Dynamics of quantum breathers in a quantum trimer

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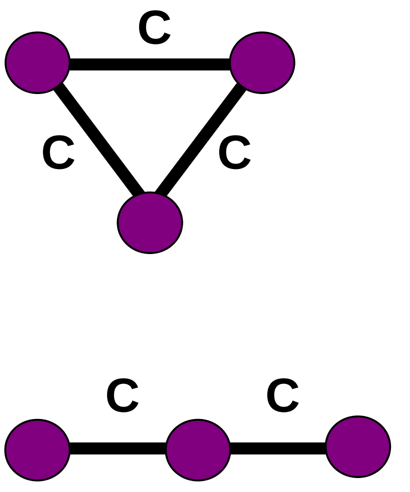
Trimer model

- Trimer models have been widely considered to study the appearance of quantum breathers, which are known to exist in the classical versions [1, 2, 3, 4, 5, and more…].



[1] S. De Filippo, M. Fusco Girard and M. Salerno, Nonlinearity 2, 477 (1989).

[2] A. Chefles, J. Phys. A: Math. Gen. 29, 4515 (1996).

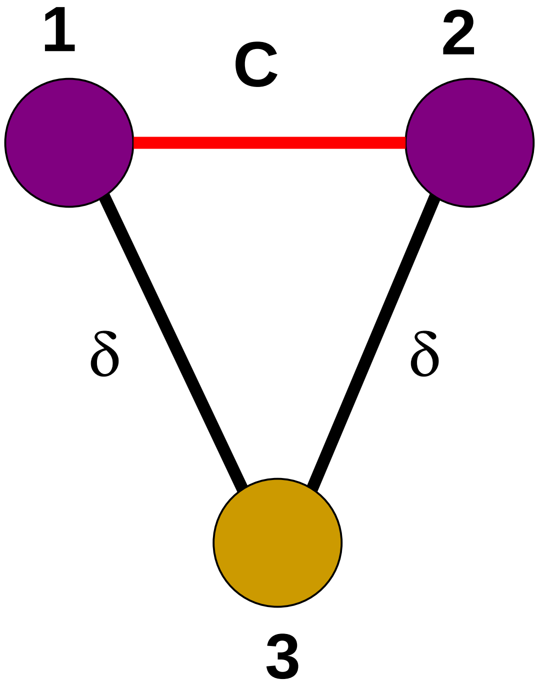
[3] L. Cruzeiro-Hanson, H. Feddersen, R. Flesch, P. L. Christiansen, S. Salerno, and C. Scott, Phys. Rev. B 42, 522 (1990).

[4] H. Feddersen, P. L. Christiansen and M. Salerno, Phys. Scri. 43, 353 (1991).

[5] E. Wright, J. C. Eilbeck, M. H. Hays, P. D. Miller, and A. C. Scott, Physica D 69, 18 (1993).

In this work …

- We analyze spectral properties of a quantum trimer model [1,2] and how they reflect the time evolution of localized excitations. This model describes a nonlinear quantum dimer coupled to a third site which generates quanta number fluctuations and destroys integrability.

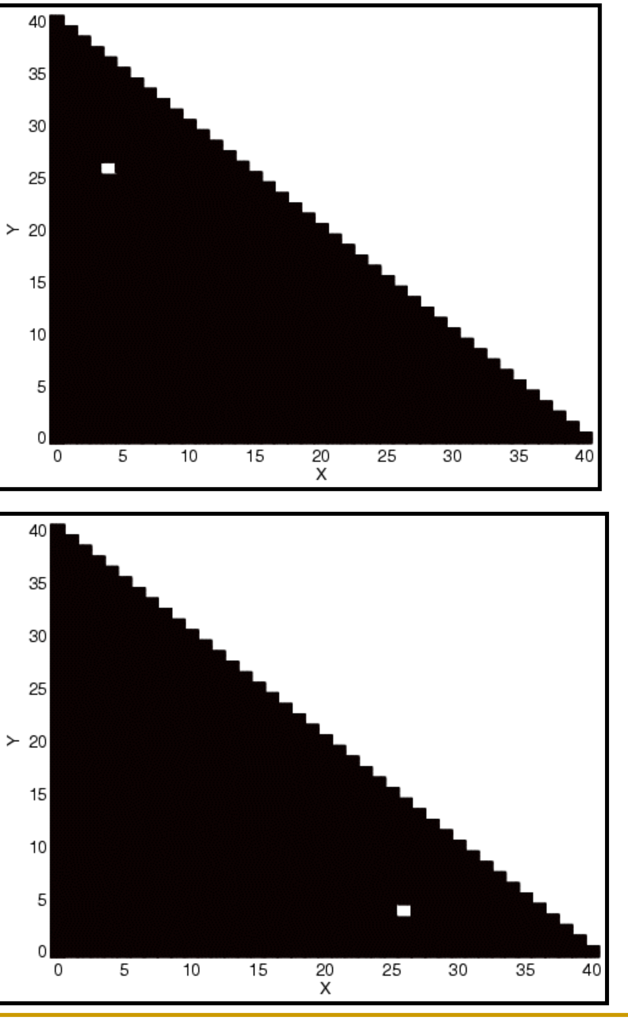


$$H = \frac{1}{2}\left[\left(a_1^+ a_1\right)^2 + \left(a_2^+ a_2\right)^2\right] + C\left(a_1^+ a_2 + a_2^+ a_1\right) + \delta\left(a_1^+ a_3 + a_3^+ a_1 + a_2^+ a_3 + a_3^+ a_2\right)$$

[1] S. Flach, V. Fleurov, and A. A. Ovchinnikov, Phys. Rev. B 63, 094304 (2001).
[2] S. Flach and V. Fleurov, J. Phys.: Condens. Matter 9, 7039 (1997).

