PASCOS 2011

Beauty is Distractive: A grazing ESP encounter during Inflation

arxiv: 1106.1891

Thorsten Battefeld
University of Goettingen
tbattefe@astro.physik.uni-goettingen.de

In collaboration with:

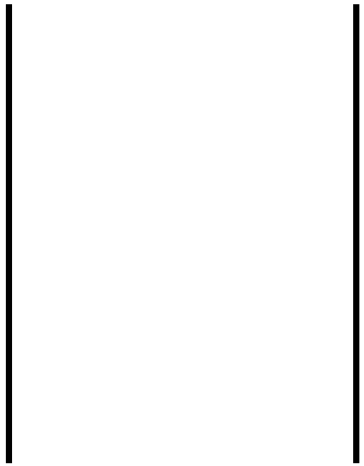
Diana Battefeld (Univ. of Goettingen), Christian Byrnes (Univ. of Bielefeld) and David Langlois (APC)

Can we constrain inflaton interactions outside
the observational window (i.e. 0-50 efolds before the end of inflation)?

Extra Species Loci/Points (ESL/ESP)

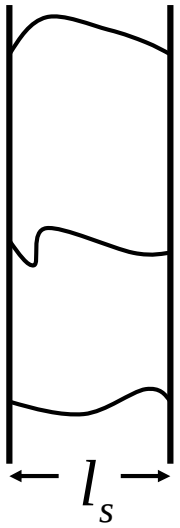
Locations, often associated with additional symmetries, where additional degrees of freedom (DOF) become light - need to be included in the low energy effective theory.

Example: D-branes
E.Witten 95.



Inter-brane-distance

scalar modulus field φ in 4D effective theory



Strings stretching between branes become light and are produced when the branes come close to each other – additional DOF.

Extra Species Loci/Points (ESL/ESP)

Other Examples: N.Seiberg, E.Witten 94; K.A.Intriligator, N.Seiberg 95;
S.H.Katz, D.R.Morrison, M.Ronen Pleser 96; M.Bershadsky,
K.A.Intrilligator, S.Kachru, D.R.Morrison, V.Sadov, C.Vafa 96;
Witten 96, …

ESL's are a common feature. Backreaction leads to attractive force towards the ESL.

Consequences:

- Moduli trapping/string Higgs effect (single encounter)
- Particle production during inflation and backreaction onto the inflaton (many encounters):
  - Trapped Inflation
    L.Kofman, A.Linde, X.Liu, A.Maloney, L.McAllister, E.Silverstein 04;
    D.Green, B.Horne, L.Senatore, E.Silverstein 09;
    D.Battefeld, T.Battefeld 10; …
  - Monodromi Inflation
    E.Silverstein, A.Westphal 08, …

Question

Are there observable consequences of a single grazing ESP encounter (D=2 or bigger) outside the observable window?

In 1106.1891 we work in the 4D, low energy effective theory and discuss

- a grazing ESP encounter (two inflatons),
- non-Gaussianities produced during such an event (bi- and tri-spectrum),
- a model where the ESP encounter provides the dominant contribution to the power-spectrum,
- connection to trapped inflation,
- modulated trapping (followup to Langlois, Sorbo 09),
- ESLs.

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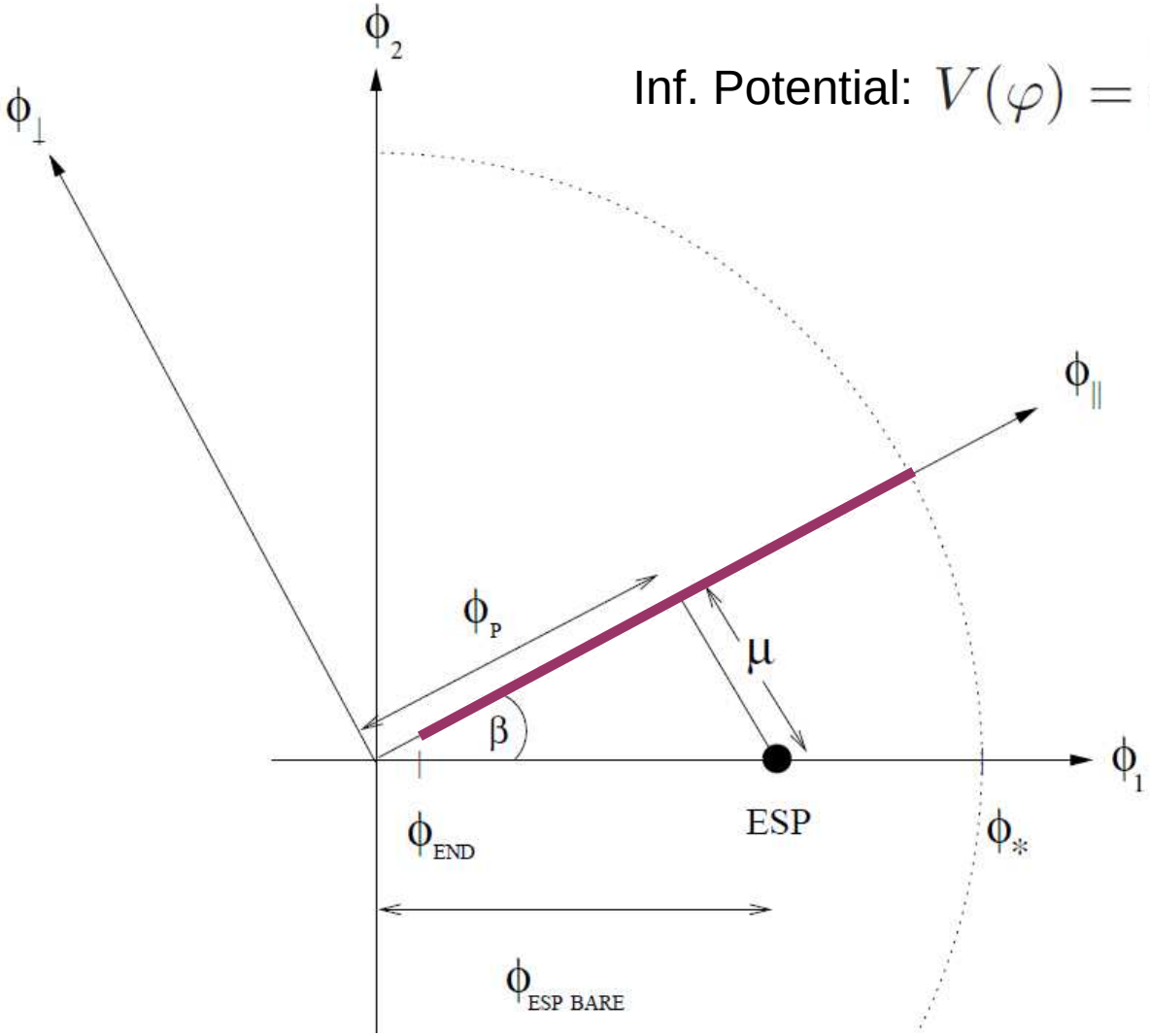
Encounter with a single ESP - Setup

New, light degrees of freedom near ESP (modeled by mass-less, scalar field χ)



Inf. Potential: $V(\varphi) = \frac{1}{2}m^2 \sum_i \varphi_i^2 \equiv \frac{1}{2}m^2 \vec{\varphi}^2$

In absence of an ESP, all initial field values on dotted line are equivalent. (purple: inflationary trajectory)

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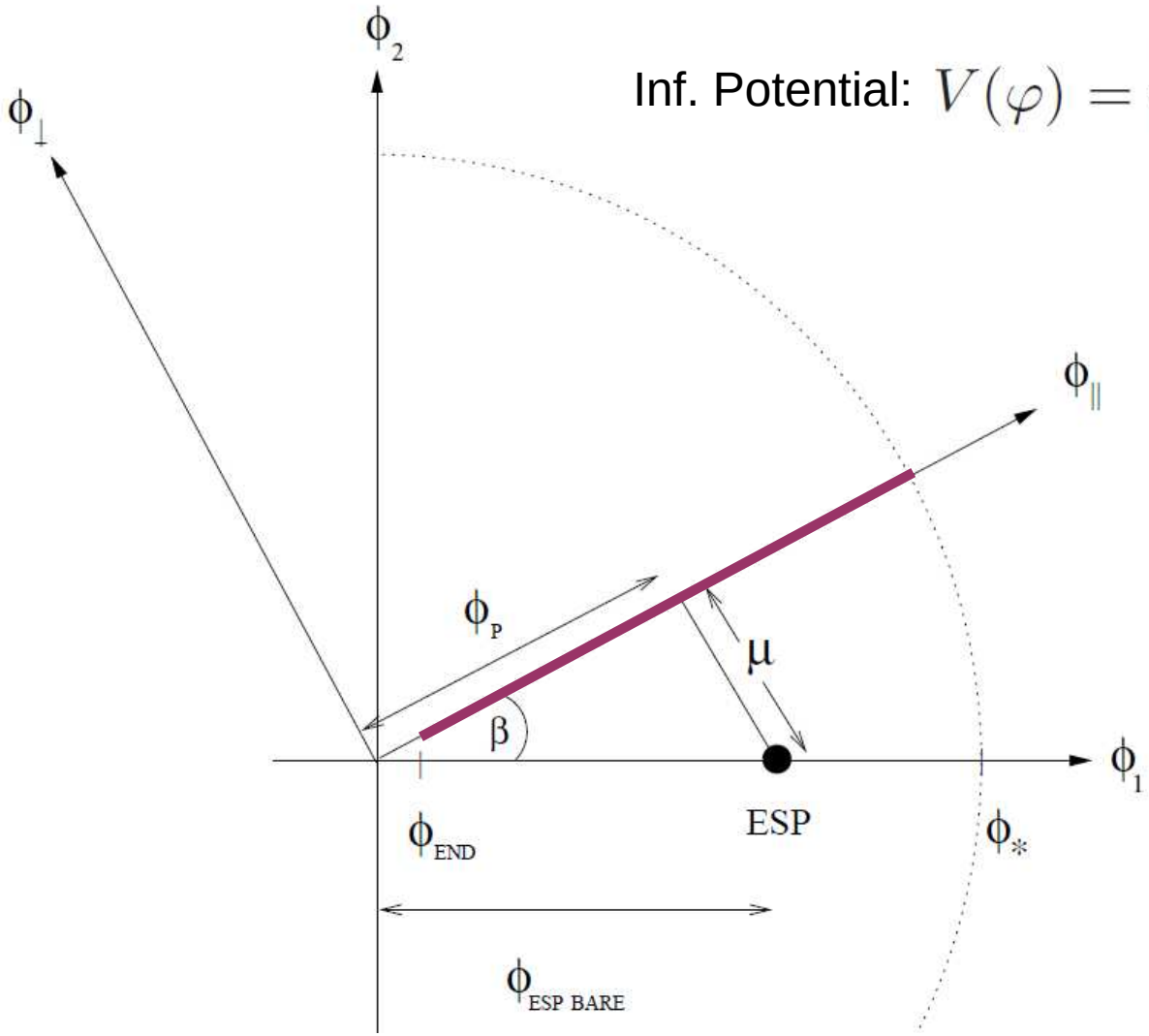

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Interaction with inflatons:

$$\mathcal{L}_{int} = -\frac{1}{2}g^2\chi^2(\vec{\varphi} - \vec{\varphi}_{\rm ESP})^2$$

Impact parameter:

$$\mu = \min(|\vec{\varphi}(t) - \vec{\varphi}_{\rm ESP}|)$$

$$v_p \equiv |\dot{\vec{\varphi}}(t_p)| \simeq \sqrt{\frac{2}{3}}m$$

Particle production

Extensively discussed in the theory of pre-heating after inflation; single field:

J.H.Traschen, R.H.Brandenberger 90;
L.Kofman, A.D.Linde, A.A.Starobinsky 97; …
review: B.A.Bassett, S.Tsujikawa, D.Wands 05

Multiple fields:

D.Battefeld, S.Kawai 08;
D.Battefeld 08;
D.Battefeld, T.B., J.T.Giblin 09;
J.Braden, L.Kofman, N.Barnaby 10;

We can directly apply these known results;

L.Kofman, A.D.Linde, A.A.Starobinsky 97; L.Kofman, A.Linde, X.Liu, A.Maloney, L.McAllister, E.Silverstein 04; D.Battefeld, T.Battefeld 10

