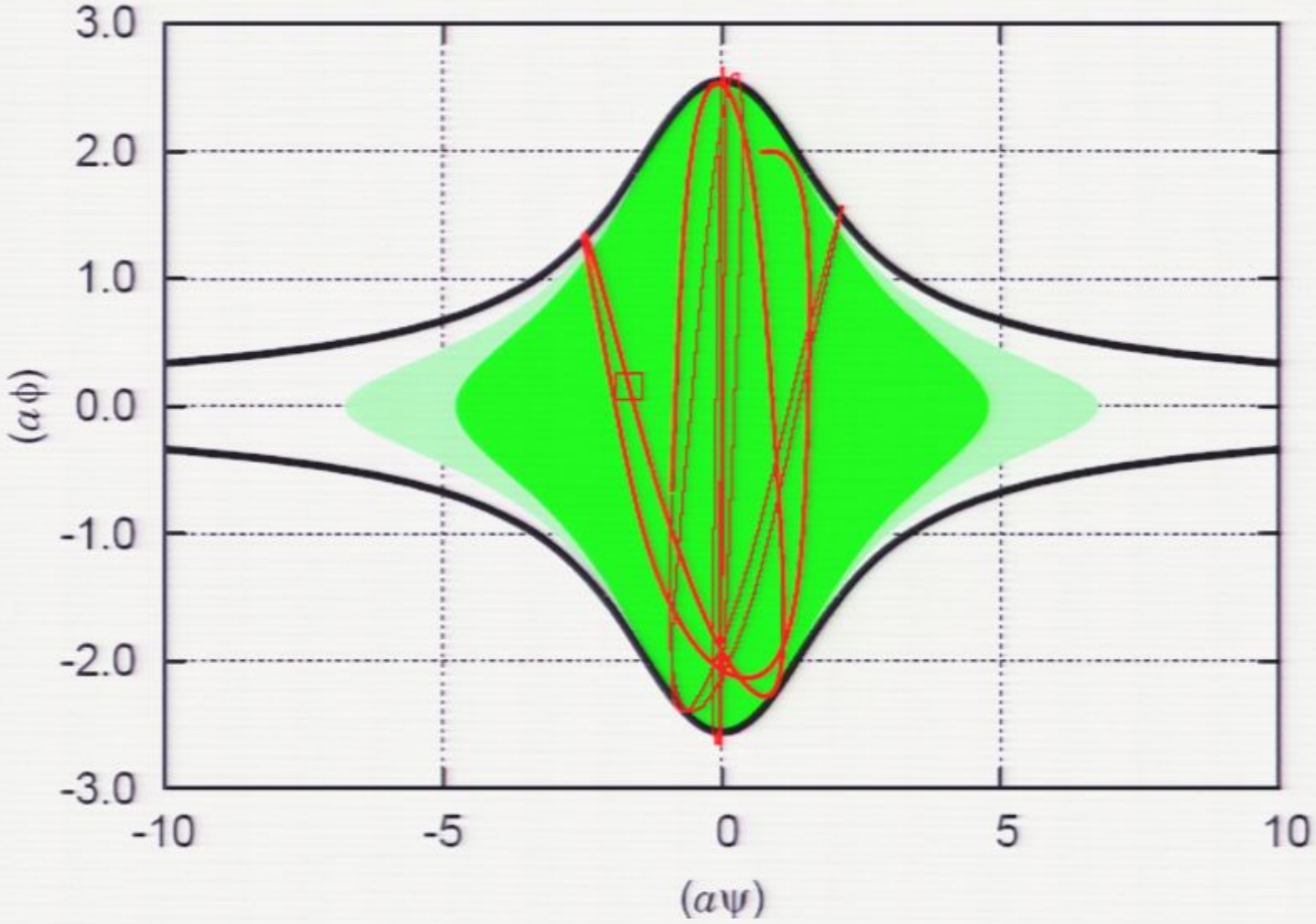

3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
10
$(a\phi)$
$(a\psi)$

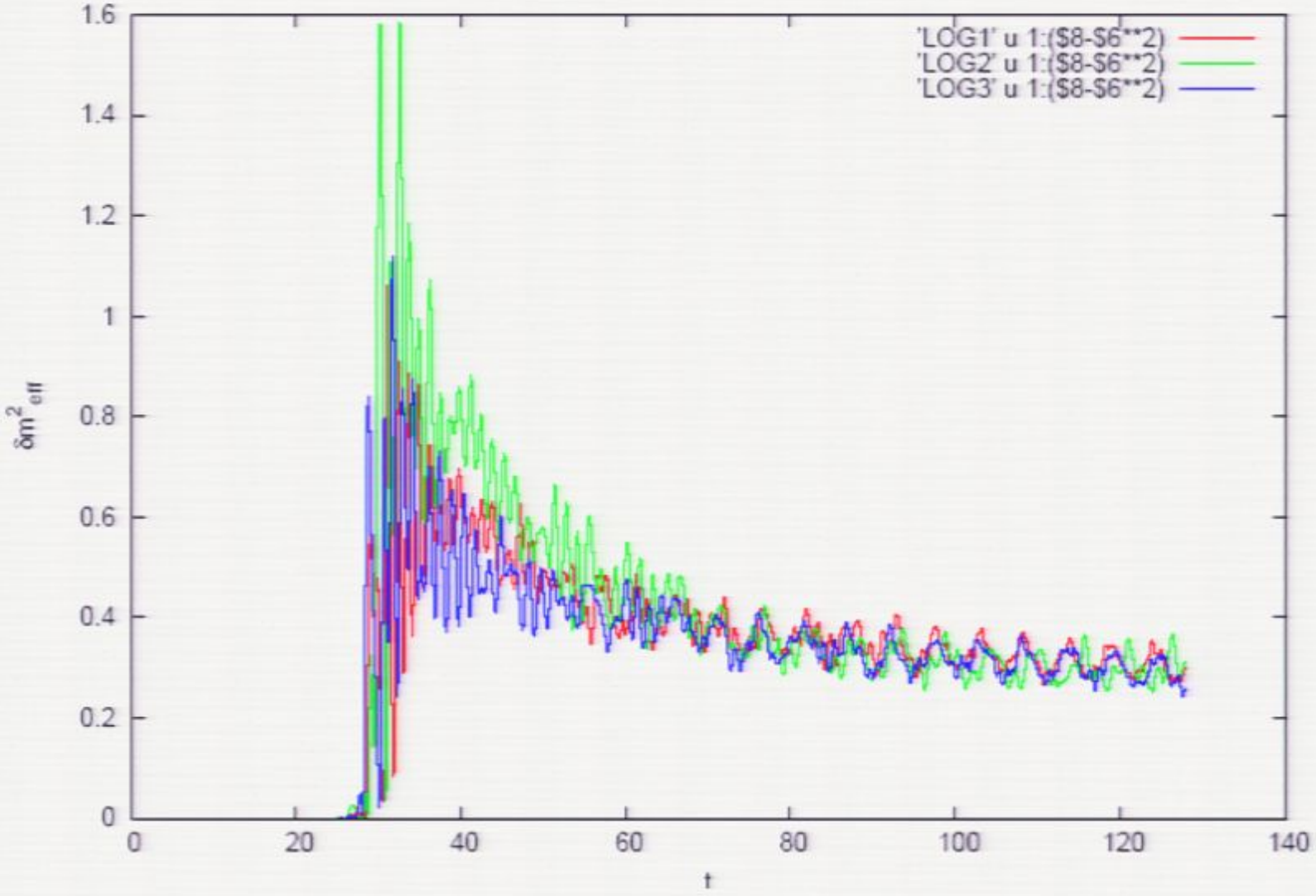

V_{eff}
E
x

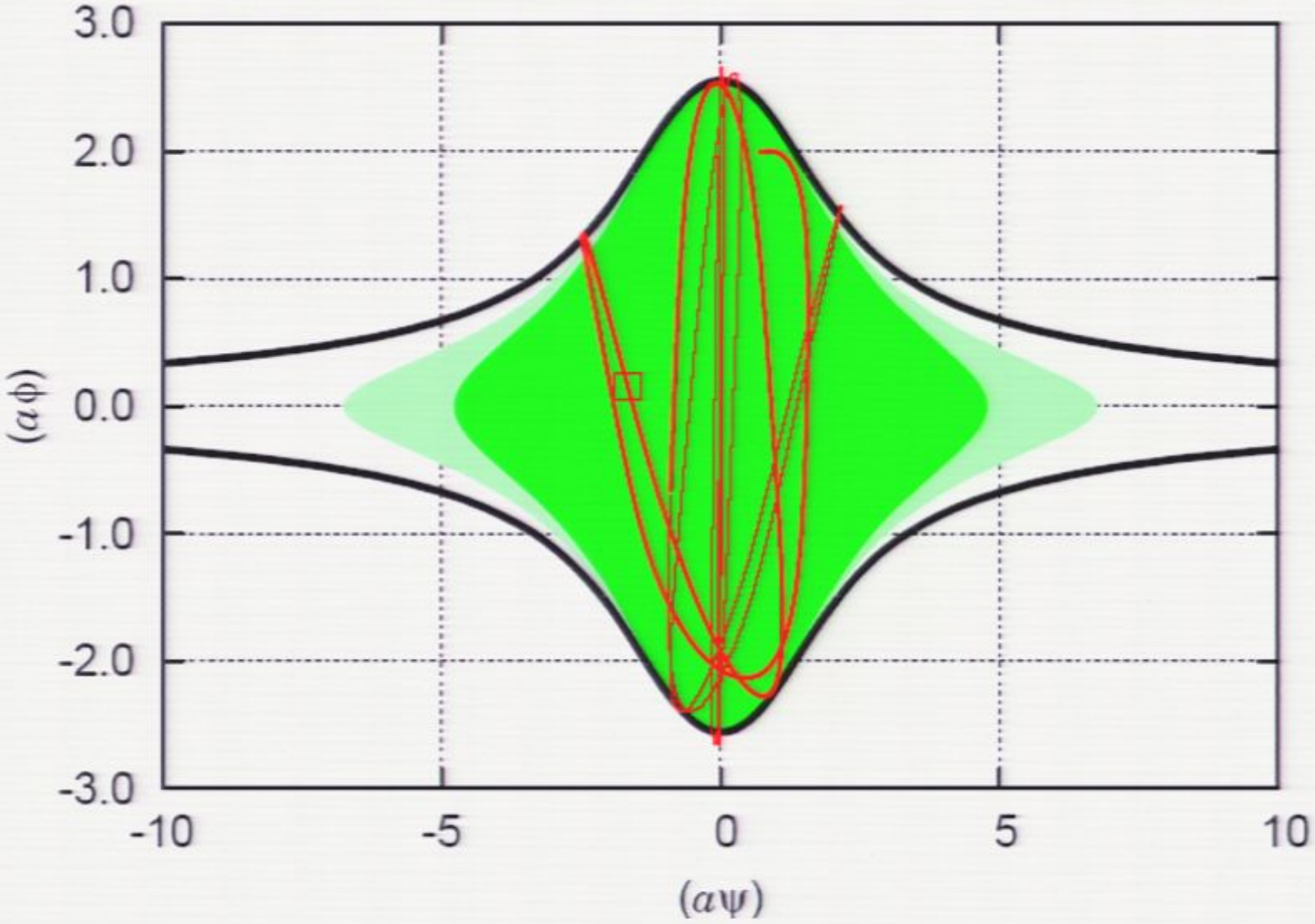

3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
10
$(\alpha\phi)$
$(\alpha\psi)$


'LOG1' u 1:($8-$6**2)
'LOG2' u 1:($8-$6**2)
'LOG3' u 1:($8-$6**2)
δm²eff
t
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0
20
40
60
80
100
120
140

Billiard no spikes

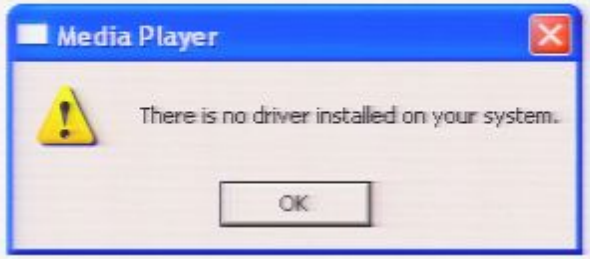

3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
10
$(a\phi)$
$(a\psi)$

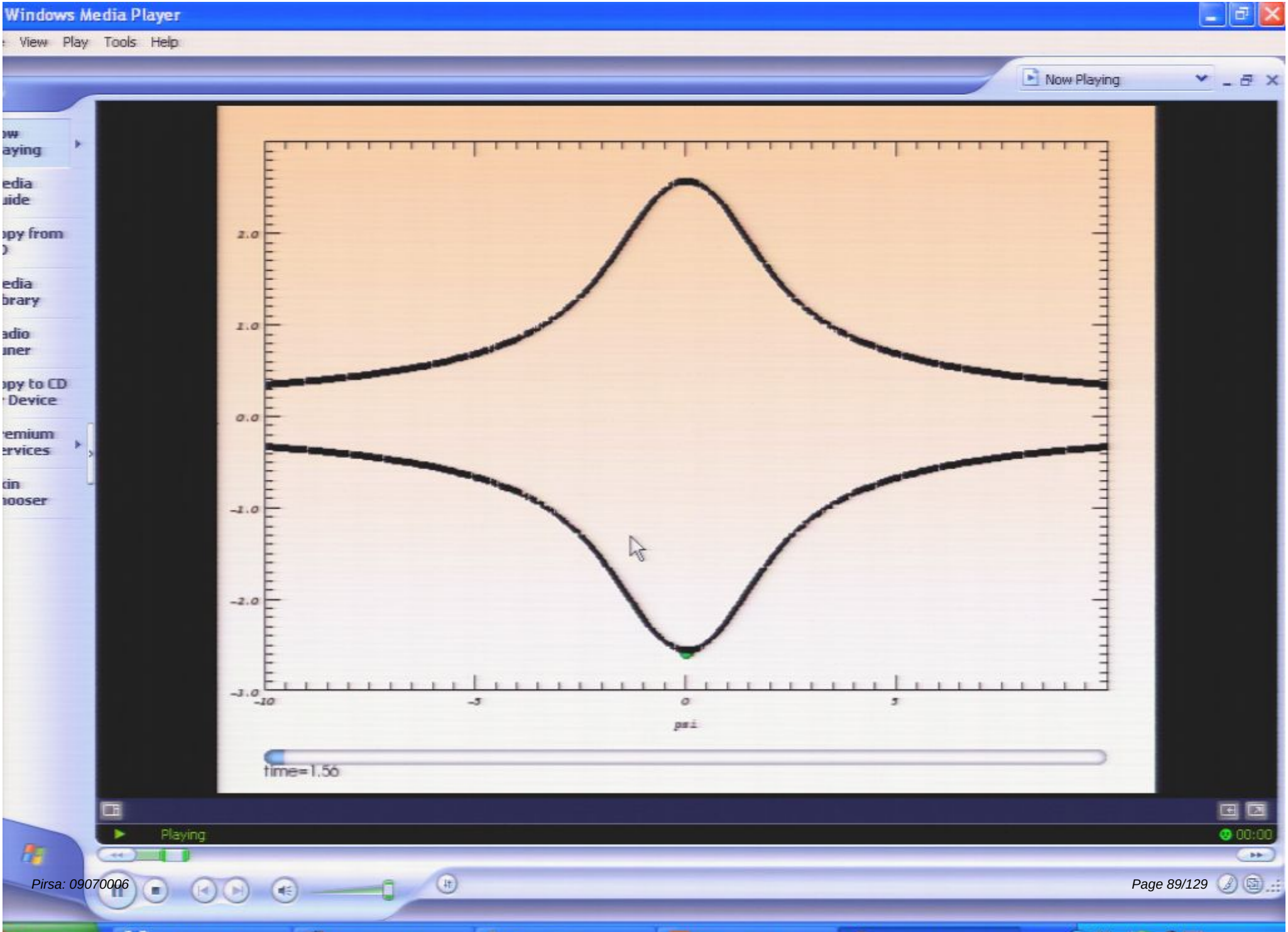

'LOG1' u 1:($8-$6**2)
'LOG2' u 1:($8-$6**2)
'LOG3' u 1:($8-$6**2)
δm²eff
t
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0
20
40
60
80
100
120
140