Classical-quantum correspondence

- A quantum breather (QB) corresponds to a nearly degenerated pair of eigenstates of the quantum system. The inverse energy splitting corresponds to the tunneling time of an original classical breather between the two sites of the dimer part



Spectrum

$$H\left|\phi^{\mu}\right\rangle = E_{\mu}\left|\phi^{\mu}\right\rangle$$

$$\sum_{i=1}^{3} a_i^{+} a_i = \hat{B}$$

$$\hat{B}\left|n_1, n_2, n_3\right\rangle = b\left|n_1, n_2, n_3\right\rangle,$$

$$b = n_1 + n_2 + n_3$$

$$\left|n_1, n_2, n_3\right\rangle_{S,A} = \frac{1}{\sqrt{2}}\left(\left|n_1, n_2, n_3\right\rangle \pm \left|n_2, n_1, n_3\right\rangle\right)$$

- We numerically diagonalize the symmetric and anti-symmetric decomposition of H in the number-of-bosons basis

Time evolution of excitations

$$\langle n_j \rangle(t) = \langle \Psi_t | \hat{n}_j | \Psi_t \rangle$$

$$P_t = \left| \langle \Psi_0 | \Psi_t \rangle \right|^2$$

$$|\Psi_0\rangle = \left| \left(\frac{b}{2} + \upsilon\right), 0, \left(\frac{b}{2} - \upsilon\right) \right\rangle$$

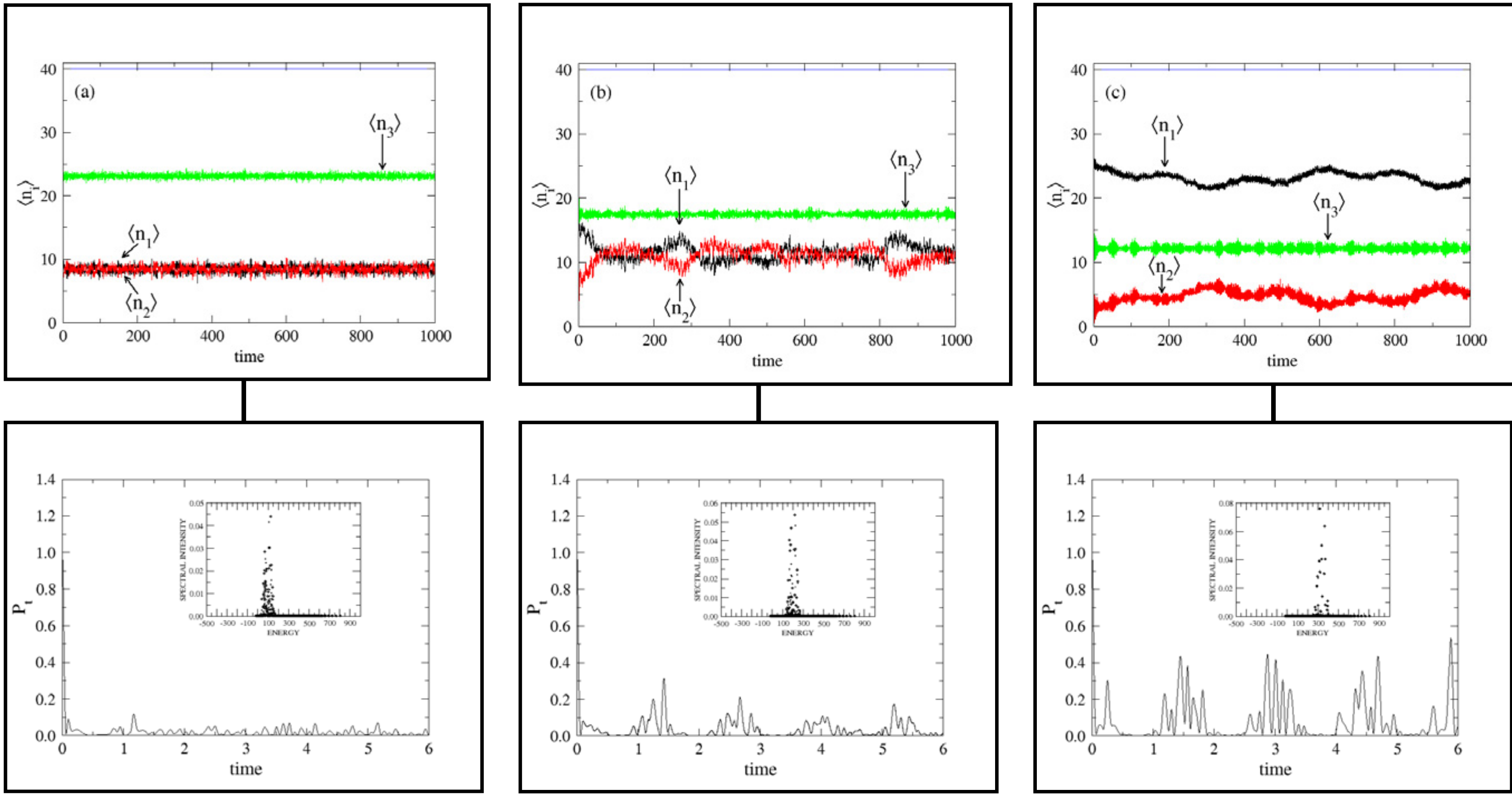
$$b = 40, \quad C = 2, \quad \delta = 1$$