Particle production and backreaction

Energy density

$$\rho_\chi \approx n_p \left(\frac{a_p}{a}\right)^3 m_\chi^{eff}$$

with $m_\chi^{eff} = g|\vec{\varphi} - \vec{\varphi}_{\rm ESP}|$

Number density

$$n \equiv n_p \left(\frac{a_p}{a}\right)^3 \Theta(t - t_p)$$

with

$$n_p = \frac{g^{3/2} v_p^{3/2}}{(2\pi)^3} e^{-\frac{\pi g \mu^2}{v_p}}$$

Once particles are produced, backreaction yields a classical attractive force towards the ESP:

$$\ddot{\varphi}_i + 3H\dot{\varphi}_i + \frac{\partial V}{\partial \varphi_i} = -\frac{\partial \rho_\chi}{\partial \varphi_i}$$

L.Kofman, A.D.Linde, A.A.Starobinsky 97; L.Kofman, A.Linde, X.Liu, A.Maloney, L.McAllister, E.Silverstein 04; D.Battefeld, T.Battefeld 10

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$$\mu \approx \frac{\varphi_p}{\varphi_*} \varphi_\perp^*$$

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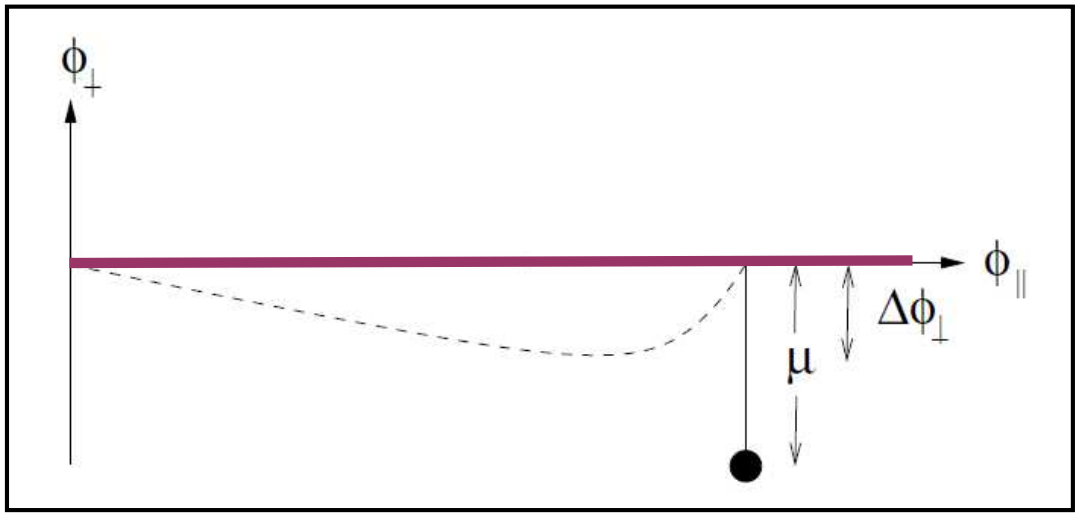
Can compute observables (Power-spectrum, NG, …) in delta-N formalism (see paper)

Consequence:



- Slowing down
- Bending of trajectory
- Potentially trapped

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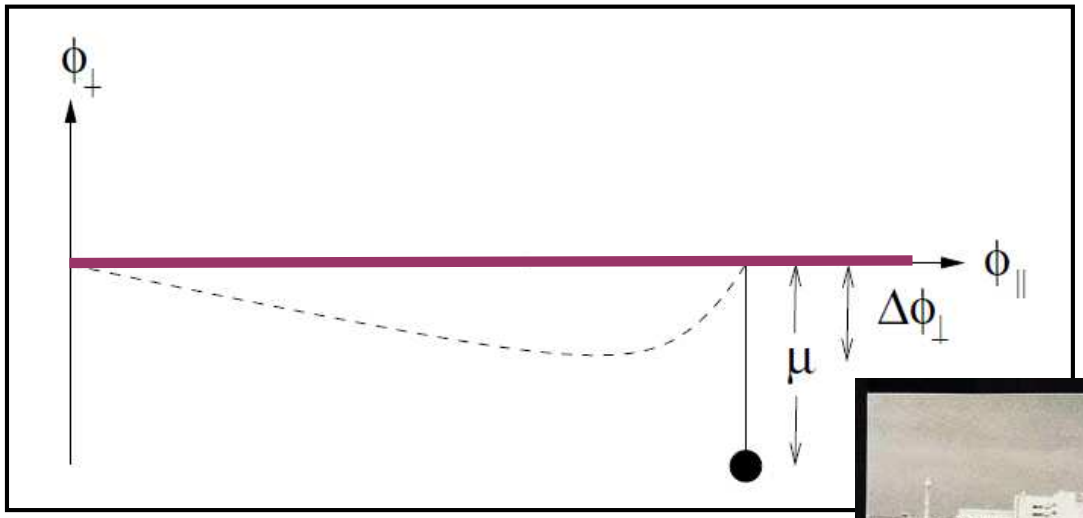

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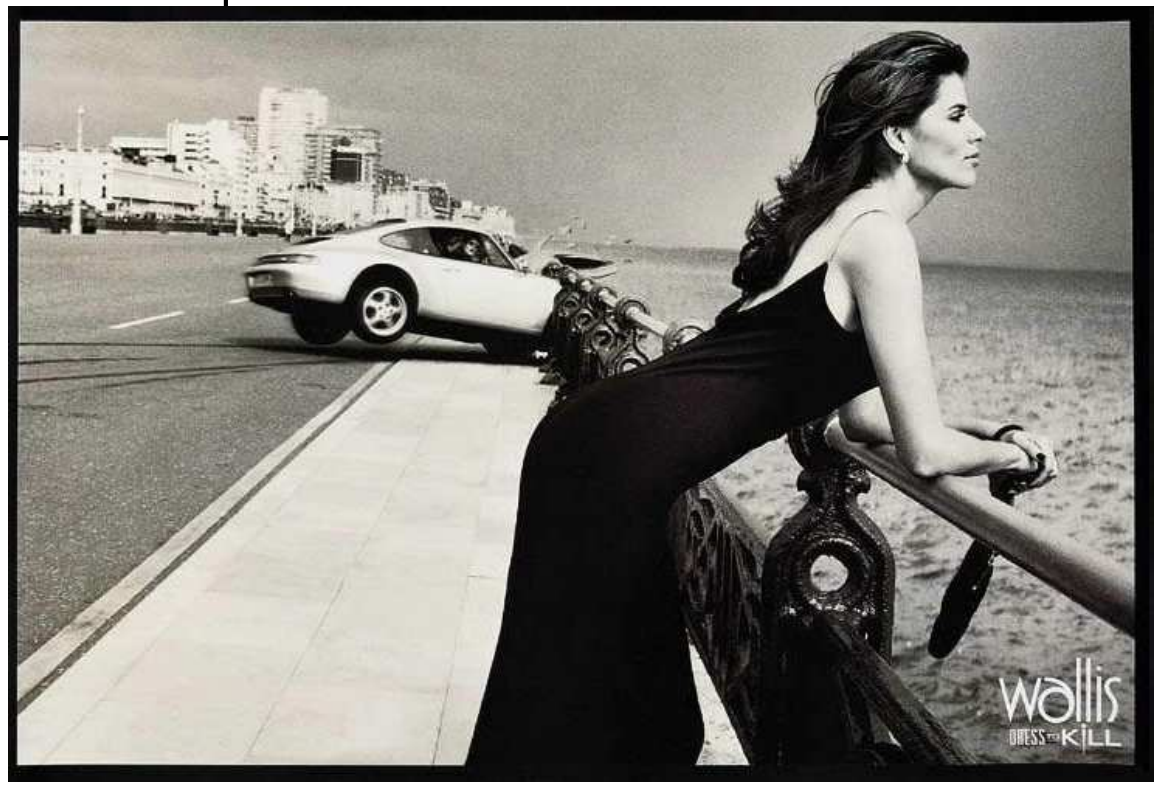

photographer: Bob Carlos

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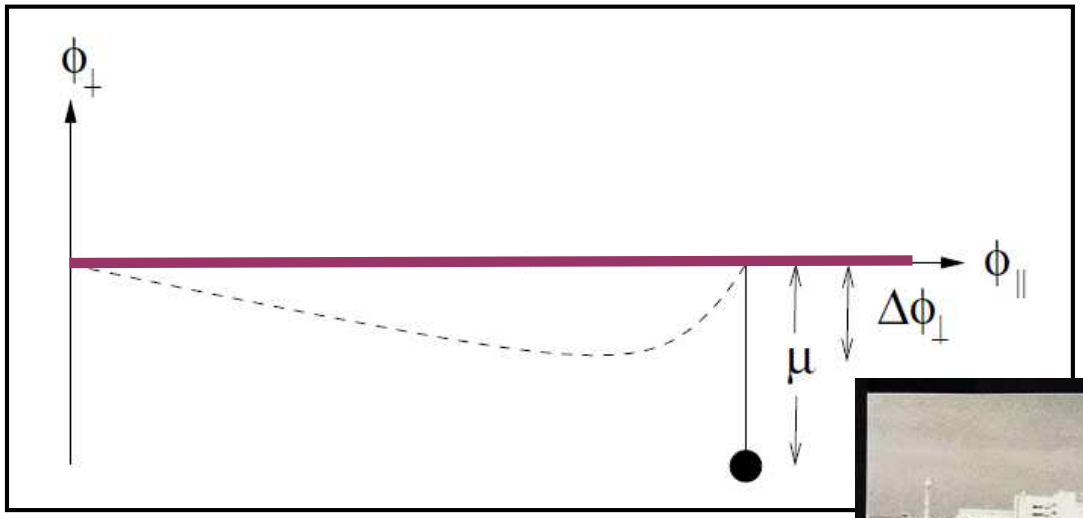

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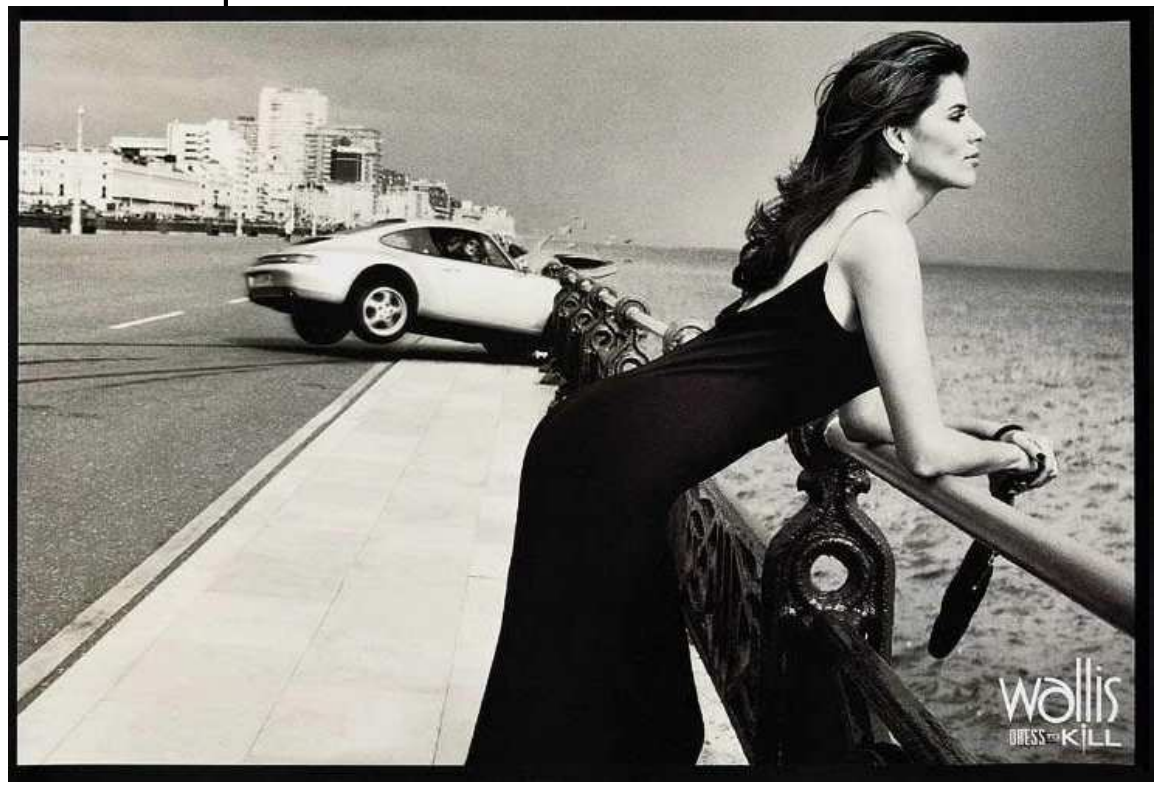

