Nuclear structure calculations: mean-field and beyond

Petar Marević[1,2]

[1]CEA,DAM,DIF
[2]IPNO,PhT

May 30th 2017, PHENIICS Fest

Very brief outline of the talk:

EDF formalism

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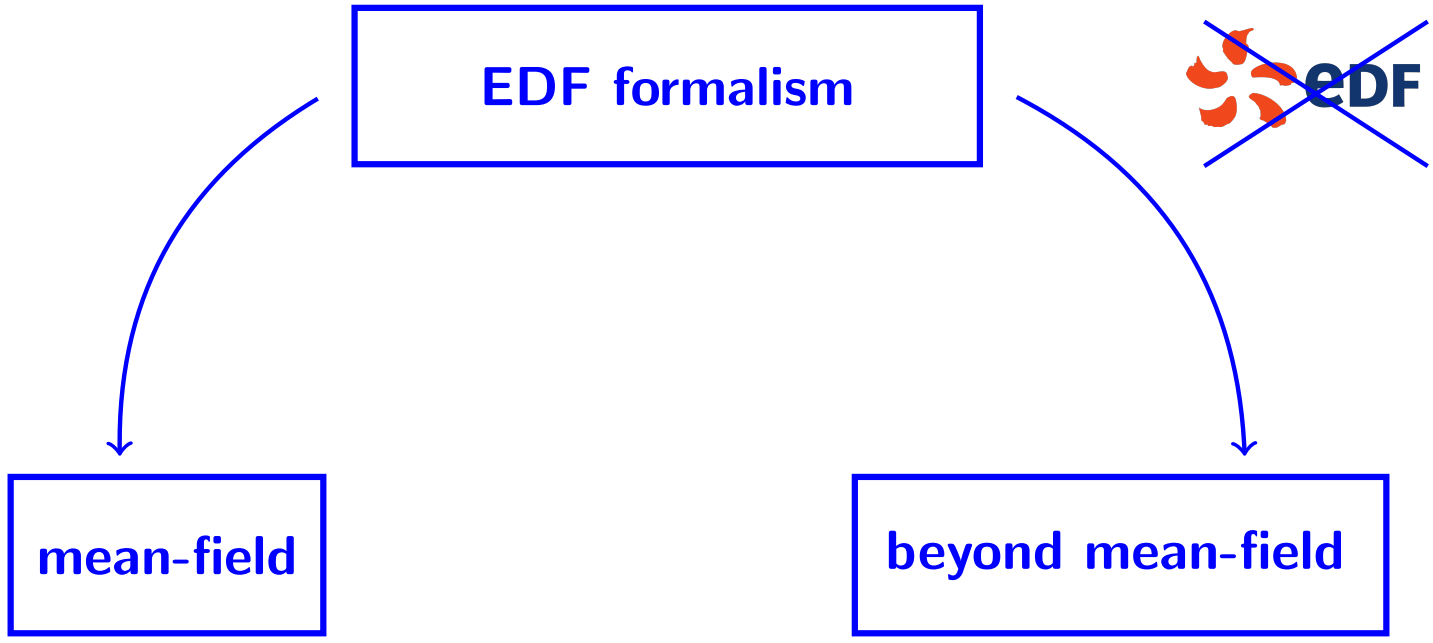

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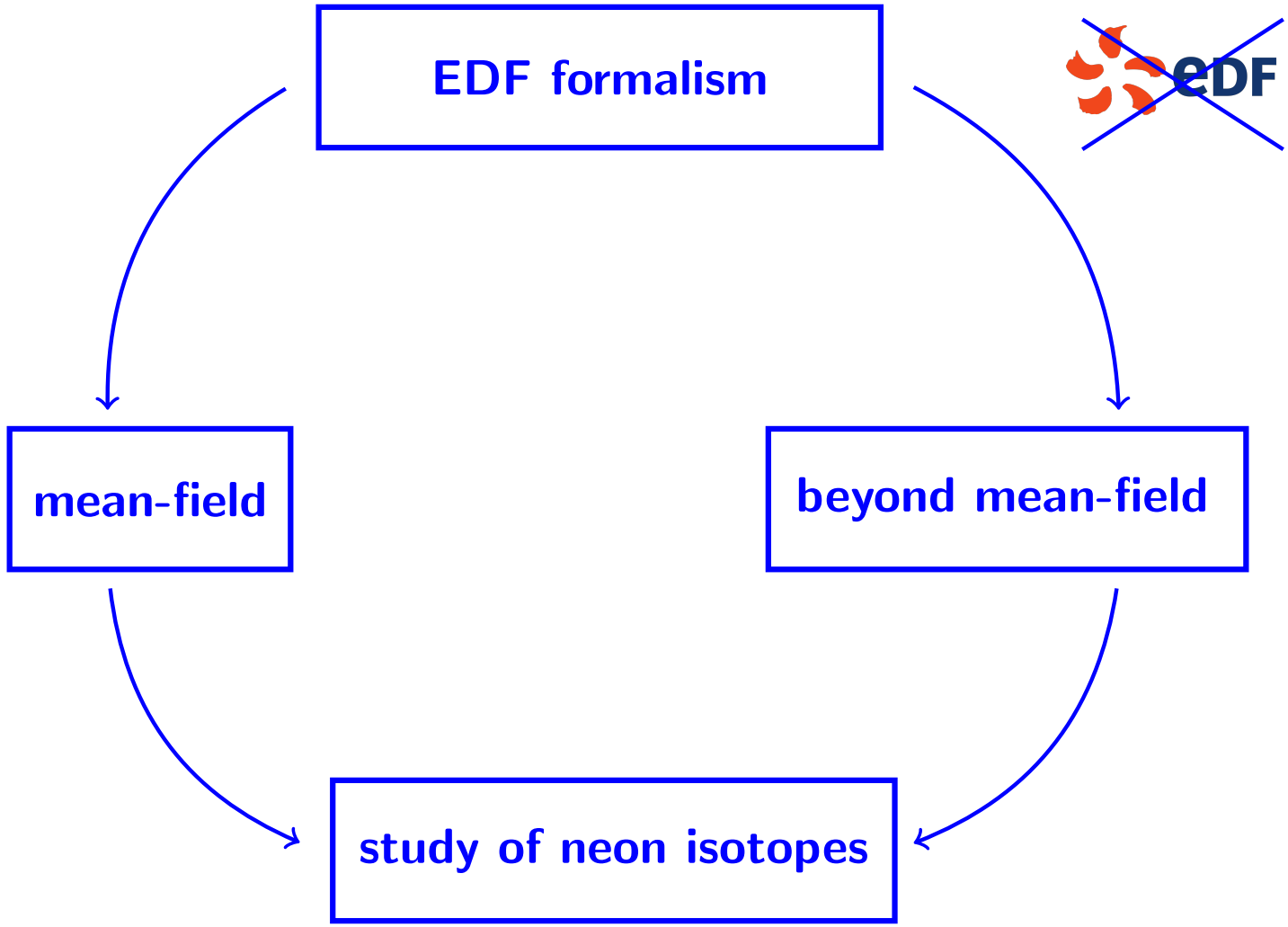
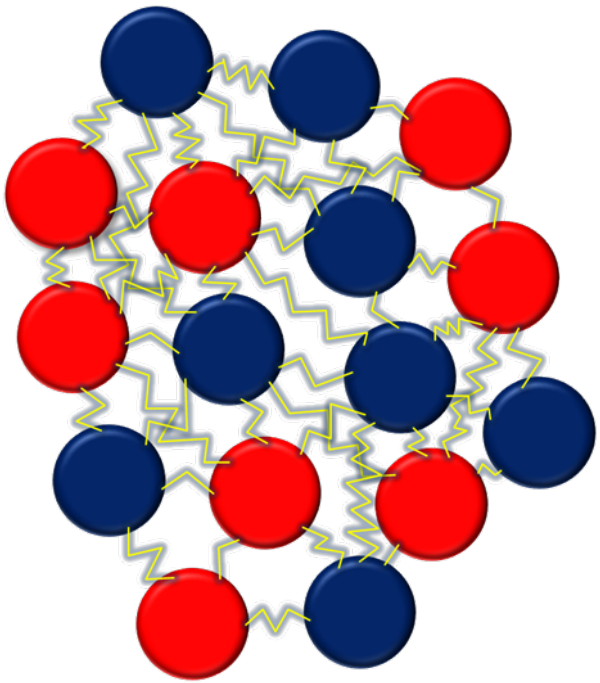
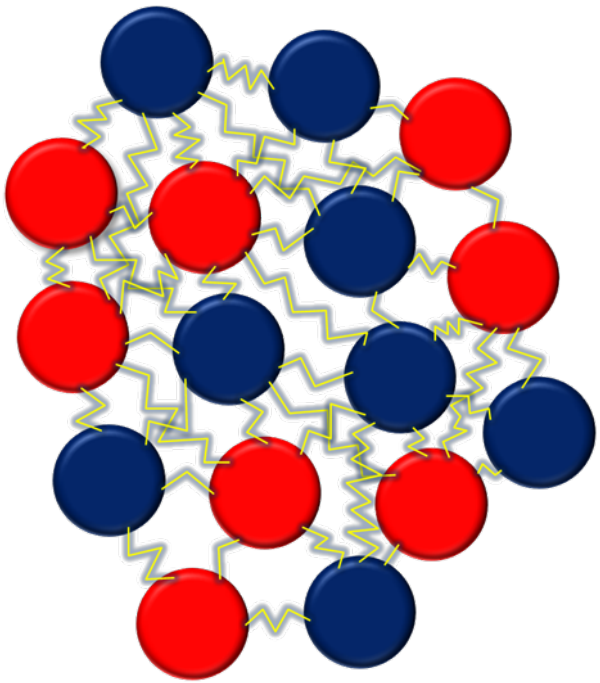
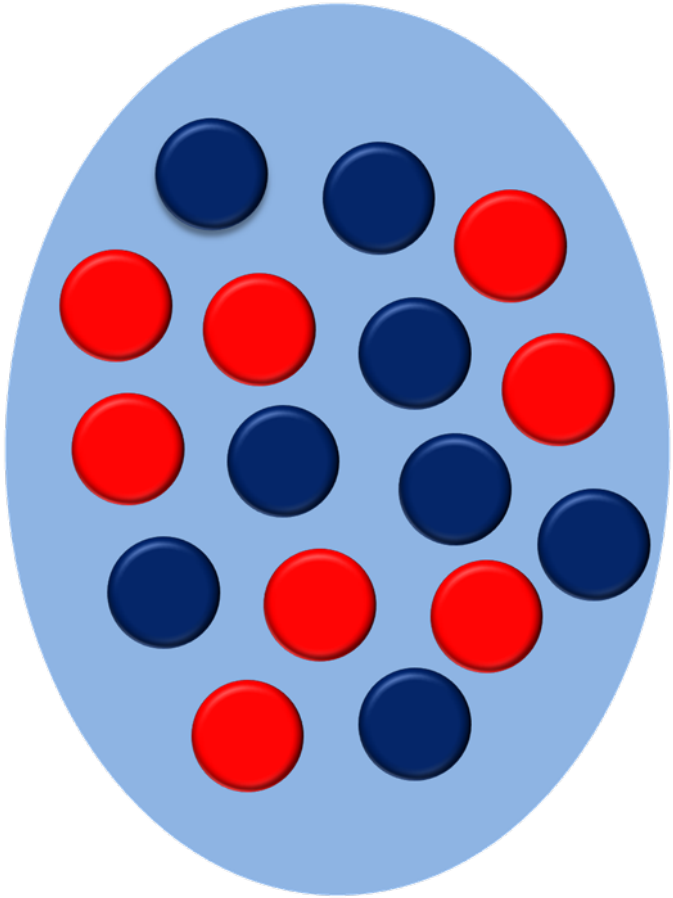
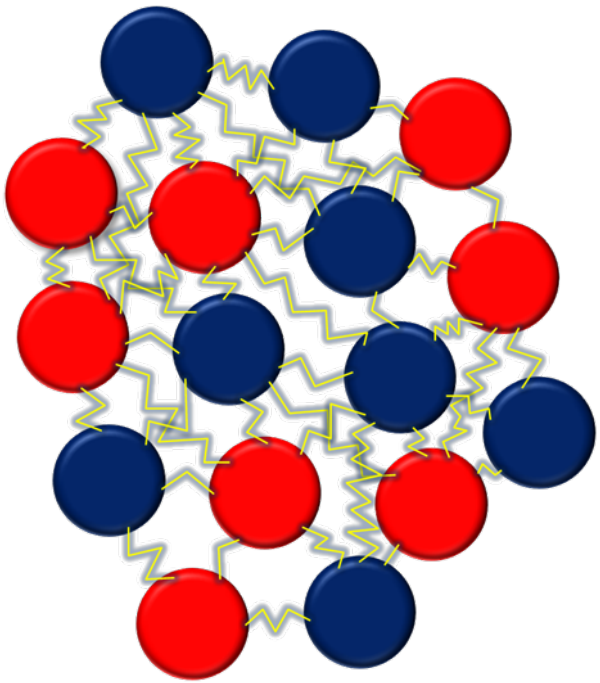


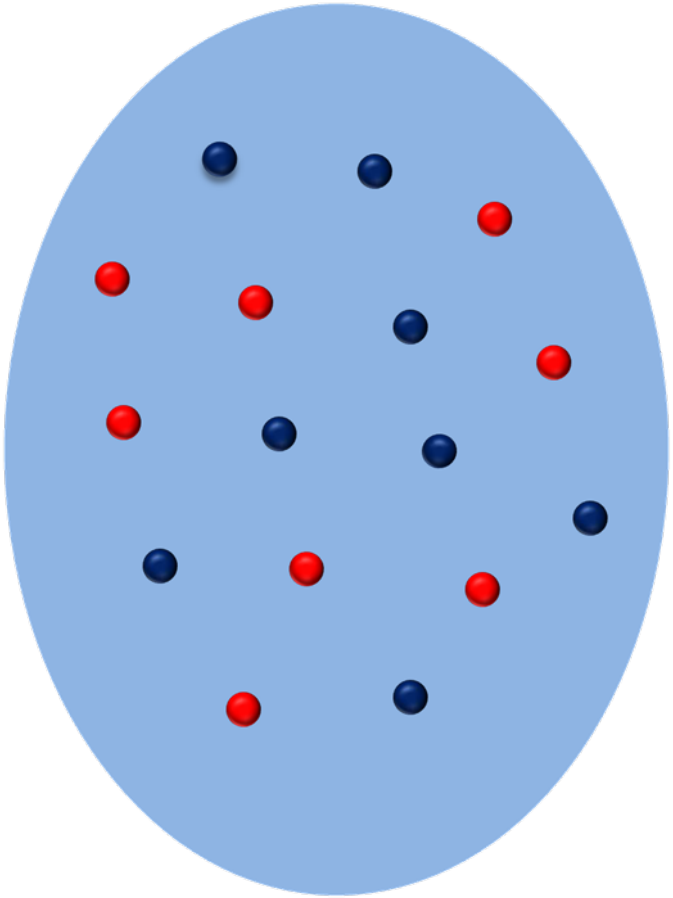
Mean-field: what does it mean?