- We computed expectation values of the number of quanta at every site in the trimer and survival probabilities of several initial excitations as a function of time

$$I_\mu^0 = \left| \langle \phi^\mu | \Psi_0 \rangle \right|^2$$

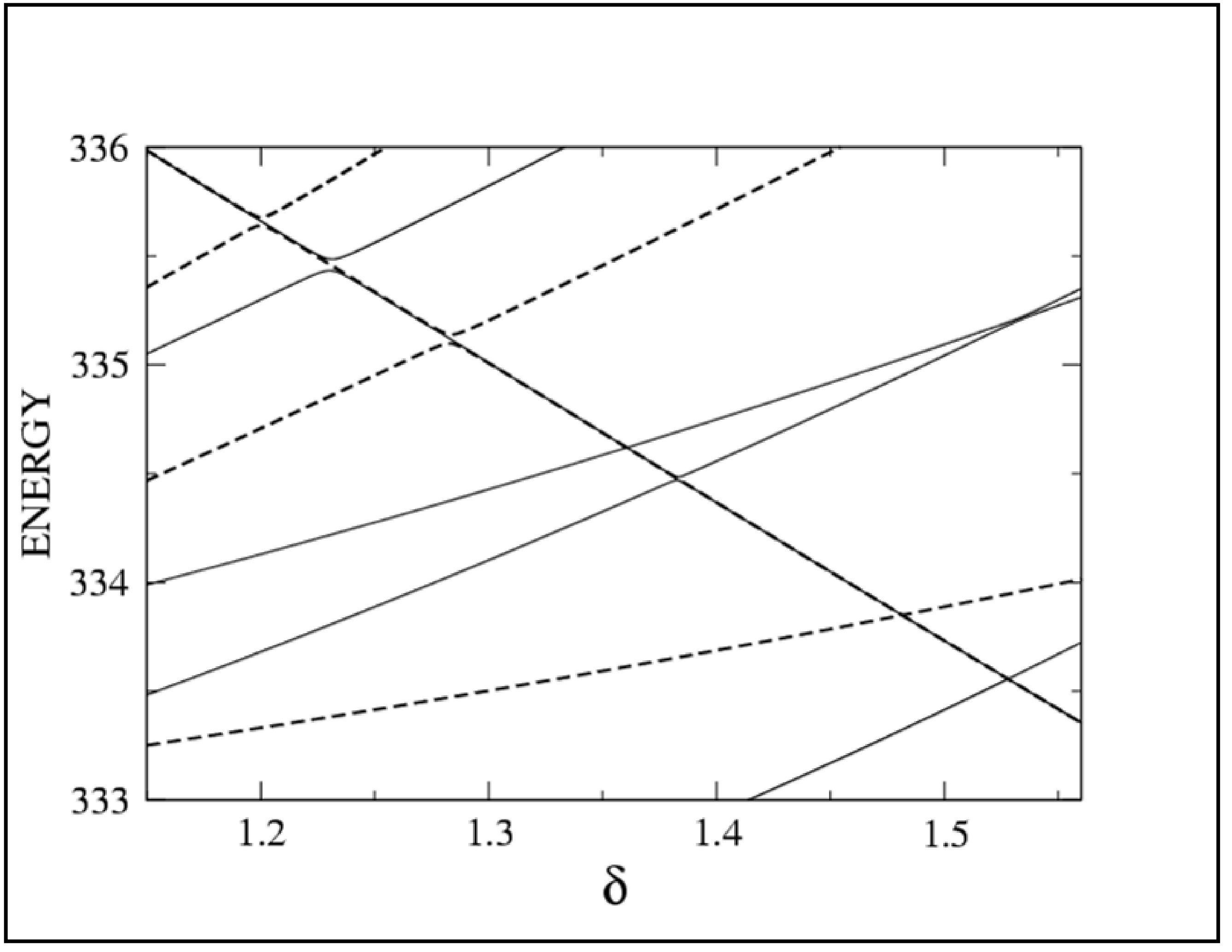
Spectral intensity of $|\Psi_0\rangle$

Expectation values of the number of quanta and survival probability



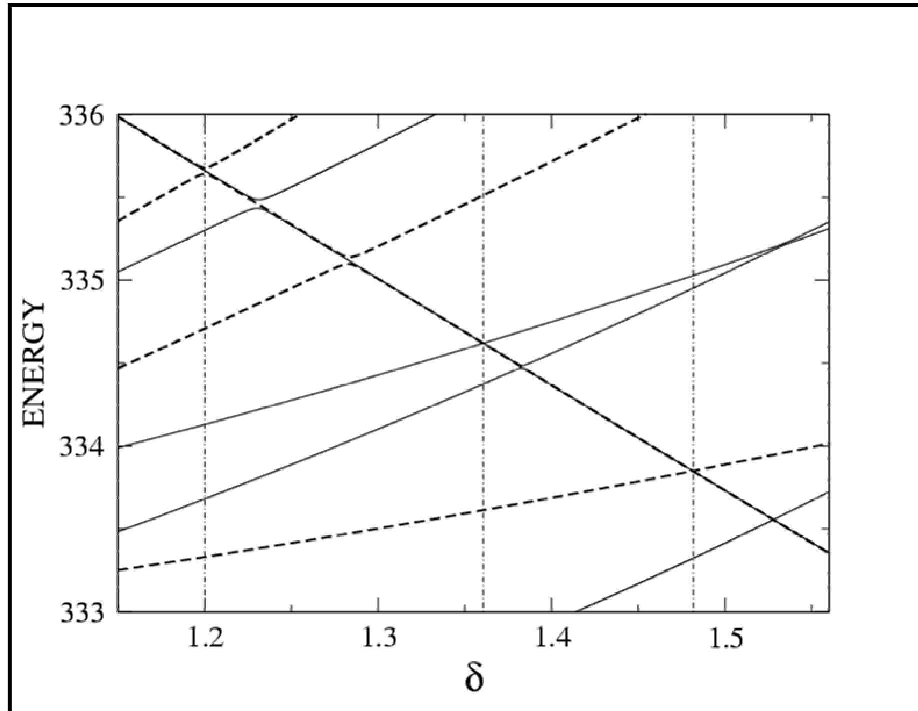
$\upsilon = -6$ $\upsilon = 0$ $\upsilon = 6$