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Beauty is Distractive

$$N = \int_{t_*}^{t_{end}} H dt = N_{\rm SR} + \Delta N$$

$$\Delta N = \Delta N_{sl} + \Delta N_{ge}$$

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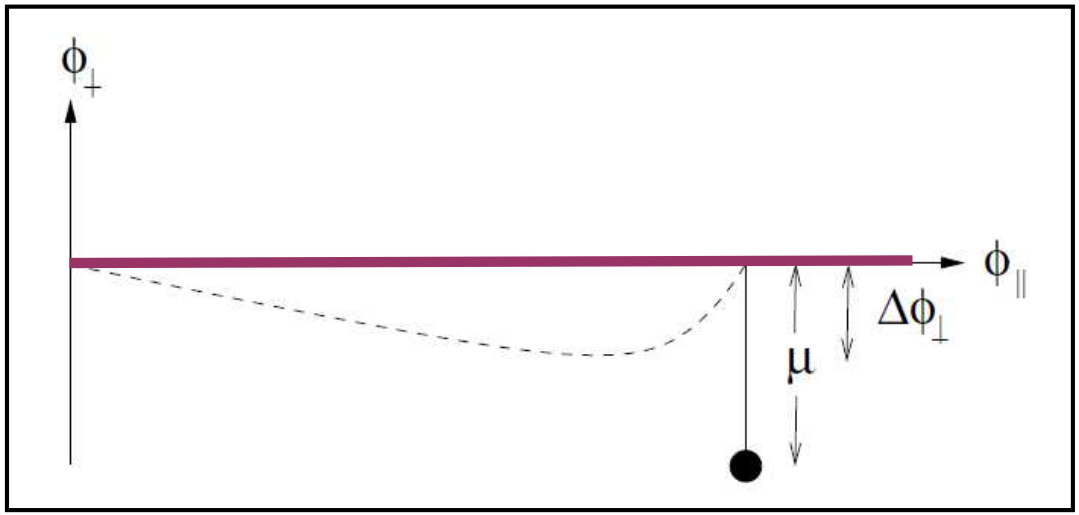

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Often dominant effect:

$$\Delta N_{sl} \approx -\frac{H_p \Delta\varphi_\parallel}{\dot\varphi_*} = \frac{g^{5/2} v_p^{1/2}}{9 H_p (2\pi)^3} e^{-\pi g \frac{\mu^2}{v_p}}$$

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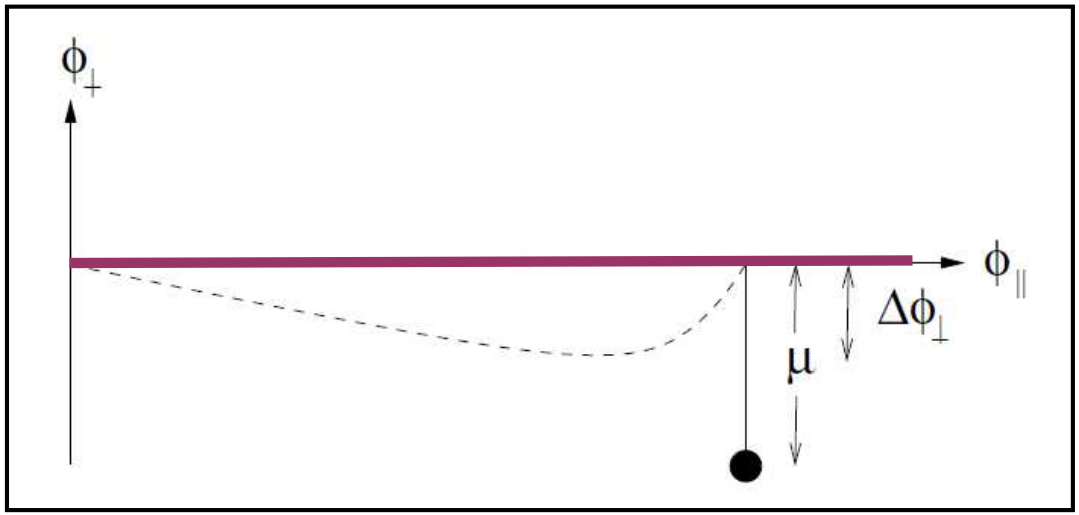

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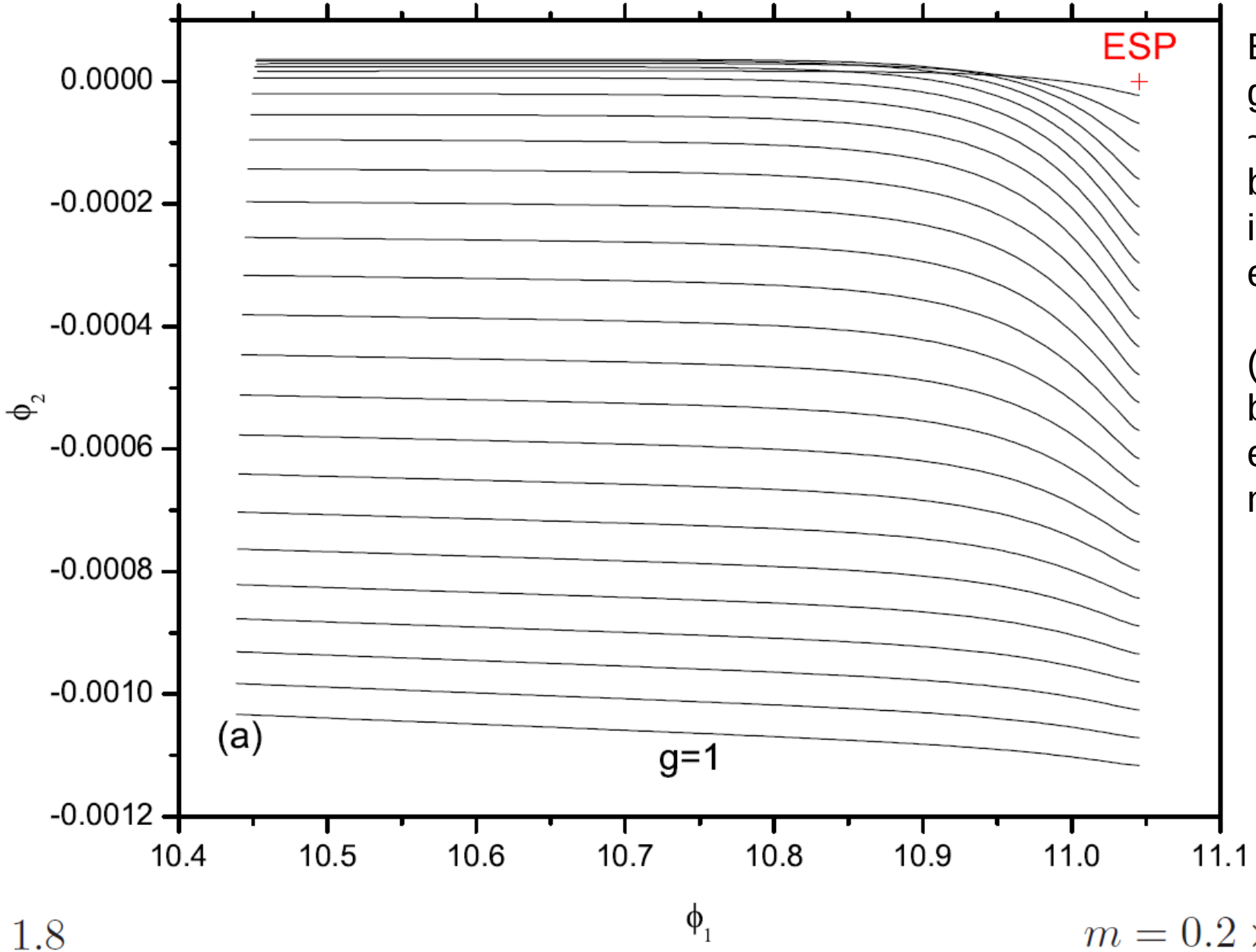
Can use delta-N formalism to compute observables.

Example: no trapping, slowing down dominates



ESP is grazed ~30 e-folds before inflation ends

(slow roll before encounter no shown)

$g_{\rm trap} \approx 1.8$

$m = 0.2 \times m_{\rm COBE}$

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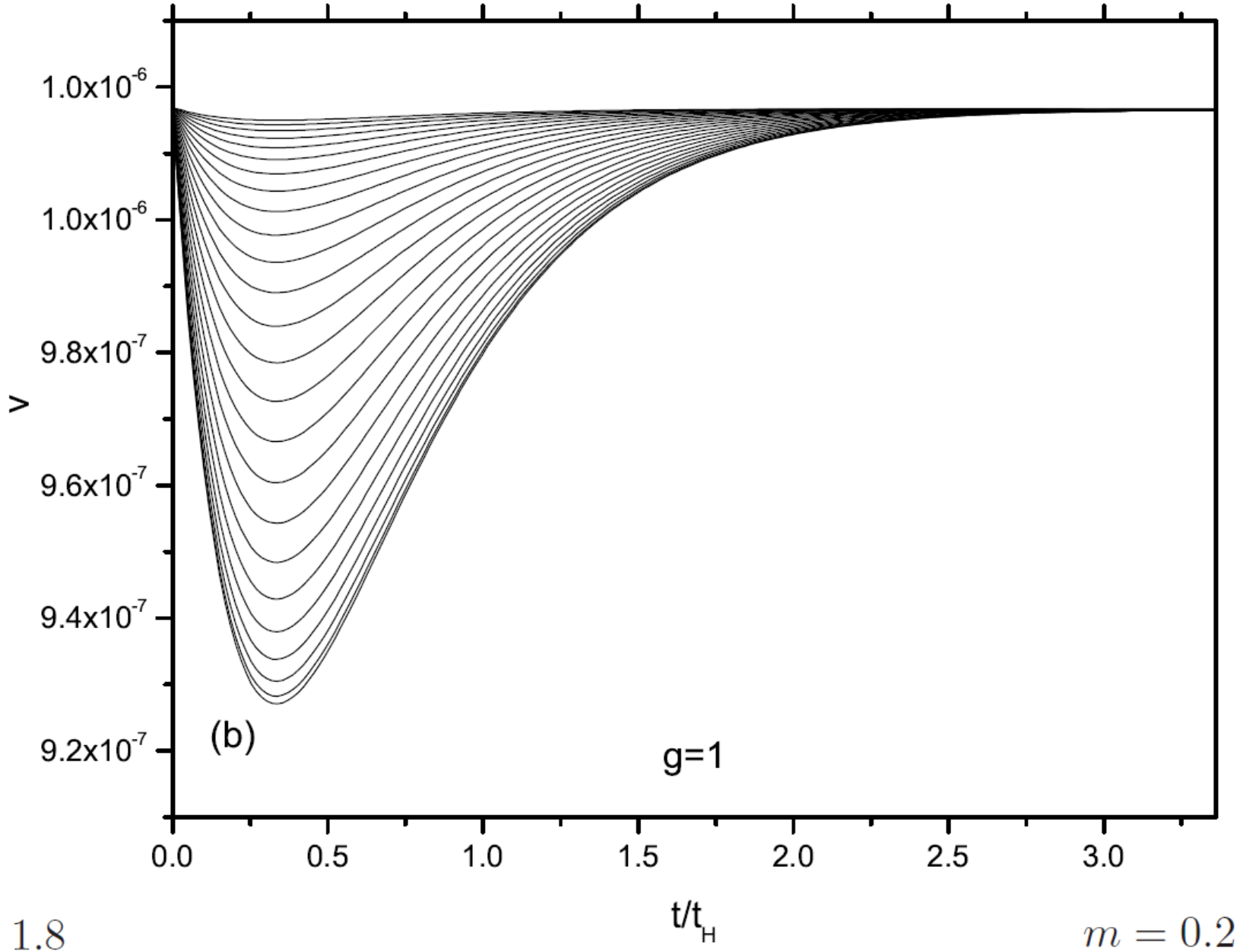