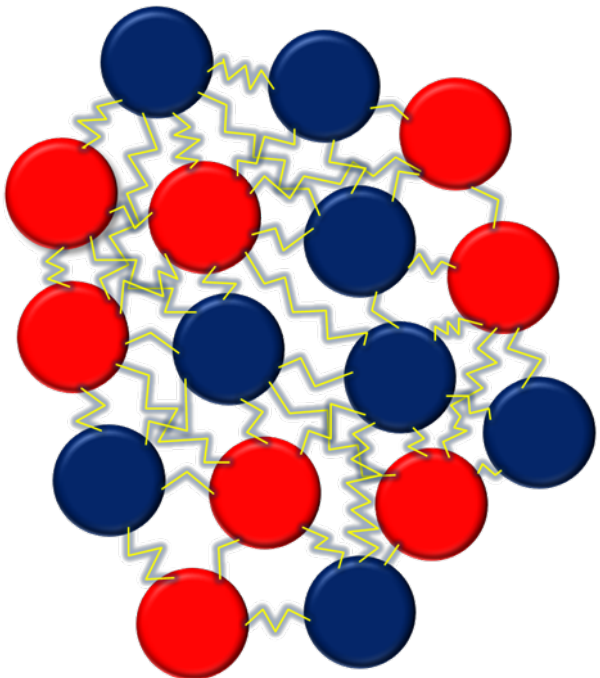


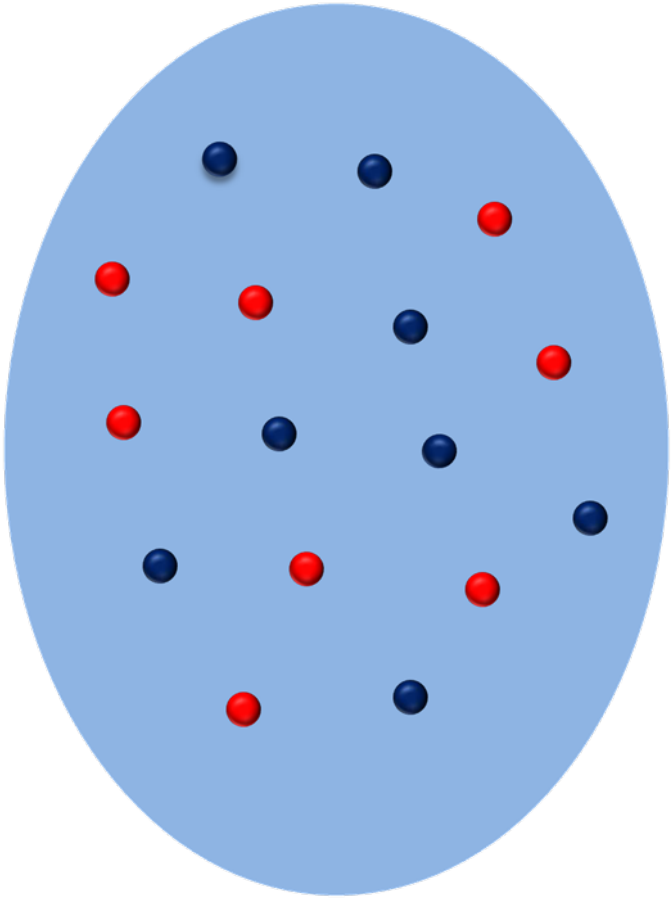




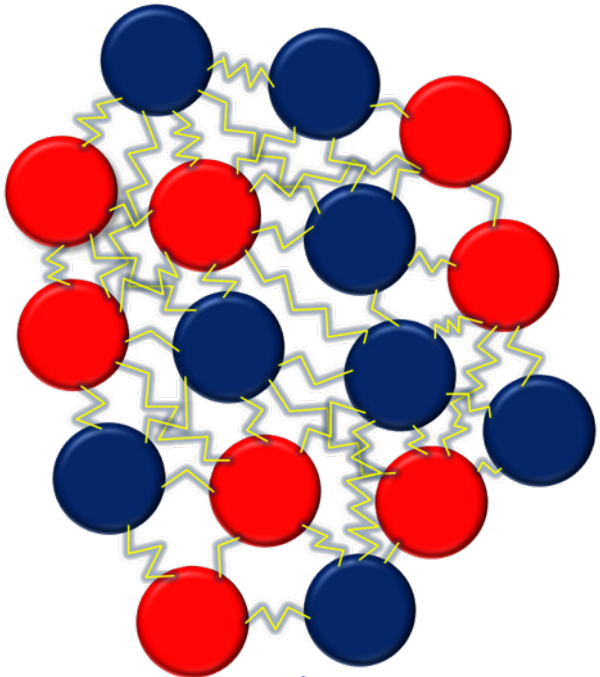








correlated wave function



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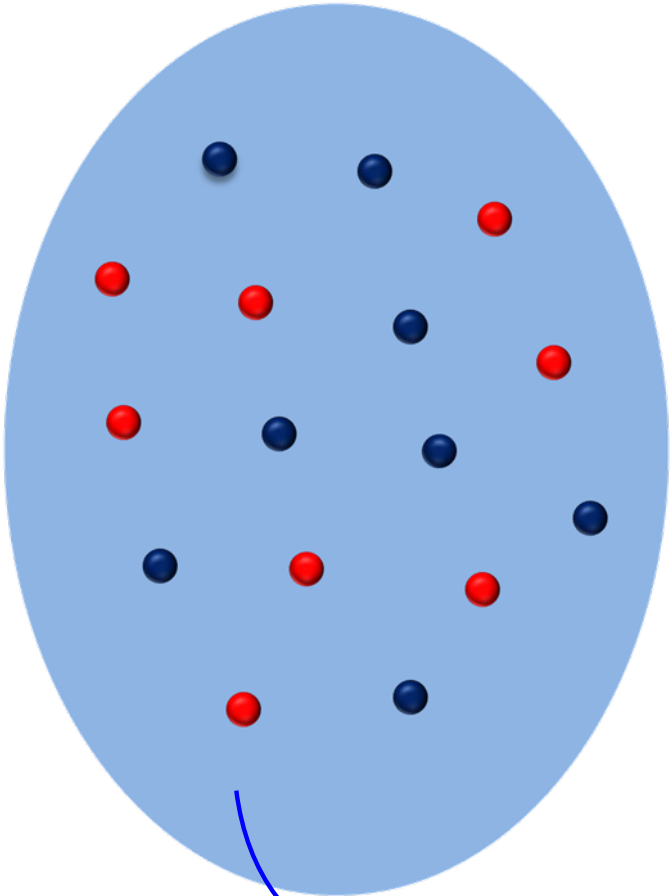
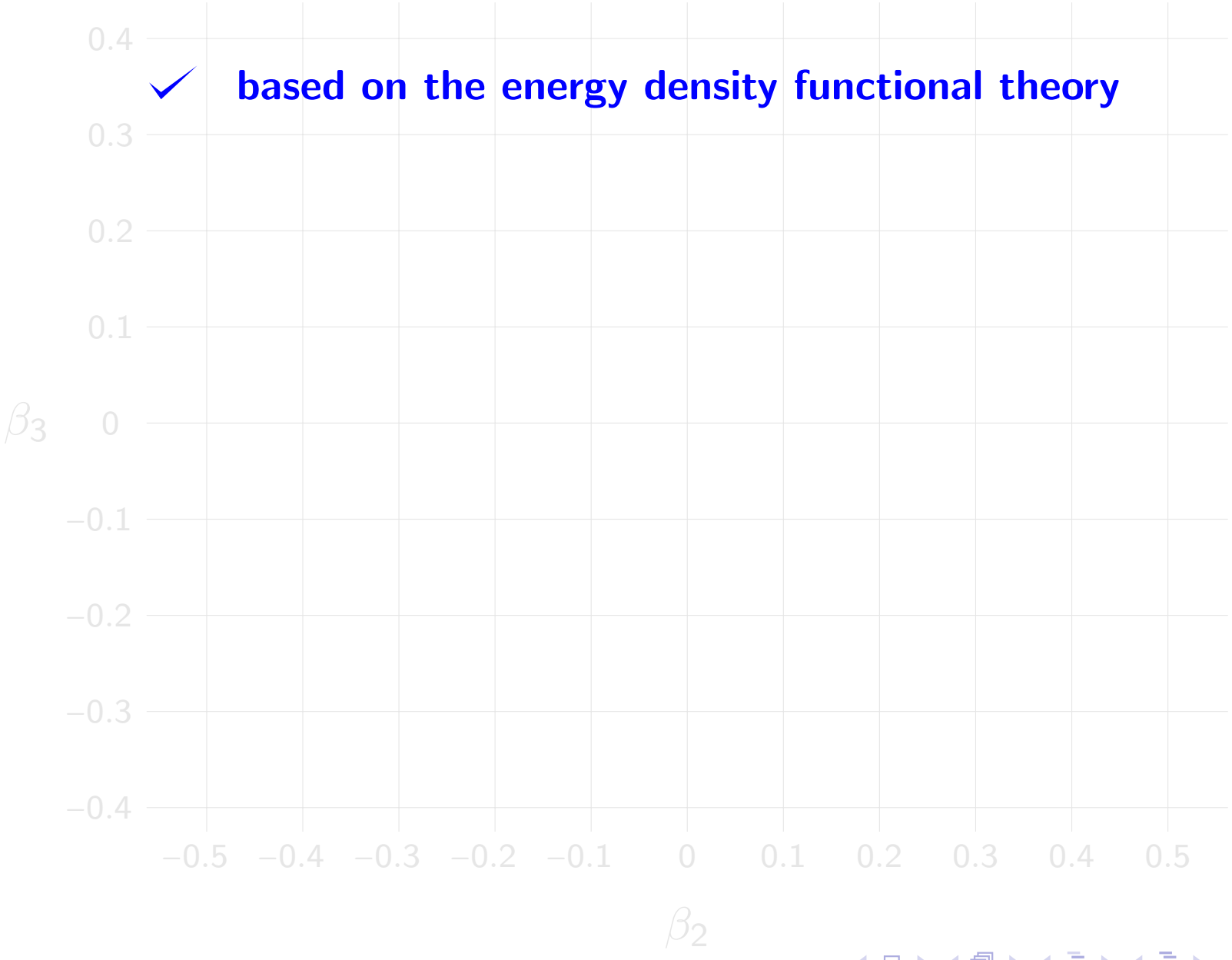
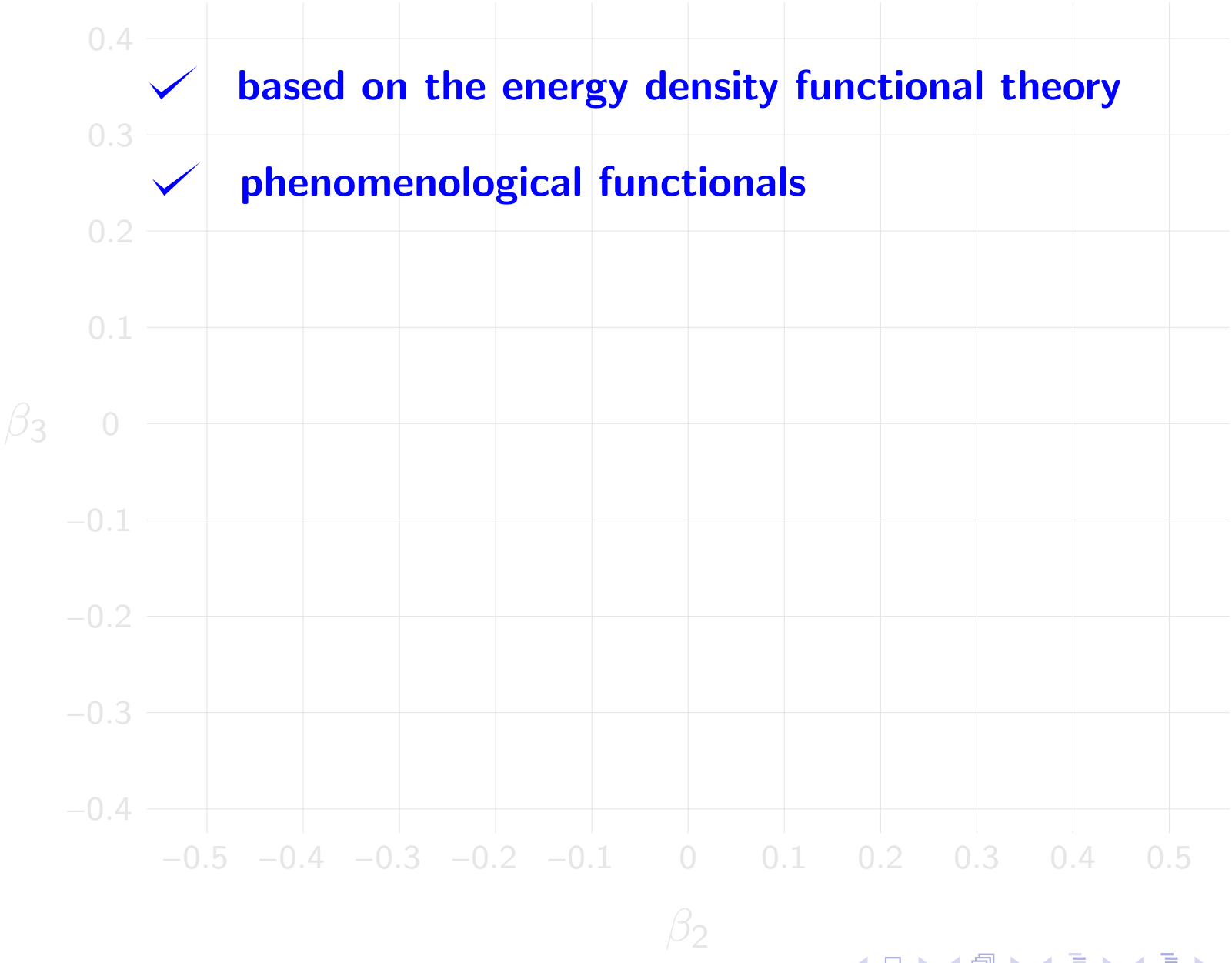


simple wave function

0.4
0.3
0.2
0.1
β_3
0
−0.1
−0.2
−0.3
−0.4
−0.5 −0.4 −0.3 −0.2 −0.1 0 0.1 0.2 0.3 0.4 0.5
β_2



✓ **based on the energy density functional theory**



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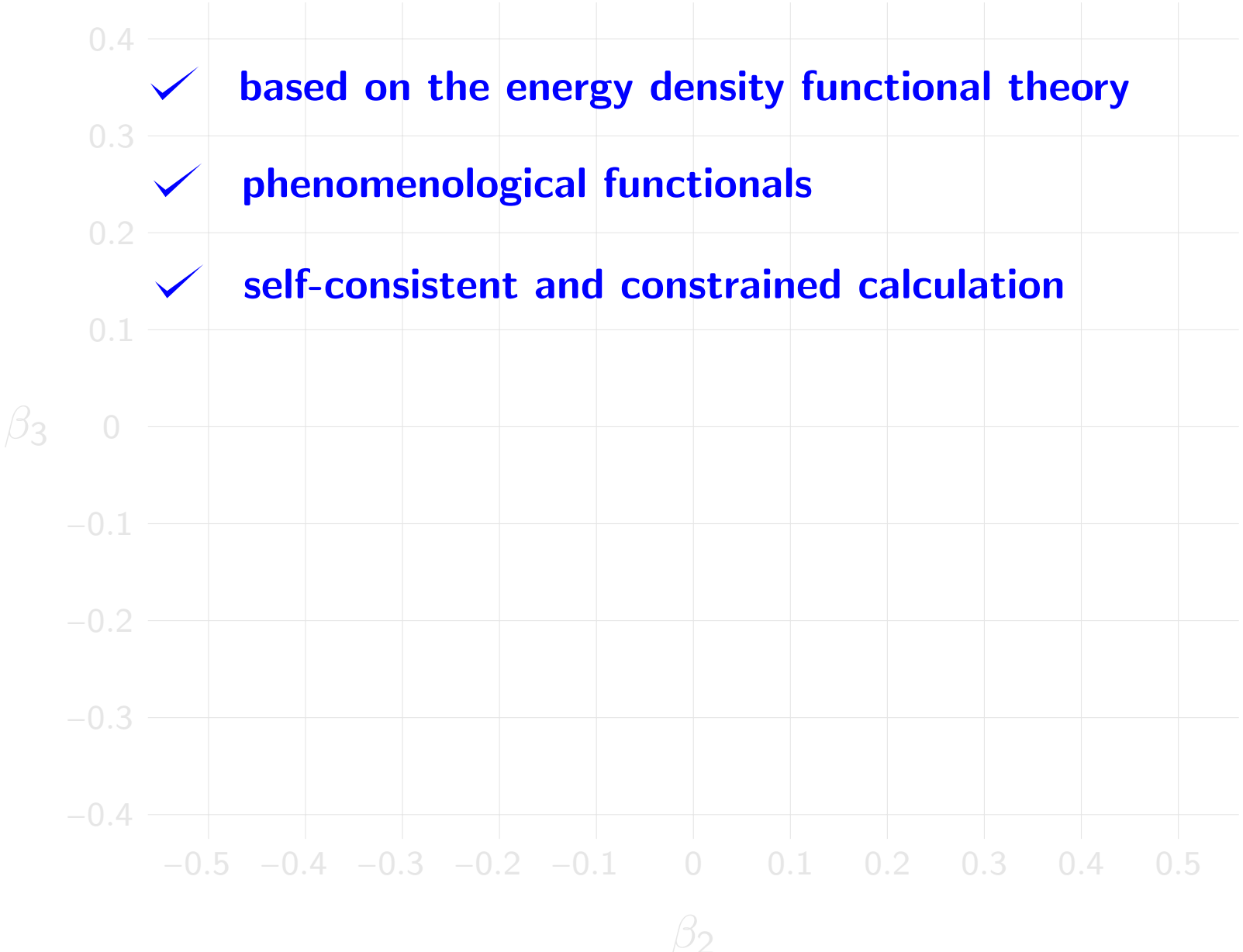
- ✓ **phenomenological functionals**



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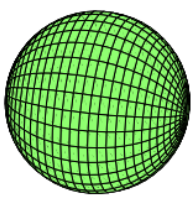	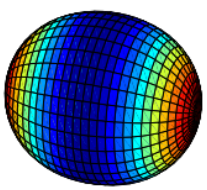	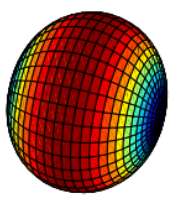	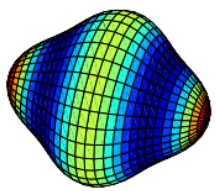
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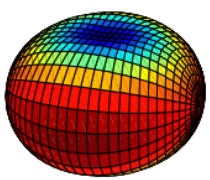	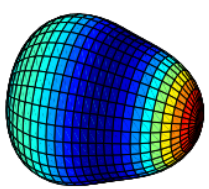	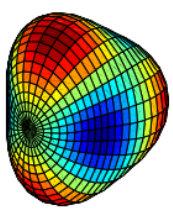	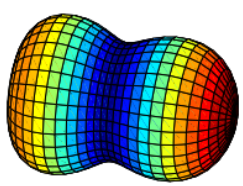

arXiv:1303.0621 [nucl-th]

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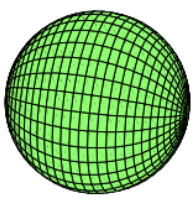	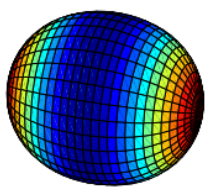	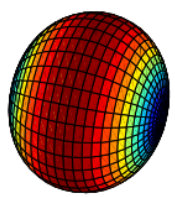	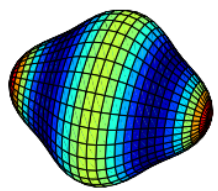
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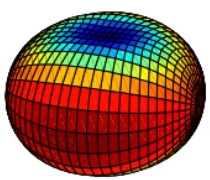	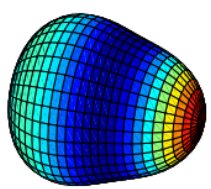	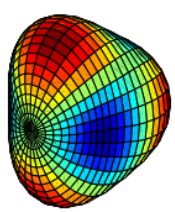	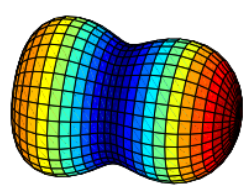

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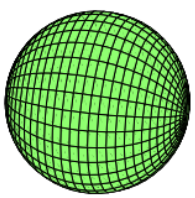	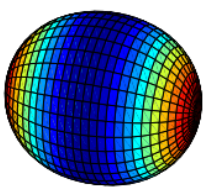	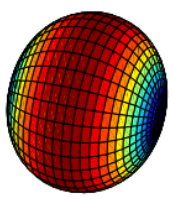	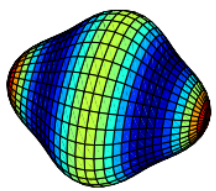
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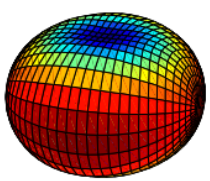	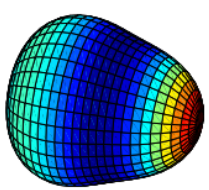	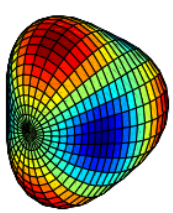	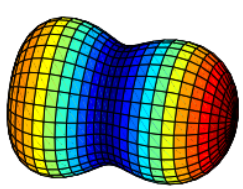