Spectrum: Tunneling pairs



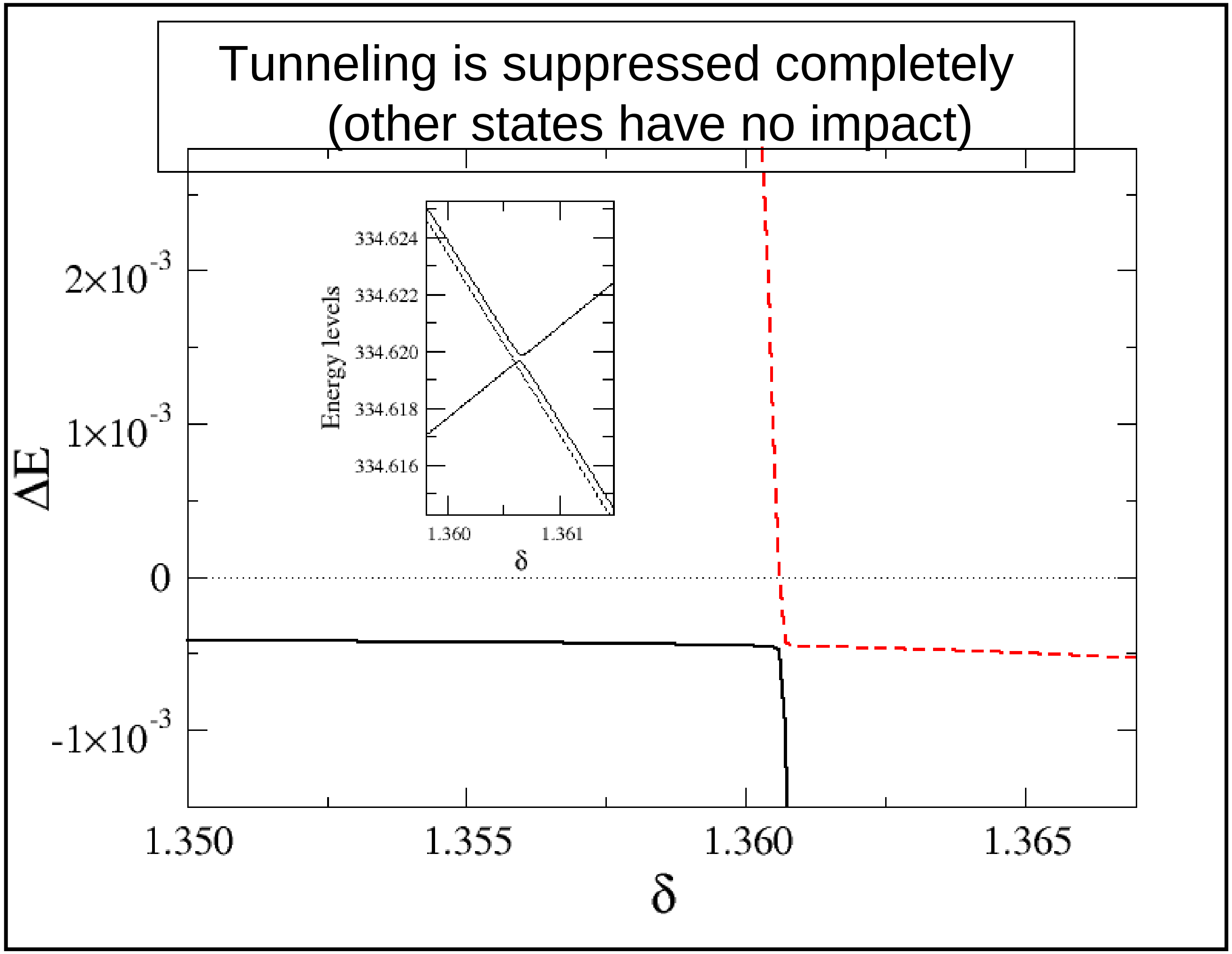
Avoided crossing between energy levels

- Energy levels show avoided crossings when we vary the parameter that regulates the non-integrability of the system



- We analyze three particular avoided crossings computing the energy separation between a single state and a quantum breather tunneling pair. We found out three different situations:

- *Case (a):* Energy levels intersect once (degeneracy point). Existence of an asymmetric quantum breather.



Density: How does an asymmetric eigenstate look?