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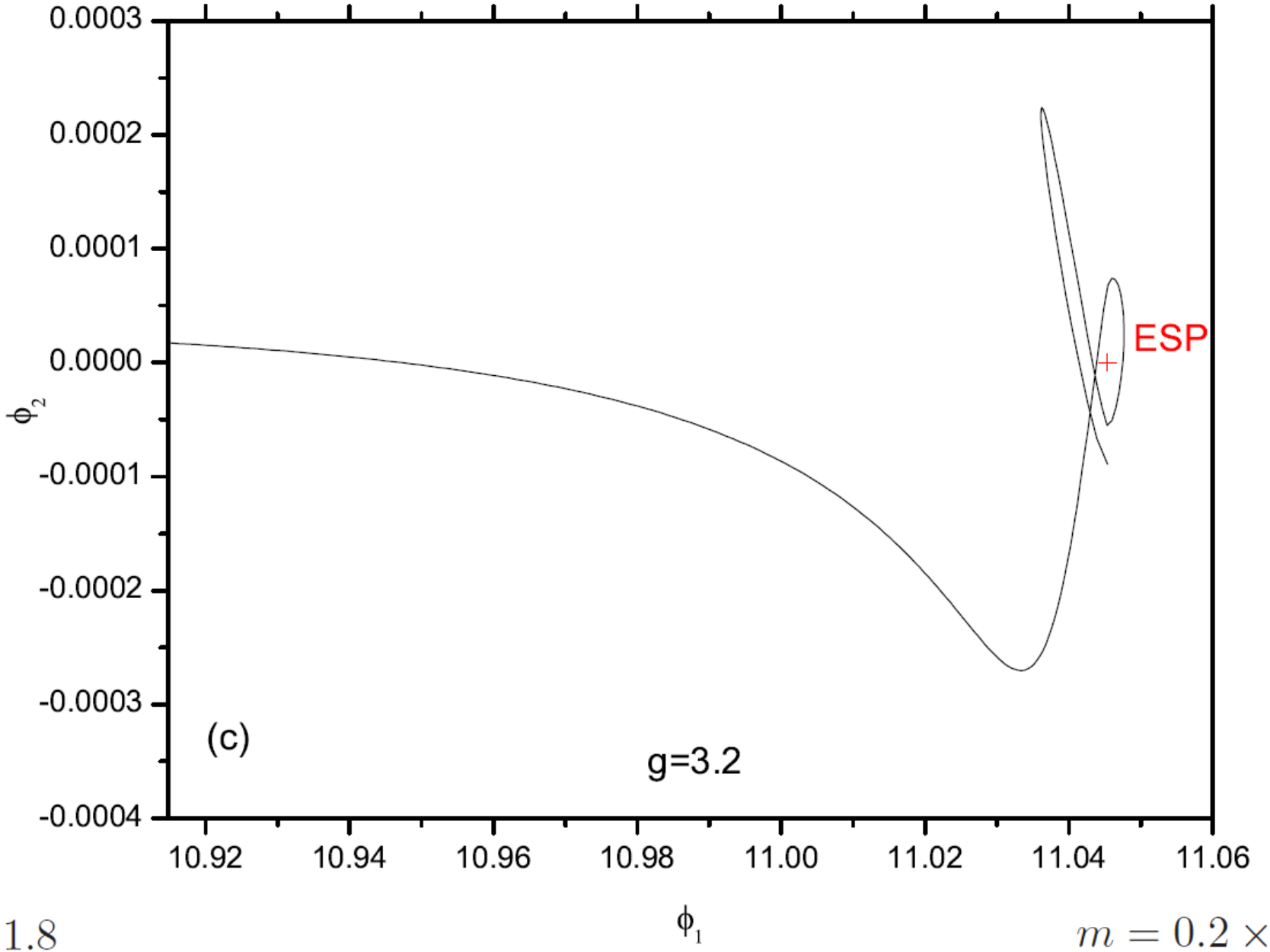

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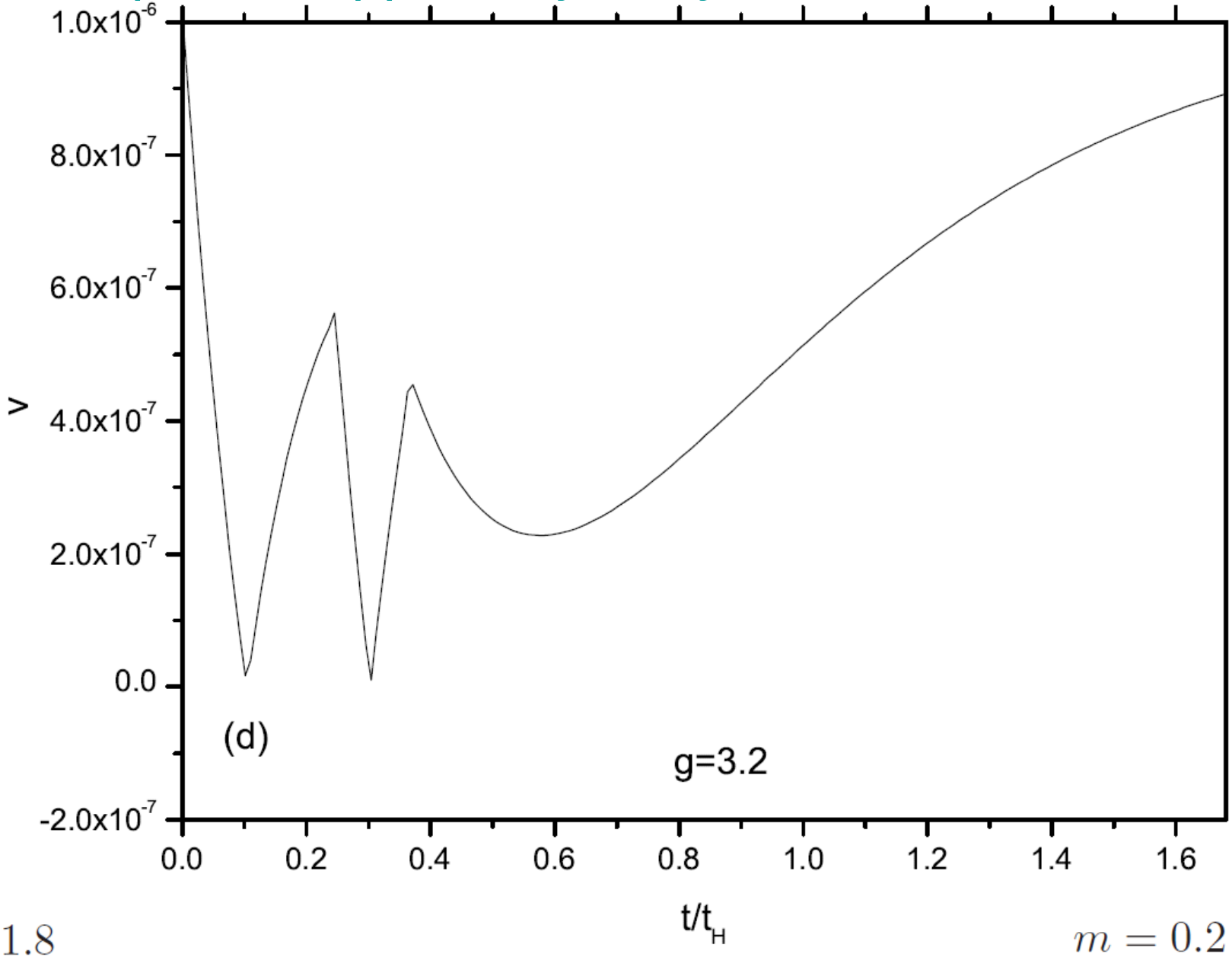

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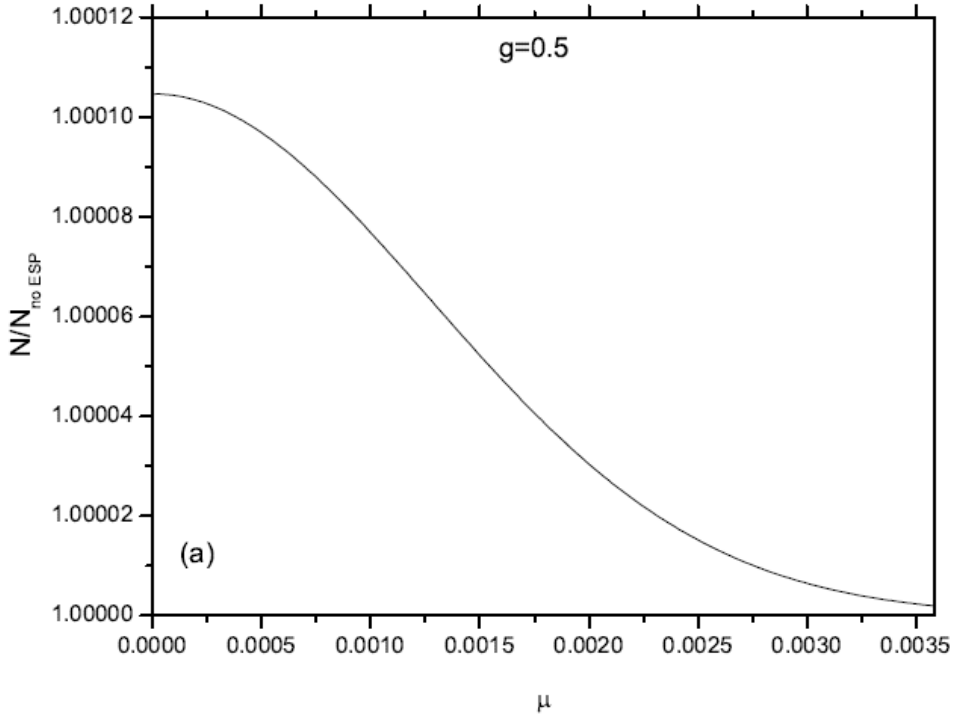