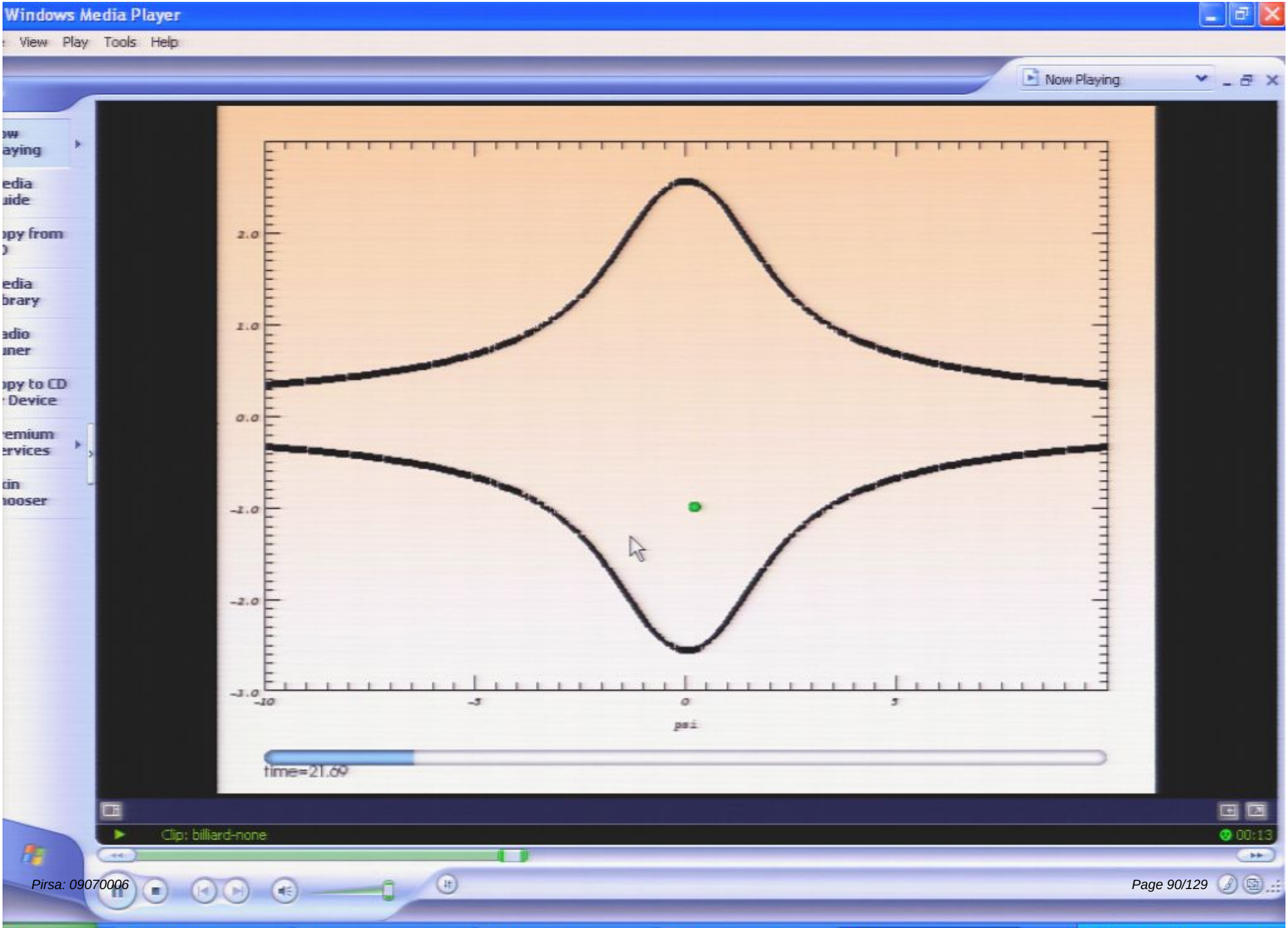

3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
10
$(\alpha\phi)$
$(\alpha\psi)$