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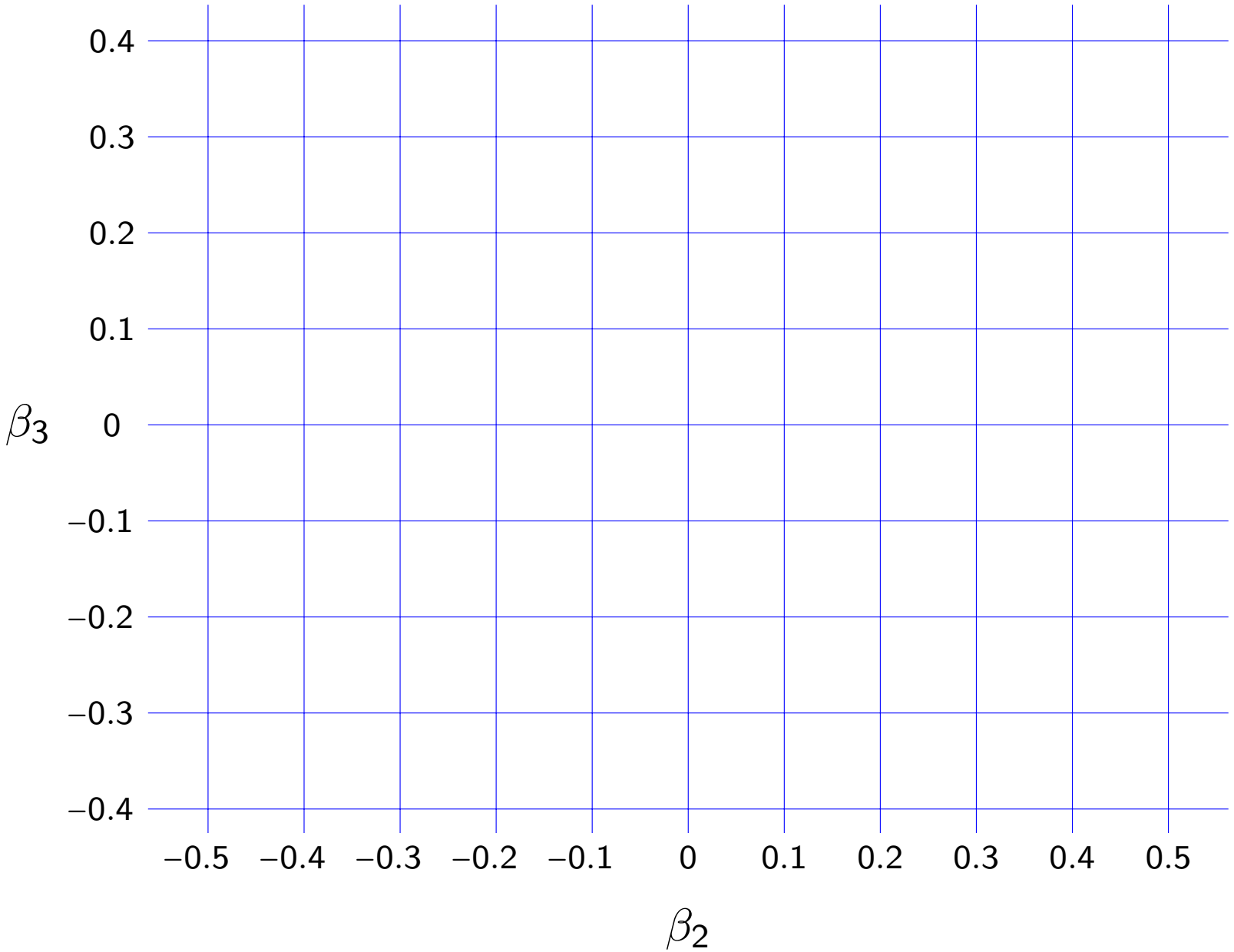
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0.3
0.2
0.1
β_3
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−0.1
−0.2
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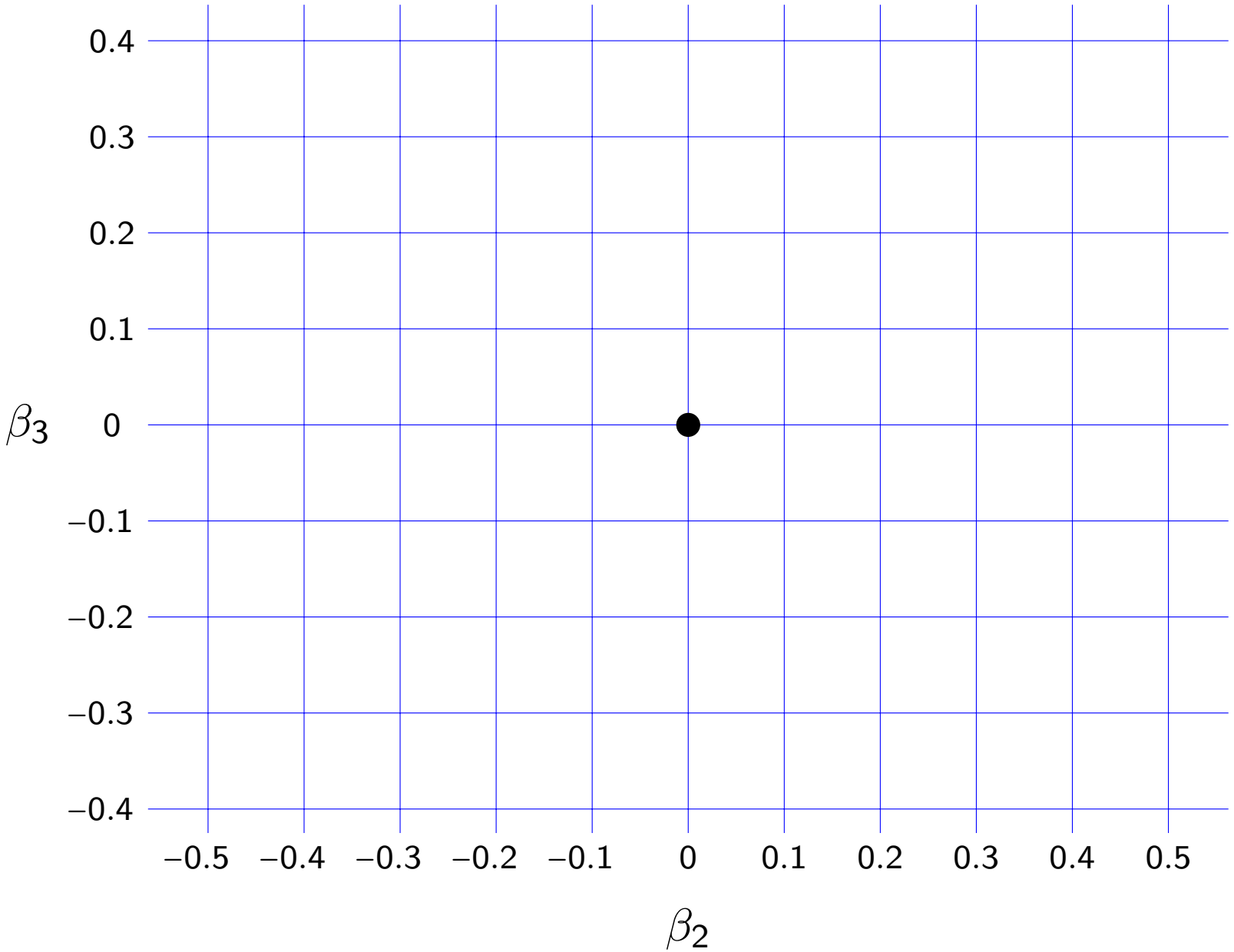
−0.4
−0.5 −0.4 −0.3 −0.2 −0.1 0 0.1 0.2 0.3 0.4 0.5
β_2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β_3
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0
0.1
0.2
0.3
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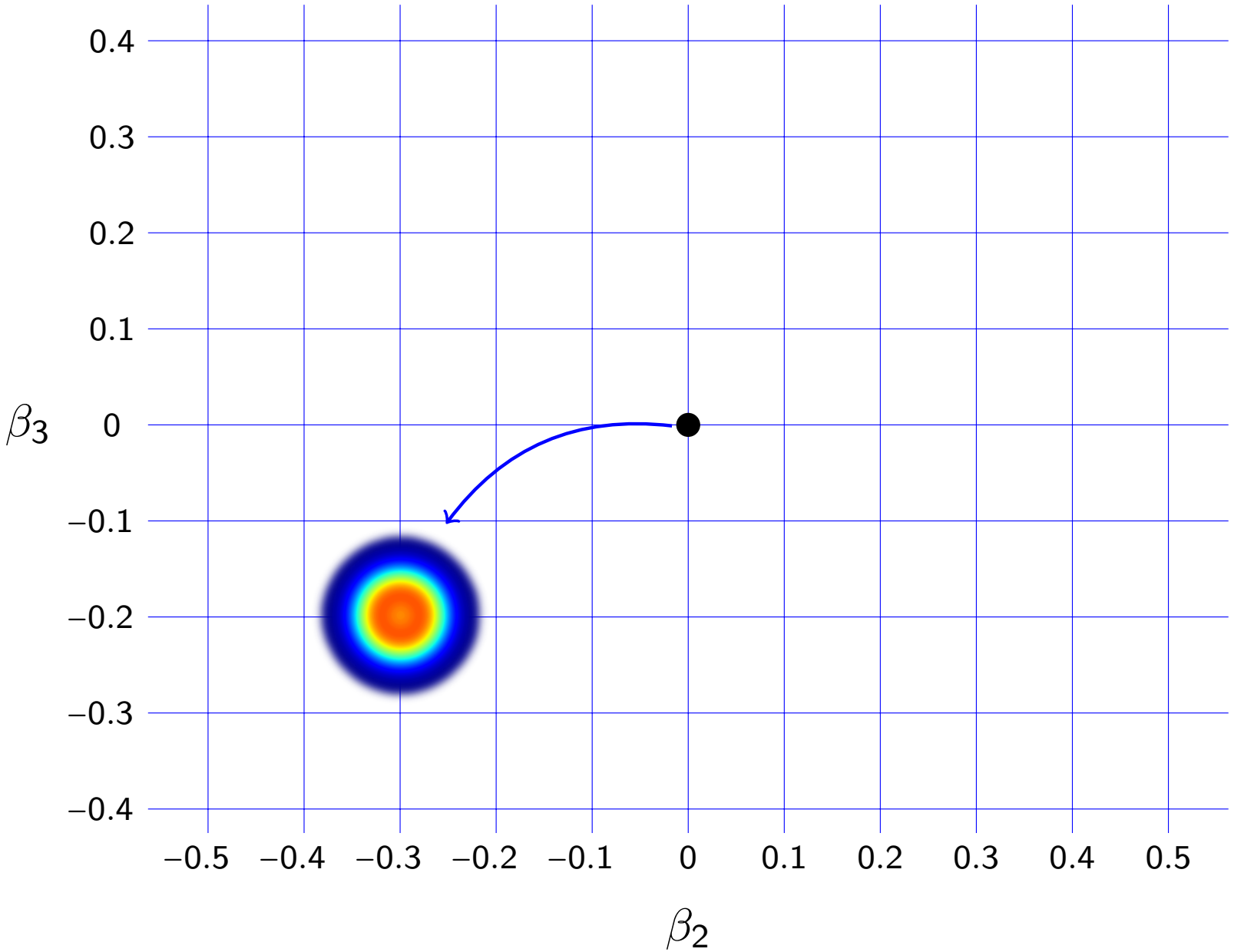
0.5
β_2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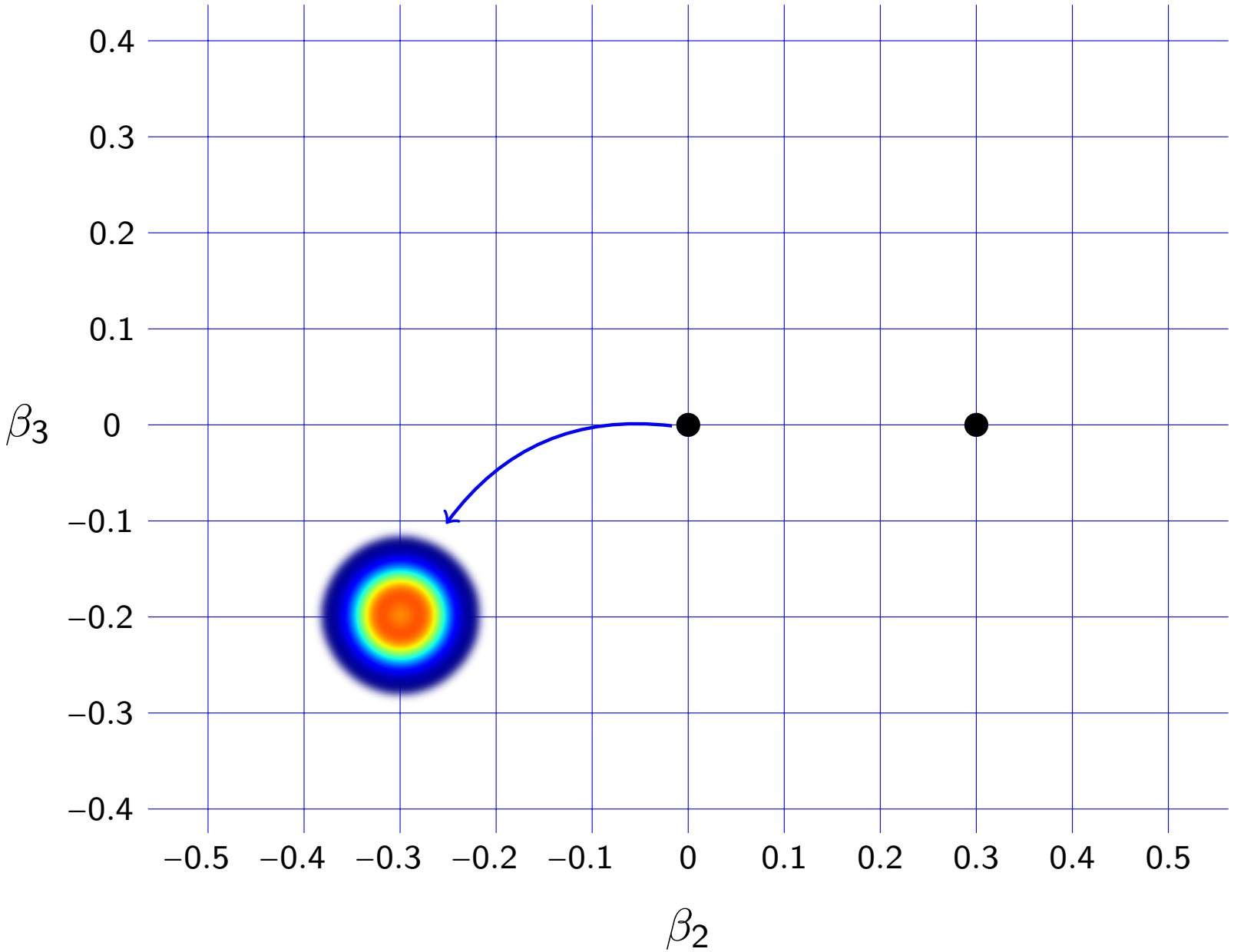