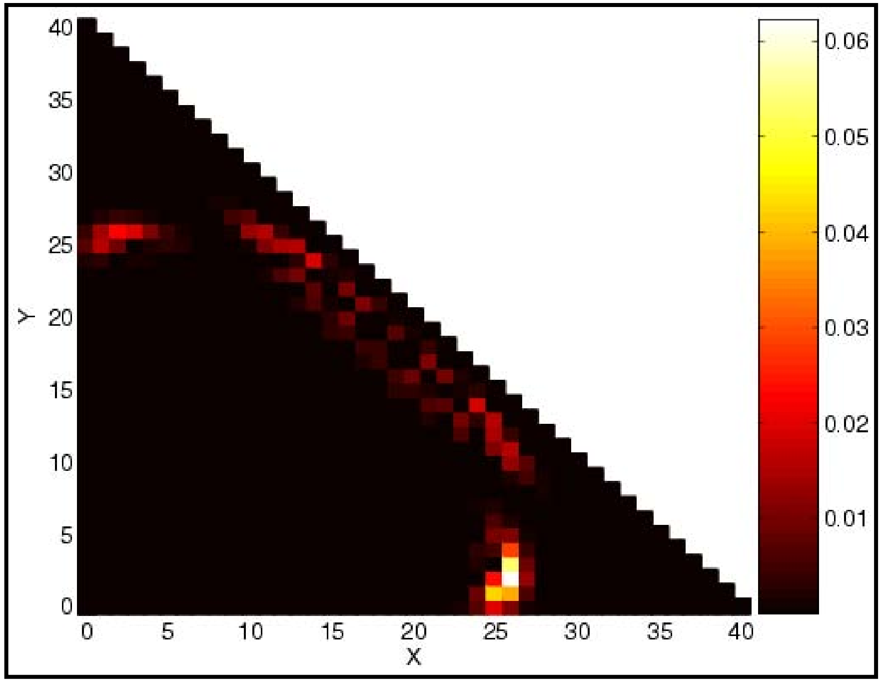
$$\rho(n_1,n_2) = \left|\langle n_1,n_2,n_3 | \phi\rangle\right|^2$$

$$|\phi\rangle = \left(|\phi\rangle_{\mu_d}^{(S)} \pm |\phi\rangle_{\nu_d}^{(A)}\right)/\sqrt{2}$$

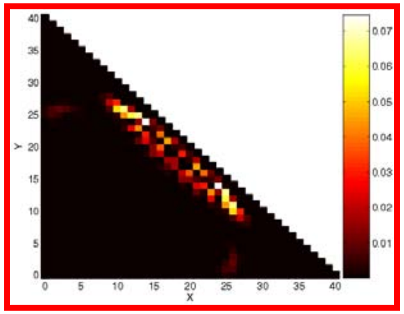
$$n_3 = b - n_1 - n_2$$

States in the degeneracy point: tunneling partially suppressed for all times

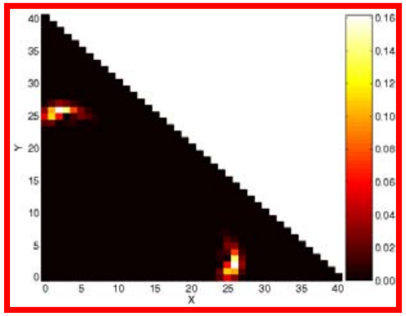
$$|\phi\rangle = \left(|\phi\rangle_{285}^{(S)} + |\phi\rangle_{268}^{(A)}\right)/\sqrt{2}$$