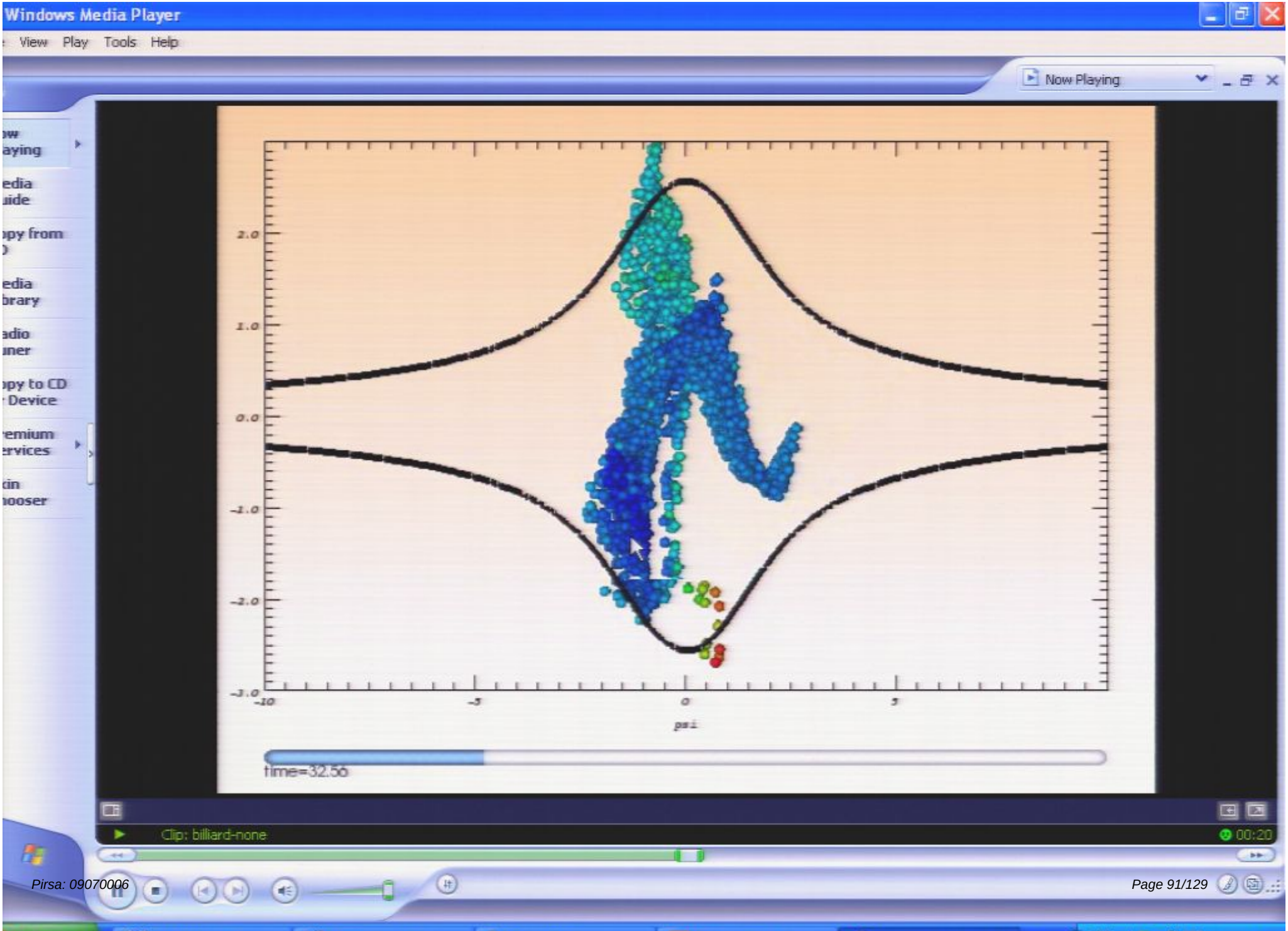
Billiard no spikes

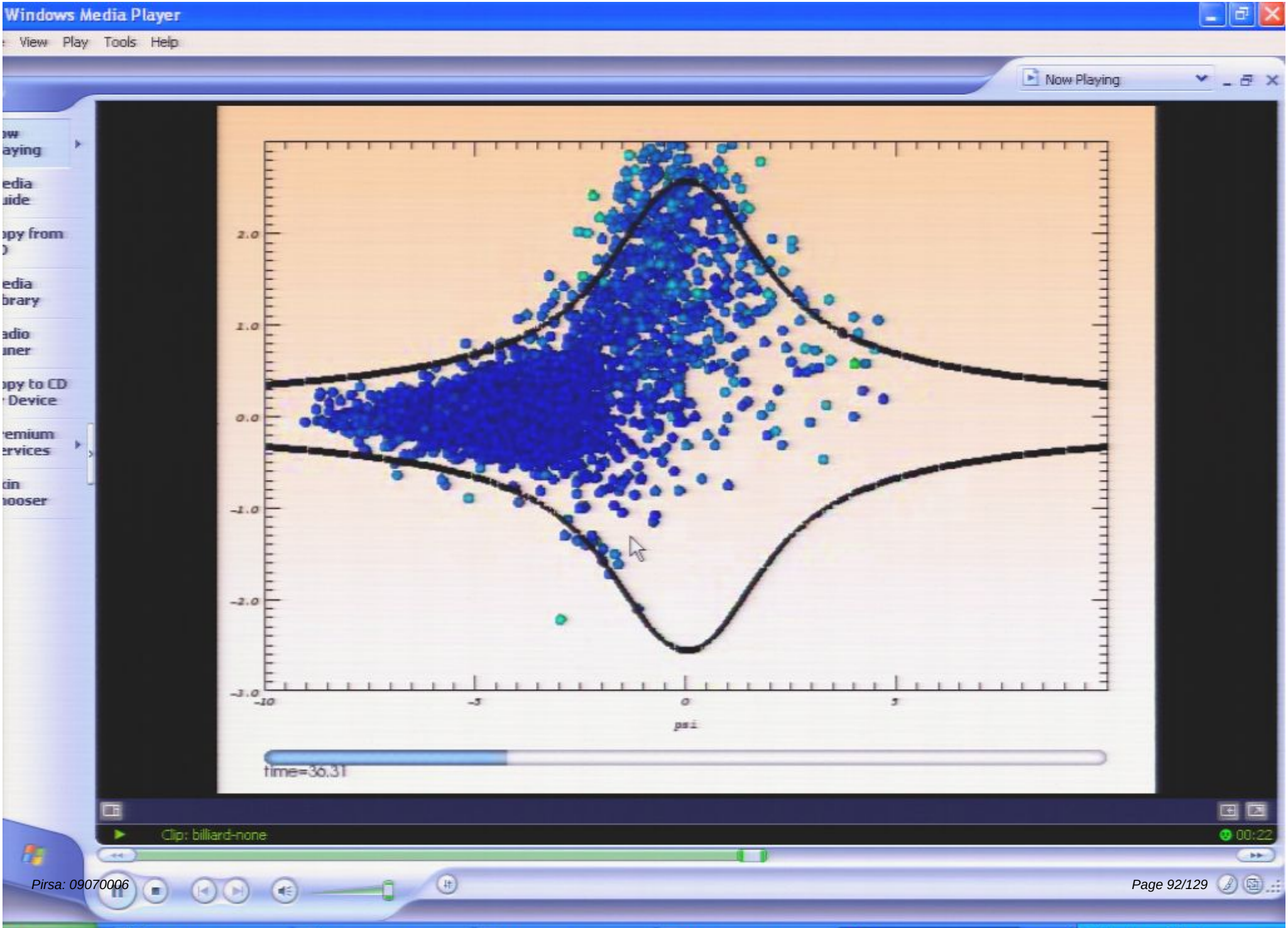
Billiard no spikes

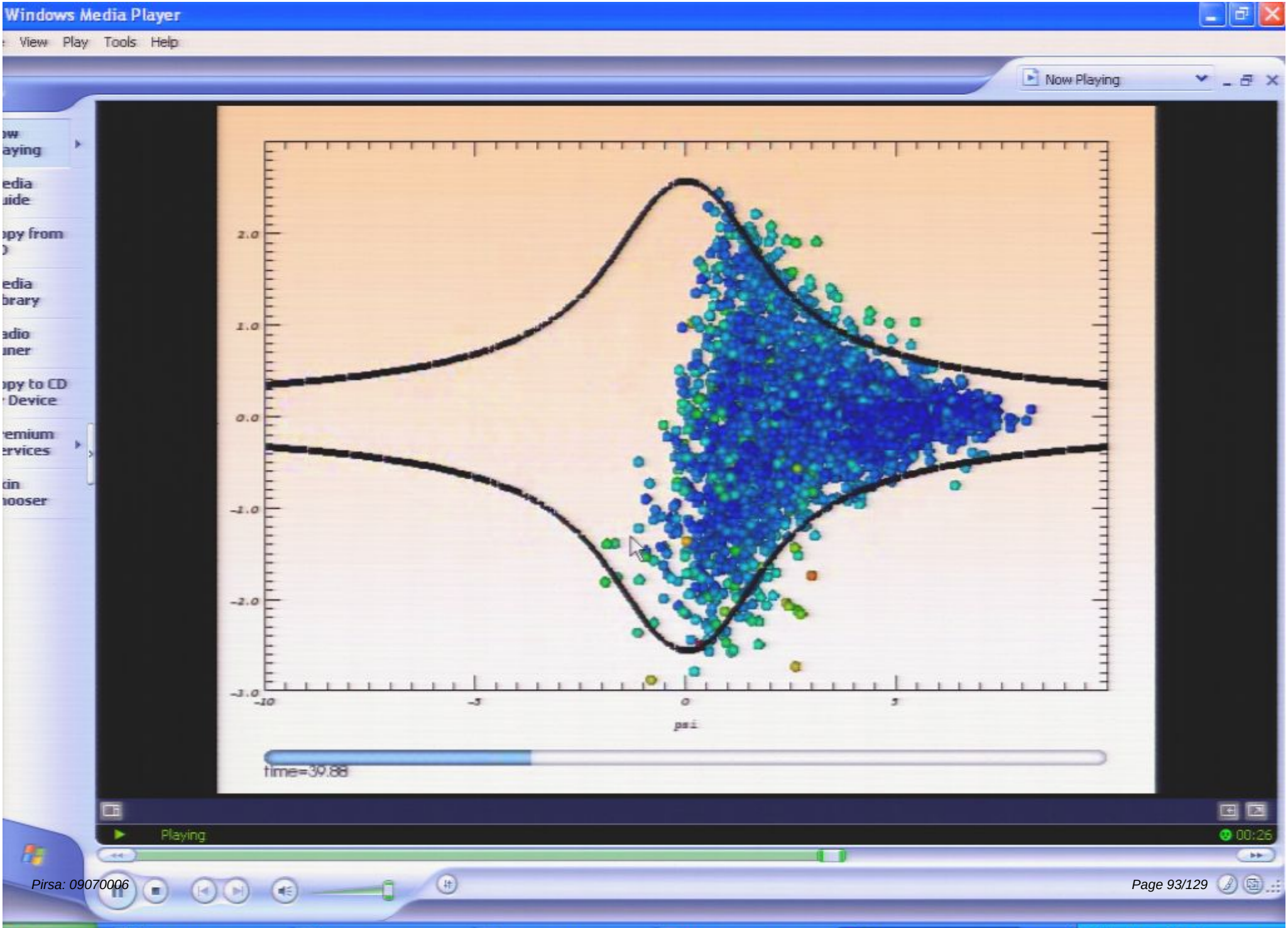


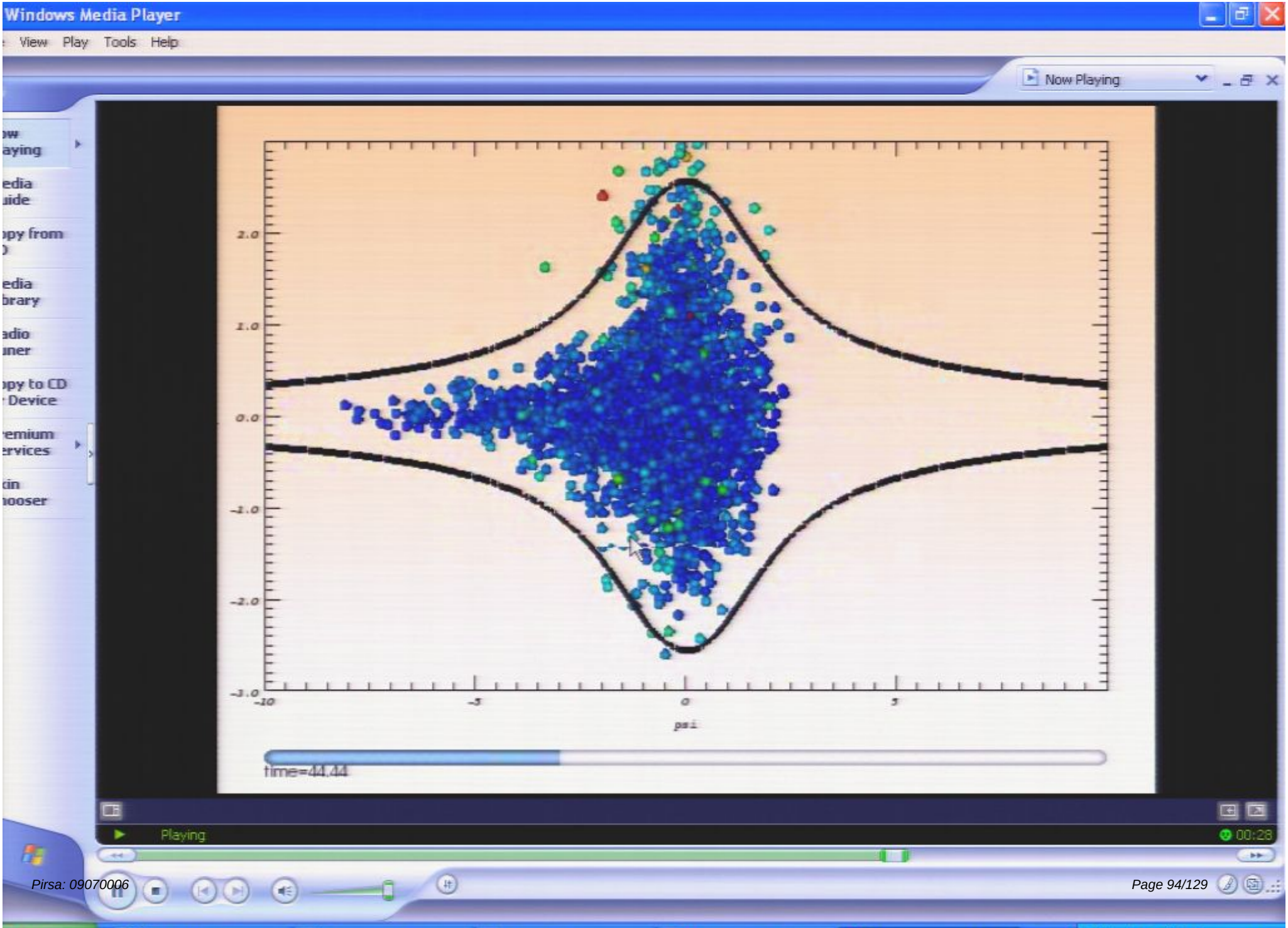

Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=1.56
Playing
00:00

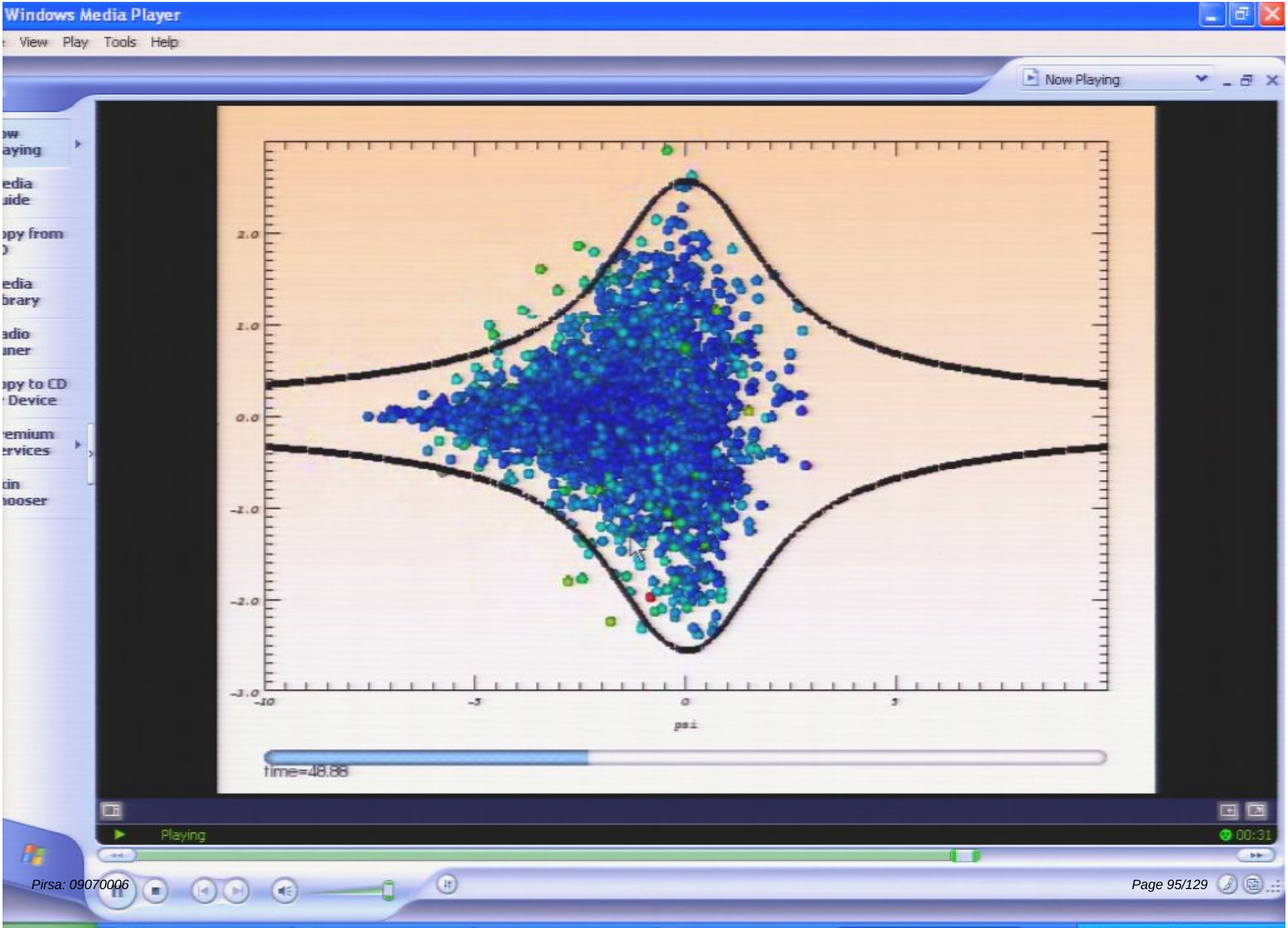

Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=21.69
Clip: billiard-none
00:13

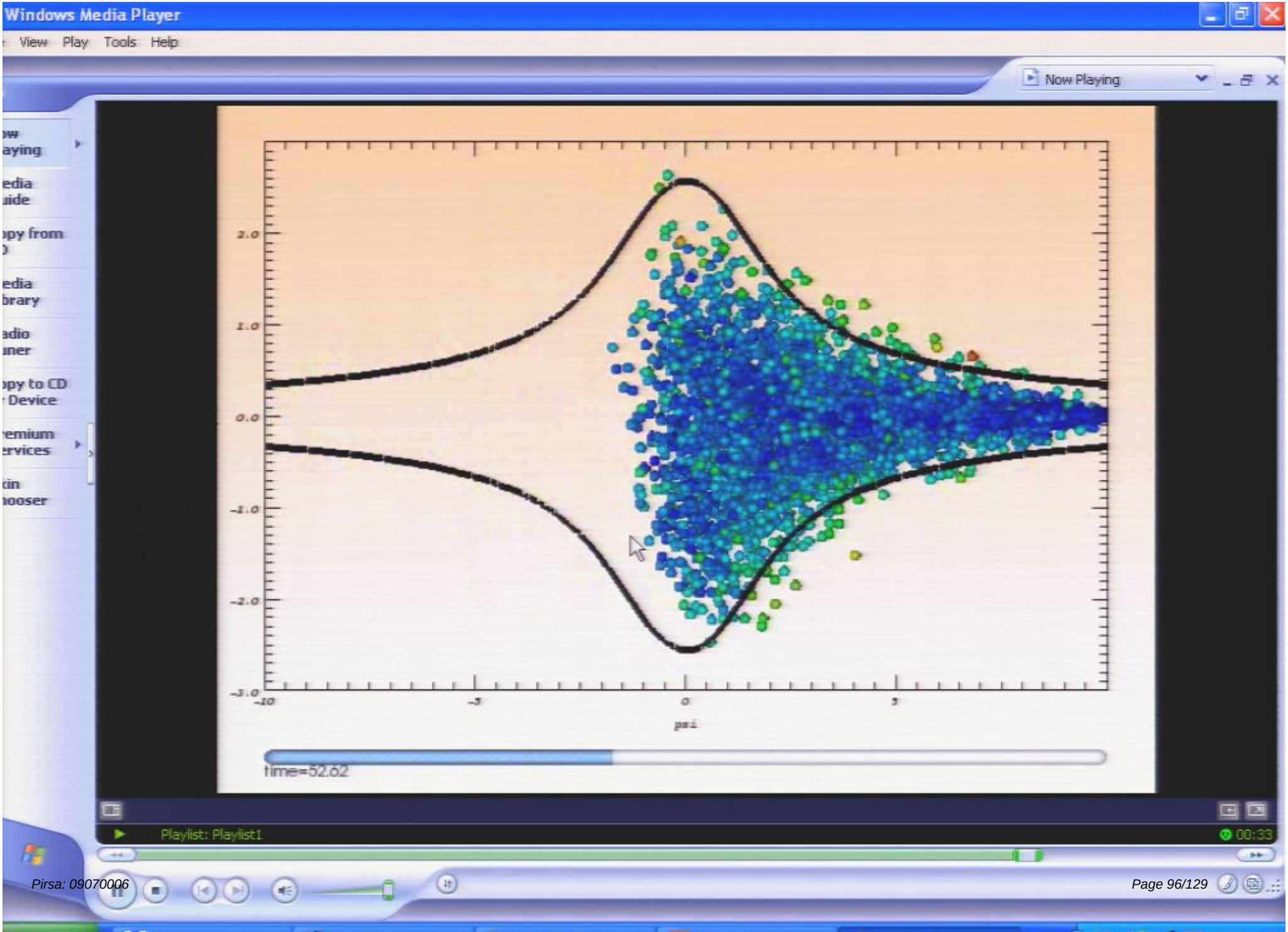

Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=32.56
Clip: billiard-none
00:20

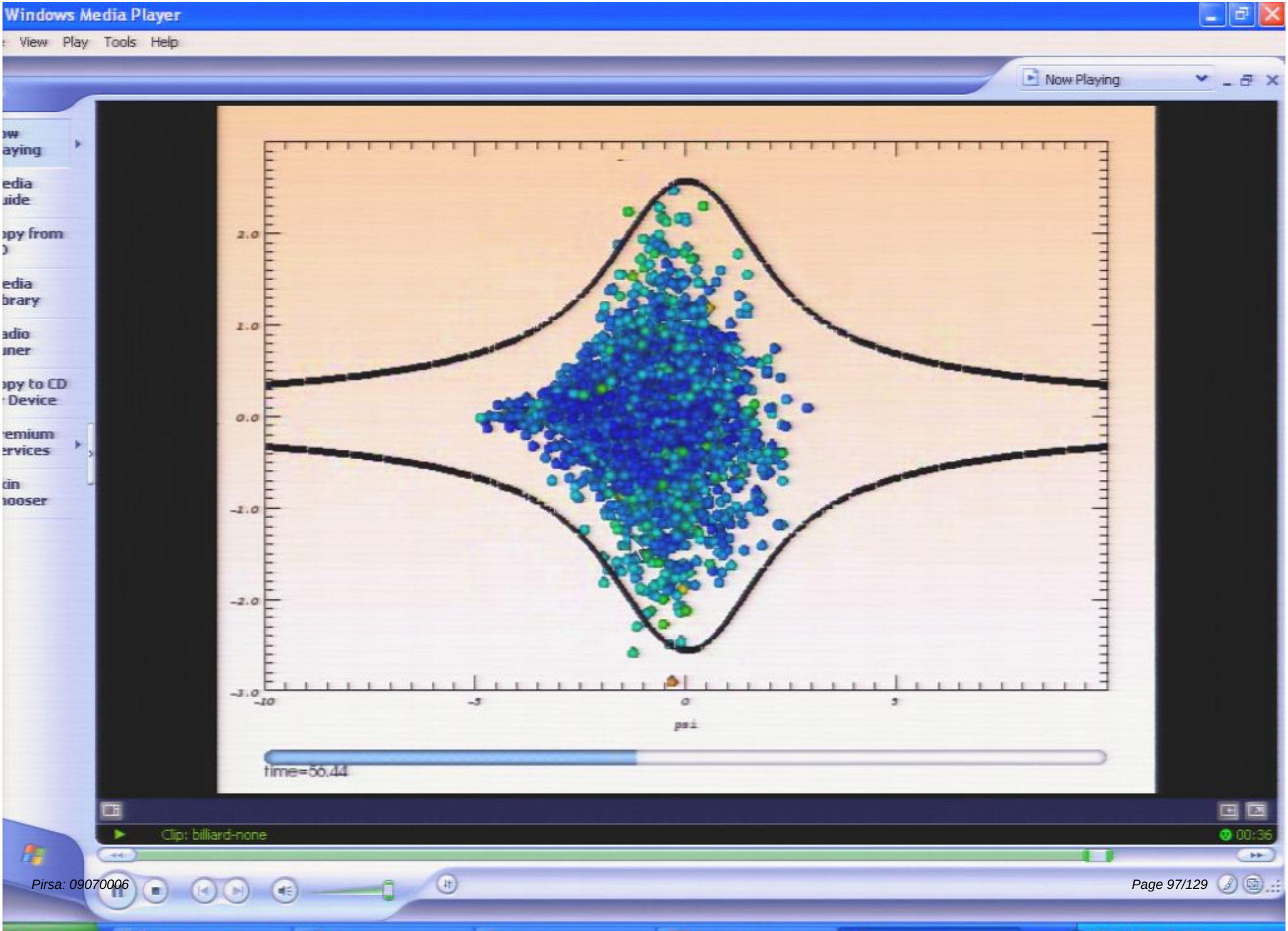

Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=36.31
Clip: billiard-none
00:22