β_2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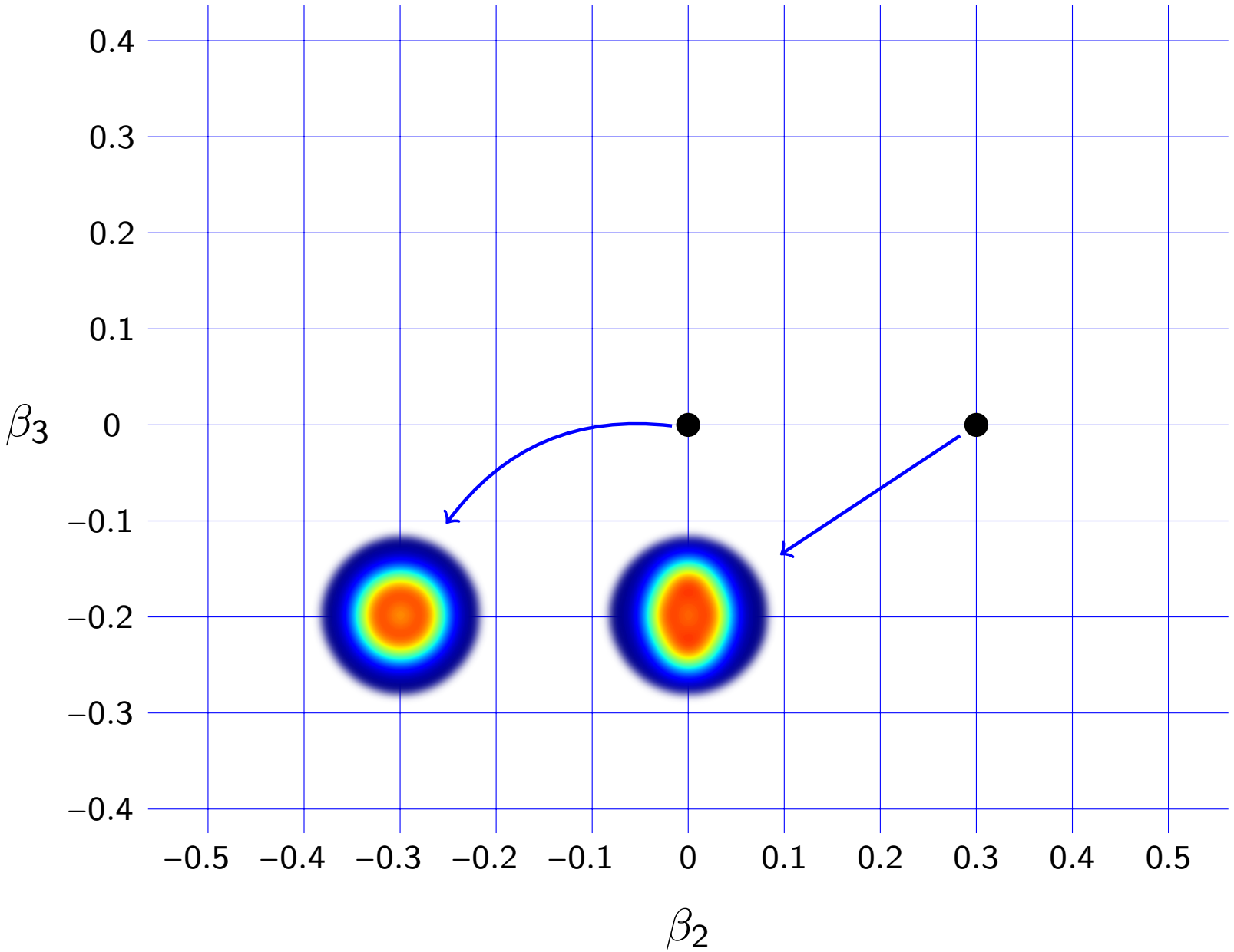
β_2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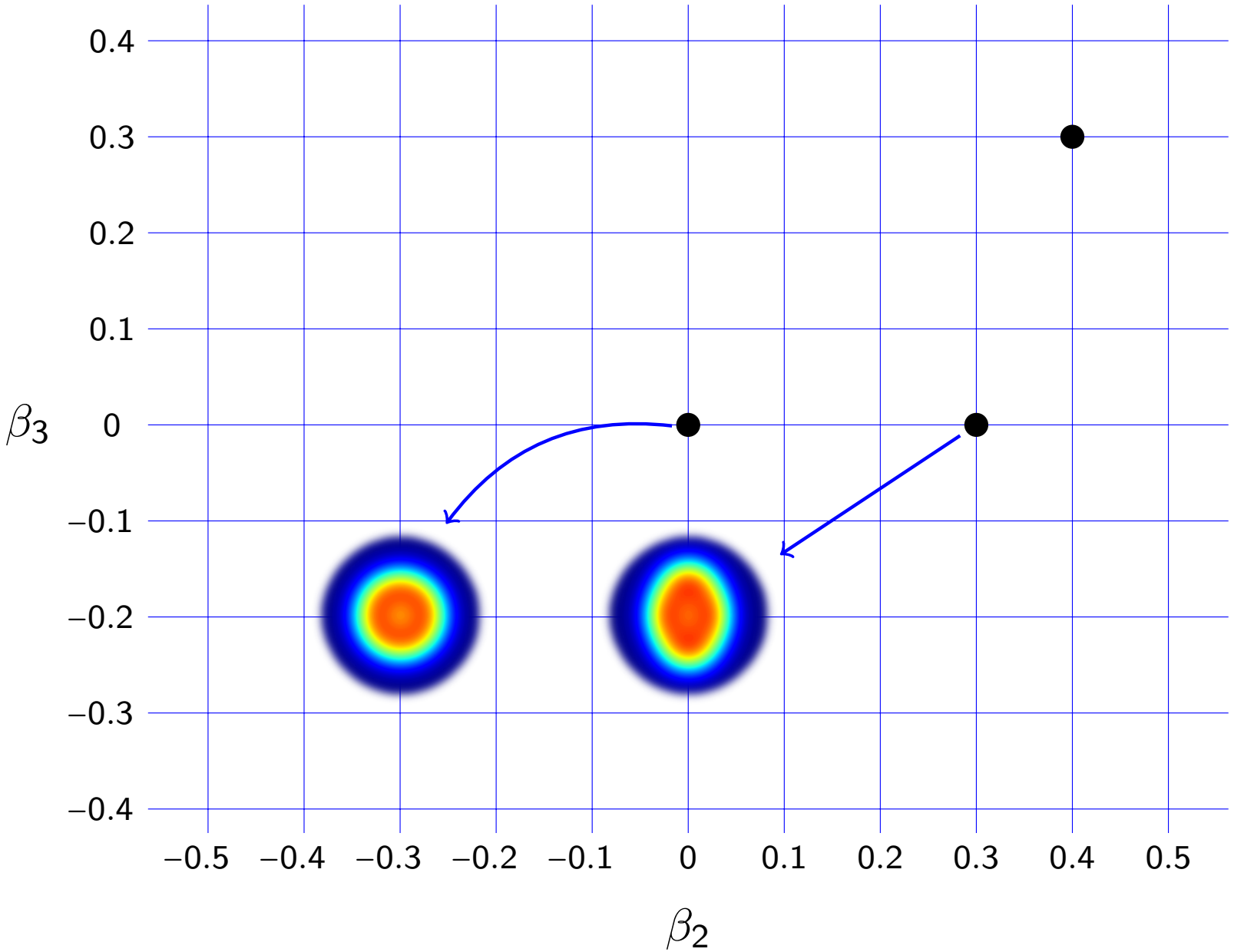
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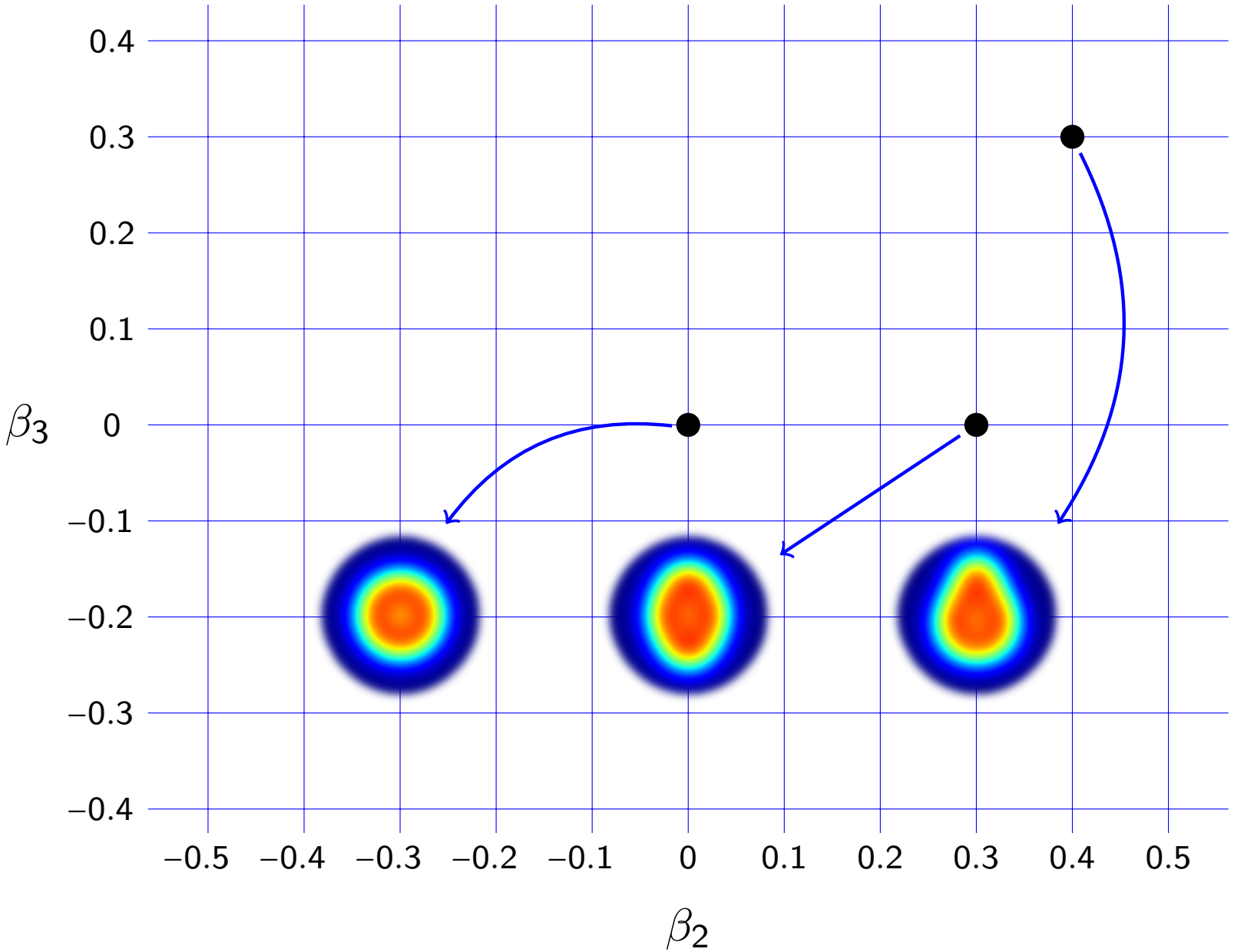
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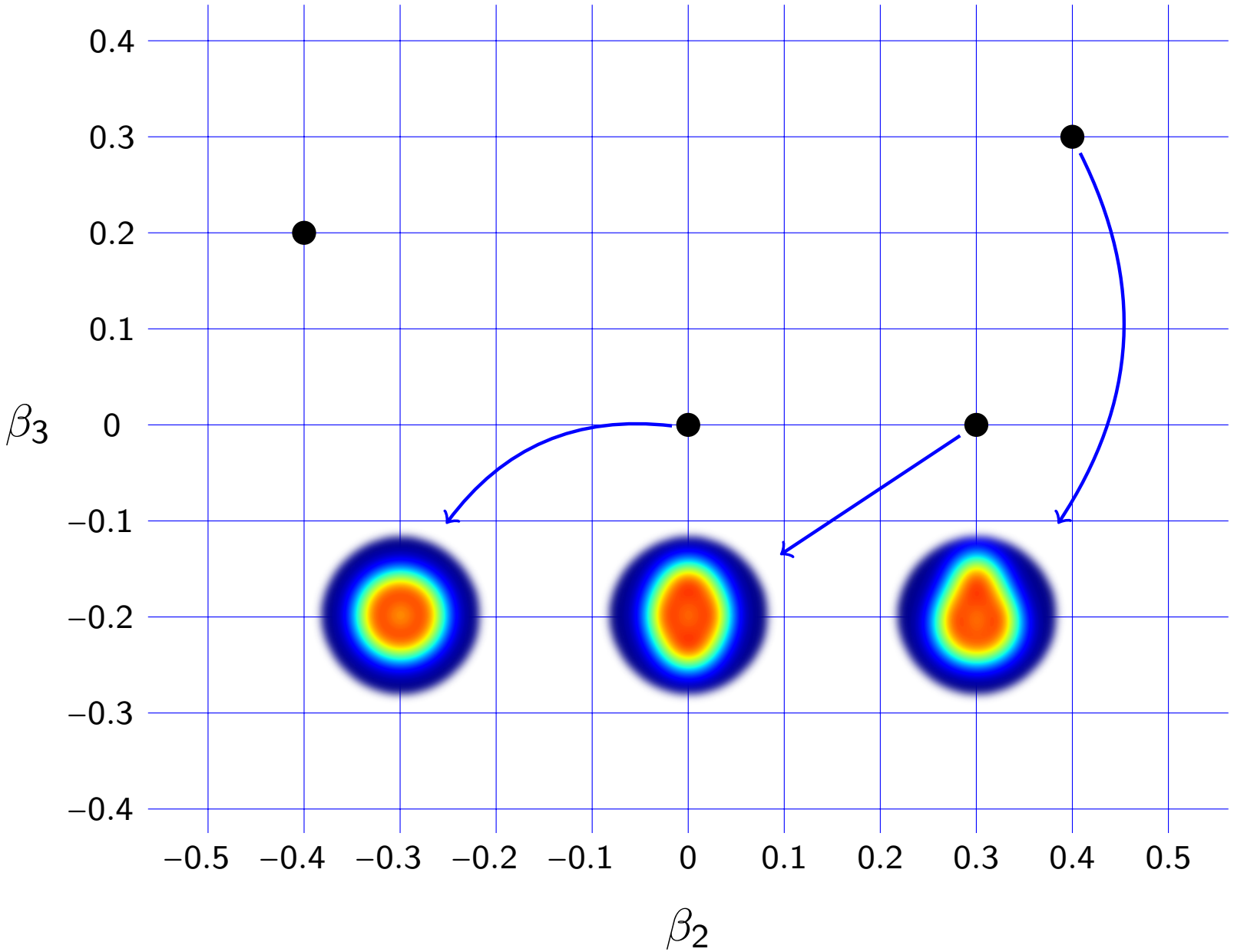
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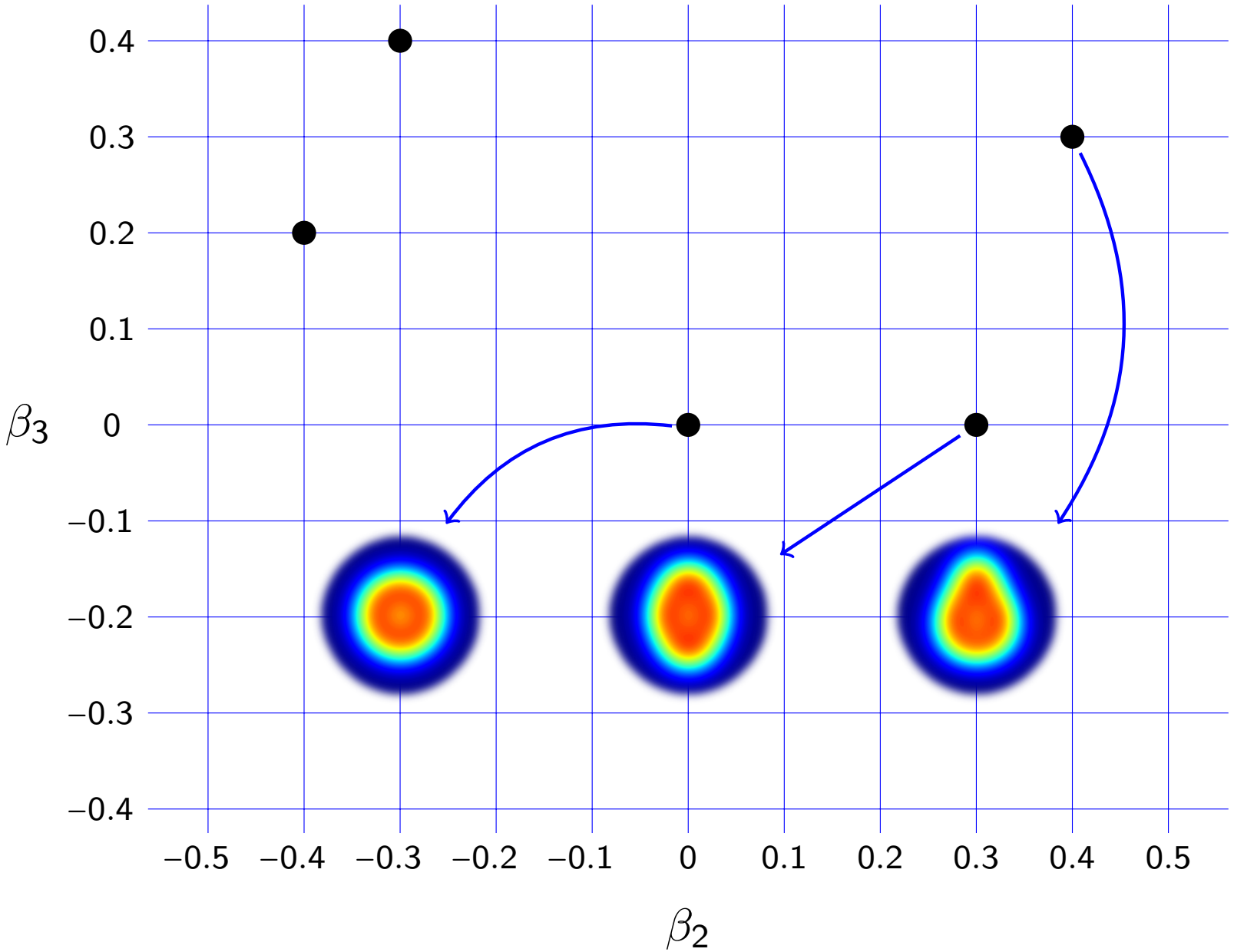
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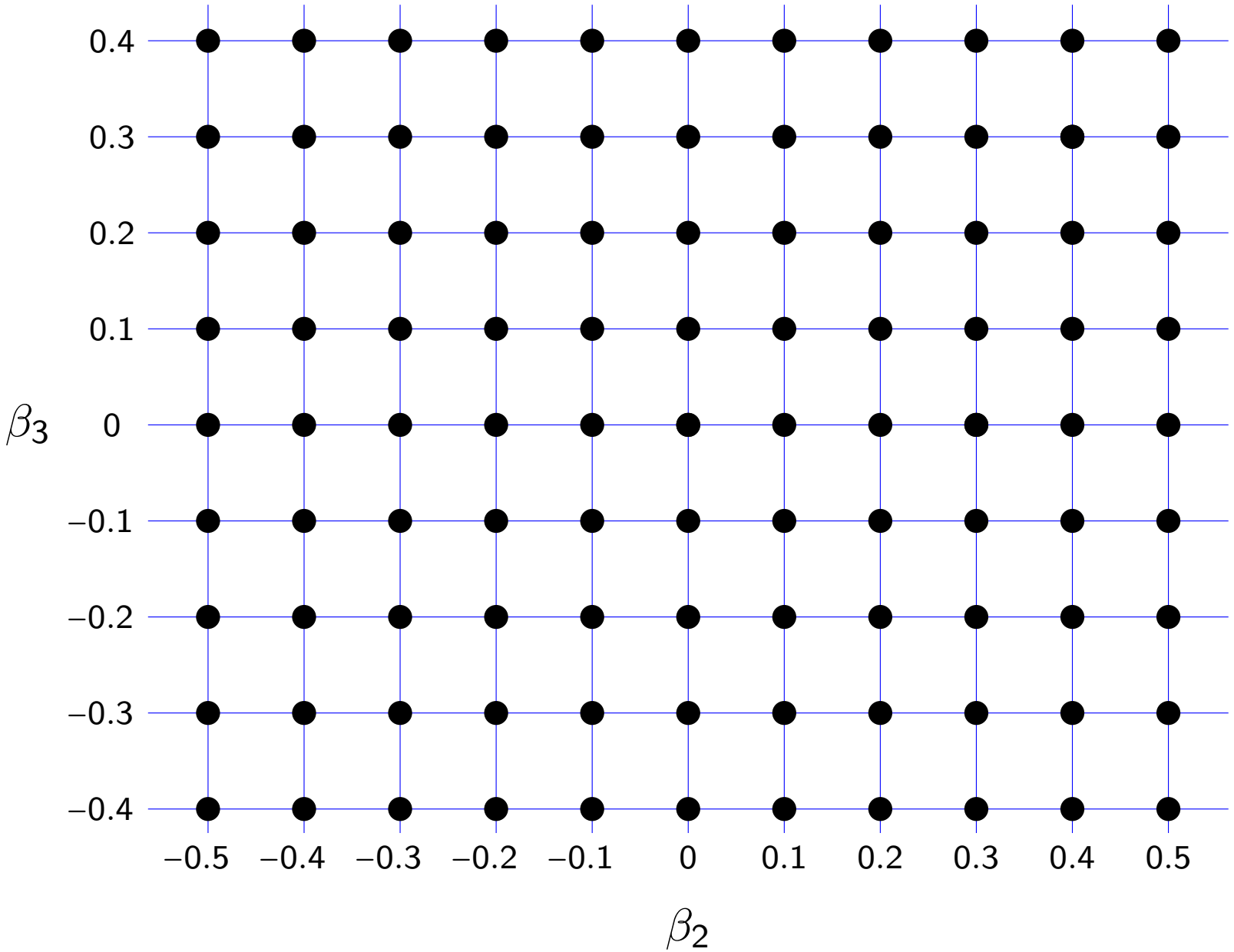
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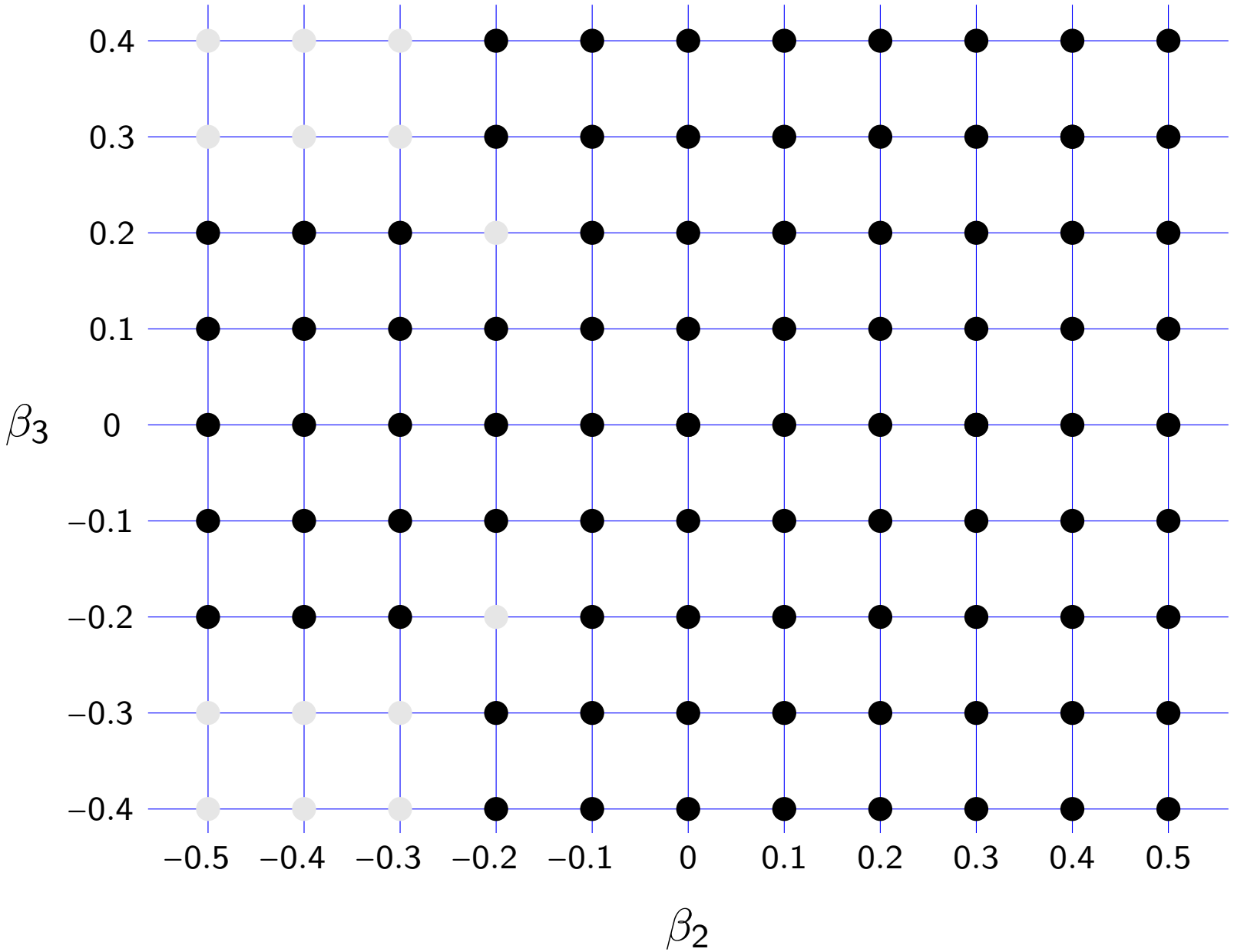
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β_2