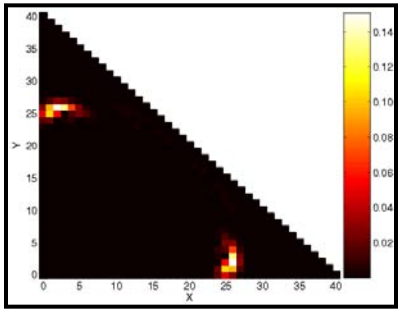
- There is partial localization



$|\phi\rangle_{285}^{(S)}$

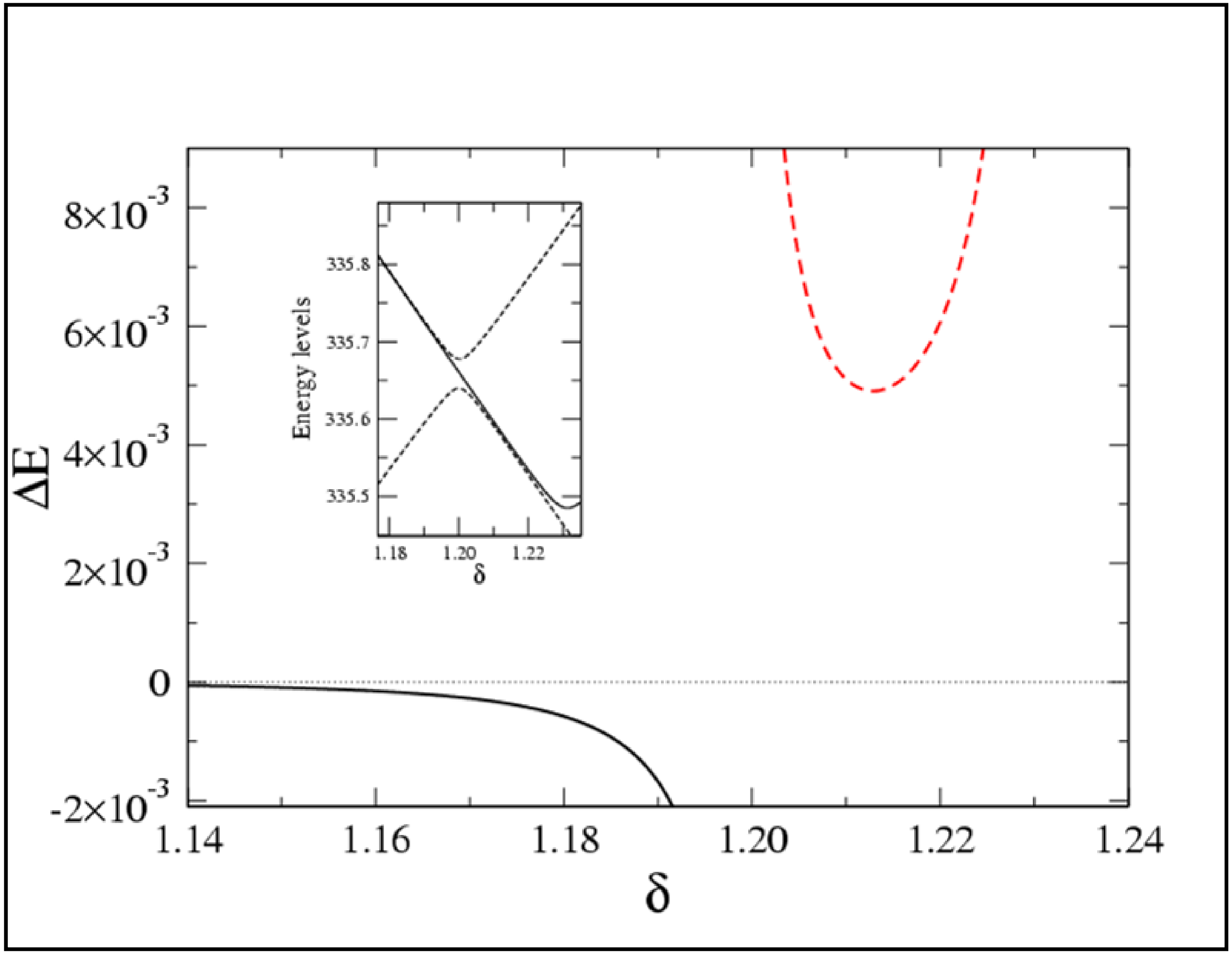


$|\phi\rangle_{268}^{(A)}$

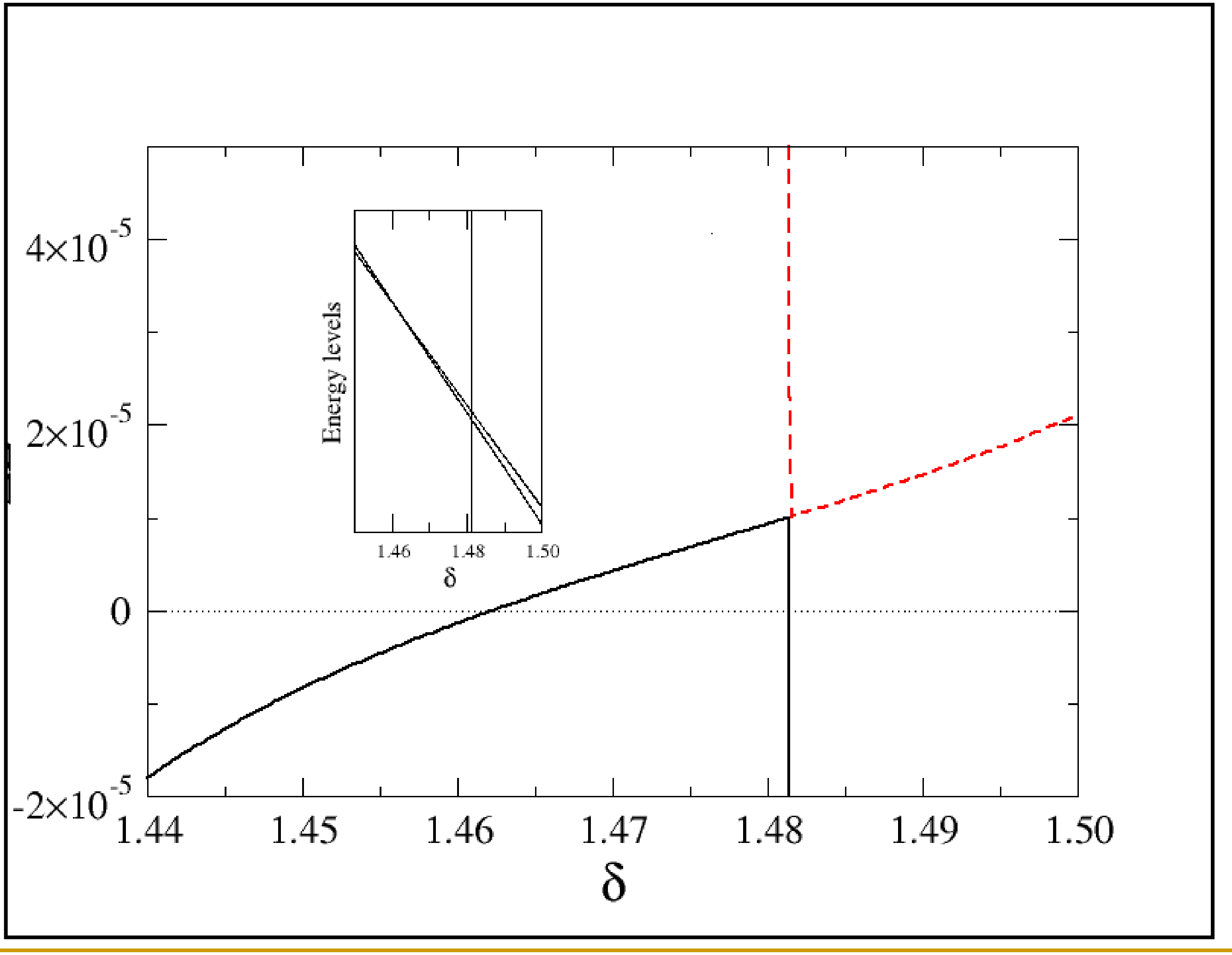


$|\phi\rangle_{286}^{(S)}$

- *__Case (b):__* Influence of other states. Energy levels do not intersect due to a nearby avoided crossing