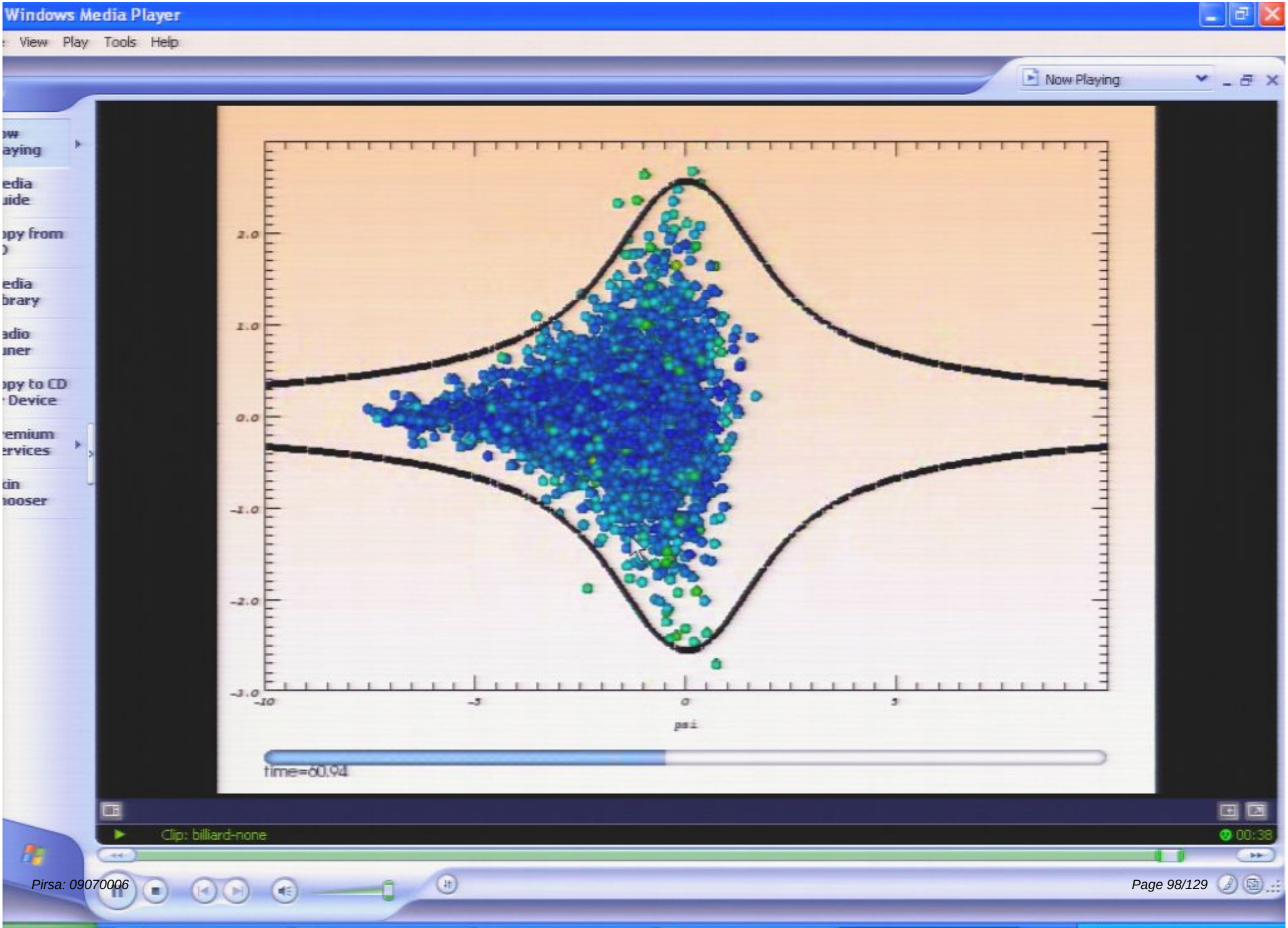

Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=39.88
Playing
00:26

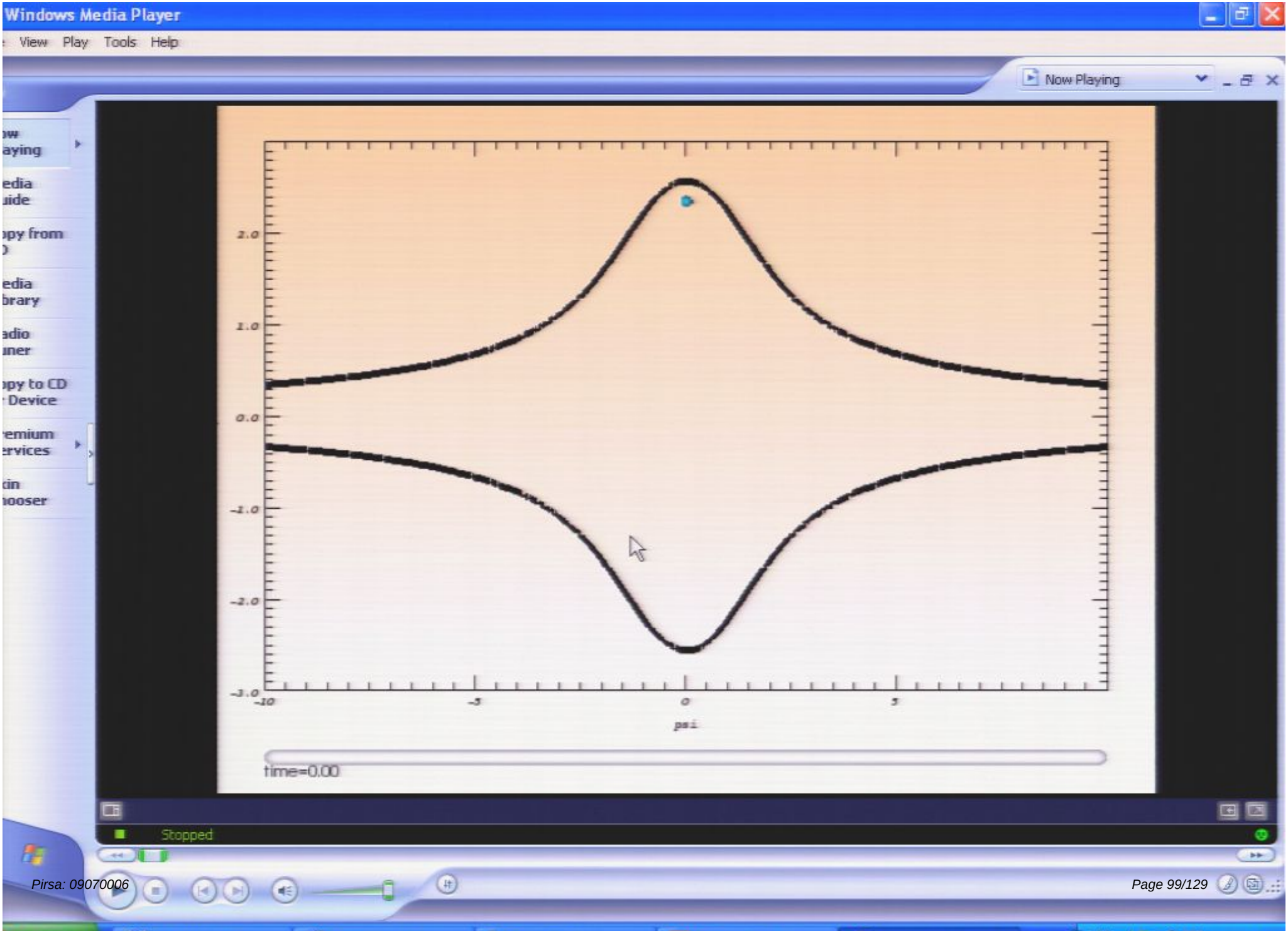

Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=44.44
Playing
00:28


Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=48.88
Playing
00:31


Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=52.62
Playlist: Playlist1
00:33


Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=56.44
Clip: billiard-none
00:36

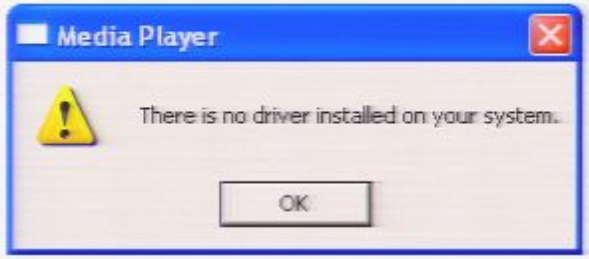

Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=60.94
Clip: billiard-none
00:38