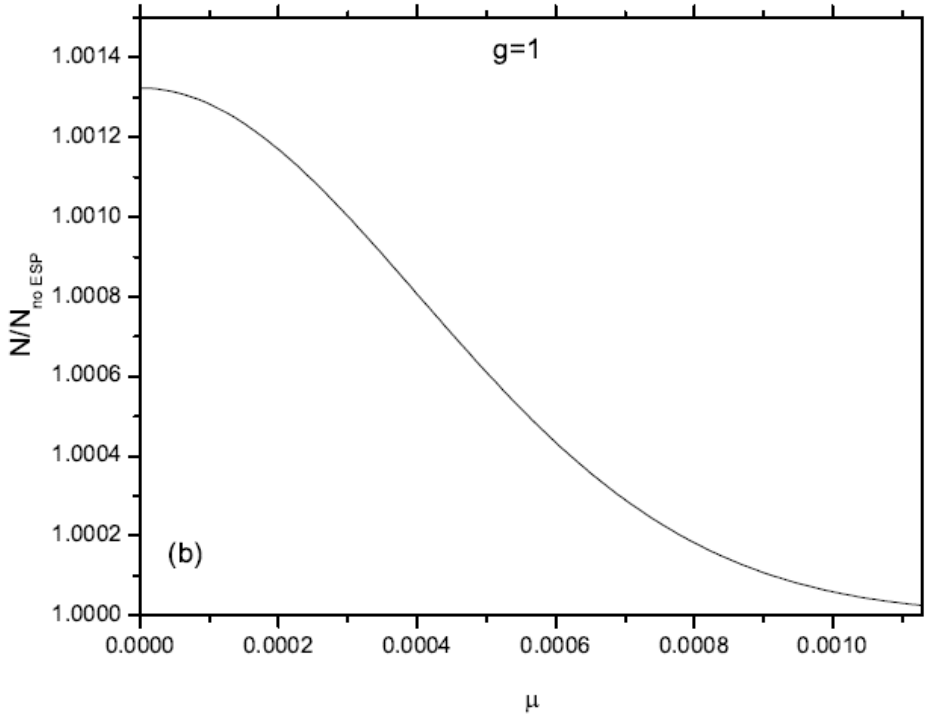

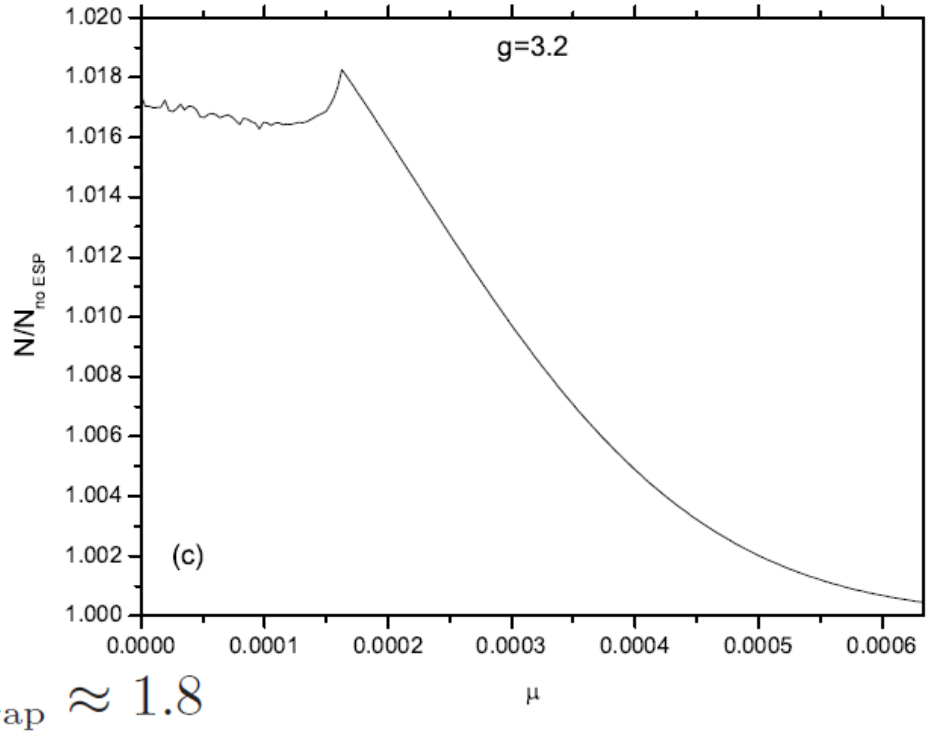

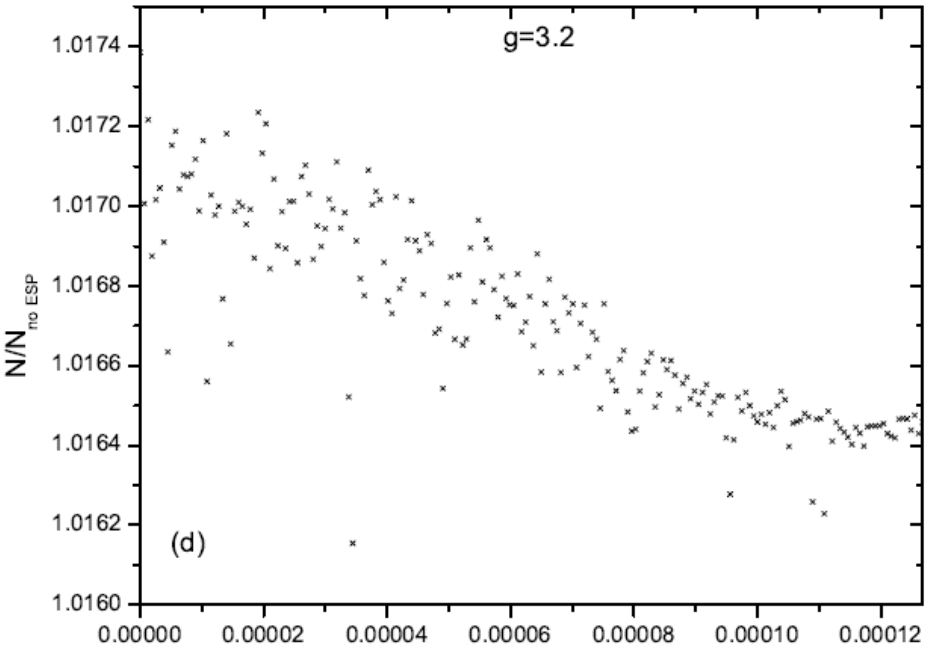

$g_{\mathrm{trap}} \approx 1.8$

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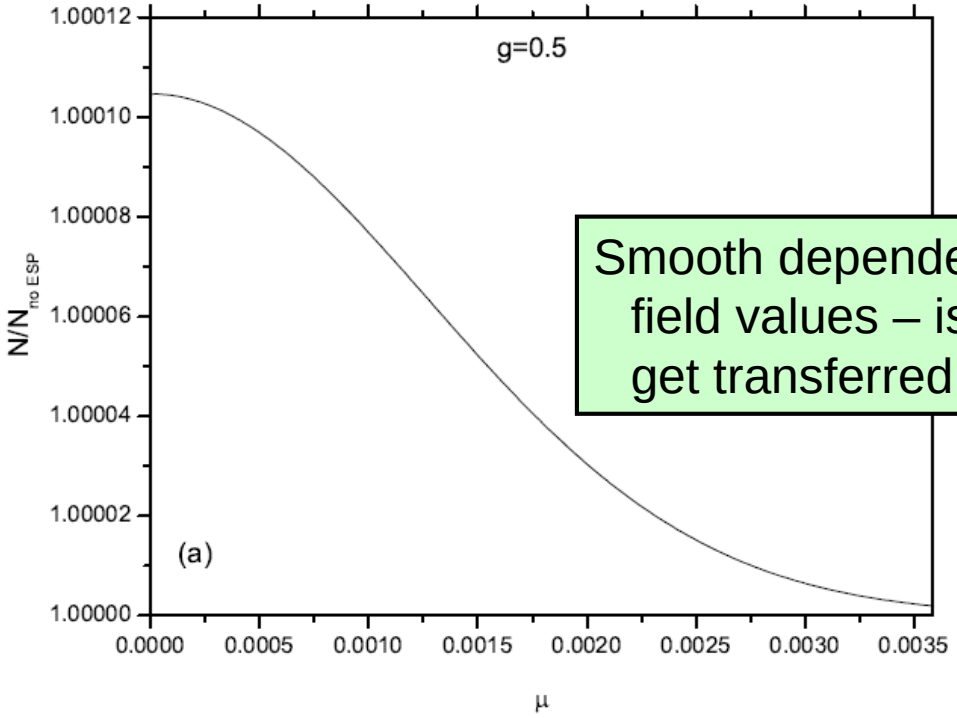
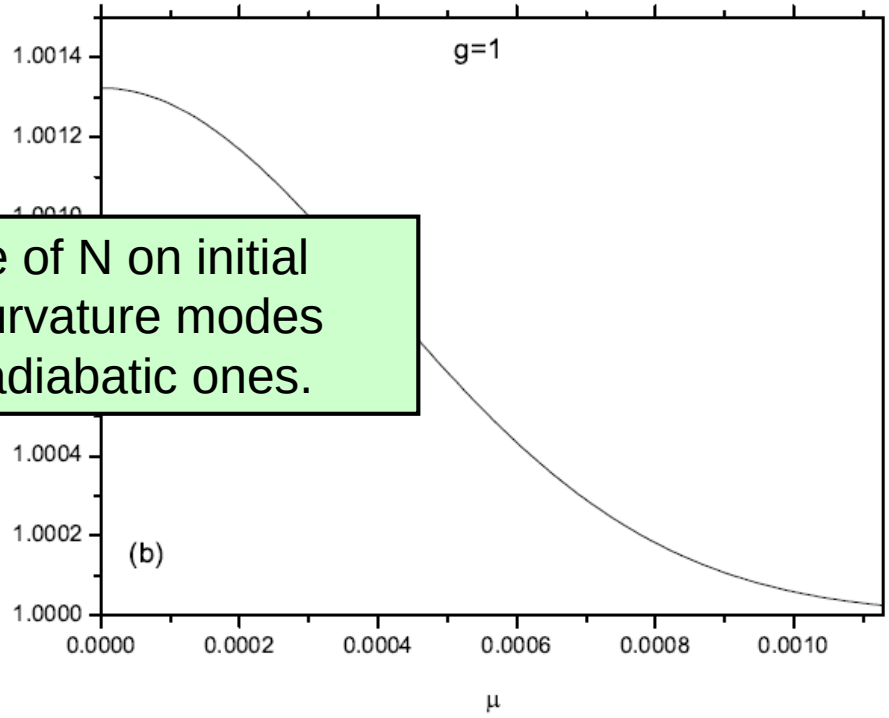
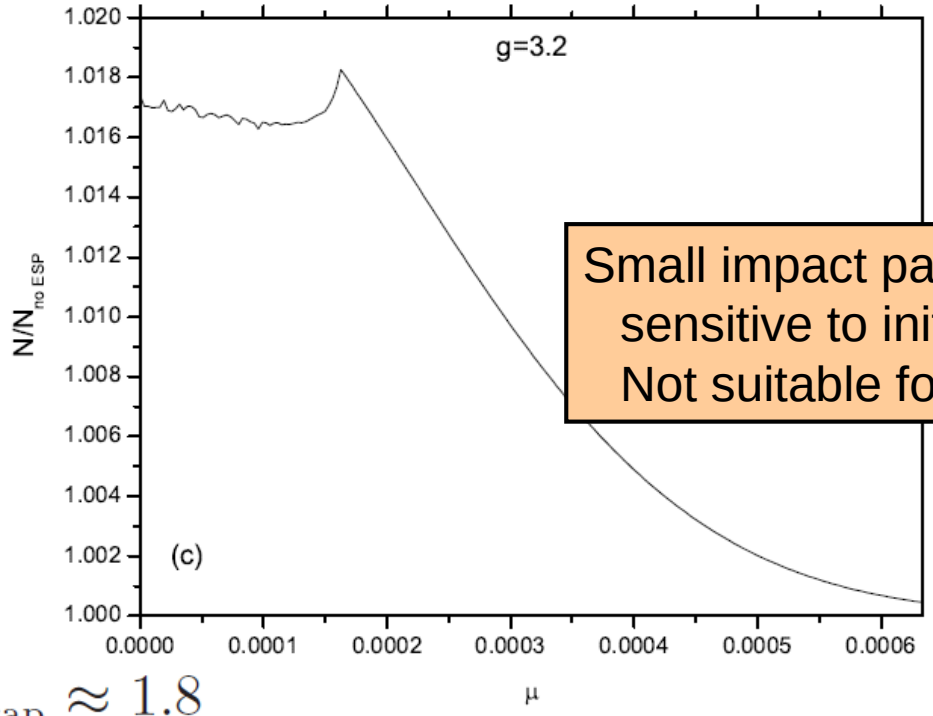
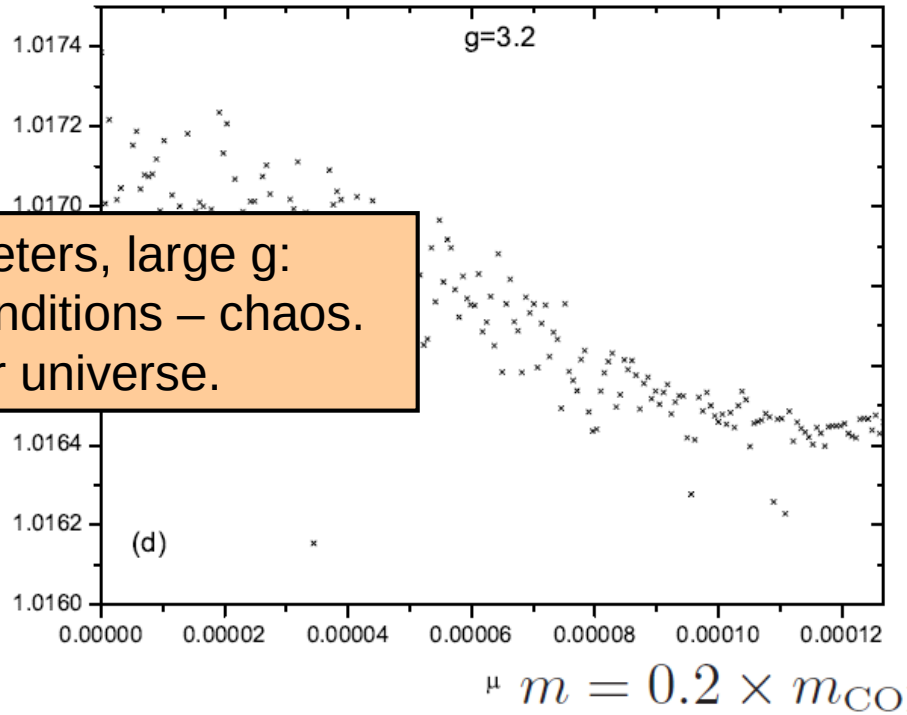




Smooth dependence of N on initial field values – isocurvature modes get transferred to adiabatic ones.