Going beyond mean-field

broken symmetry	in which nuclei?	due to?
translational	all	localized mean-field

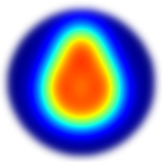
broken symmetry	in which nuclei?	due to?
translational	all	localized mean-field
rotational	deformed	deformation

broken symmetry	in which nuclei?	due to?
translational	all	localized mean-field
rotational	deformed	deformation
particle number	superfluid	pairing

broken symmetry	in which nuclei?	due to?
translational	all	localized mean-field
rotational	deformed	deformation
particle number	superfluid	pairing
parity	octupole deformed	octupole deformation

broken symmetry	in which nuclei?	due to?
translational	all	localized mean-field
rotational	deformed	deformation
particle number	superfluid	pairing
parity	octupole deformed	octupole deformation

parity is broken whenever $\beta_3 \neq 0$ $|\Phi(\beta_3)\rangle$



broken symmetry	in which nuclei?	due to?
translational	all	localized mean-field
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particle number	superfluid	pairing
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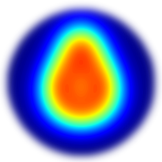
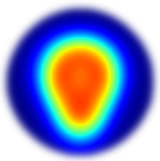
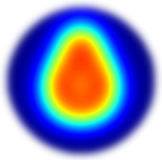


by applying symmetry operator $\hat{\Pi}|\Phi(\beta_3)\rangle$

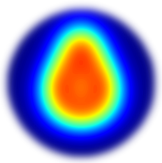


broken symmetry	in which nuclei?	due to?
translational	all	localized mean-field
rotational	deformed	deformation
particle number	superfluid	pairing
parity	octupole deformed	octupole deformation

parity is broken whenever $\beta_3 \neq 0$ $|\Phi(\beta_3)\rangle$ 

by applying symmetry operator $\hat{\Pi}|\Phi(\beta_3)\rangle$ 

symmetry-restored state corresponds to a linear combination:

$|\Psi_\pi\rangle = \mathcal{N}_\pi($  $\pm$  $)$

broken symmetry	in which nuclei?	due to?
translational	all	localized mean-field
rotational	deformed	deformation
particle number	superfluid	pairing
parity	octupole deformed	octupole deformation

pa

b

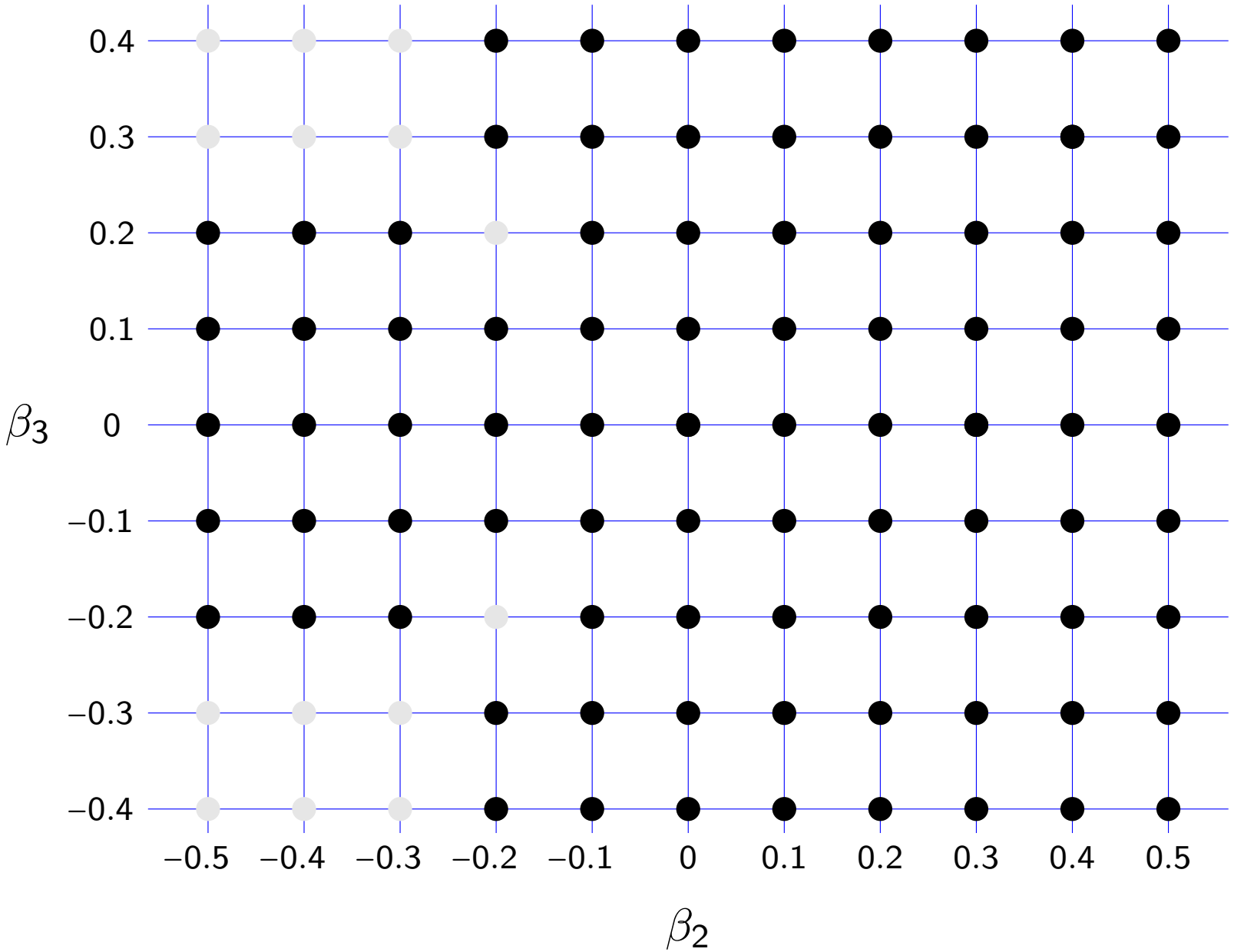
syr n:

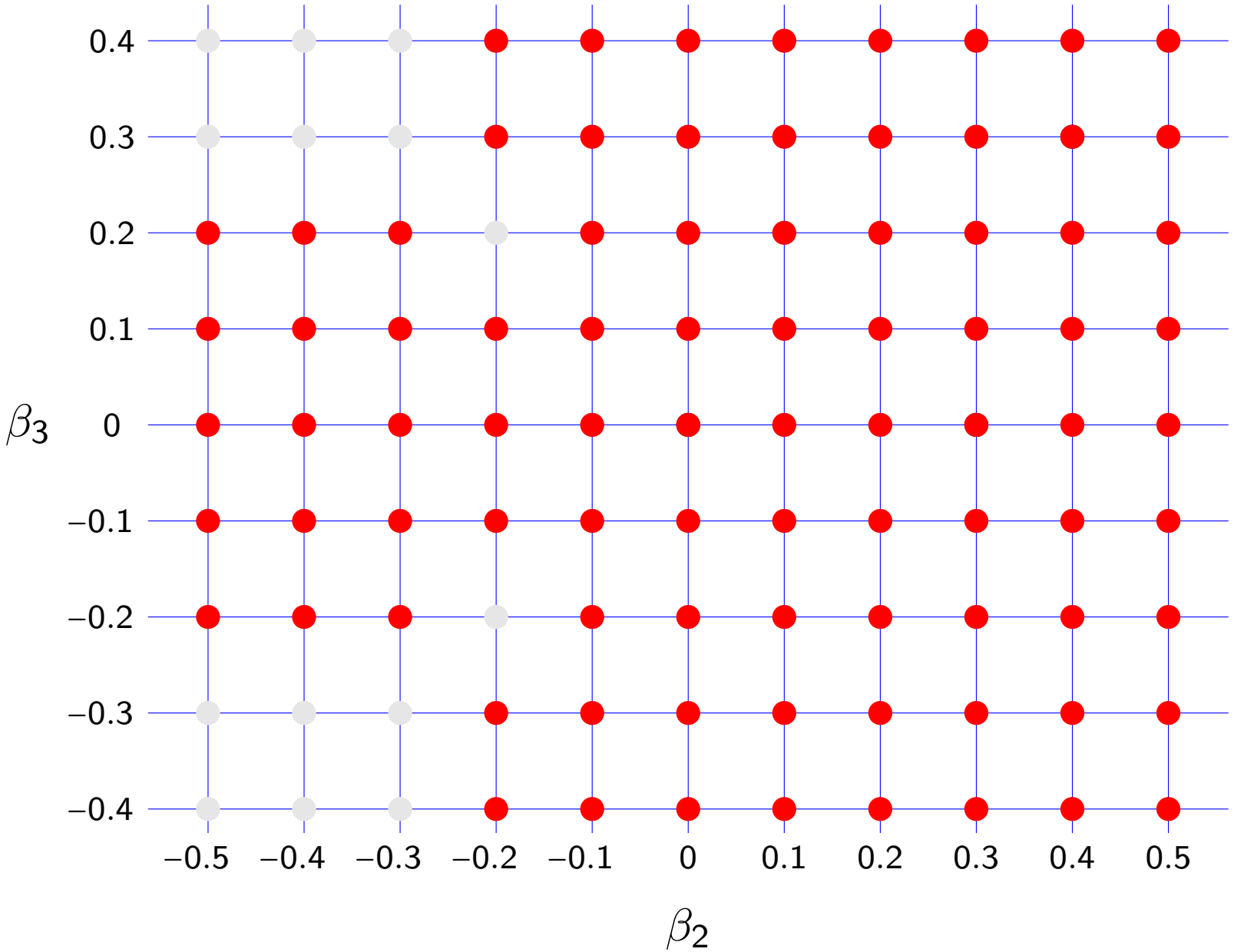
$$\hat{R}(\alpha,\beta,\gamma) = exp(-i\alpha J_z)exp(-i\beta J_y)exp(-i\gamma J_z)$$

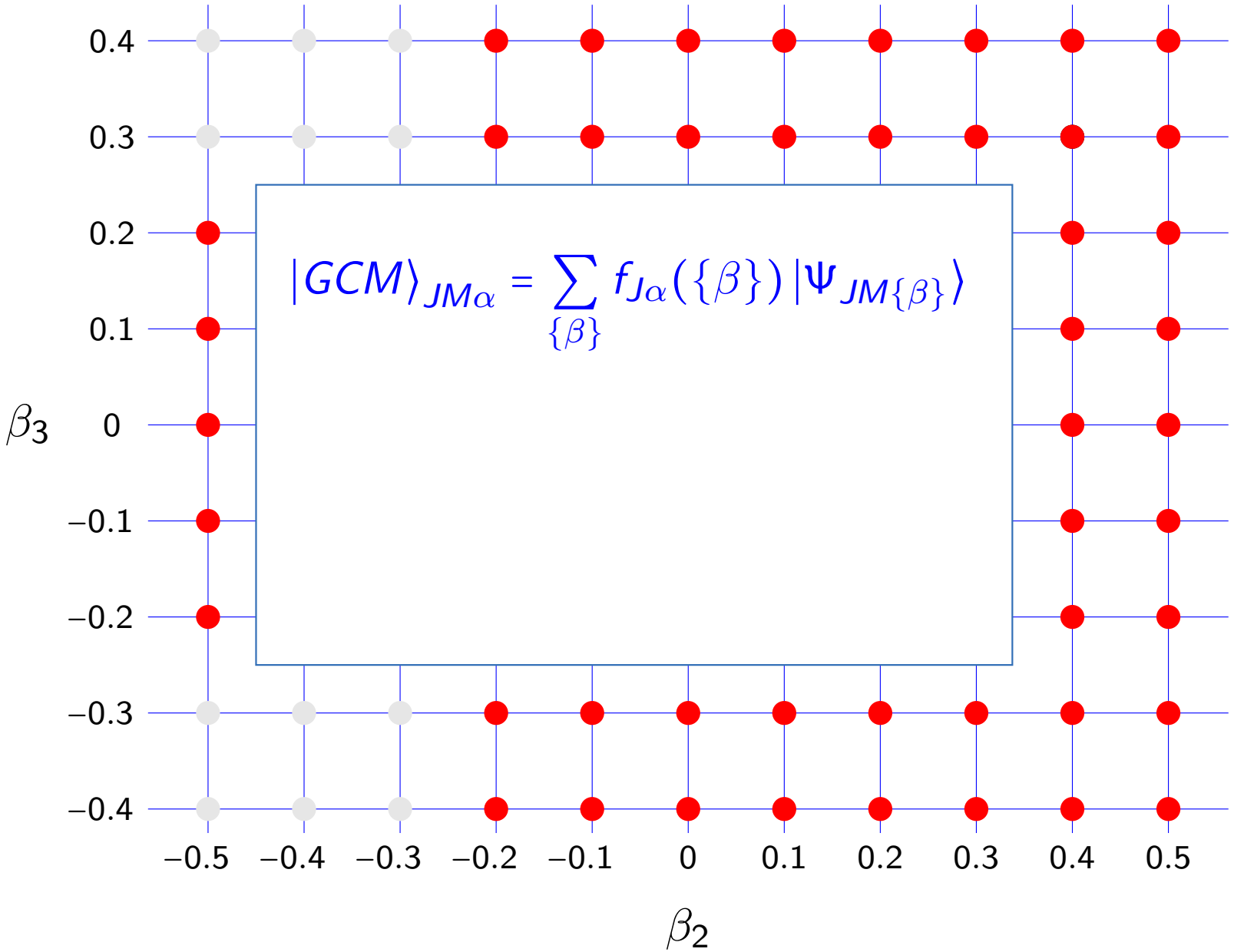
$$\hat{P}^J_{MK} = \frac{2J+1}{8\pi^2}\int d\alpha \int d\beta \sin\beta \int d\gamma D^{J*}_{MK}(\alpha,\beta,\gamma)\hat{R}(\alpha,\beta,\gamma)$$

