Decoherence and einselection in equilibrium in an adapted Caldeira Leggett model

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and

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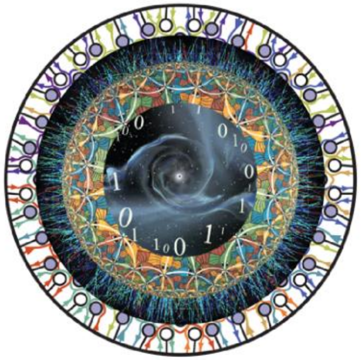

Quantum Entanglement in Cosmology

IPMU

May 21, 2019

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Outline

1. Motivations
2. Introduction to einselection and the toy model
3. Einselection in equilibrium (technical explorations and overall assessment)
4. Eigenstate Einselection Hypothesis (if there is time)
5. Conclusions

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With A. Arrasmith

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Comments on the arrow of time in cosmology (at board)

Q: What features of the universe are correlated with classicality?

- Arrow of time?
- Locality?
- Etc.

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Traditionally connected with arrow of time

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➔ Explore the process of einselection ; relate to AoT, etc.

But what about einselection in eqm?

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This talk: a more focused technical discussion in service of these big picture motivations

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➔ Explore the process of einselection ... relate to AoT, etc.

But what about einselection in eqm?

If you are handed a theory, what are the classical degrees of freedom?

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Einselection:

The preference of special “pointer” states of a system due to interactions with the environment

“Preference” →

- Stability of pointer states
- Destruction of non-pointer states (including “Schrödinger cat” superpositions of pointer states)
- Pure non-pointer states → mixtures of pointer states via entanglement with the environment.

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About to illustrate this with our toy model

Important for the emergence of classicality

The Caldeira-Leggett Model:

$$W = S \otimes E$$

“World”

“System”
(SHO)

“Environment”

The Caldeira-Leggett Model:

$$W = S \otimes E$$

$$H = \underbrace{H_{SHO}^{S} \otimes \mathbf{1}^{E}}_{\text{Self-Hamiltonian of System}} + q_{SHO} H_{I}^{E} + \mathbf{1}^{S} \otimes H^{E}$$

Self-Hamiltonian of System

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Different (non-commuting) H's

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<u>CL:</u>

i) Model *E* as an infinite set of SHOs with different frequencies

ii) Take special (order of) limits and parameter choices to get an <u>*(irreversible) stochastic equation*</u> that describes this (unitary) evolution under certain conditions (including AoT)

iii) Demonstrate einselection etc. (CL and others)

The Caldeira-Leggett Model:

Different (non-commuting) H's

$$H = H_{SHO}^{S} \otimes \mathbf{1}^{E} + q_{SHO} H_{I}^{E} + \mathbf{1}^{S} \otimes H^{E}$$

Random Hermitian matrices

<u>Adapted CL:</u>

i) Model *E* as *finite* system

ii) Solve <u>*full unitary evolution in all regimes*</u> (numerical)

iii) Demonstrate Einselection under certain conditions (AoT)

iv) Explore scope of einselection (eqm?)