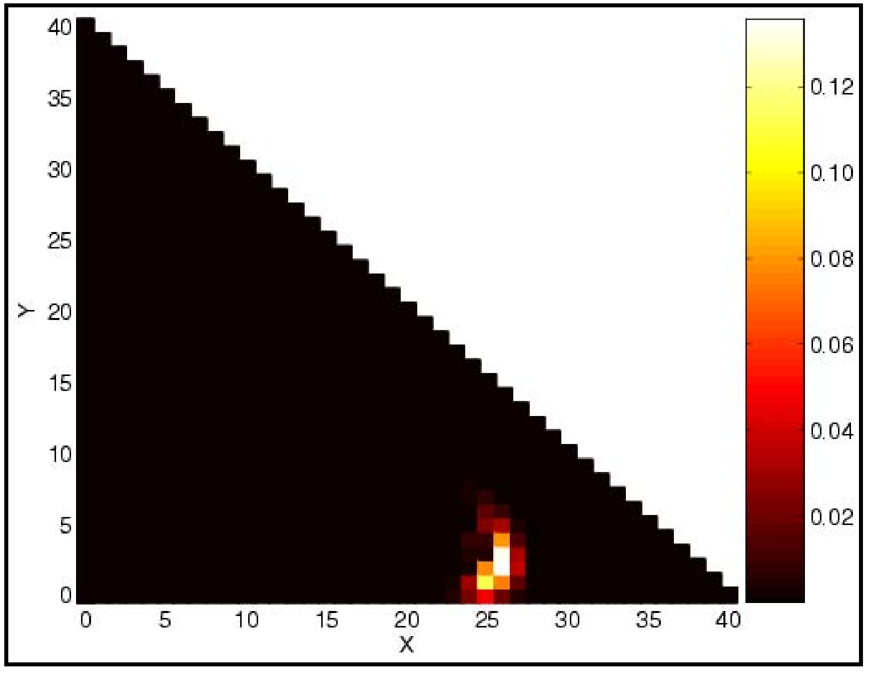


- *<u>Case (c):</u>* Energy levels intersect twice. The asymmetric quantum breather is more strongly localized

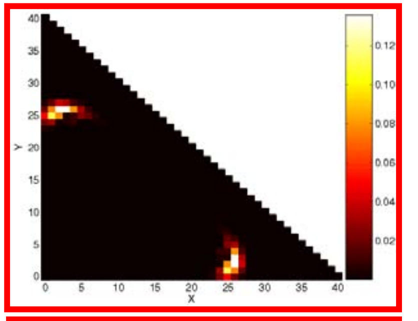


States in the degeneracy point: tunneling strongly suppressed for all times

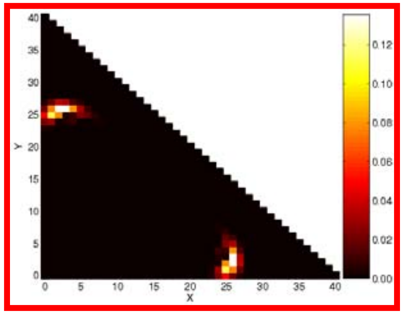
$$|\phi\rangle = \left(|\phi\rangle_{284}^{(S)} + |\phi\rangle_{268}^{(A)}\right)/\sqrt{2}$$