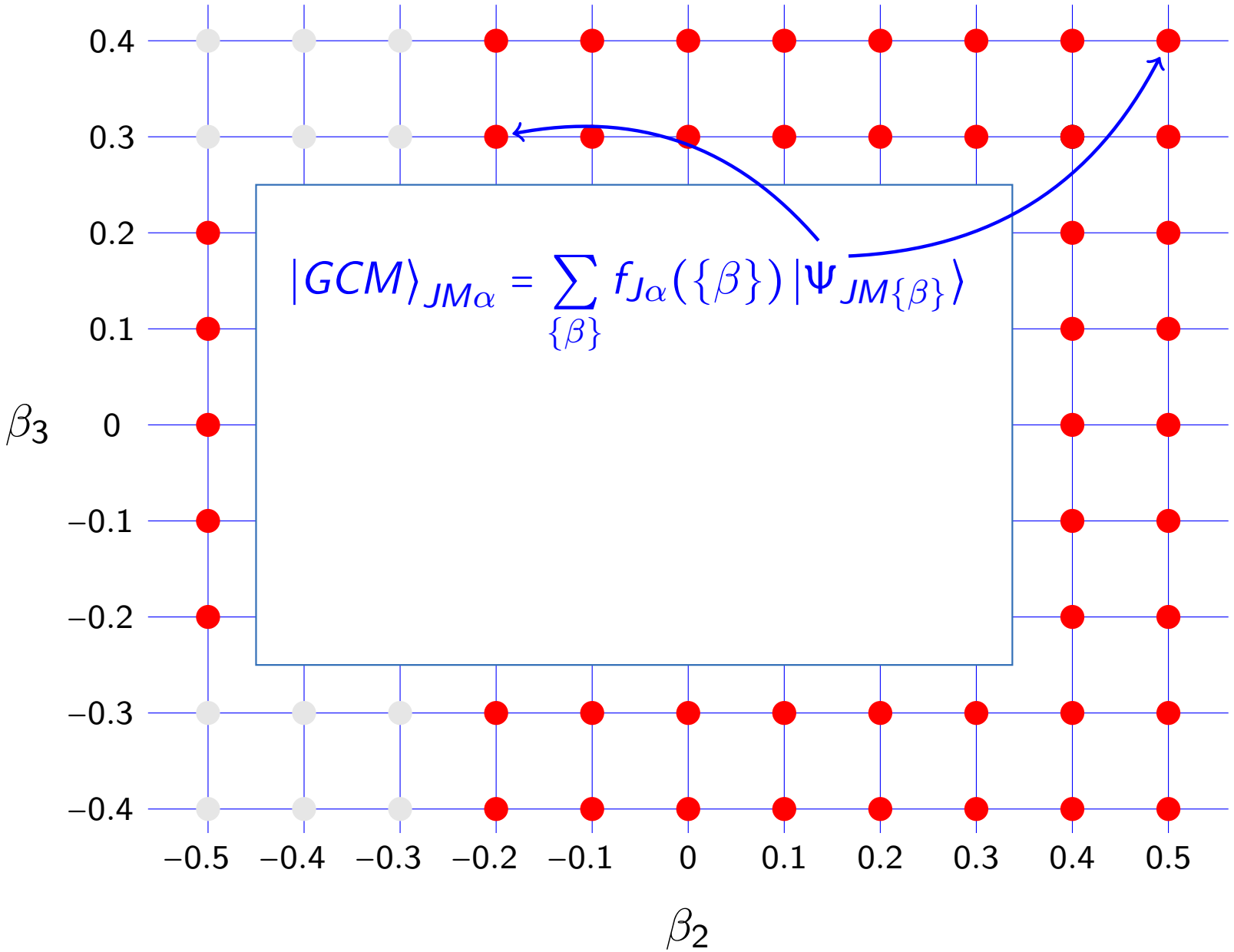
$$|\Psi_{JM\{\beta\}}\rangle = \sum_K g_K \hat{P}^J_{MK}|\Phi(\{\beta\})\rangle$$

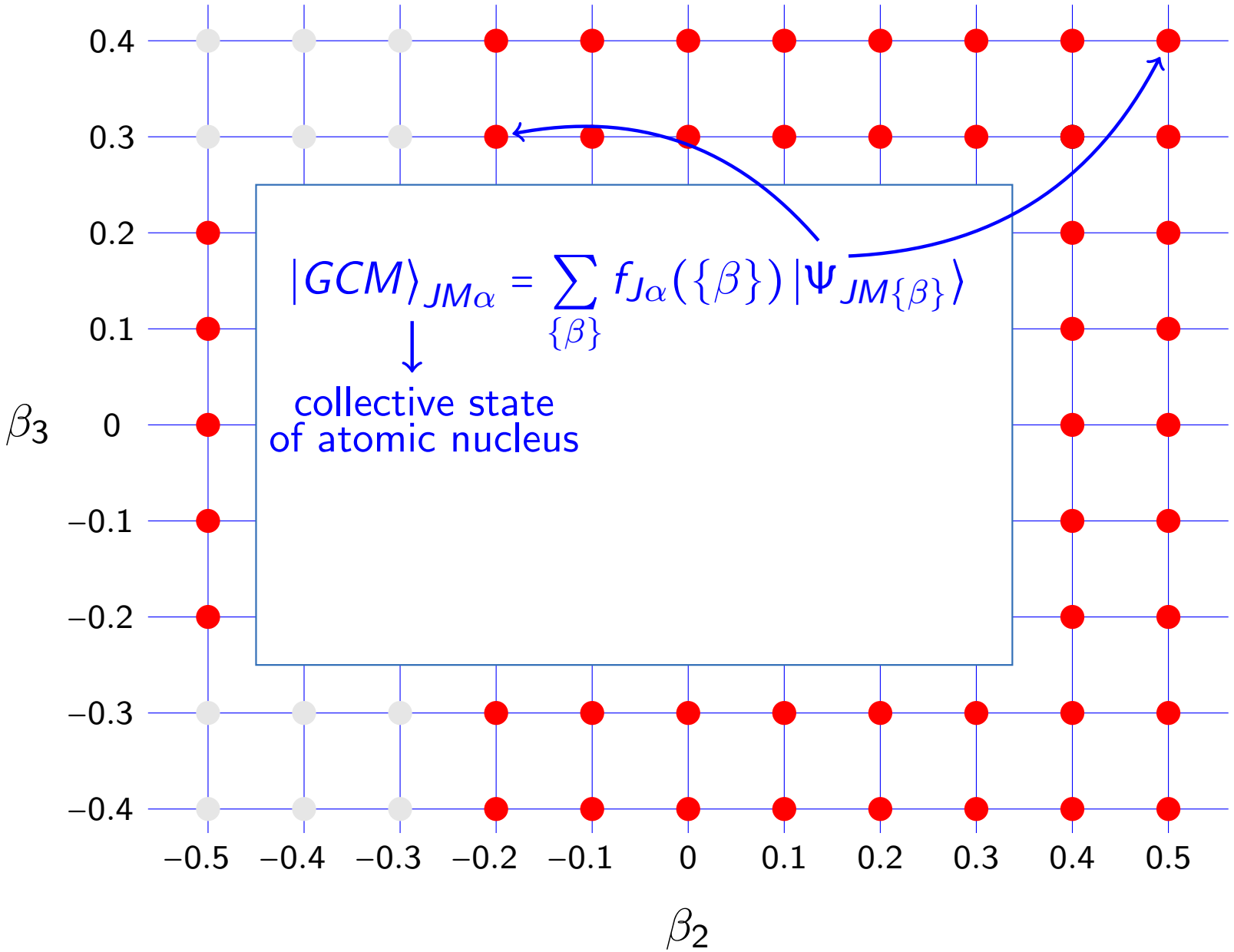
$|\Psi_\pi\rangle = \mathcal{N}_\pi($ $\pm$ $)$

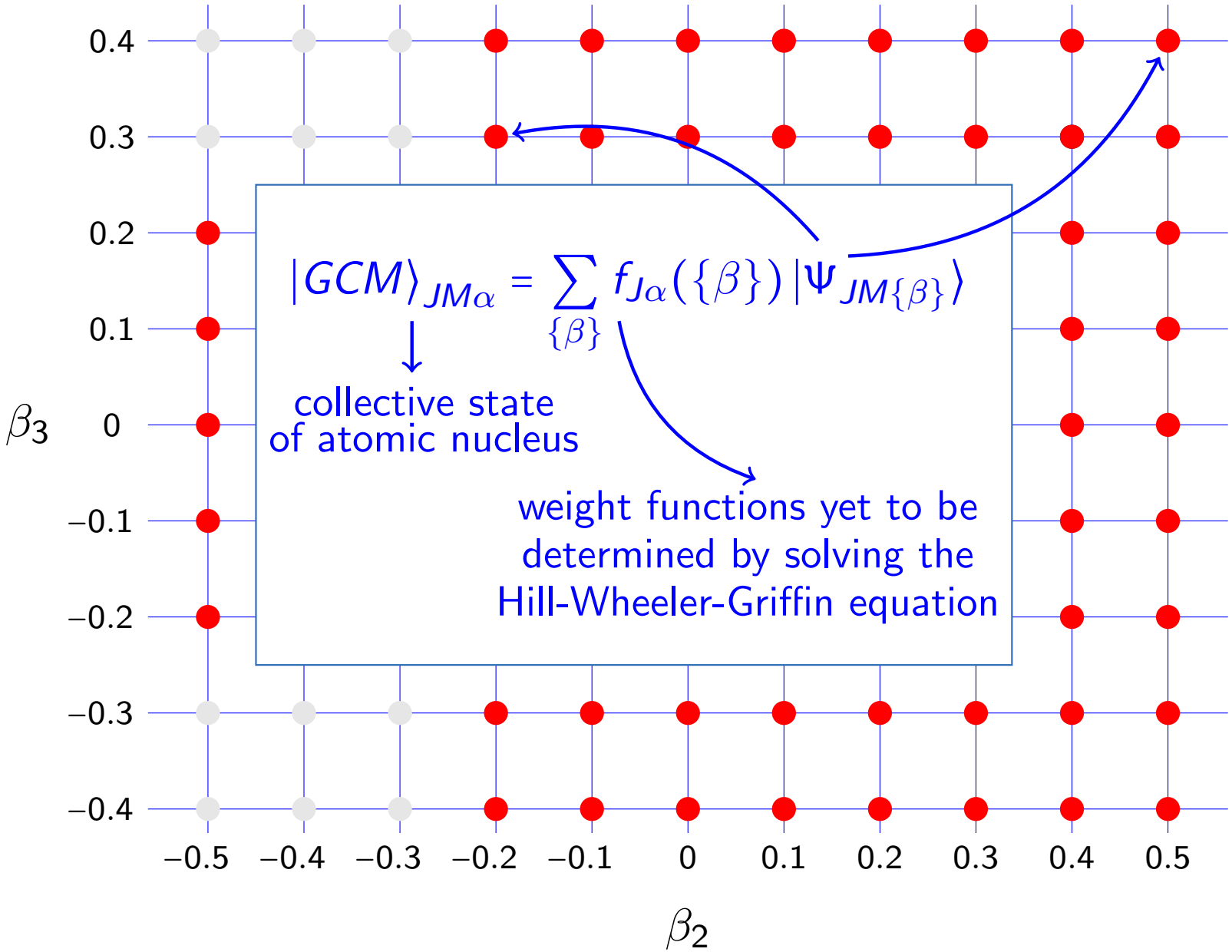

0.4
0.3
0.2
0.1
β_3
0
−0.1
−0.2
−0.3
−0.4
−0.5 −0.4 −0.3 −0.2 −0.1 0 0.1 0.2 0.3 0.4 0.5
β_2


0.4
0.3
0.2
0.1
β_3
0
−0.1
−0.2
−0.3
−0.4
−0.5 −0.4 −0.3 −0.2 −0.1 0 0.1 0.2 0.3 0.4 0.5
β_2

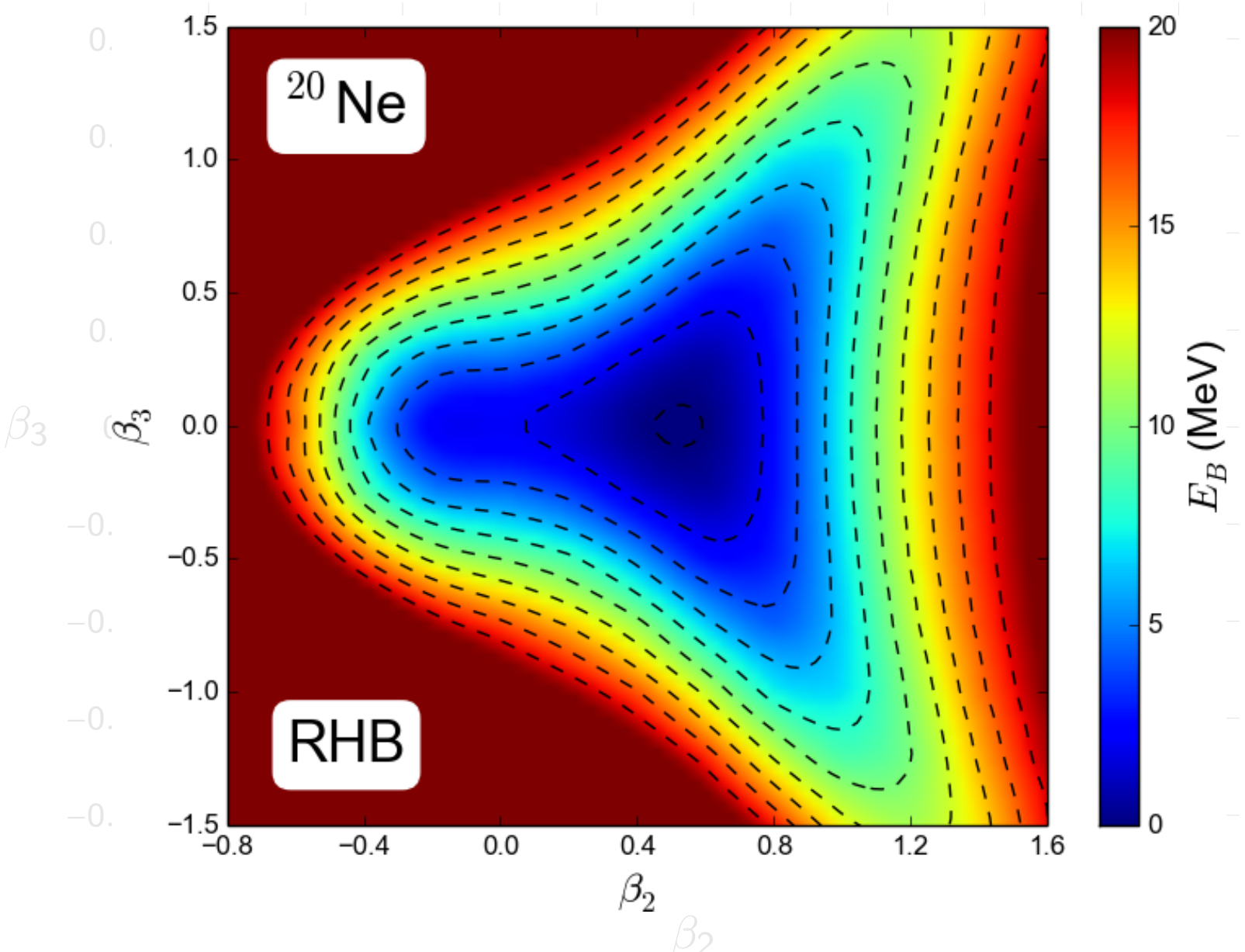

$|GCM\rangle_{JM\alpha} = \sum_{\{\beta\}} f_{J\alpha}(\{\beta\}) |\Psi_{JM\{\beta\}}\rangle$
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
β_3
−0.5 −0.4 −0.3 −0.2 −0.1 0 0.1 0.2 0.3 0.4 0.5
β_2

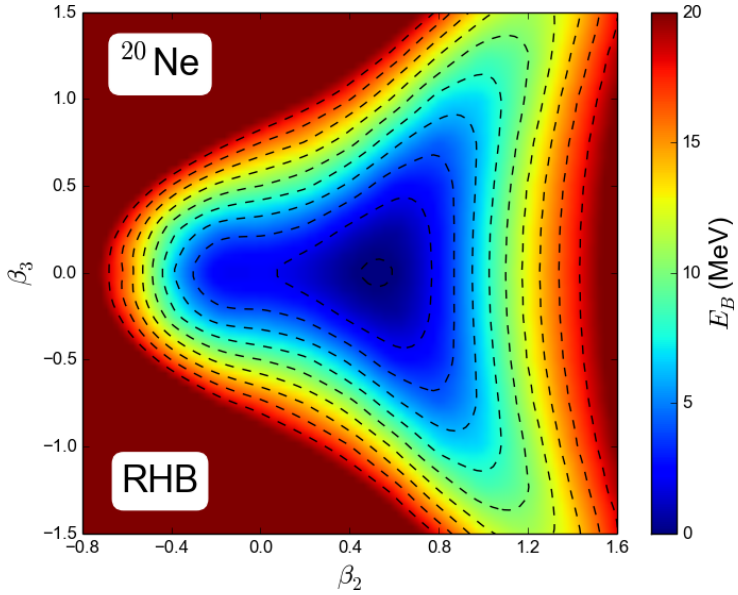

$|GCM\rangle_{JM\alpha} = \sum_{\{\beta\}} f_{J\alpha}(\{\beta\}) |\Psi_{JM\{\beta\}}\rangle$
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
β_3
−0.5 −0.4 −0.3 −0.2 −0.1 0 0.1 0.2 0.3 0.4 0.5
β_2