Introducing the toy model

- No interaction case ($H_I^E = \mathbf{0}$)
- Model SHO with d=30 Hilbert space

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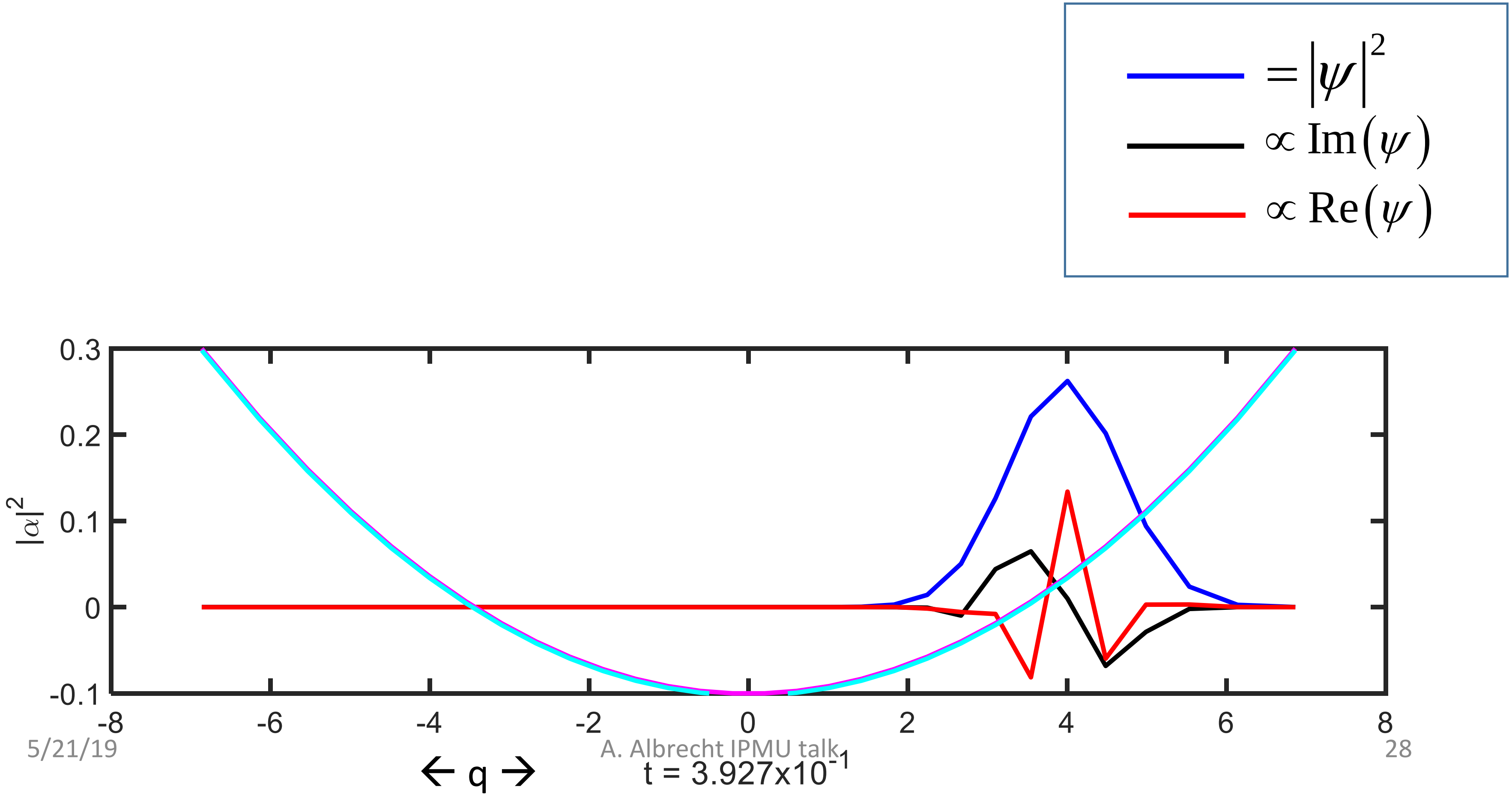