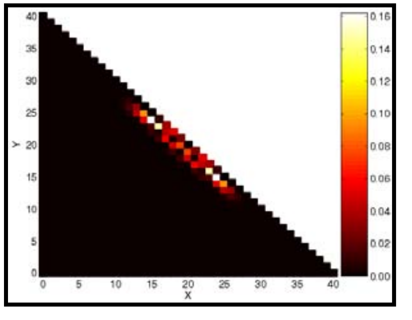
- Non-decaying quantum breather



$|\phi\rangle_{284}^{(S)}$



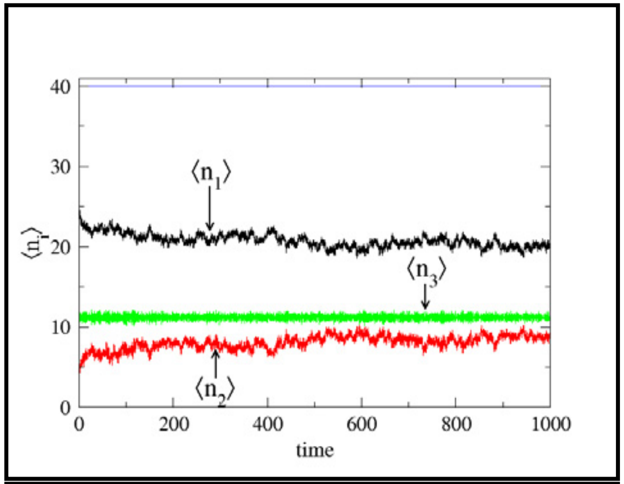
$|\phi\rangle_{268}^{(A)}$

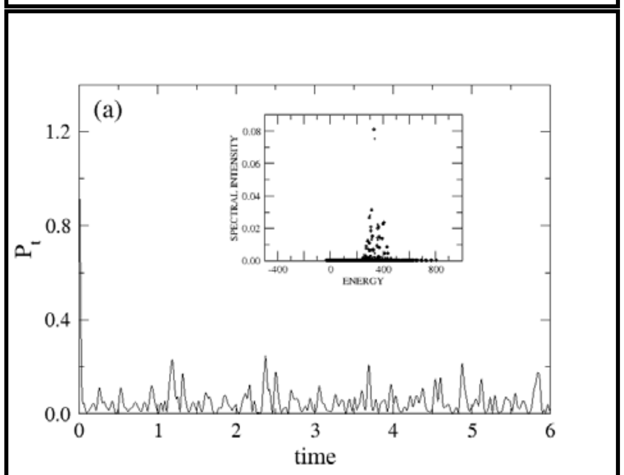


$|\phi\rangle_{267}^{(A)}$

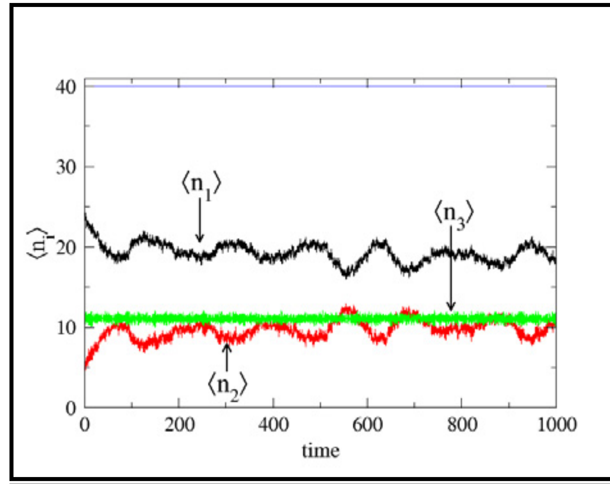
- Average number of quanta and survival probability for the initial state $|\Psi_0\rangle = |26, 2, 12\rangle$

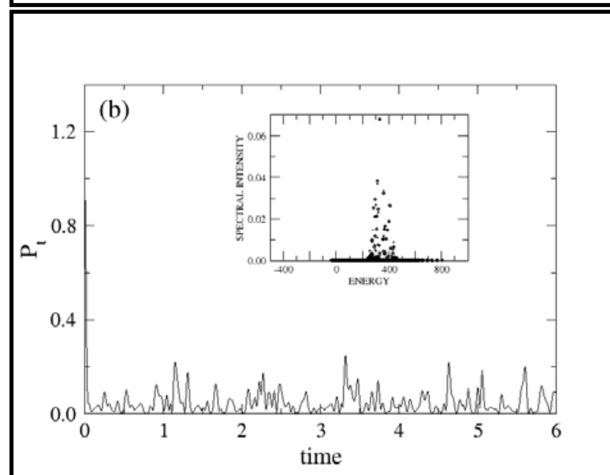
Case (a)





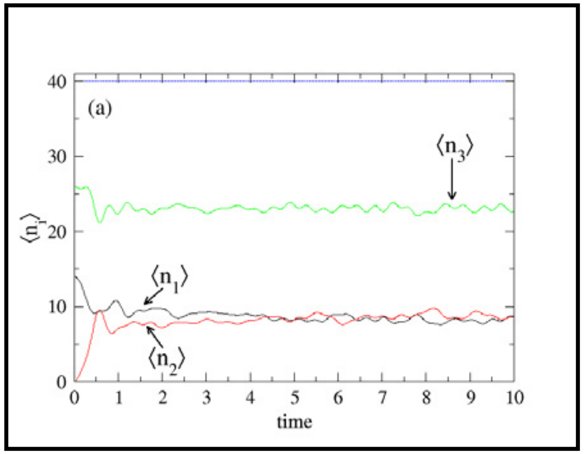
Case (c)

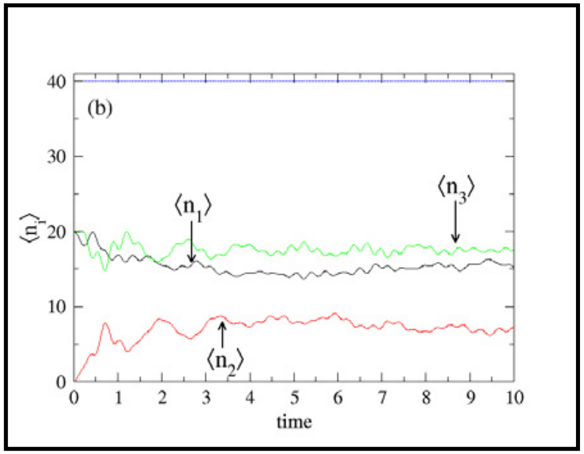


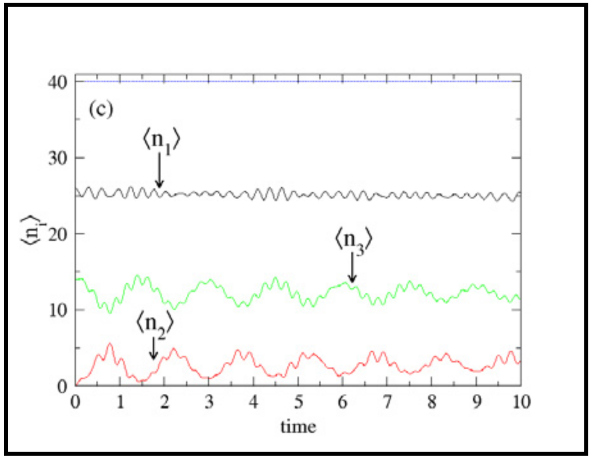


Conclusions

- Tunneling pair splitting determines lifetime of localized excitations (LE)
- Spectral intensity of LE is typically broad and insensitive to QDB existence
- Survival probability and $\langle n \rangle(t)$ are clear indicators for a LE being close or far from a QDB
- Existence of degenerate levels in the spectrum due to avoided crossings suppresses tunneling for all times for magic states and magic parameters.







$\upsilon = -6$ $\upsilon = 0$ $\upsilon = 6$

Tunneling pairs and spectral intensity