Small impact parameters, large g: sensitive to init. conditions – chaos. Not suitable for our universe.

$g_{\rm trap} \approx 1.8$

$m = 0.2 \times m_{\rm COBE}$

$g = 1$

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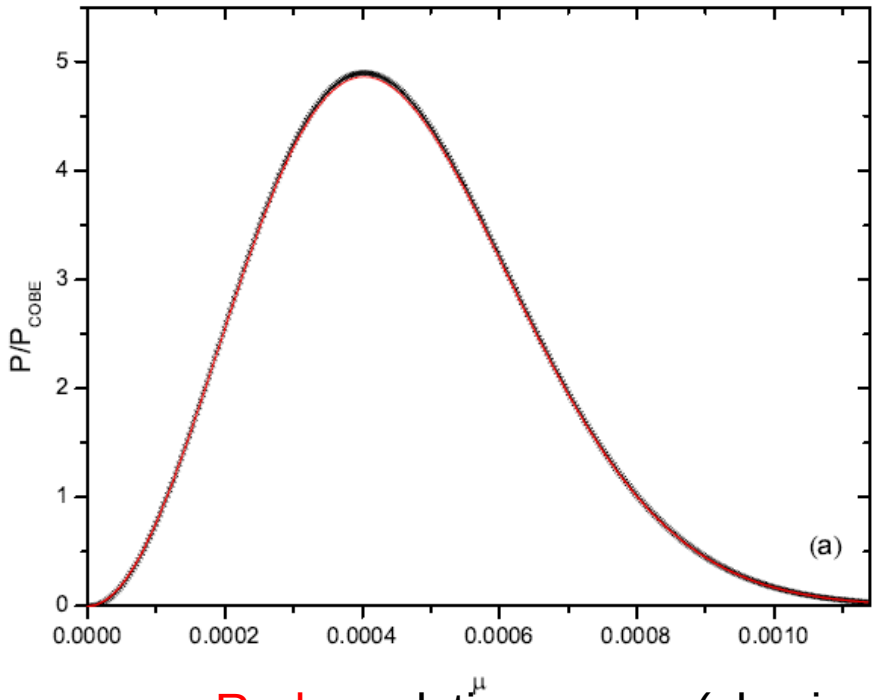
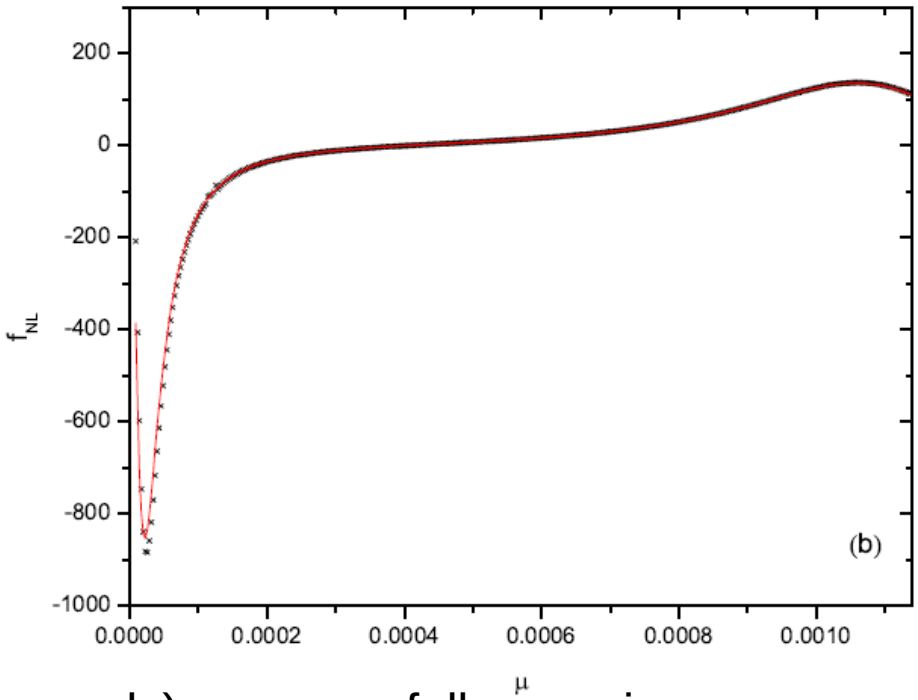
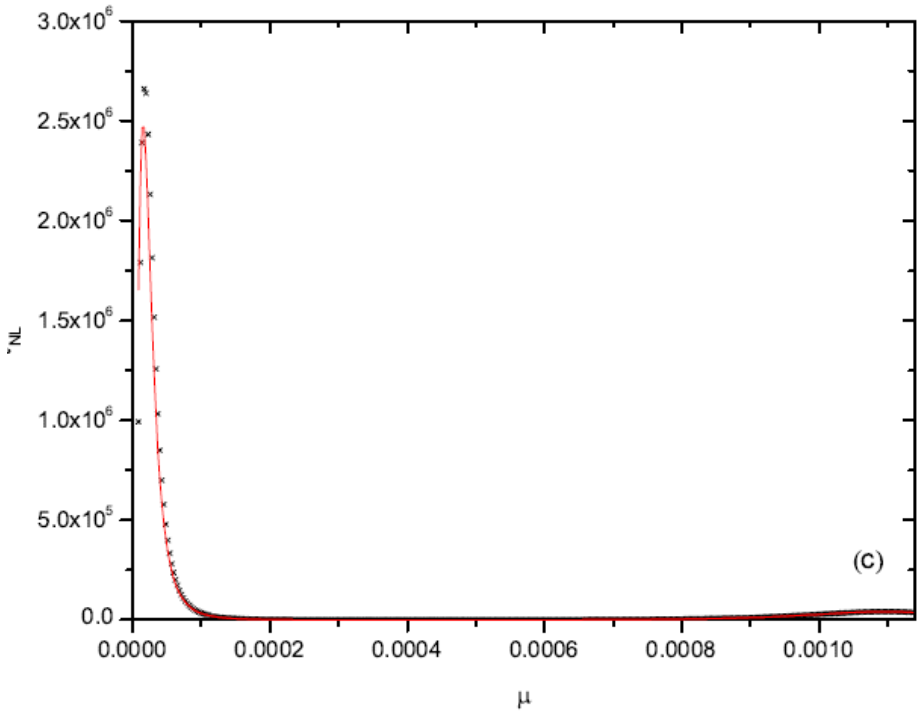
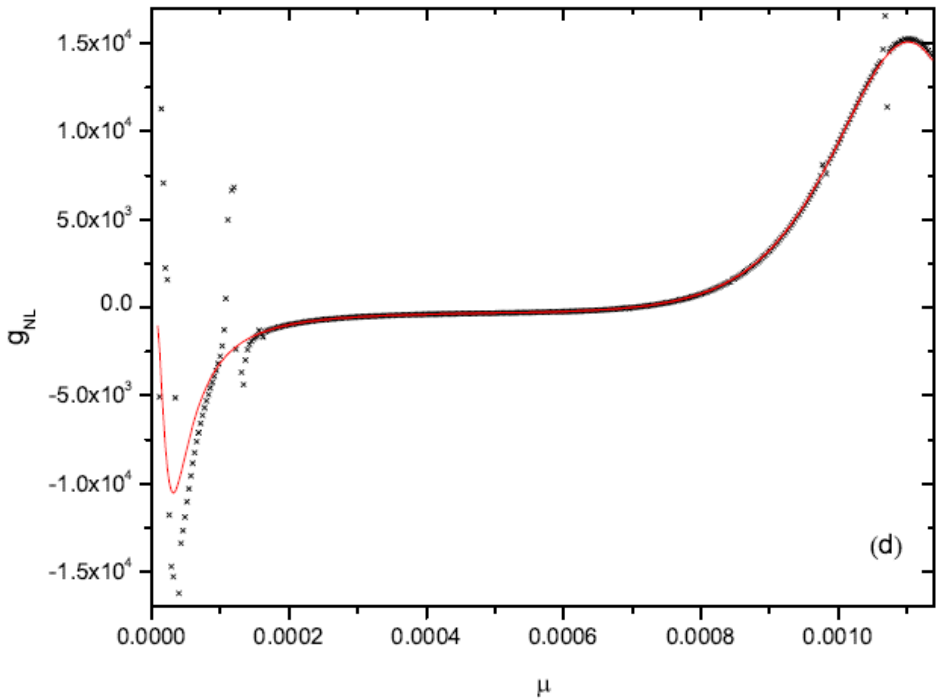




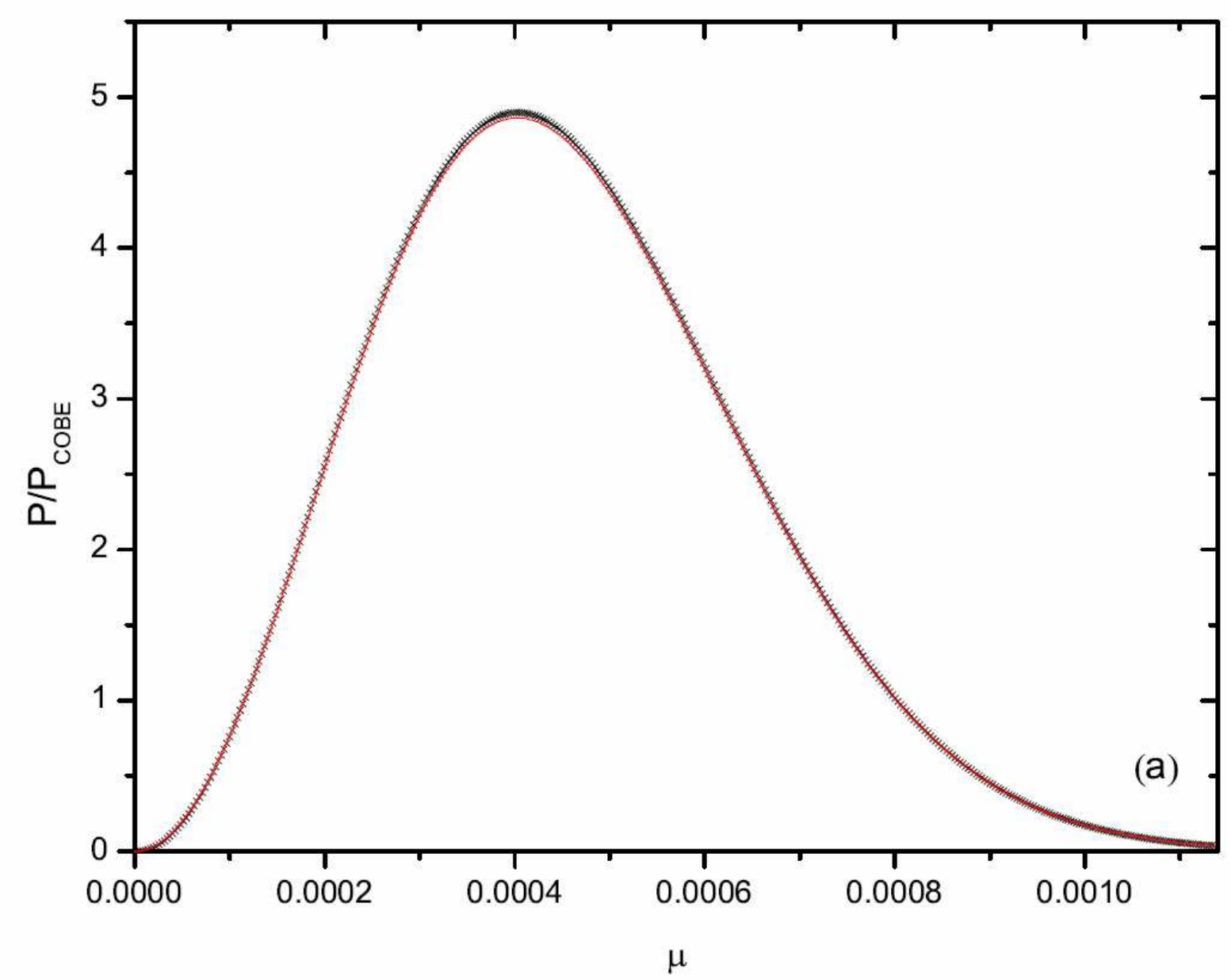
Red: analytic approx. (slowing down only); crosses: full numeric