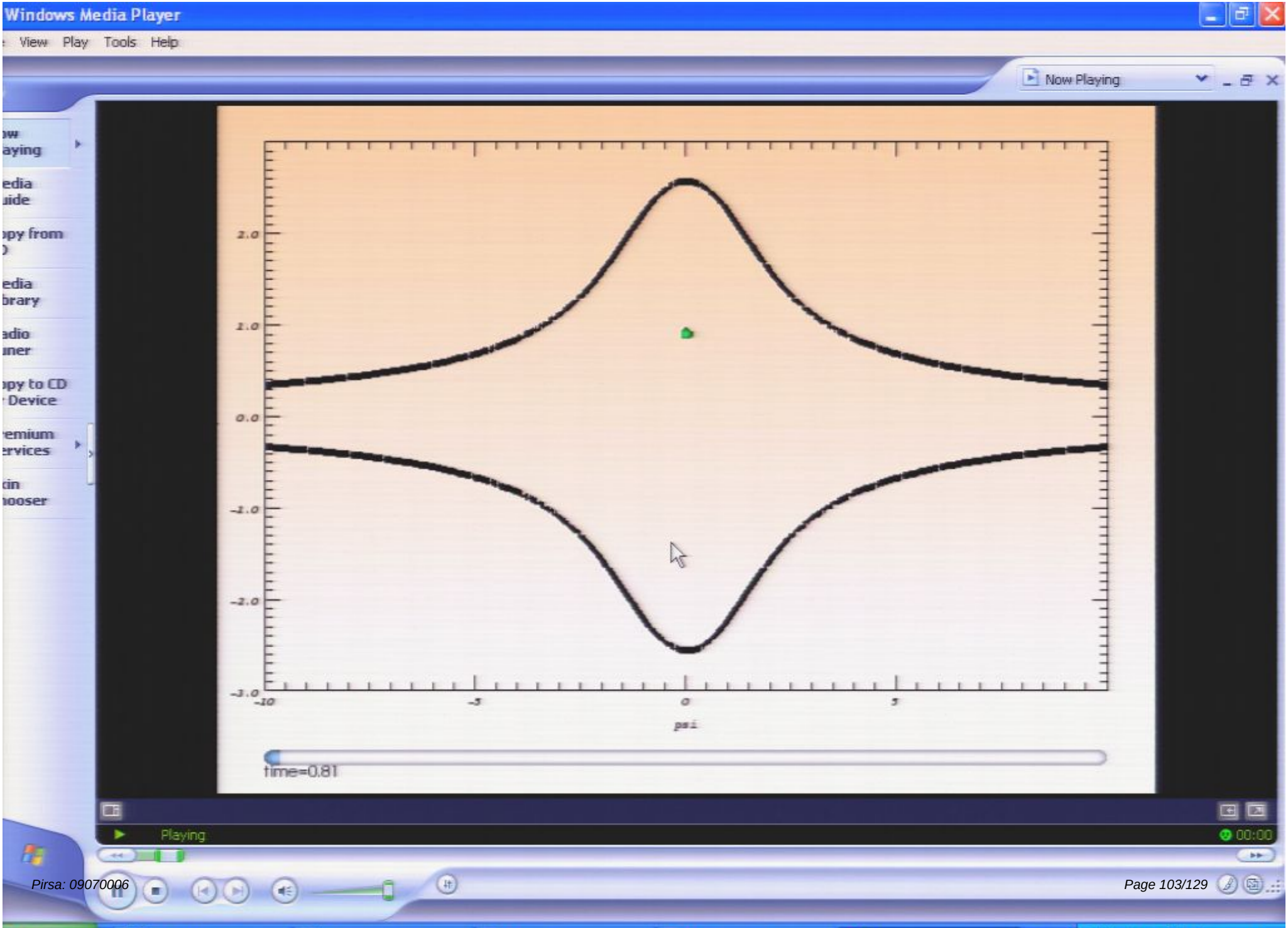

Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=0.00
Stopped

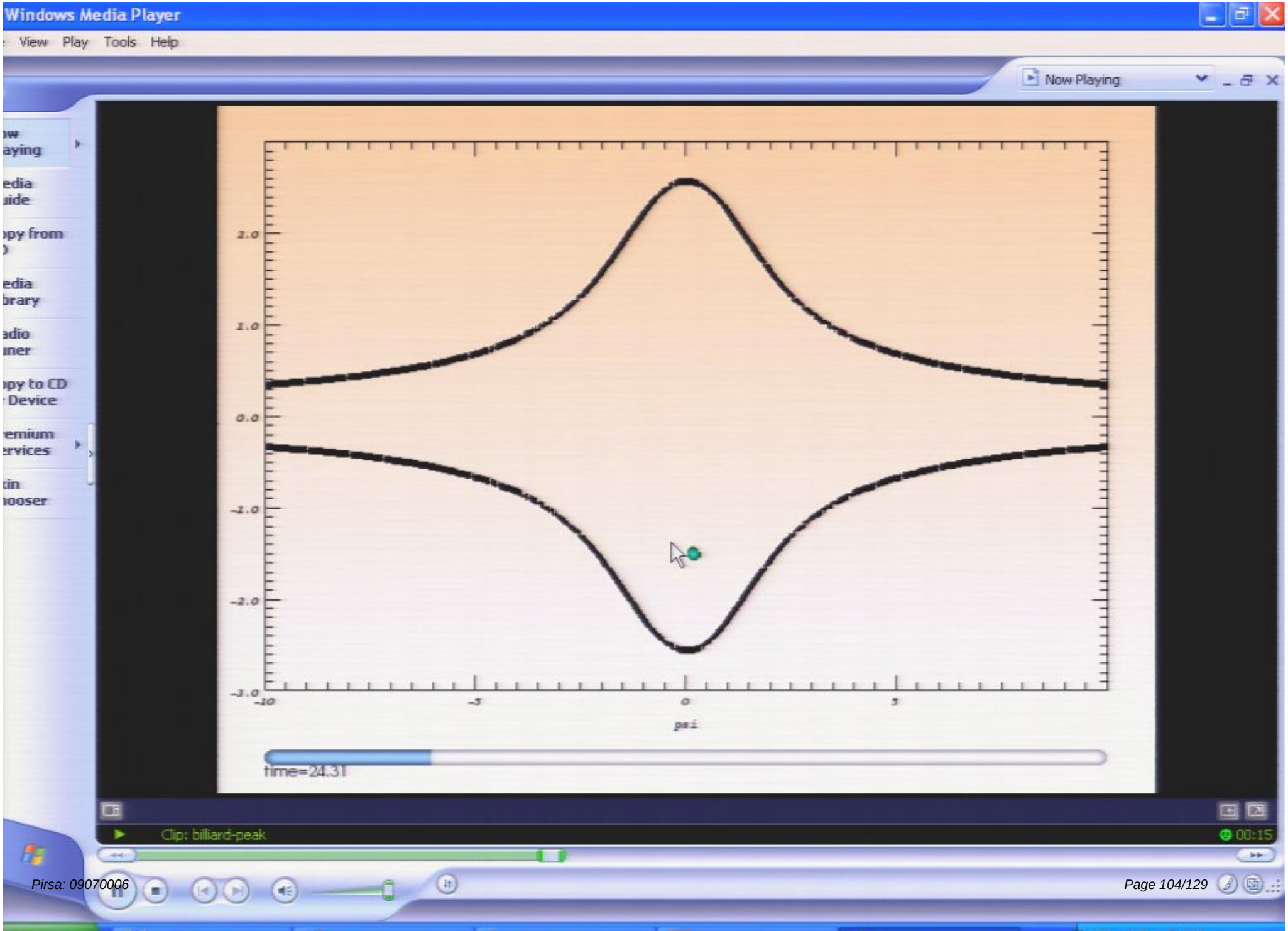
Billiard no spikes

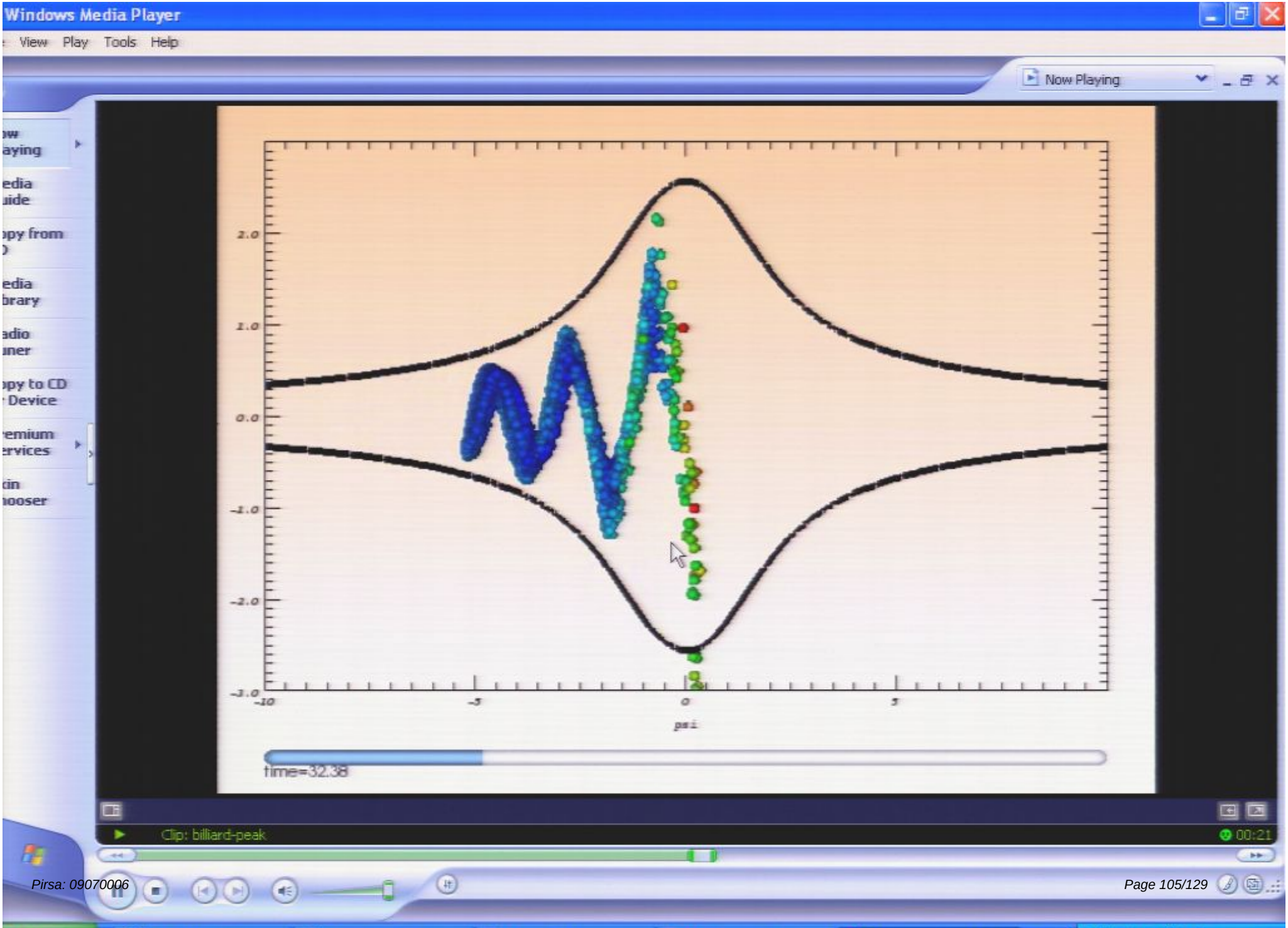
Billiar with spikes

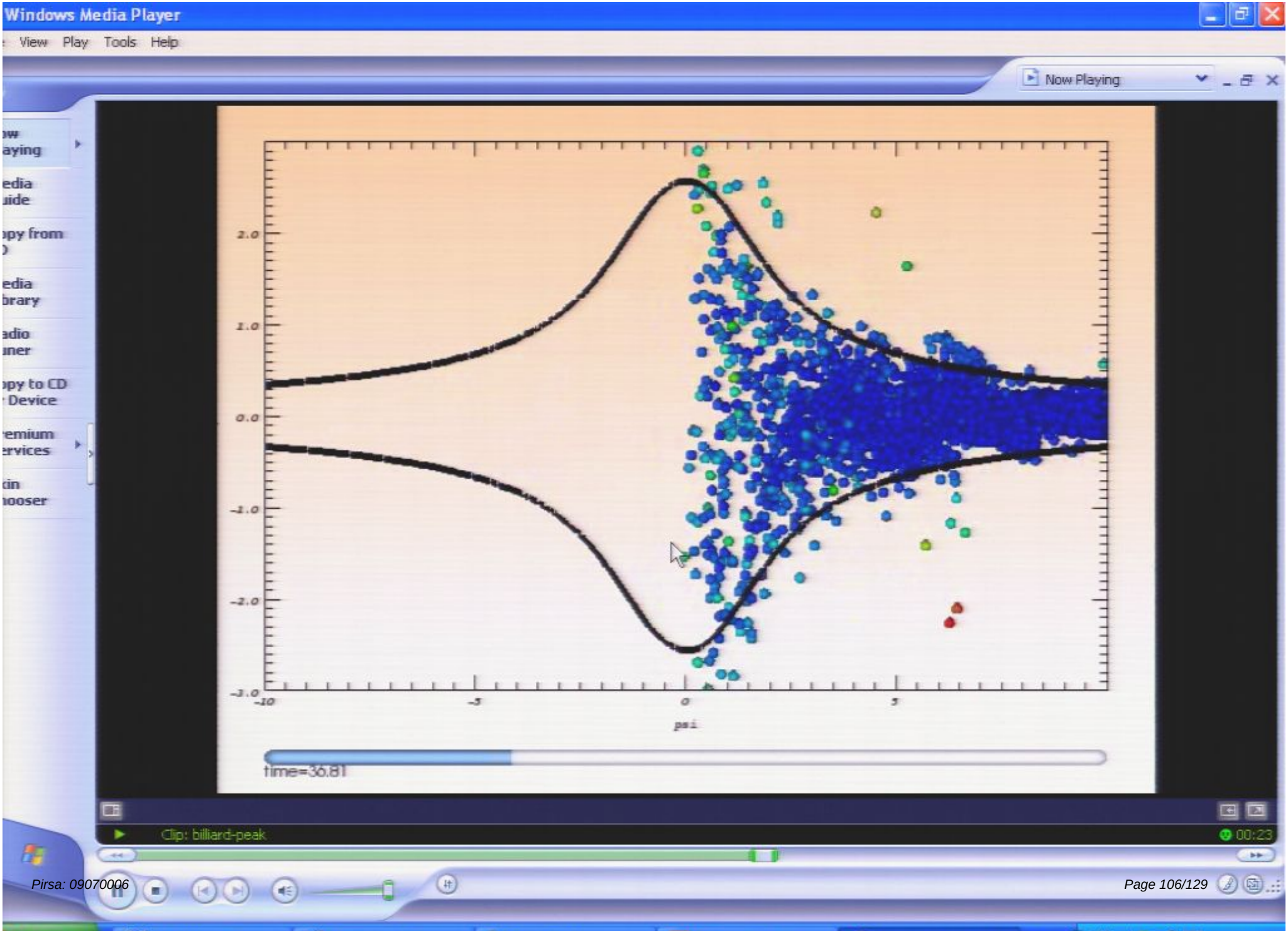
Billiar with spikes

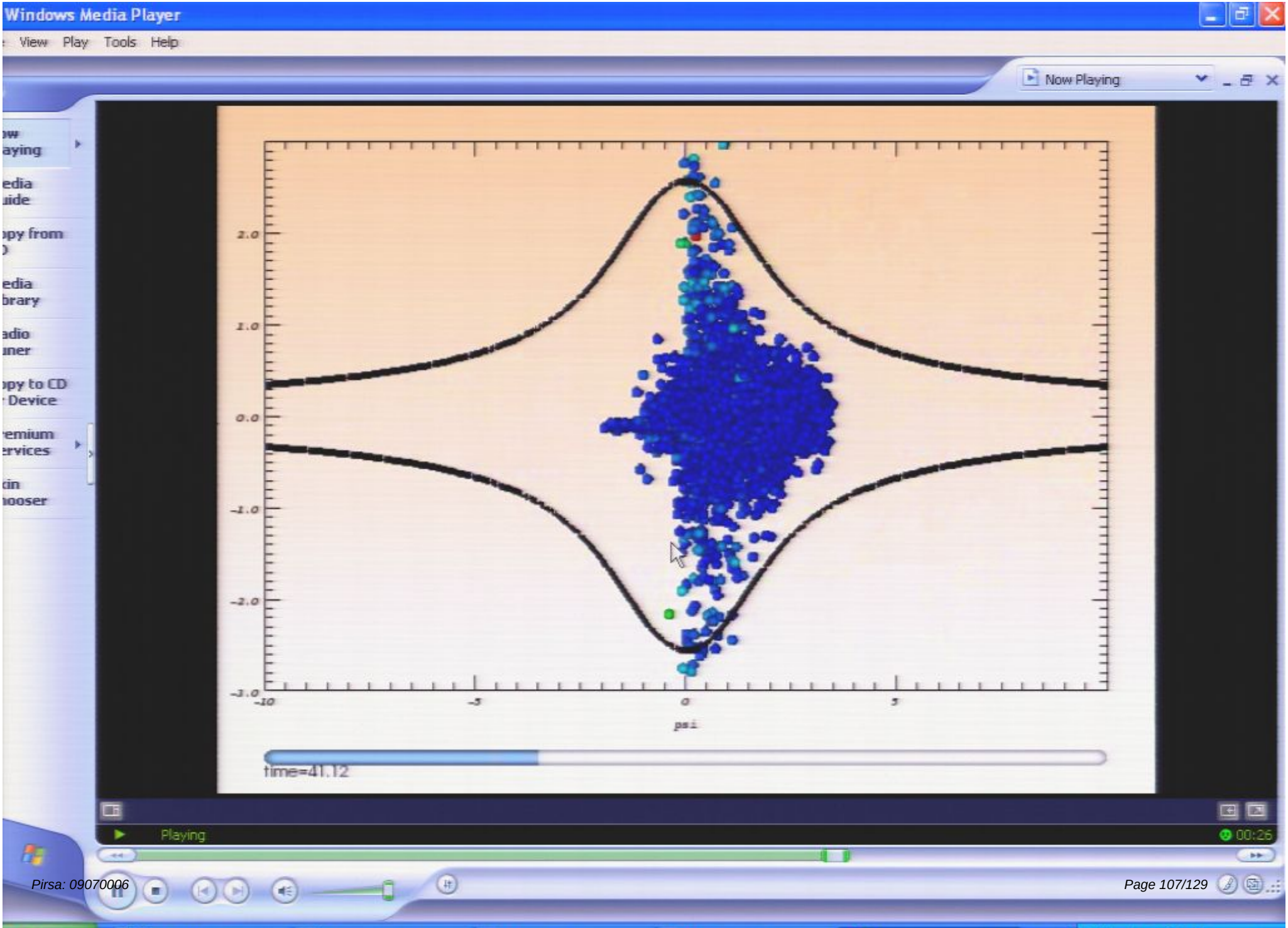


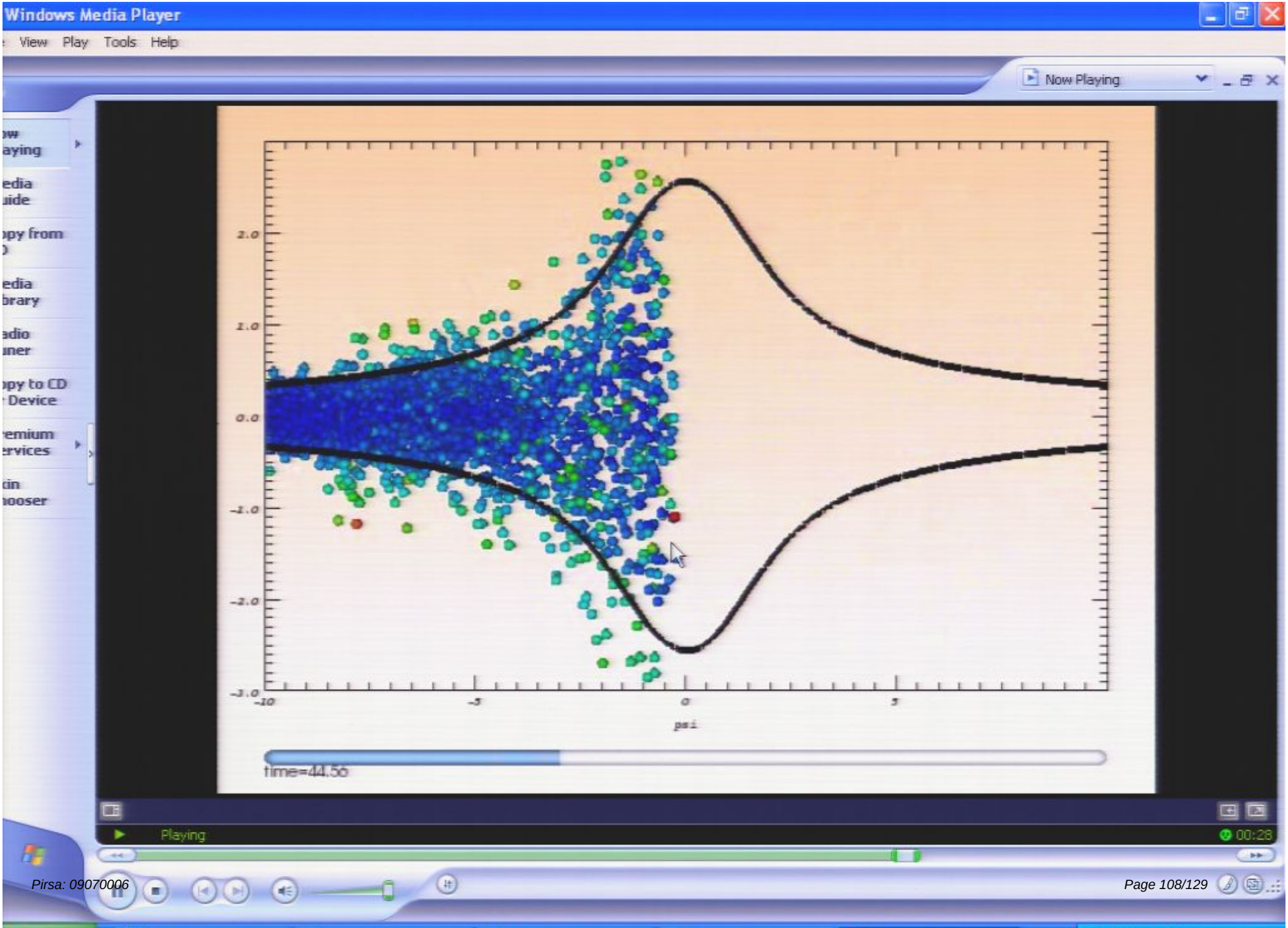

Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=0.81
Playing
00:00

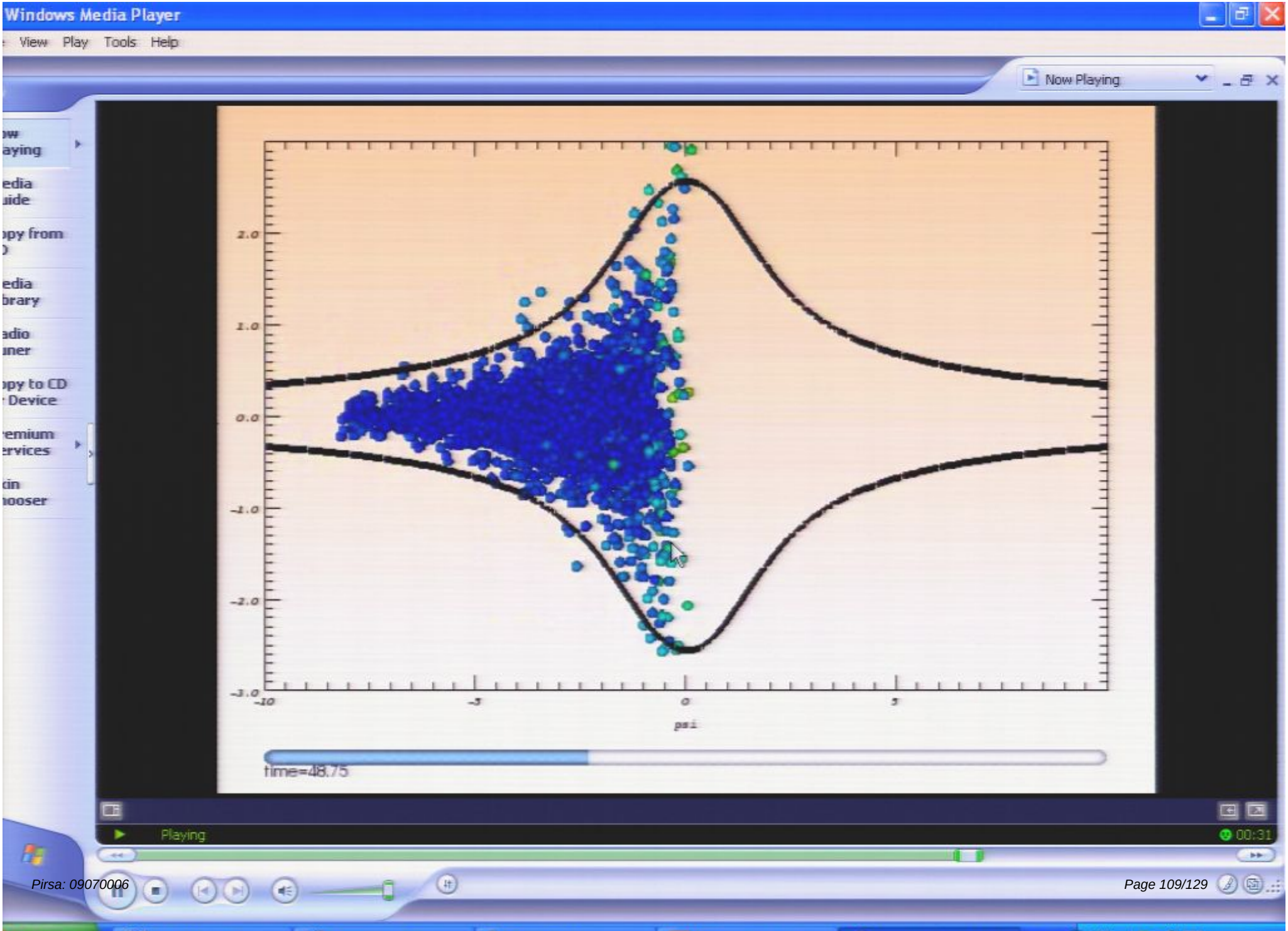

Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=24.31
Clip: billiard-peak
00:15

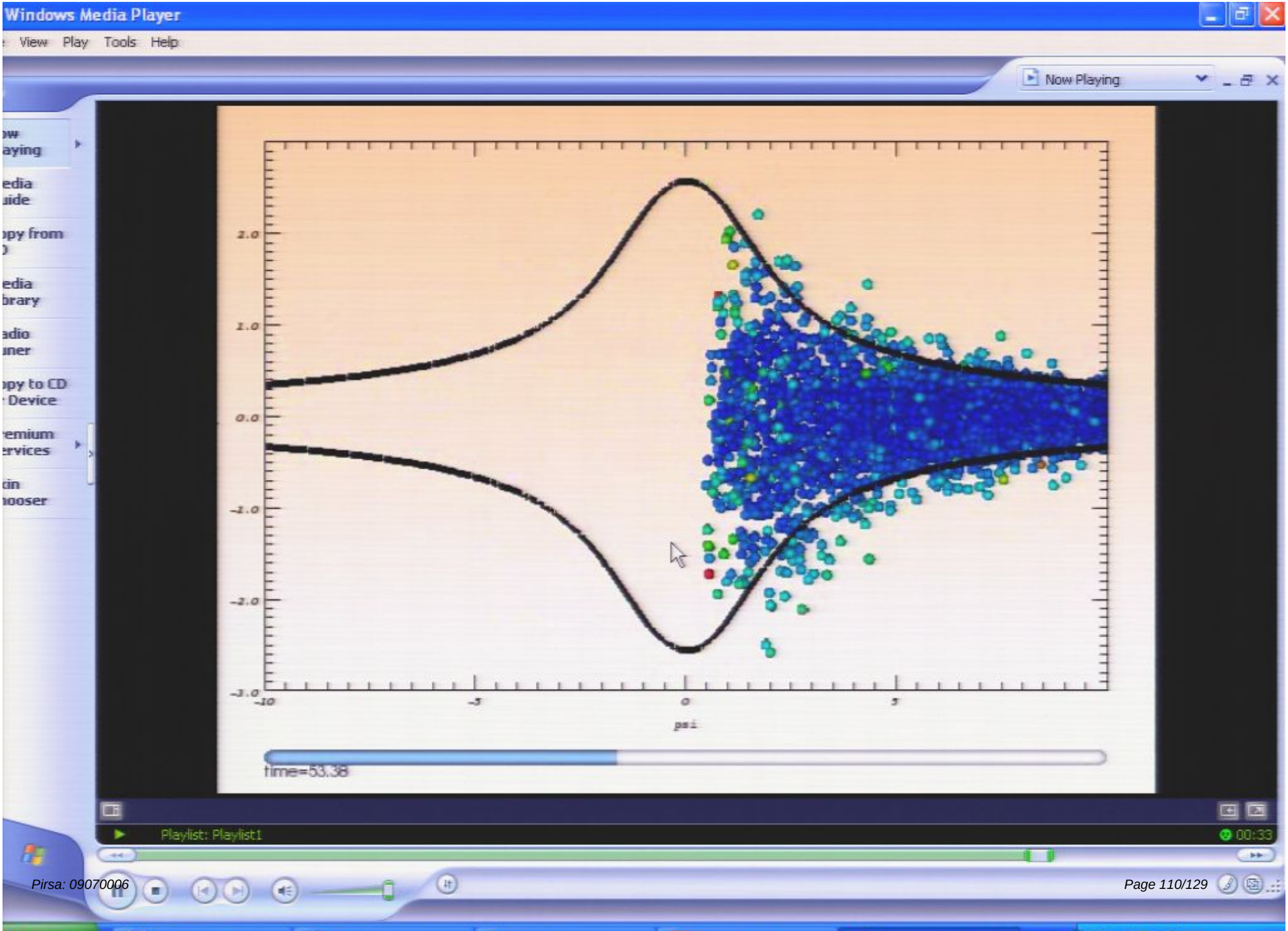

Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=32.38
Clip: billiard-peak
00:21