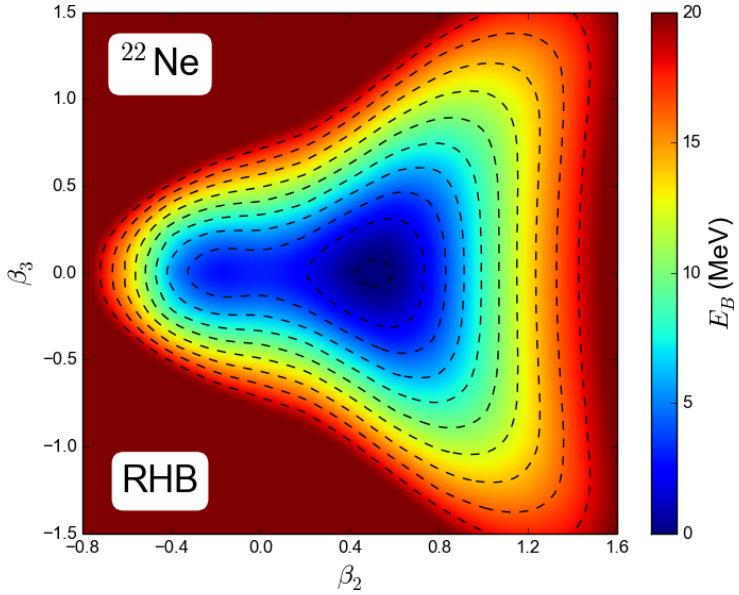

0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
β_3
−0.5 −0.4 −0.3 −0.2 −0.1 0 0.1 0.2 0.3 0.4 0.5
β_2
$|GCM\rangle_{JM\alpha} = \sum_{\{\beta\}} f_{J\alpha}(\{\beta\})\,|\Psi_{JM\{\beta\}}\rangle$
collective state
of atomic nucleus

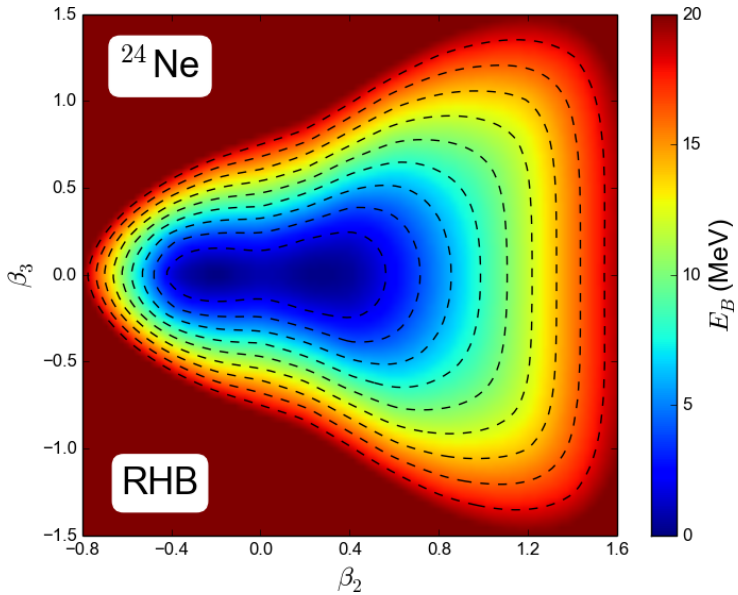

0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
β_3
−0.5 −0.4 −0.3 −0.2 −0.1 0 0.1 0.2 0.3 0.4 0.5
β_2
$|GCM\rangle_{JM\alpha} = \sum_{\{\beta\}} f_{J\alpha}(\{\beta\})\,|\Psi_{JM\{\beta\}}\rangle$
collective state
of atomic nucleus
weight functions yet to be
determined by solving the
Hill-Wheeler-Griffin equation

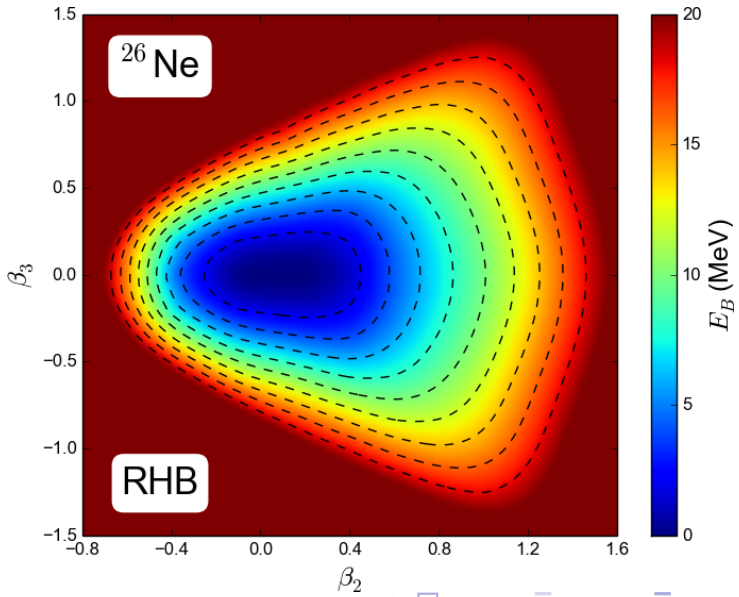
Structure of neon isotopes

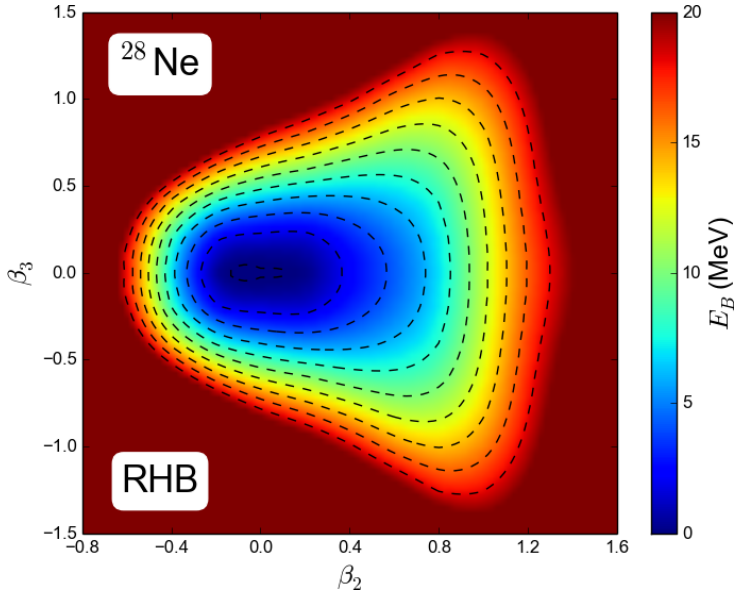

^{20}Ne
RHB
β_3
β_2
E_B (MeV)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−0.8
−0.4
0.0
0.4
0.8
1.2
1.6
20
15
10
5
0

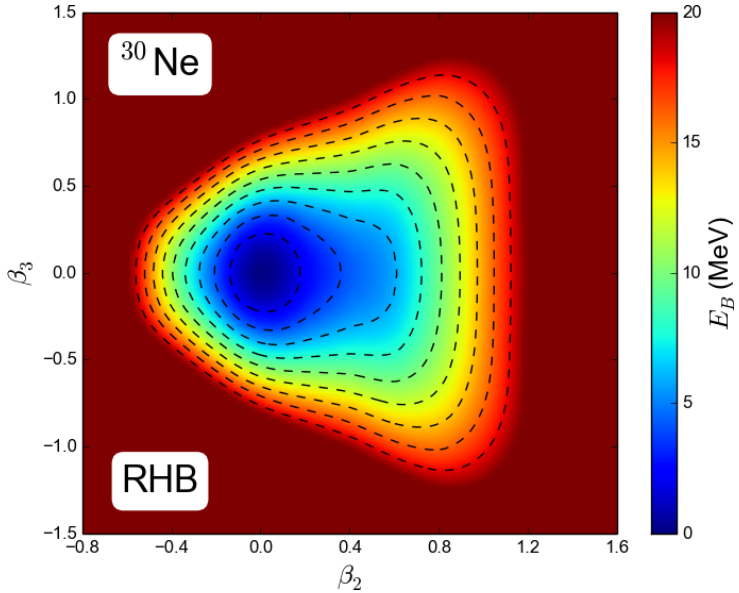

^{20}Ne
RHB
β_2
β_3
E_B (MeV)

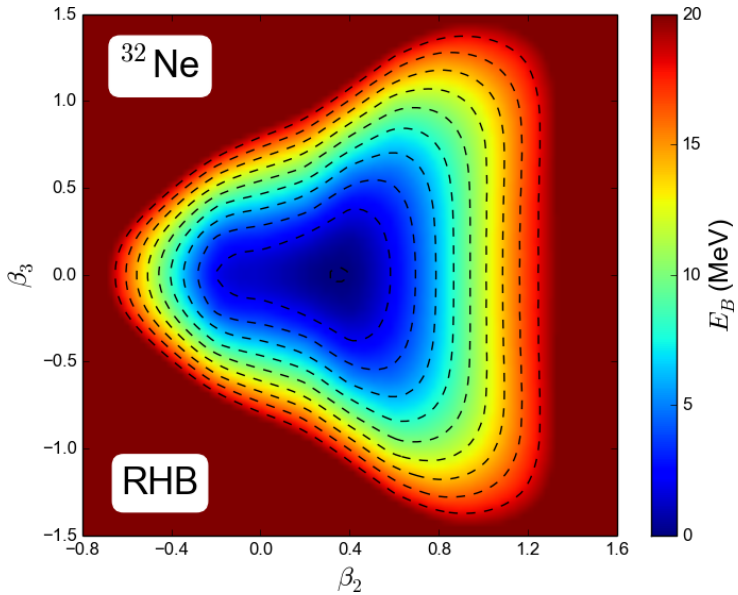

^{22}Ne
RHB
β_2
β_3
E_B (MeV)

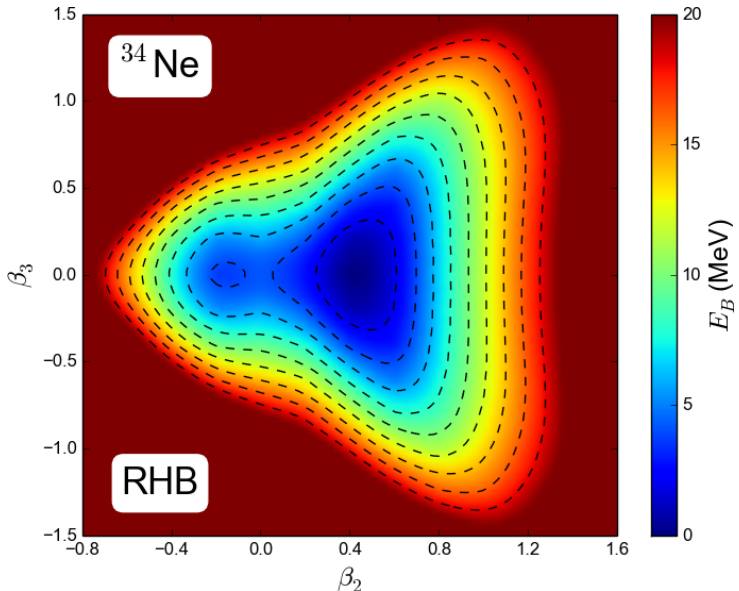

^{24}Ne
RHB
β_2
β_3
E_B (MeV)

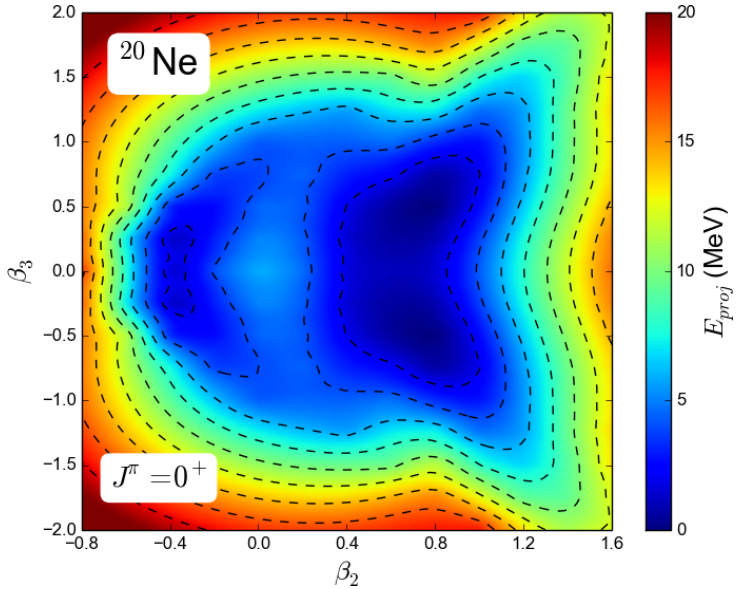

^{26}Ne
RHB
β_2
β_3
E_B (MeV)

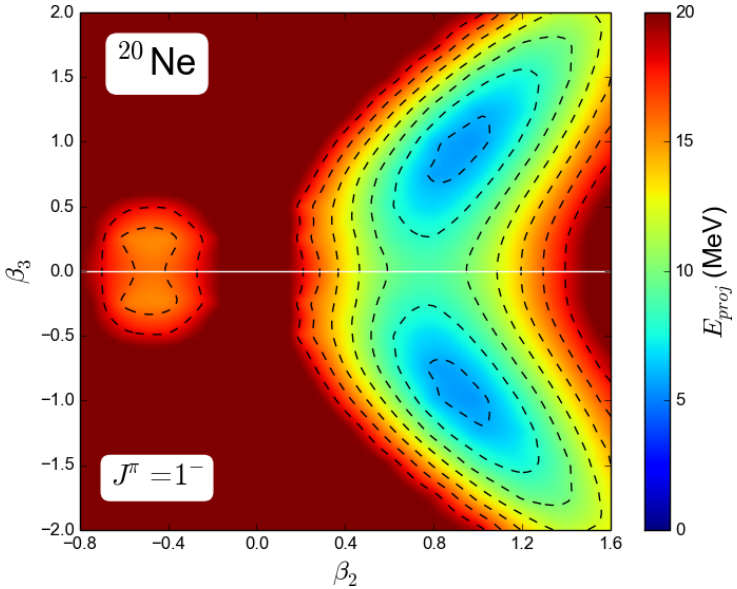

^{28}Ne
RHB
β_3
β_2
E_B (MeV)

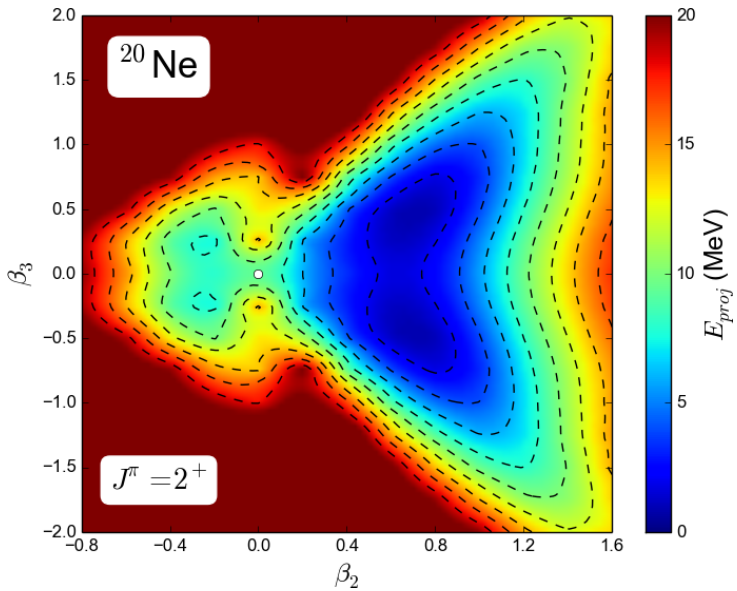

^{30}Ne
RHB
β_3
β_2
E_B (MeV)

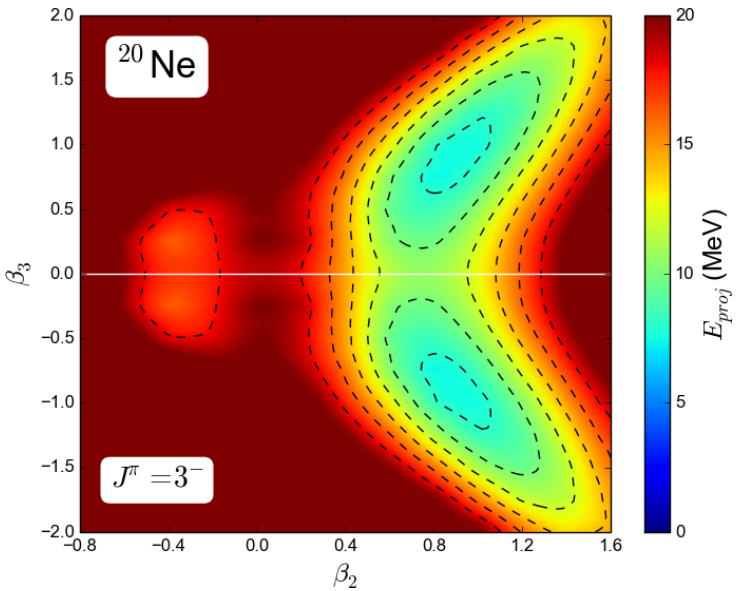

^{32}Ne
RHB
β_3
β_2
E_B (MeV)

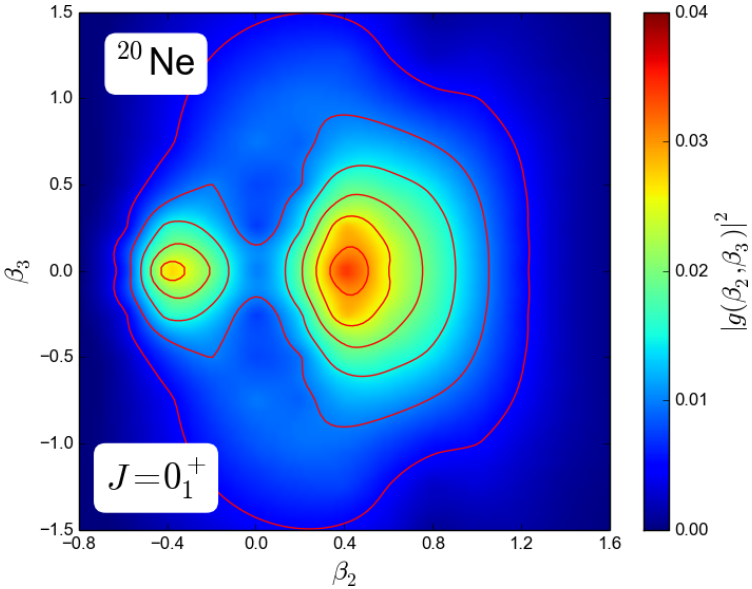

^{34}Ne
RHB
β_3
β_2
E_B (MeV)