$g = 1$ $m = 0.2 \times m_{\rm COBE}$

Amplitude of the power-spectrum



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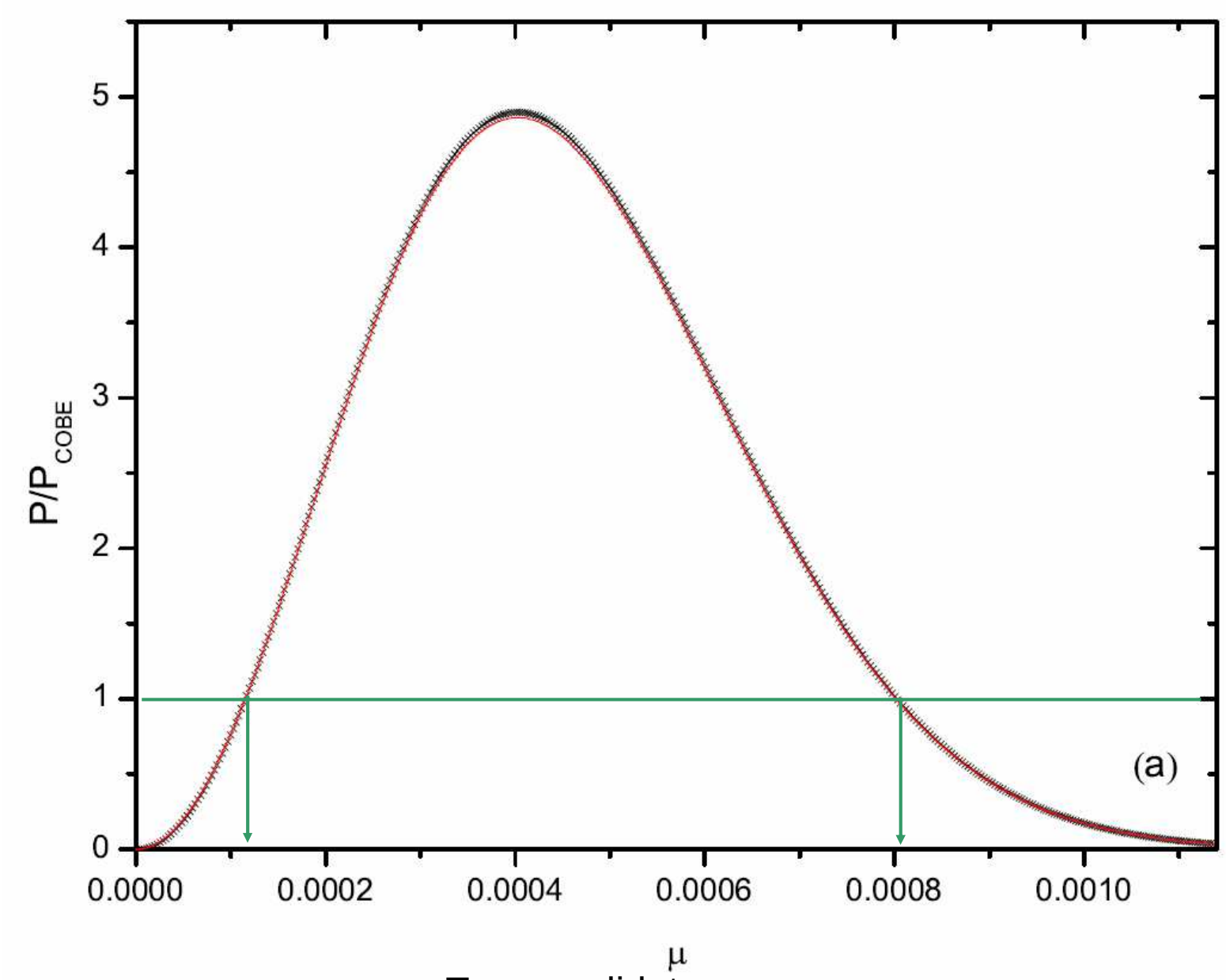
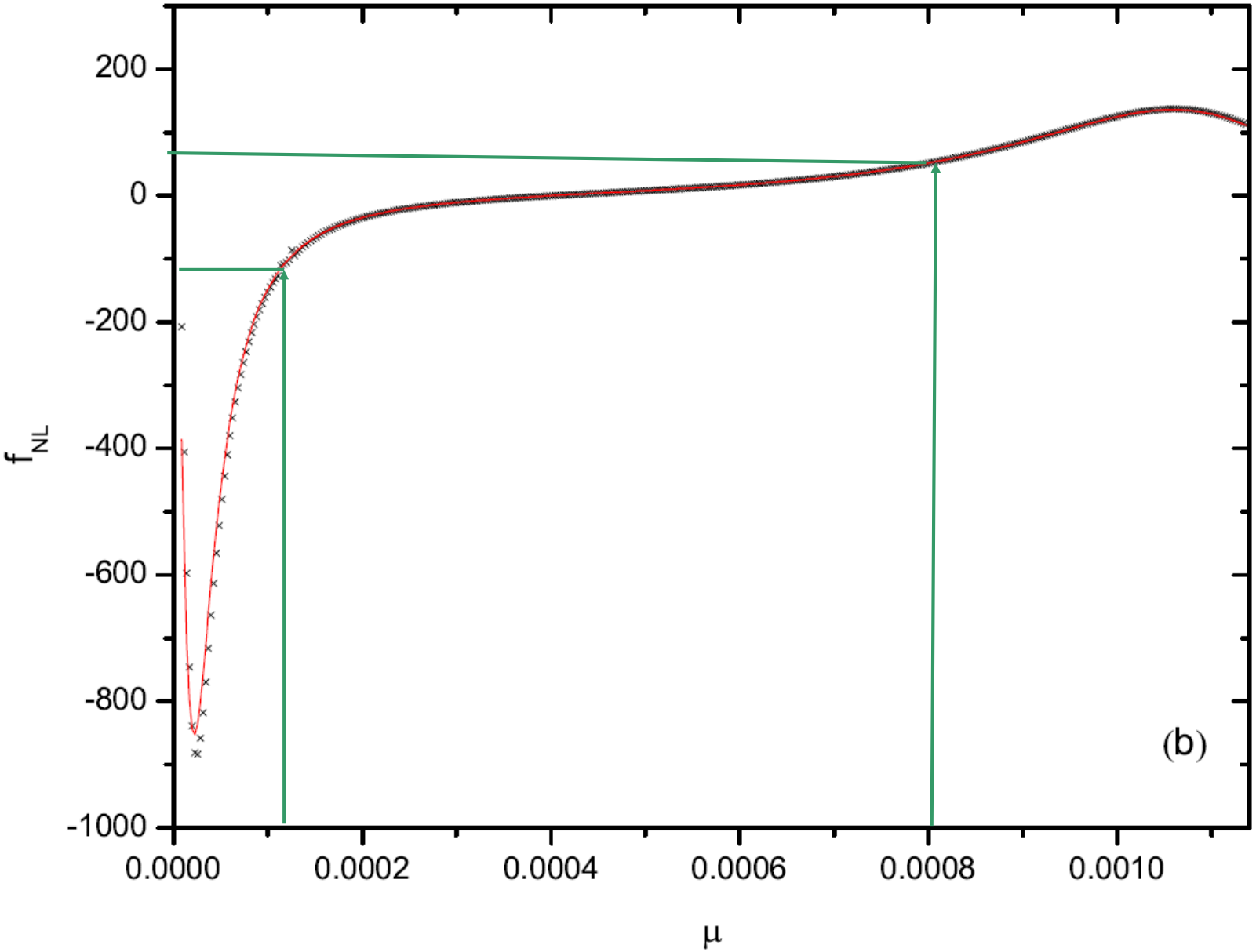


Two candidates

$g = 1$

$m = 0.2 \times m_{\mathrm{COBE}}$

The corresponding Bi-spectrum amplitude



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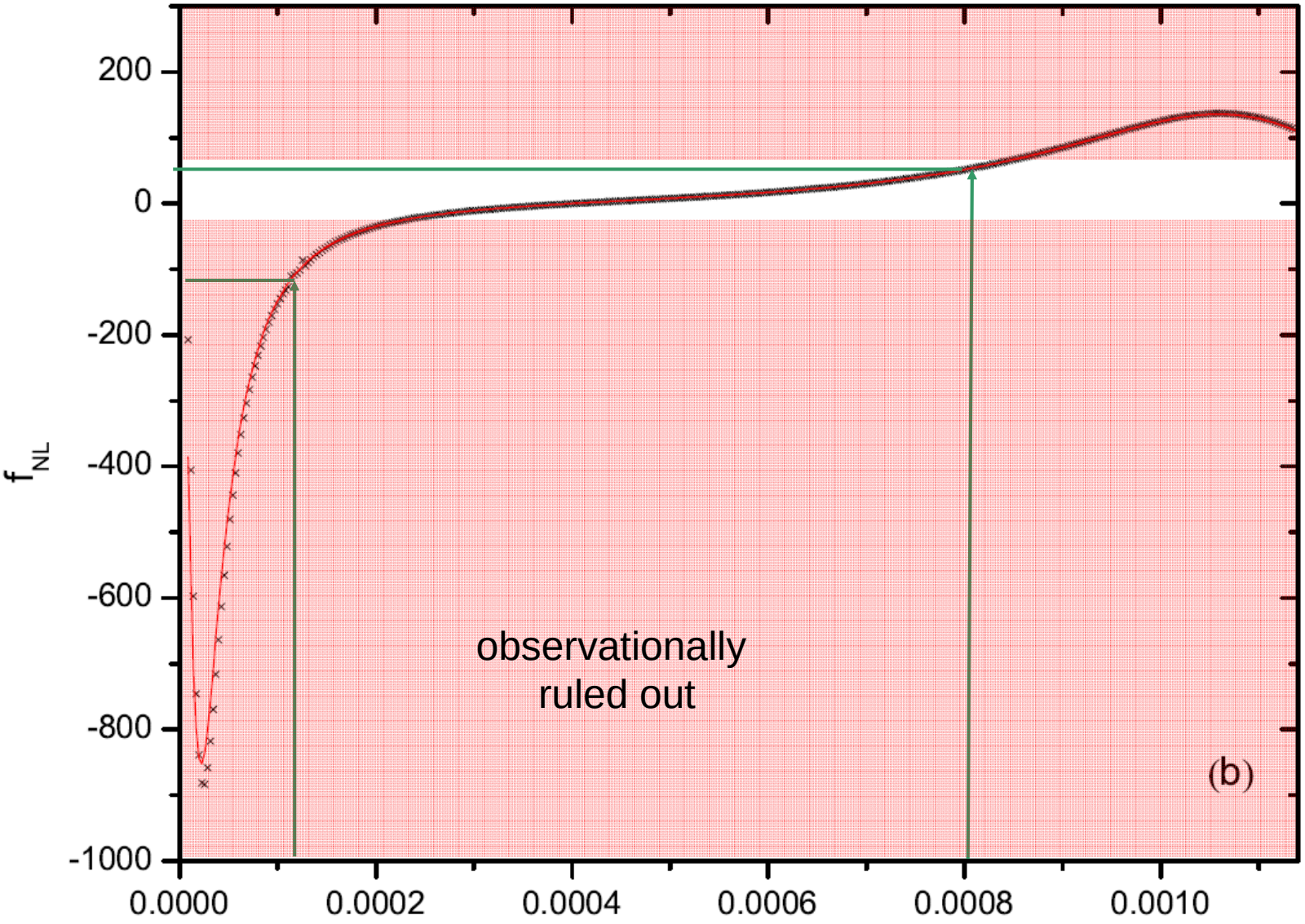
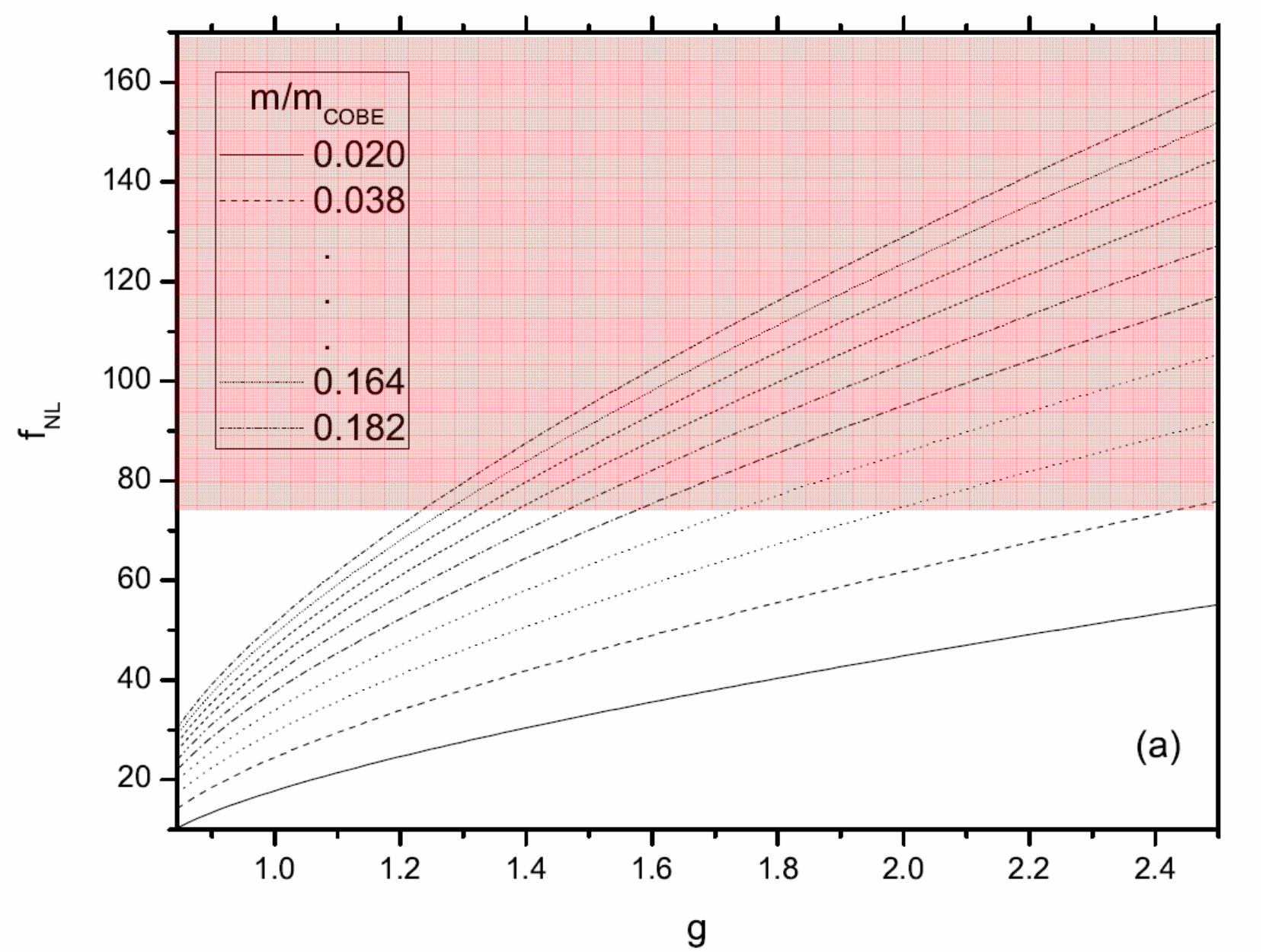