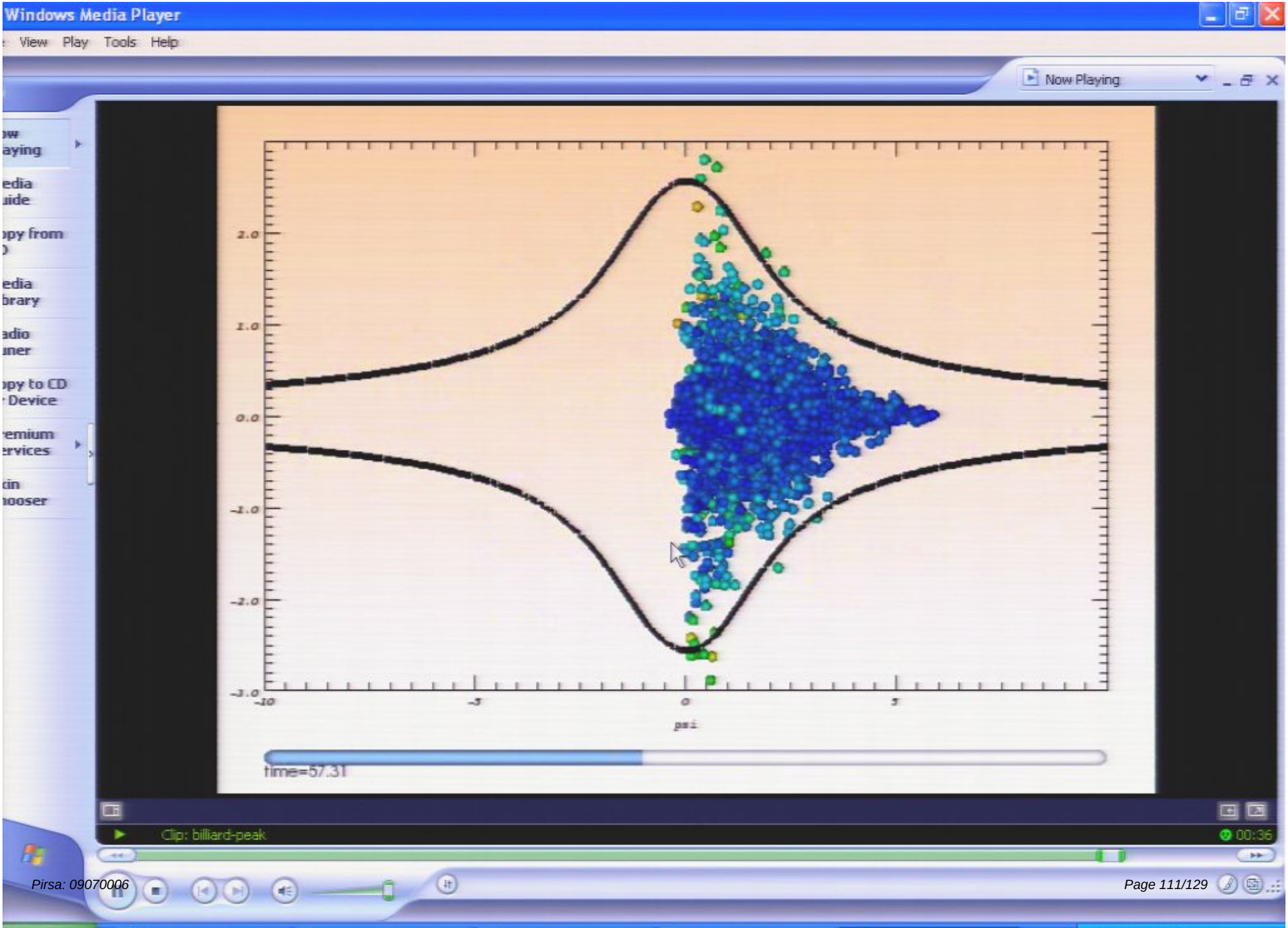

Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=36.81
Clip: billiard-peak
00:23

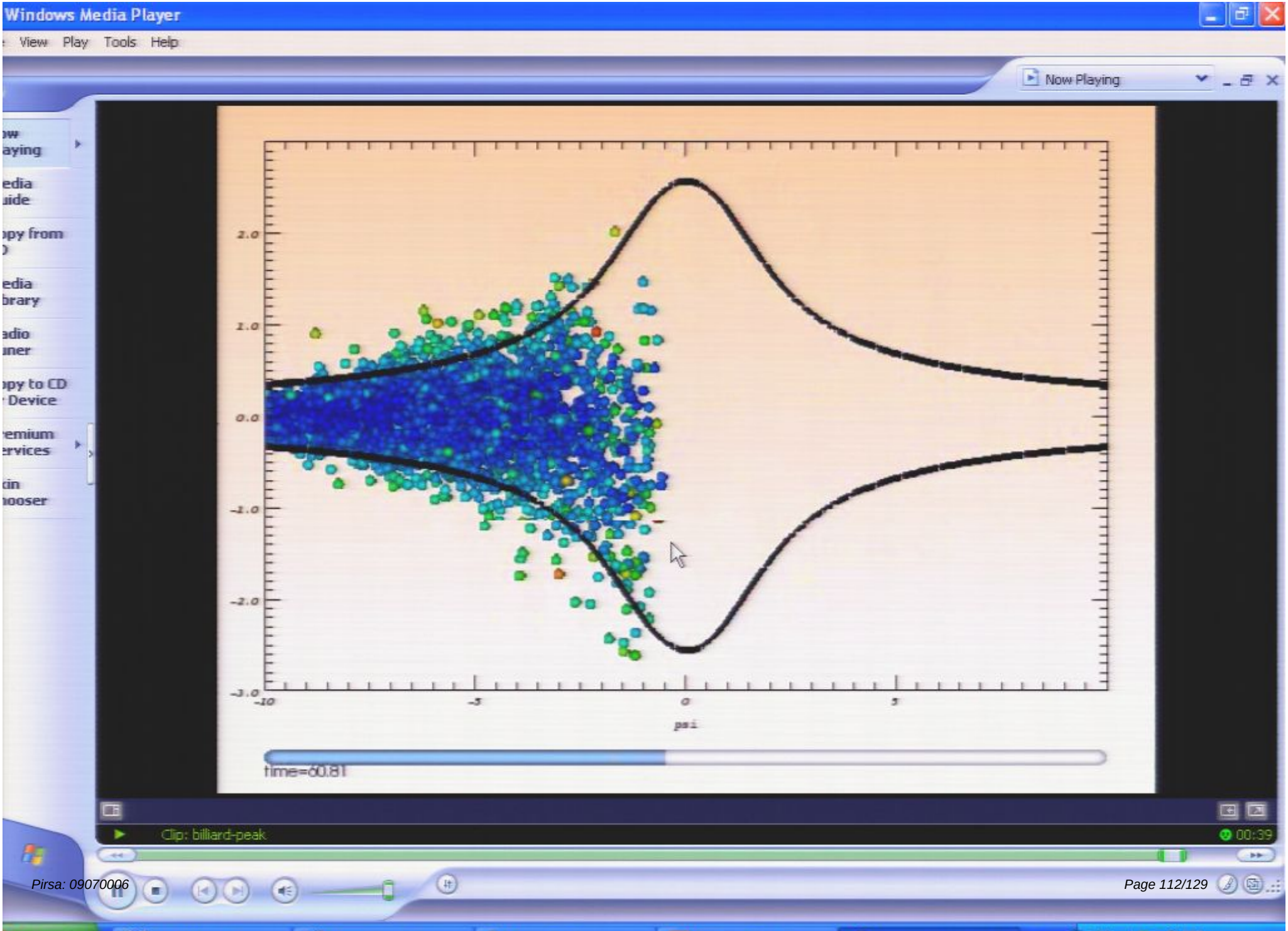

Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=41.12
Playing
00:26

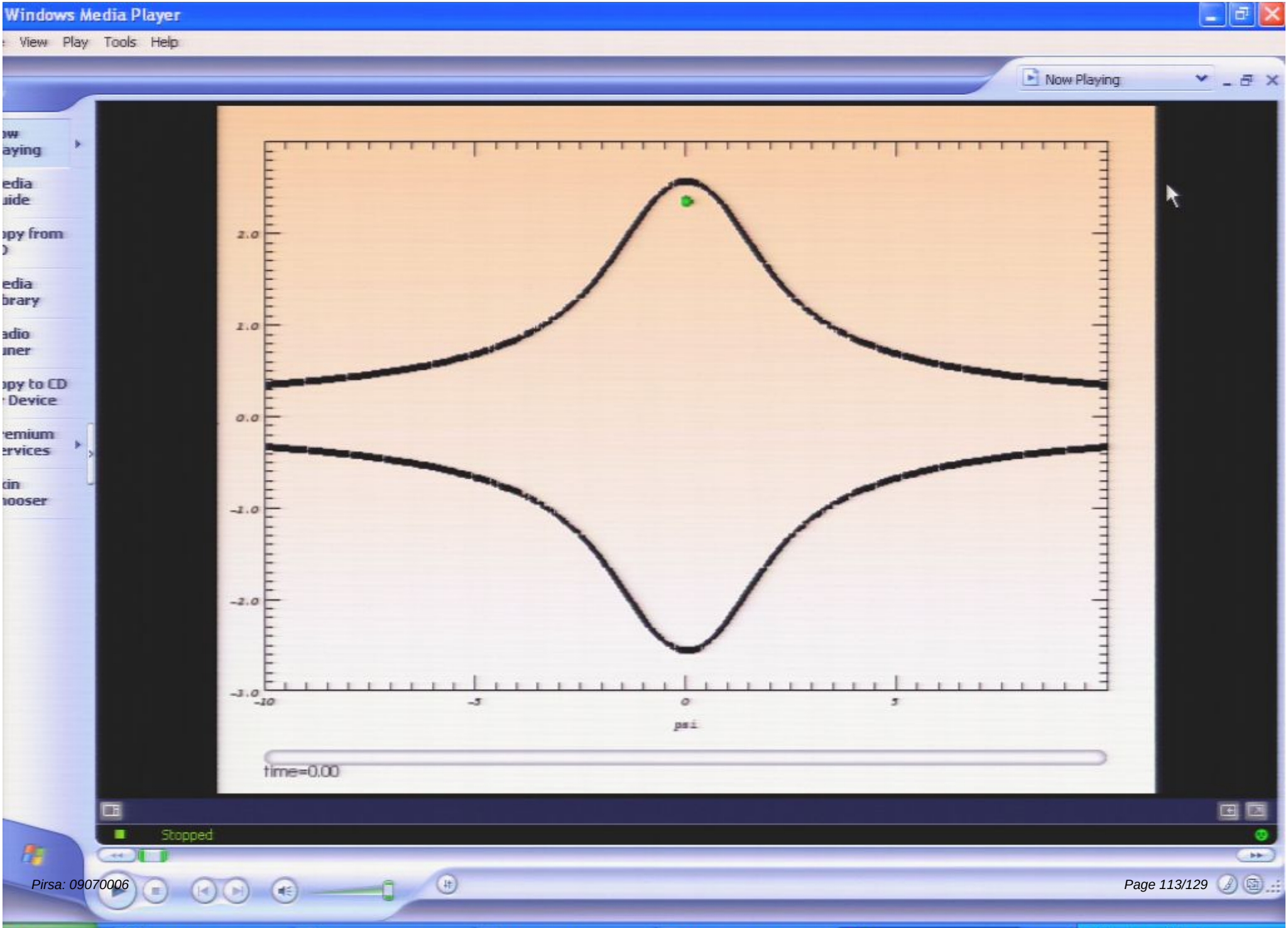

Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=44.56
Playing
00:28


Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=48.75
Playing
00:31


Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=53.38
Playlist: Playlist1
00:33

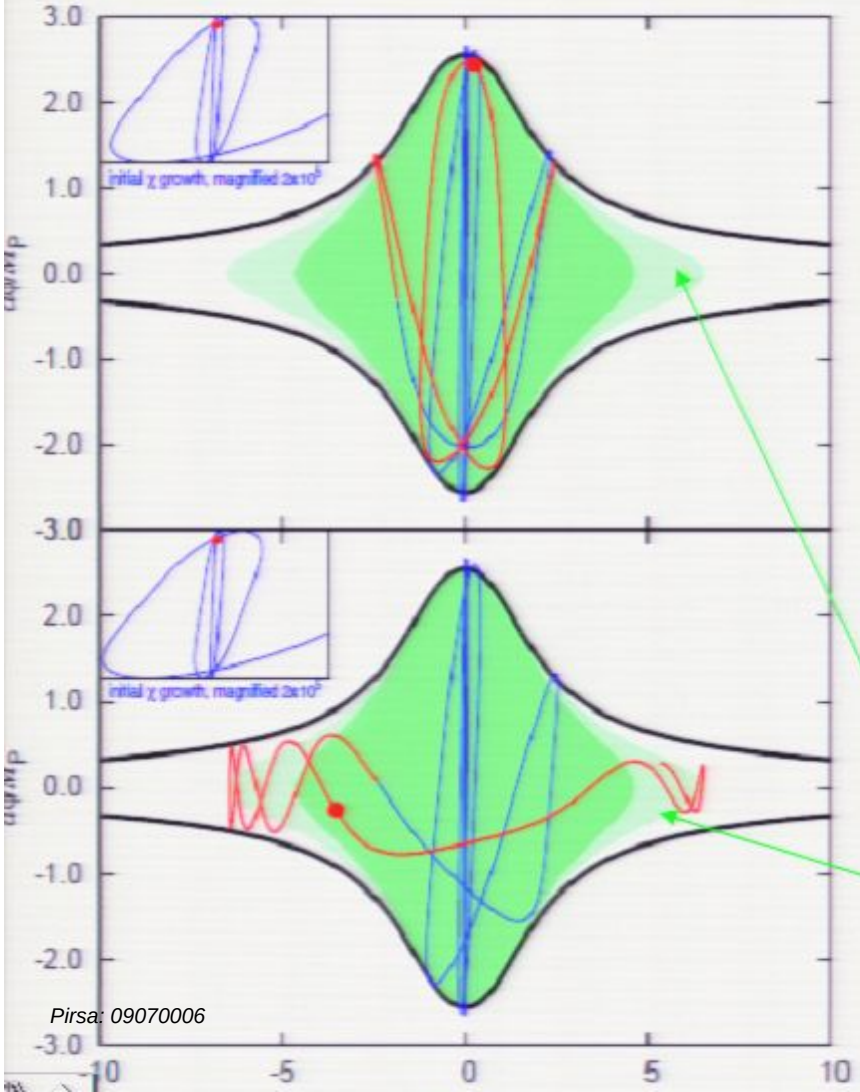

Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=57.31
Clip: billiard-peak
00:36


Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=60.81
Clip: billiard-peak
00:39


Windows Media Player
View Play Tools Help
Now Playing
2.0
1.0
0.0
-1.0
-2.0
-3.0
-10
-5
0
5
psi
time=0.00
Stopped

Instability of the k=0 mode, billiards picture

two classes of trajectories:

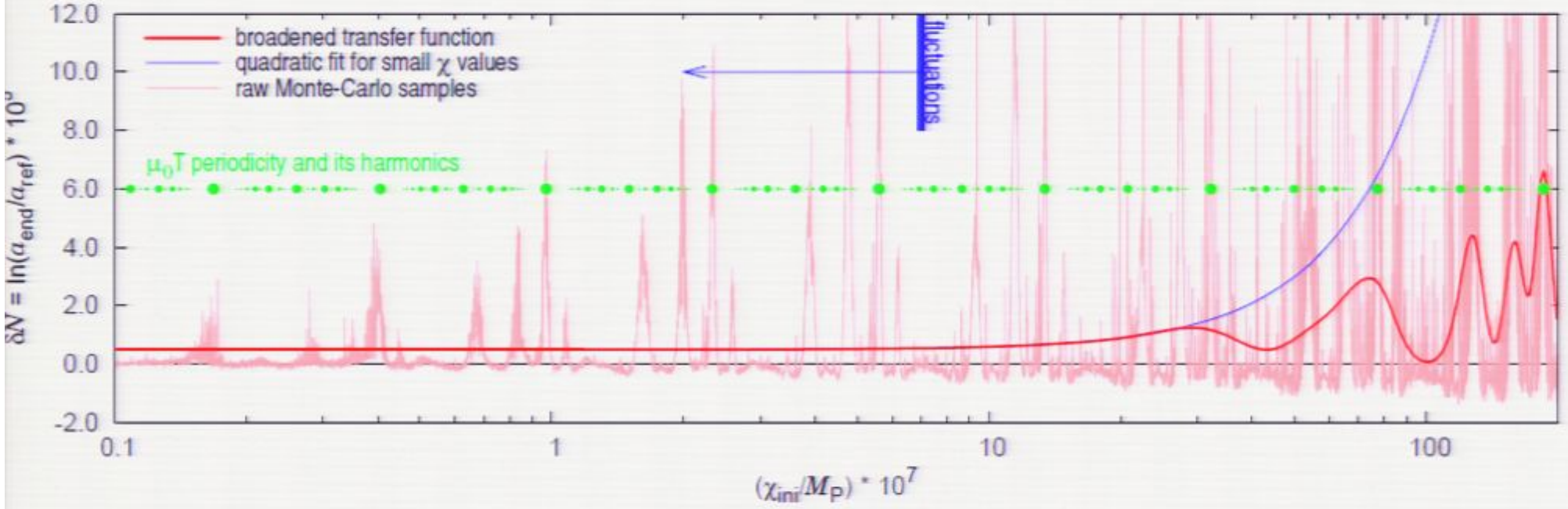


not entering the arms

entering the arms

arms close up during non-linear regime

$$V(x,y) = \frac{1}{2}g^2\phi^2\chi^2 + \sigma(\phi^2 + \chi^2)$$



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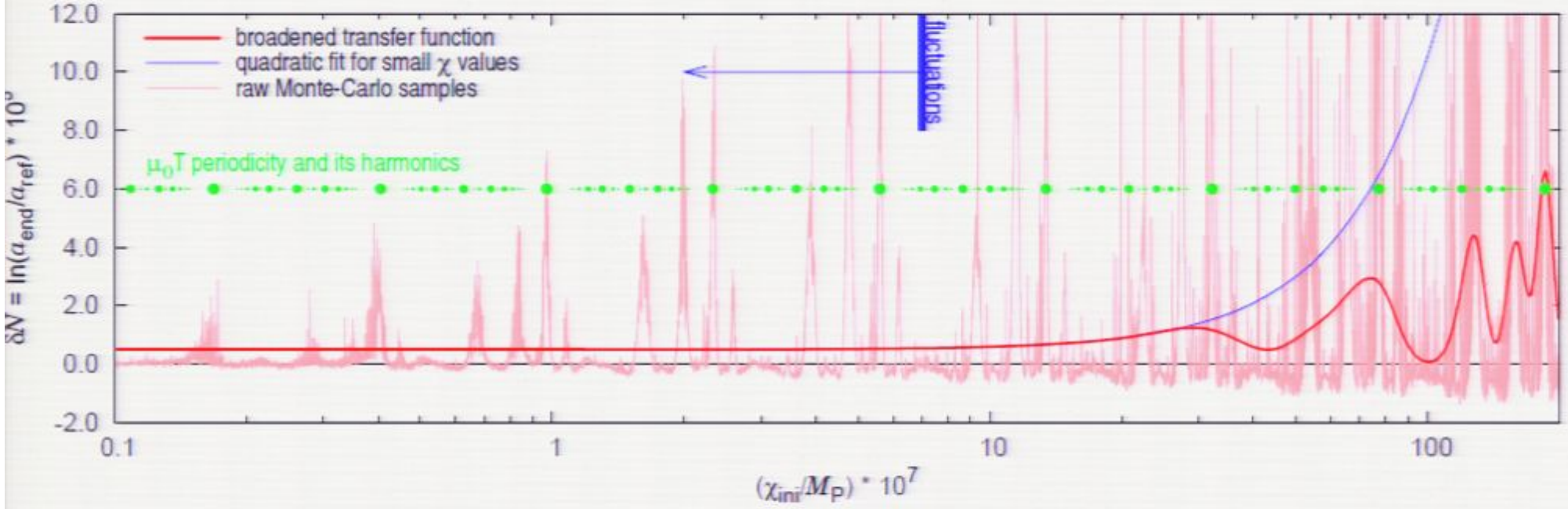
Non-Gaussian Spiked Patterns



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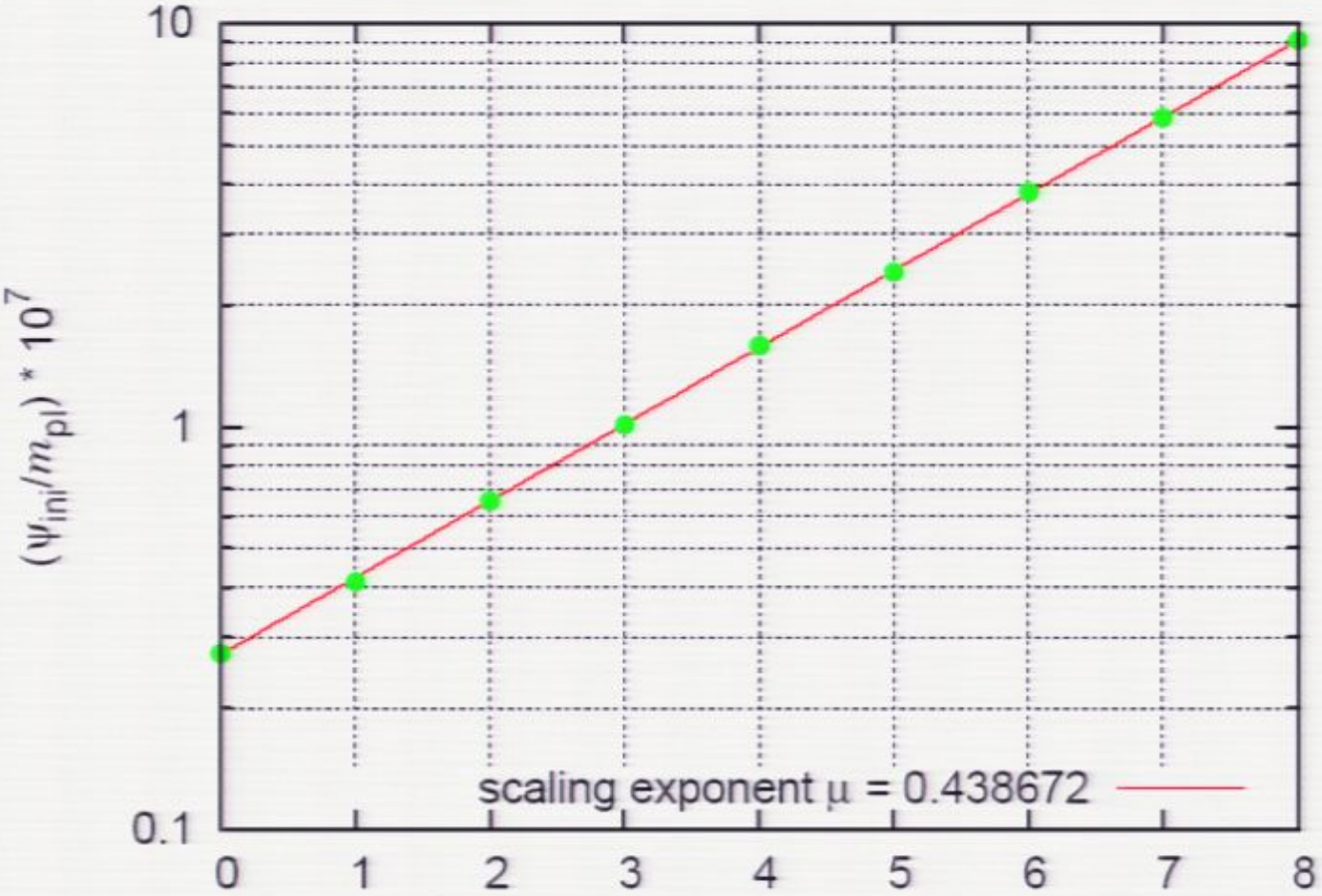

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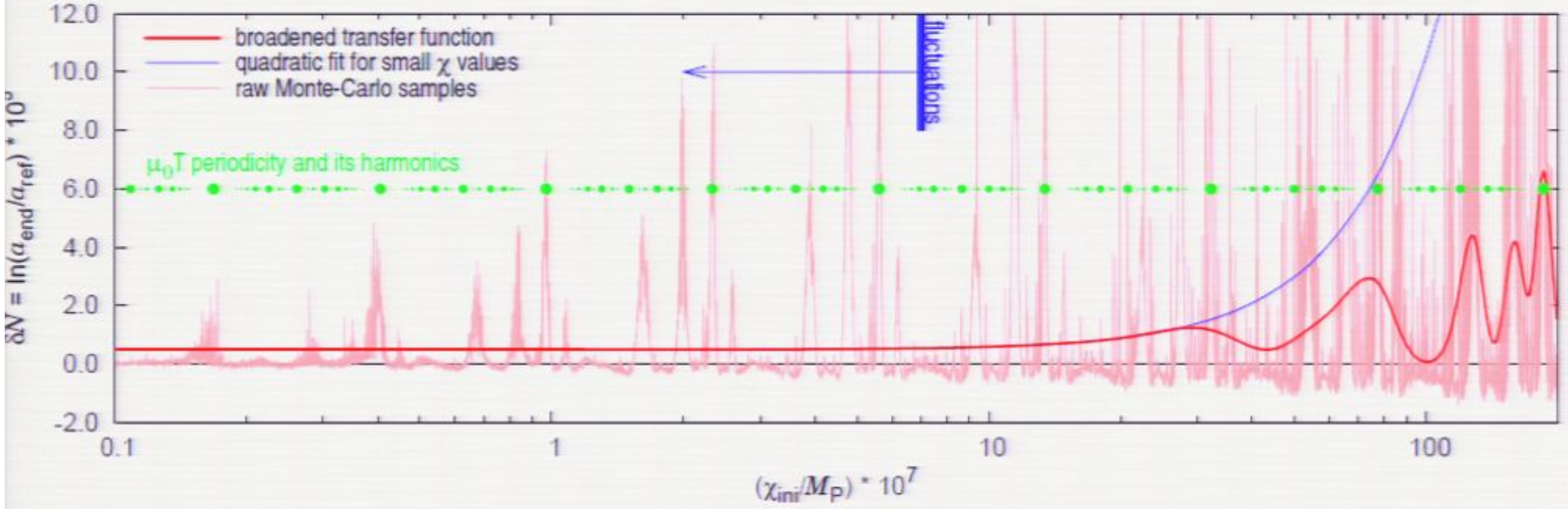

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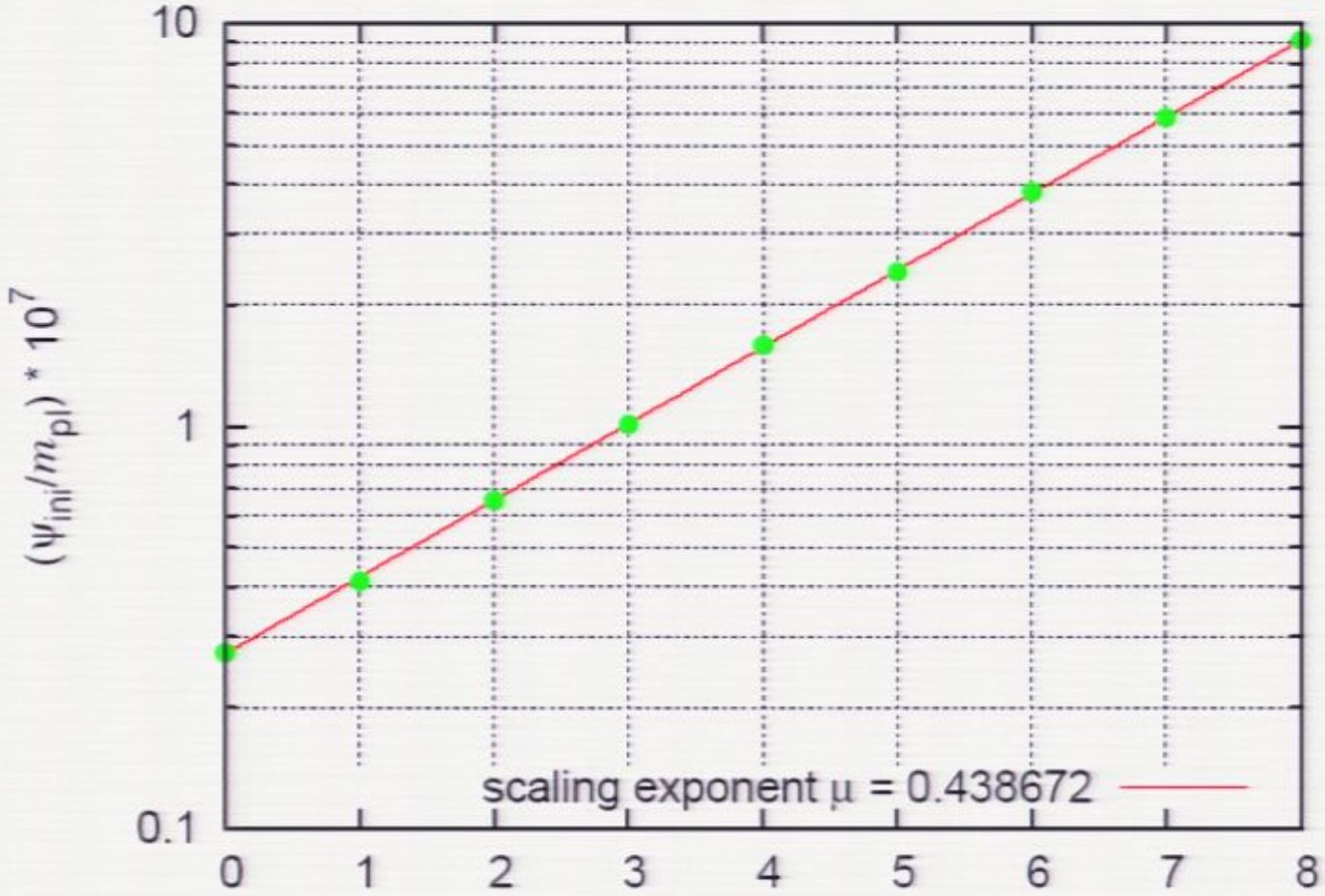

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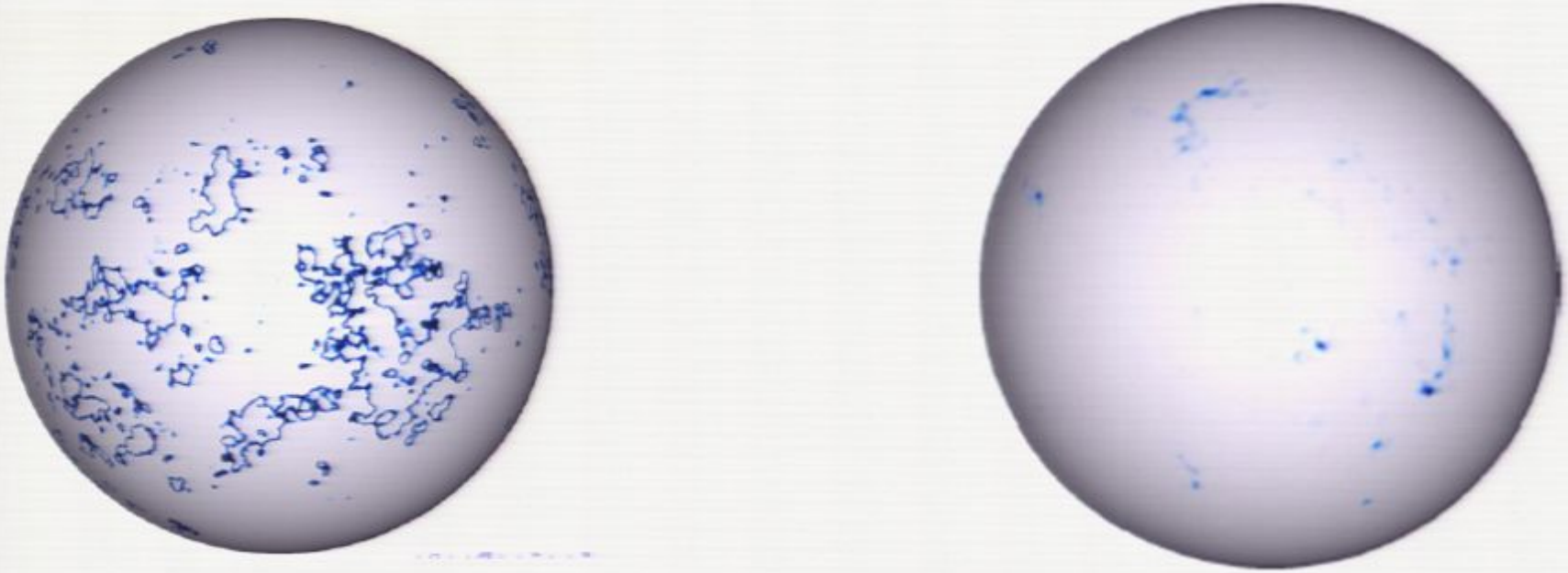


FIG. 3: What is plotted: $F(g)$ applied to scale-invariant GRF realization $\chi(x)$ with $1/f$ spectrum, with $F(g) = exp(-(g - t)^2/(2w^2))$ threshold set to $t = 5RMS(\chi)$, and peak width $w = 1RMS(\chi)$.