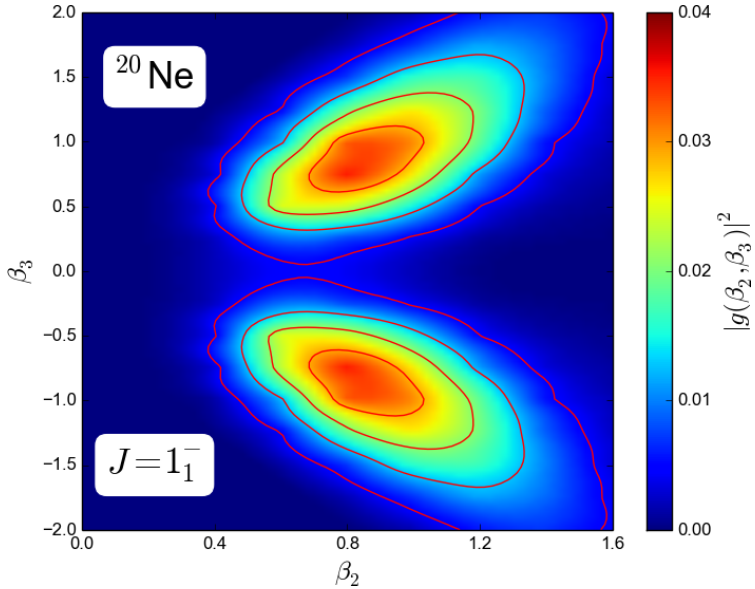

^{20}Ne
$J^\pi = 0^+$
β_3
β_2
E_{proj} (MeV)

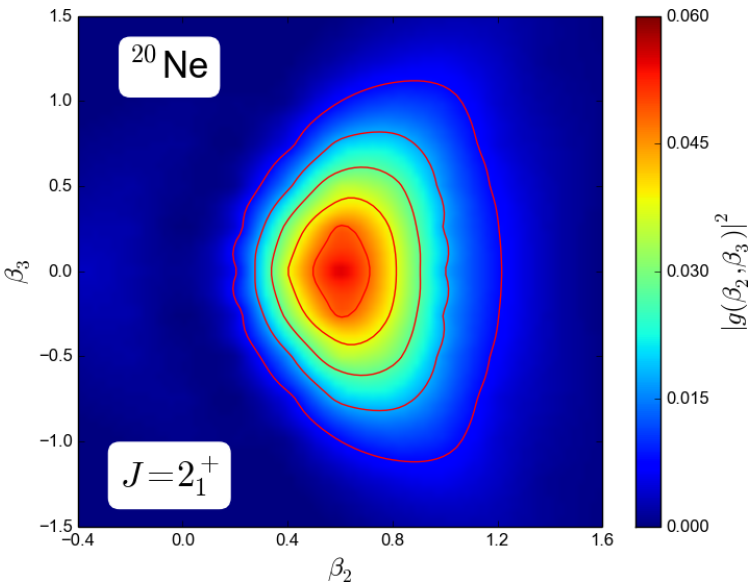

^{20}Ne
$J^\pi = 1^-$
β_3
β_2
E_{proj} (MeV)

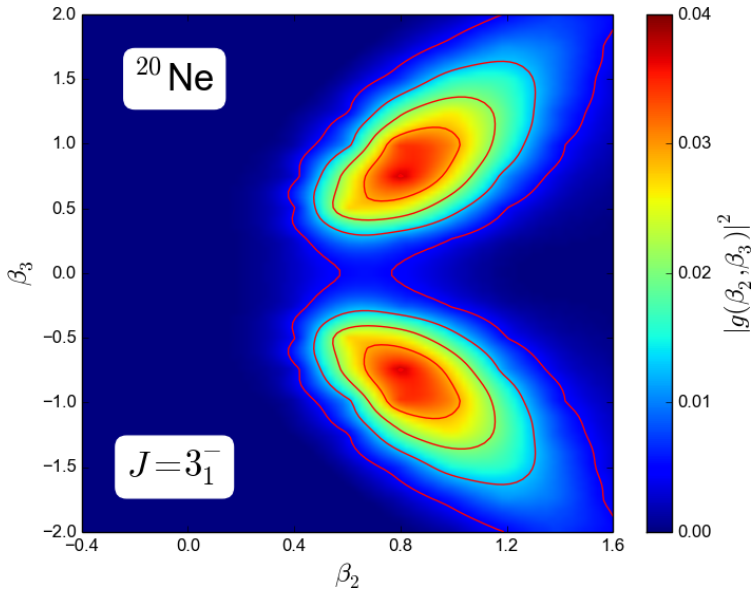

^{20}Ne
$J^\pi = 2^+$
β_3
β_2
E_{proj} (MeV)

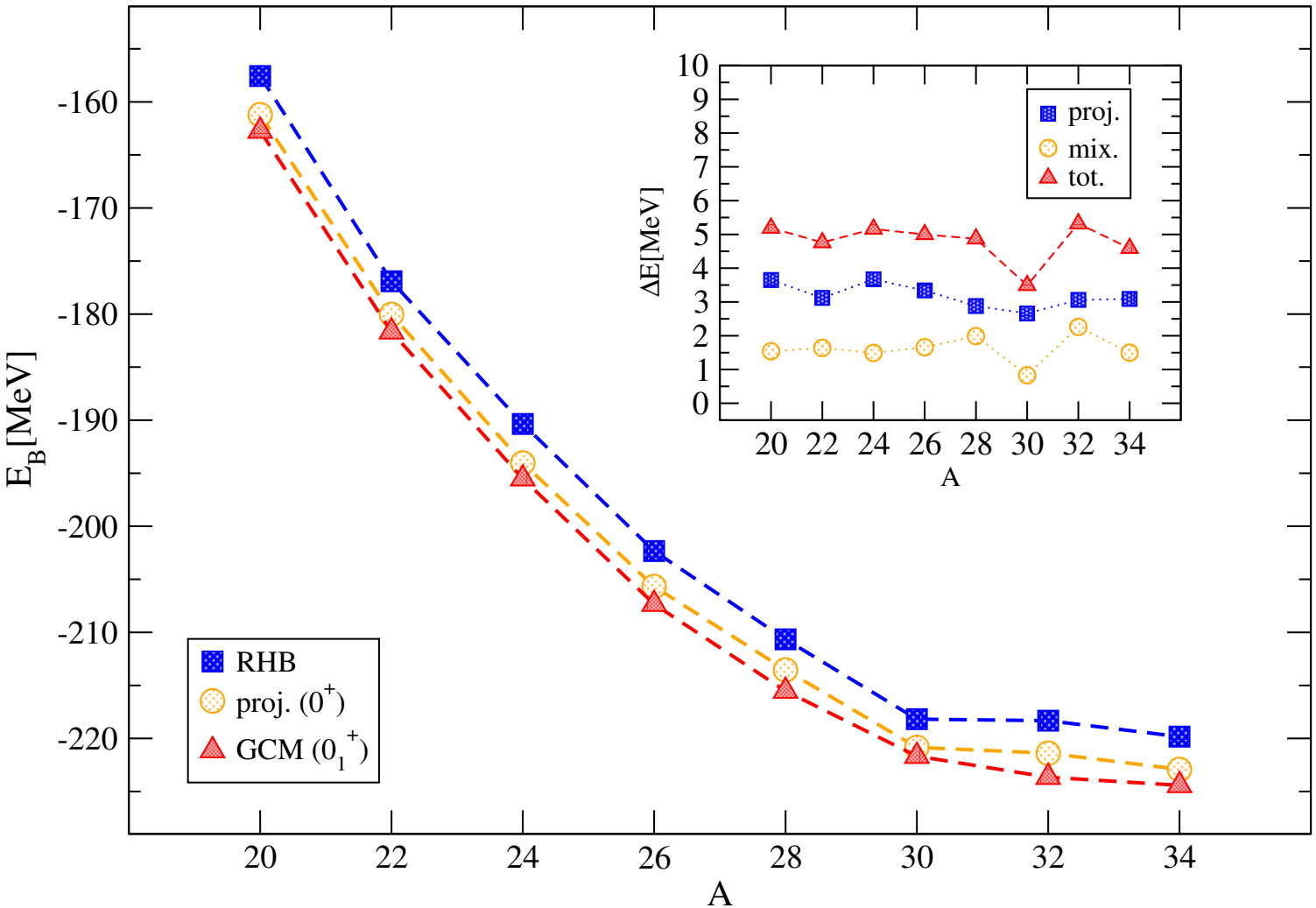

^{20}Ne
$J^\pi = 3^-$
β_3
β_2
E_{proj} (MeV)

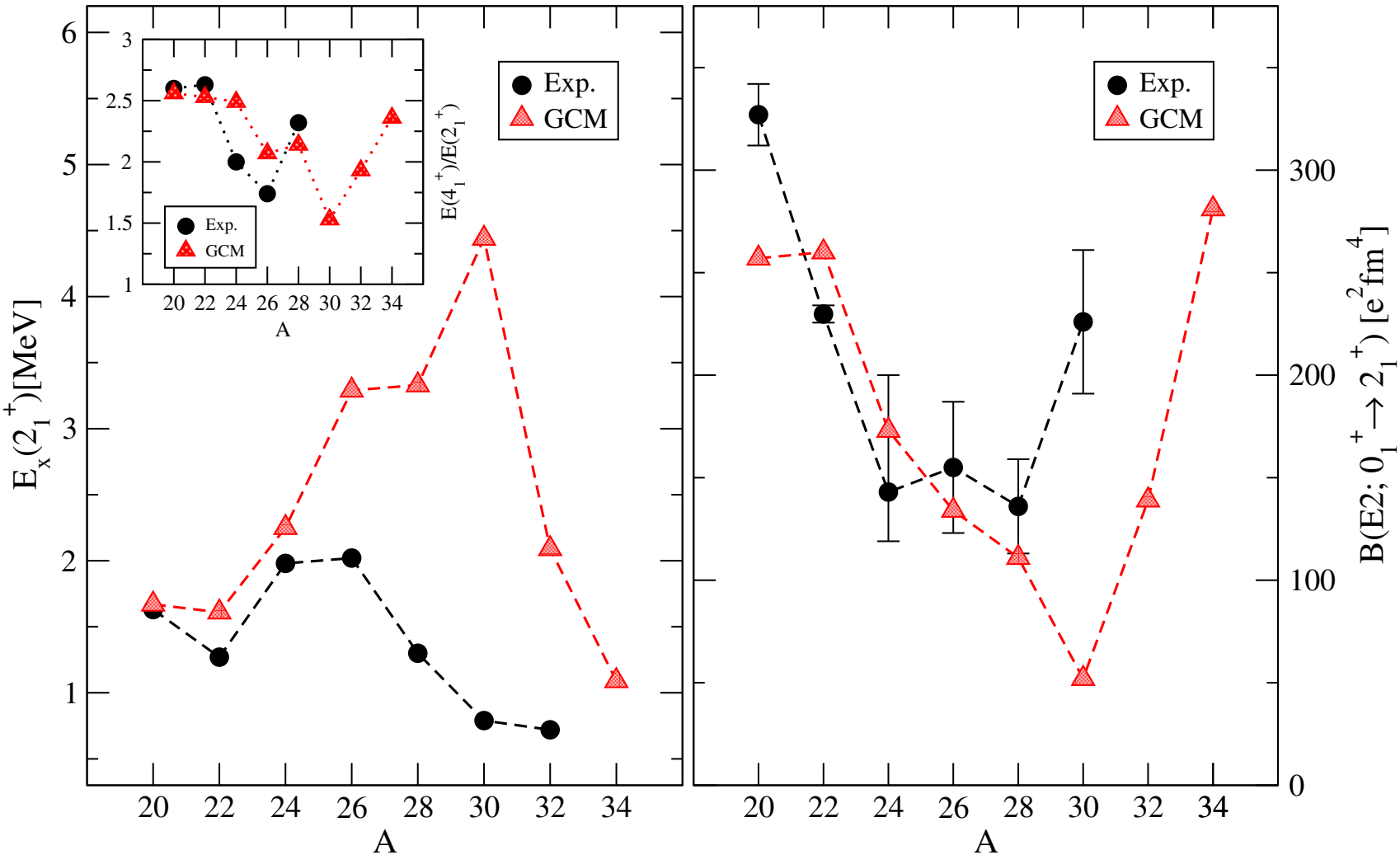

^{20}Ne
$J=0_1^+$
β_2
β_3
$|g(\beta_2,\beta_3)|^2$

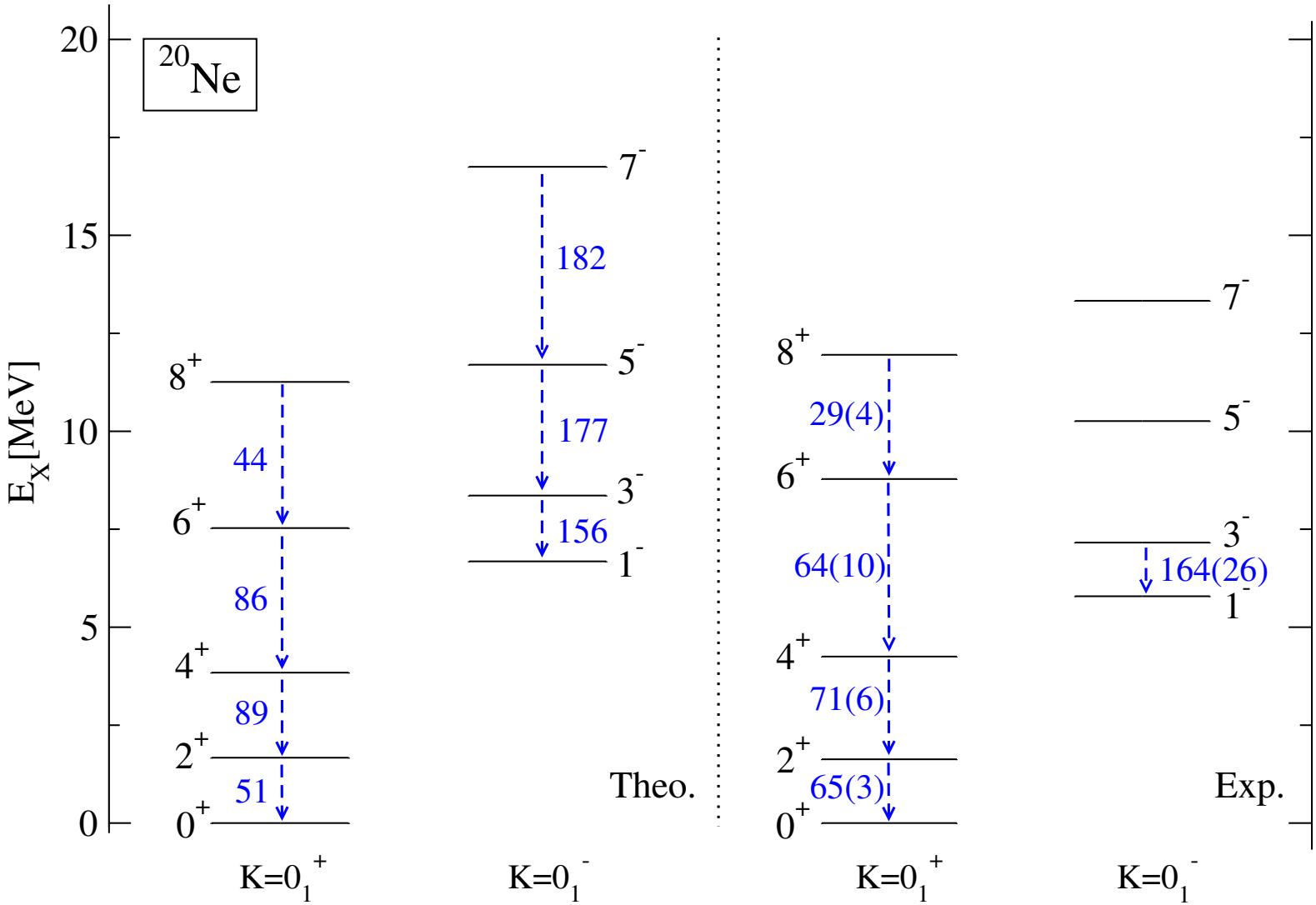

^{20}Ne
$J=1_1^-$
β_2
β_3
$|g(\beta_2,\beta_3)|^2$


^{20}Ne
$J=2_1^+$
β_2
β_3
$|g(\beta_2,\beta_3)|^2$


^{20}Ne
$J=3_1^-$
β_2
β_3
$|g(\beta_2,\beta_3)|^2$


E_B[MeV]
-160
-170
-180
-190
-200
-210
-220
20
22
24
26
28
30
32
34
A
RHB
proj. (0+)
GCM (0_1+)
ΔE[MeV]
0
1
2
3
4
5
6
7
8
9
10
proj.
mix.
tot.


Exp.
GCM
$E_x(2_1^+)$[MeV]
A
$E(4_1^+)/E(2_1^+)$
$B(E2; 0_1^+ \rightarrow 2_1^+)$ [e^2fm^4]


^{20}Ne
E_X[MeV]
20
15
10
5
0
8^+
6^+
4^+
2^+
0^+
44
86
89
51
$K=0_1^+$
7^-
5^-
3^-
1^-
182
177
156
Theo.
$K=0_1^-$
8^+
6^+
4^+
2^+
0^+
29(4)
64(10)
71(6)
65(3)
$K=0_1^+$
7^-
5^-
3^-
1^-
164(26)
Exp.
$K=0_1^-$

Nuclear structure calculations: mean-field and beyond

Petar Marević[1,2]

[1]CEA,DAM,DIF
[2]IPNO,PhT

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