One candidate remains $\bar{\mu} \equiv \mu_c \sqrt{2\bar{x}}$

$\mu = \bar{\mu} \quad N_p \approx 30 \quad \varphi_p \approx 11$



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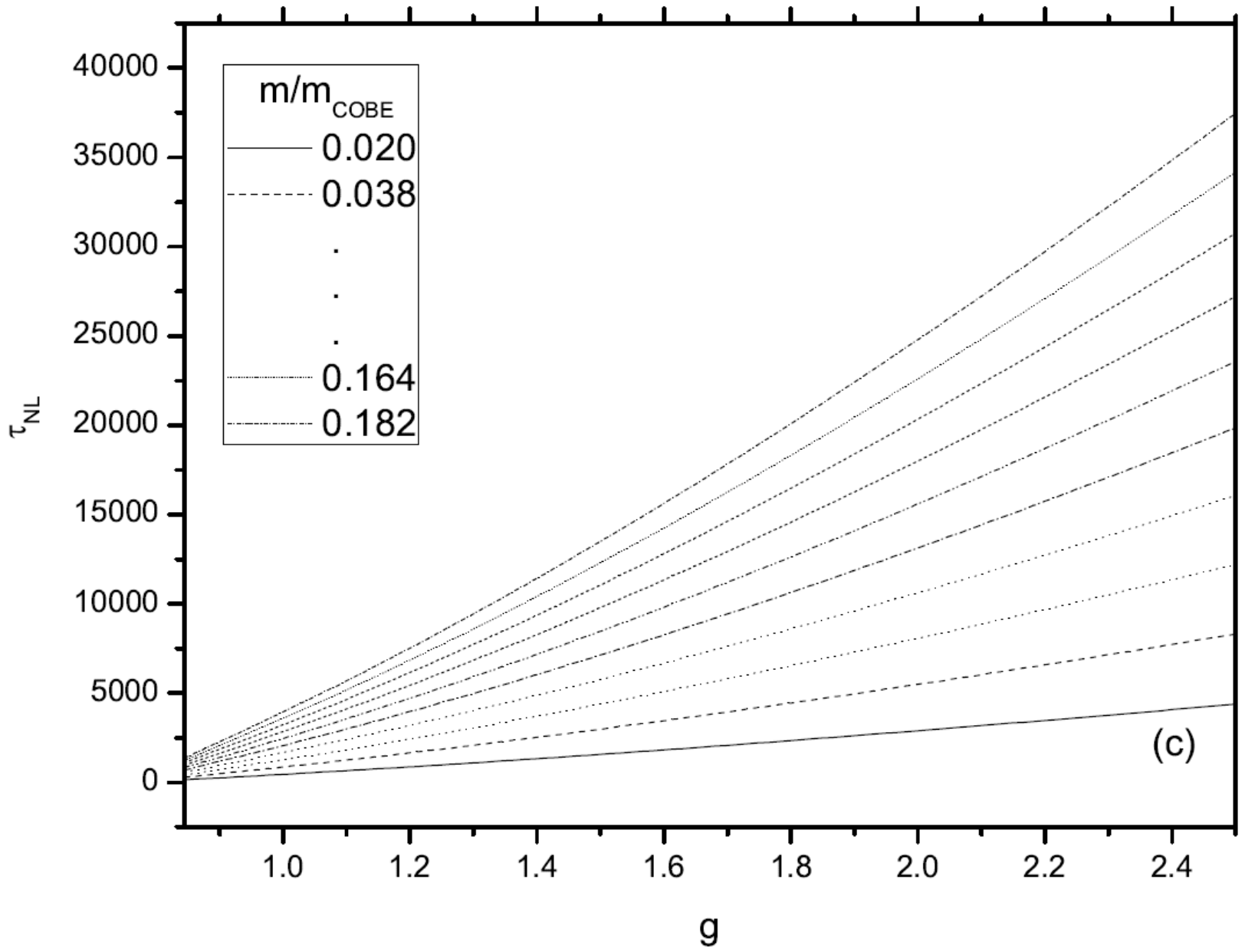

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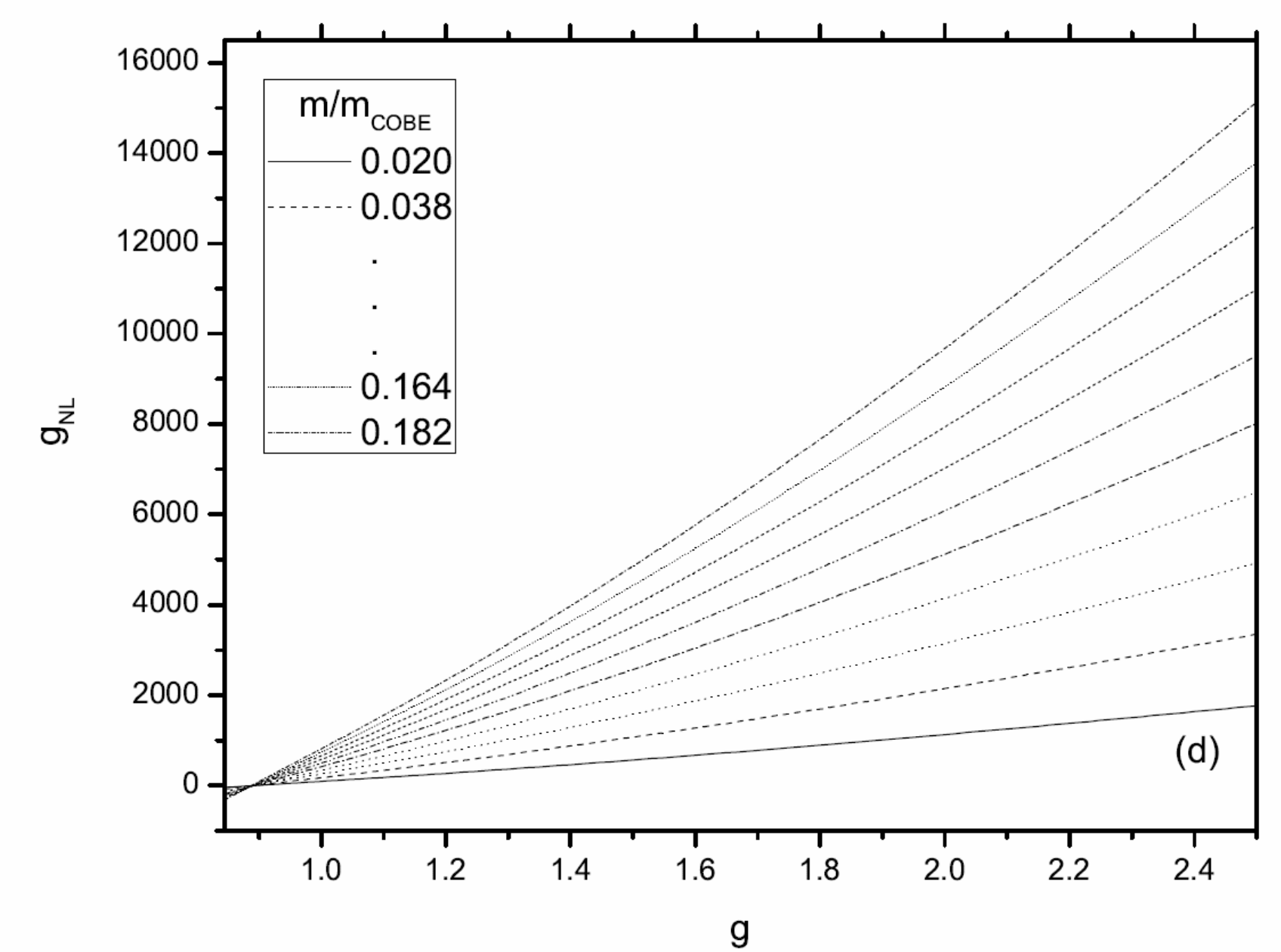

In 1106.1891:

- Analytic expressions for all plots, validity ranges, …
- Higher dimensional field spaces, multiple encounters, relation to trapped inflation.
- Additional signatures from backscattering (Barnaby et.al.)
- Modulated trapping (Langlois, Sorbo)

We can constrain inflaton interactions outside
the observational window (i.e. 0-50 efolds before the end of inflation).

Conclusion

A grazing ESP encounter can provide the dominant contribution to the power-spectrum, with observationally large NG and additional signatures on smaller scales, if the coupling to the new degrees of freedom is of order one, and the impact parameter is small (~0.001).

Constraining observationally such encounters probes the vicinity of the entire inflationary trajectory, testing for the presence of ESLs in field space. We already know that no single identifiable, strong encounter took place during the observational window, probed on CMB/LSS scales.

Thus, ESPs are rare (a handful of encounters at most during inflation, this talk) or ubiquitous (trapped inflation).

Observable (by Planck) large NG in the CMB are predicted, and gravitational waves are suppressed, if curvature perturbations originate from the encounter.

A smoking gun for a single ESP encounter is a bump in the power-spectrum on smaller scales (amplitude and NG are predicted, location is free).

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