Implication: cold spot

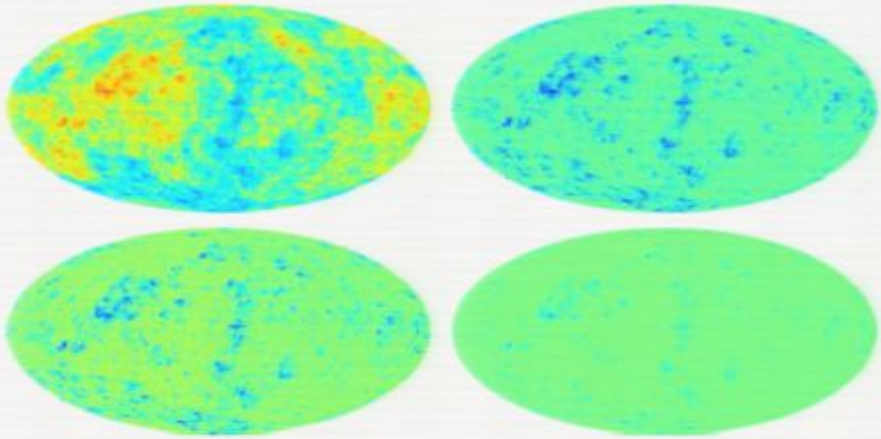
Positive δN

➔ positive curvature perturbation $\mathcal{R}$

➔ negative Newtonian potential

➔ negative $\delta T/T$ (ignoring ISW)

➔ cold spot



THE NON-GAUSSIAN COLD SPOT IN THE 3-YEAR WMAP DATA

M. Cruz[1]
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E-39005-Santander,
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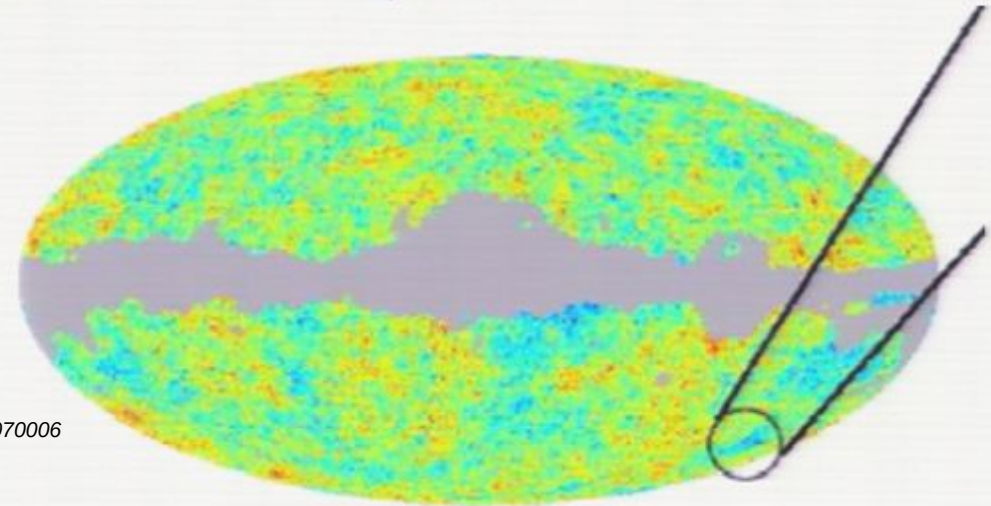

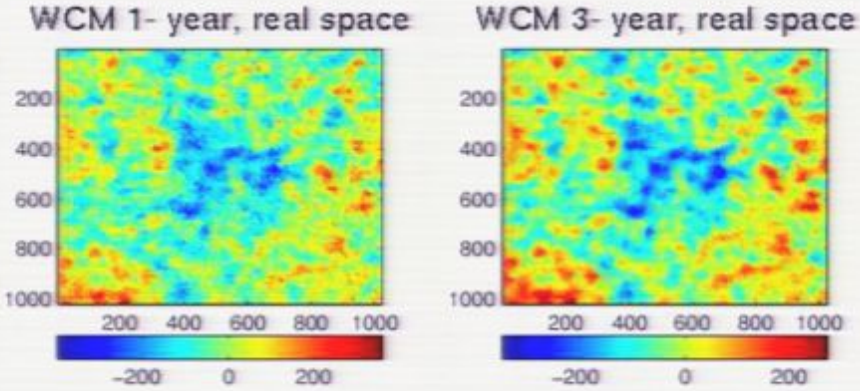

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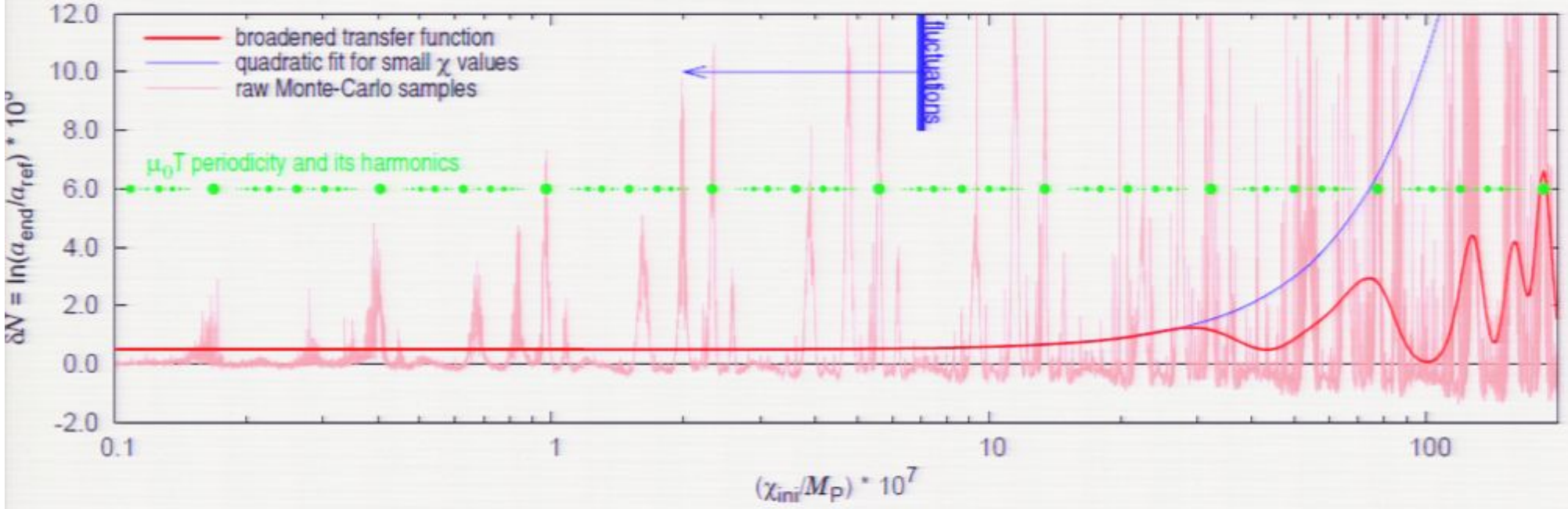

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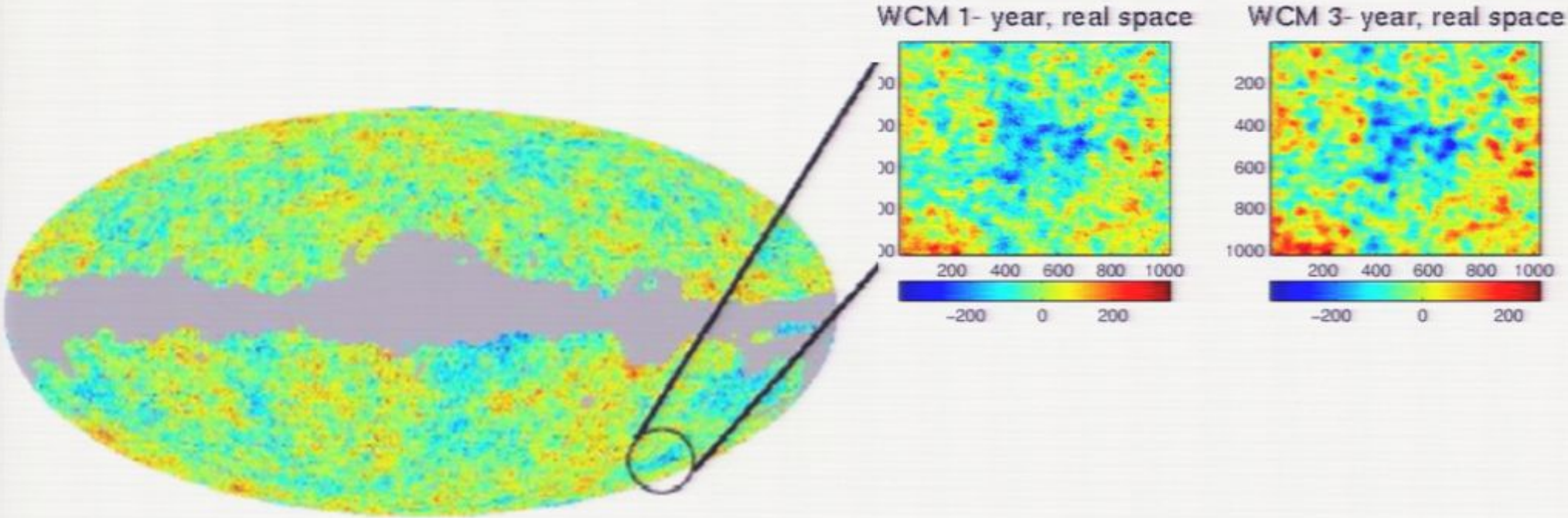

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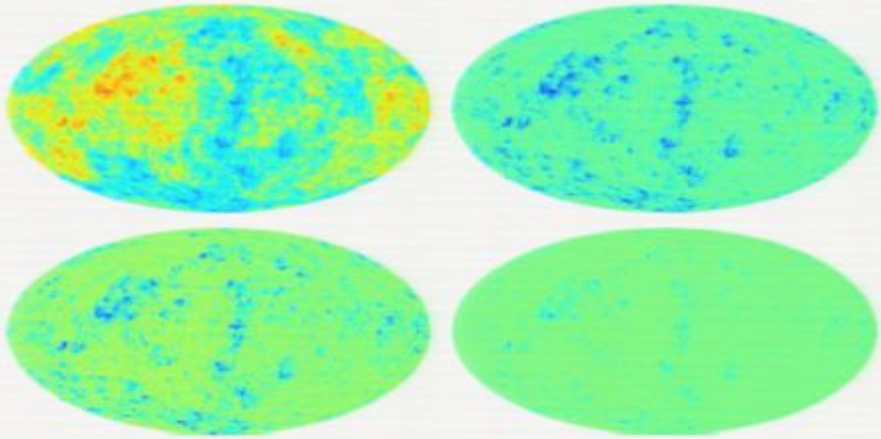

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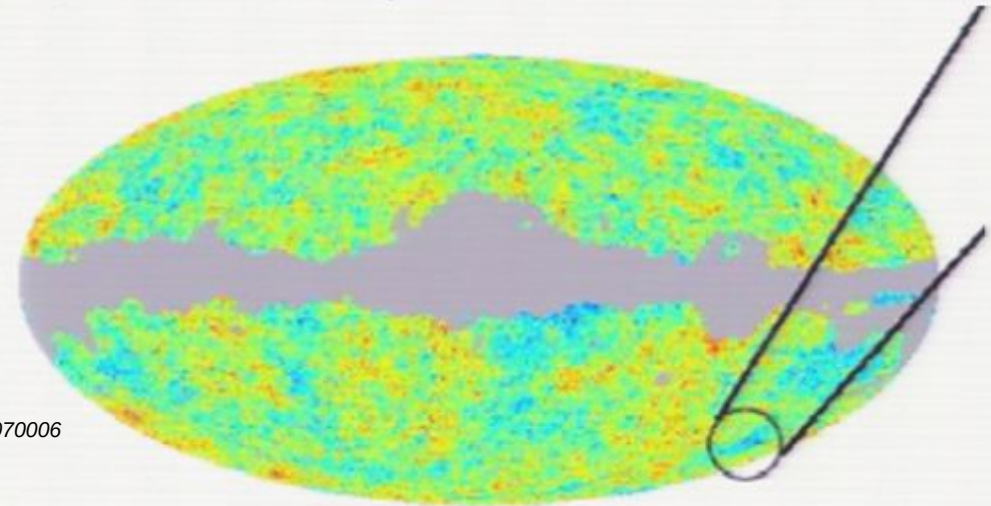

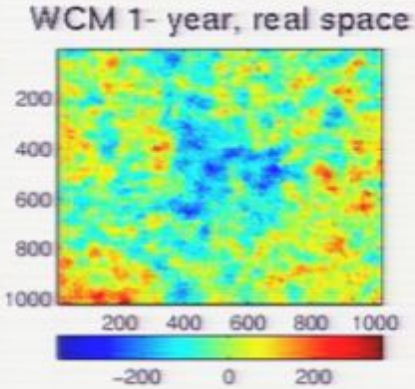

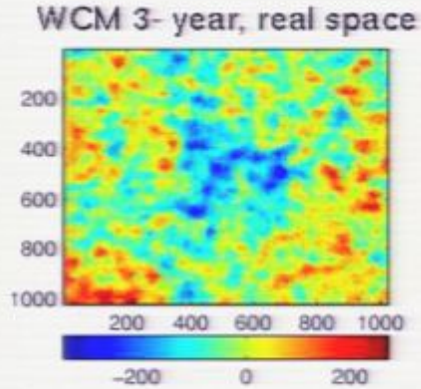

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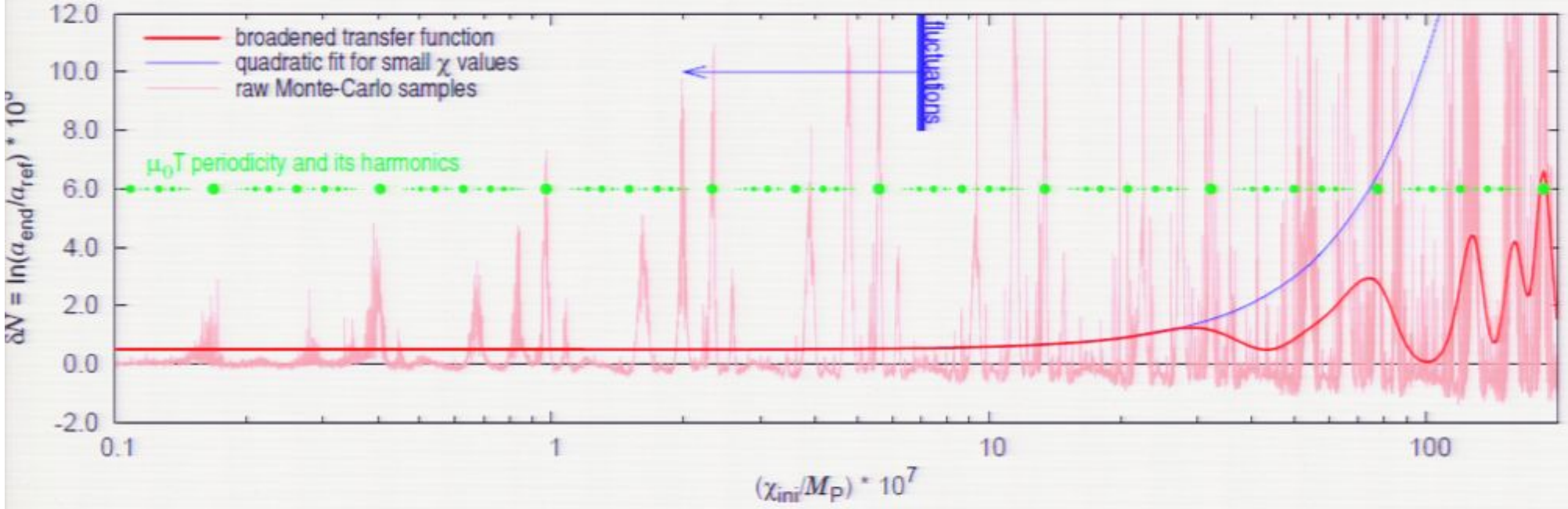

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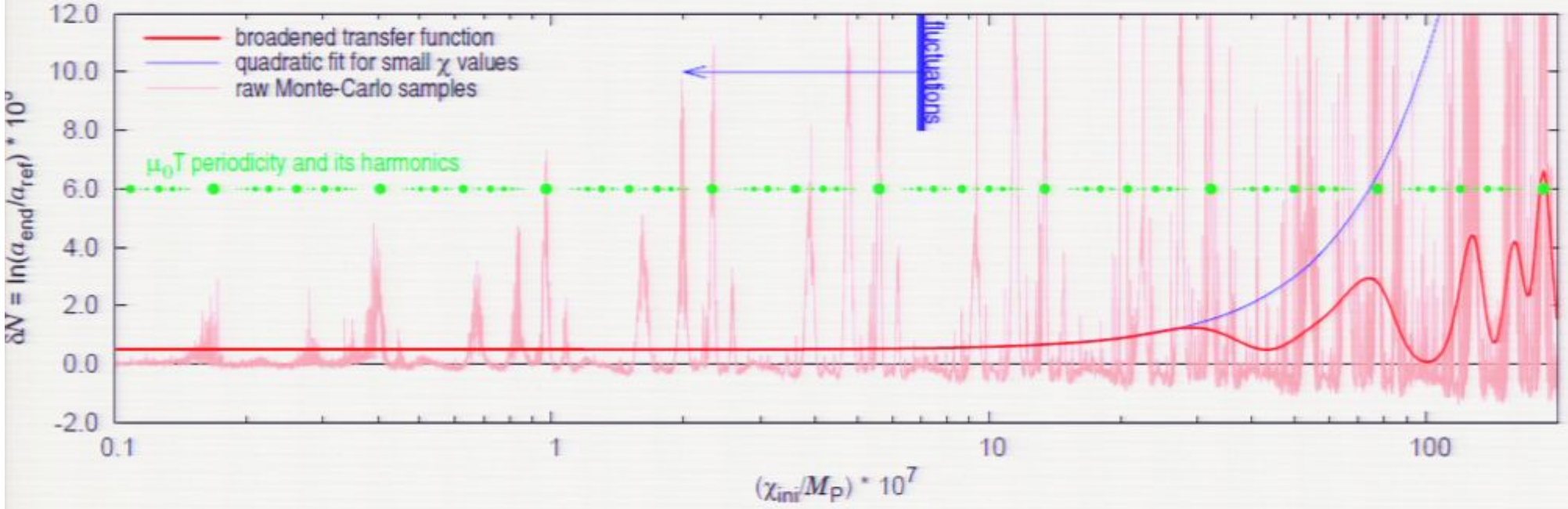

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