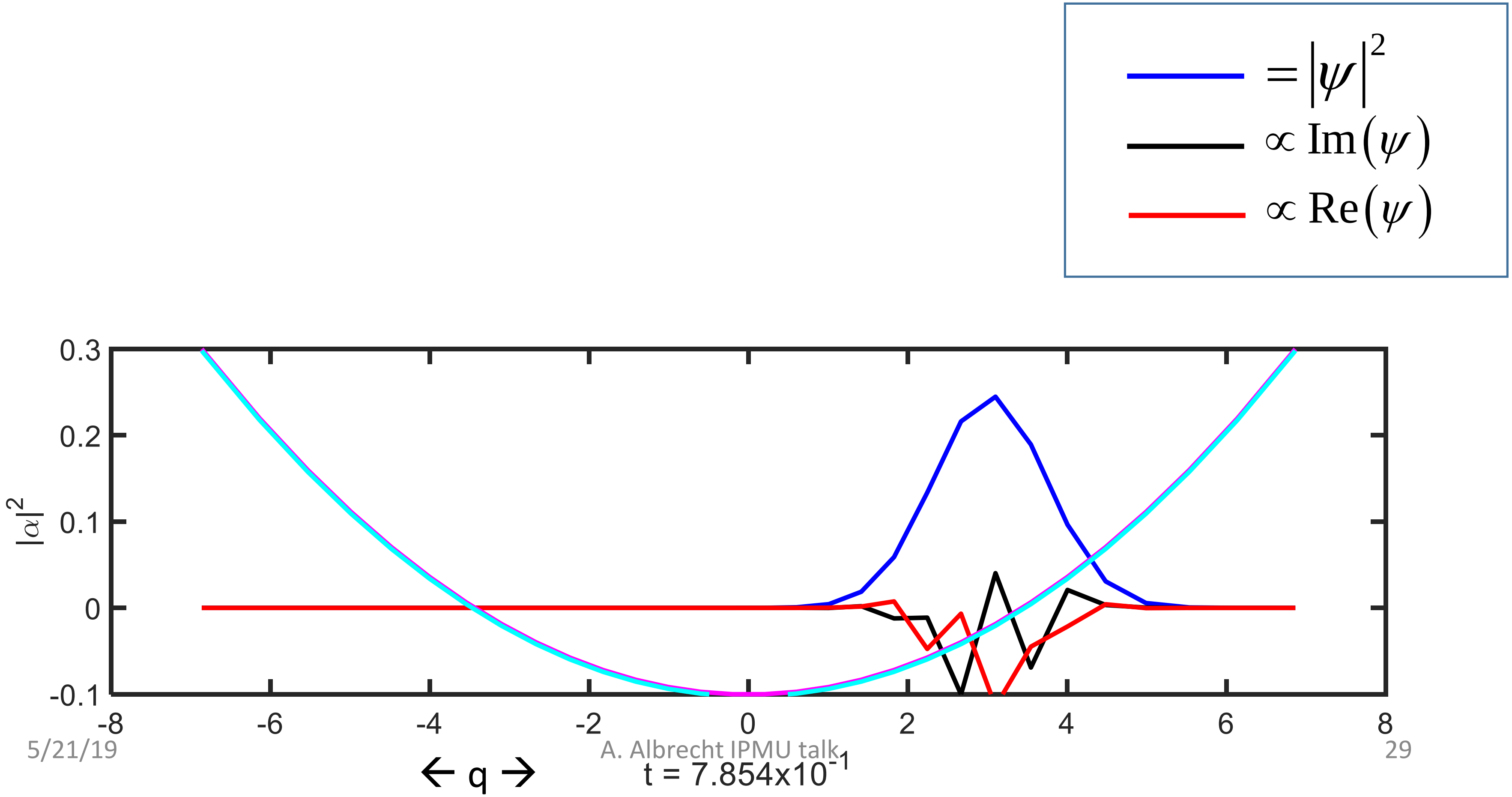
"Movie" A (Isolated SHO)

Isolated SHO



Isolated SHO



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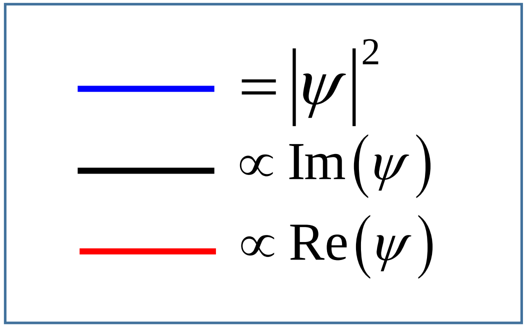

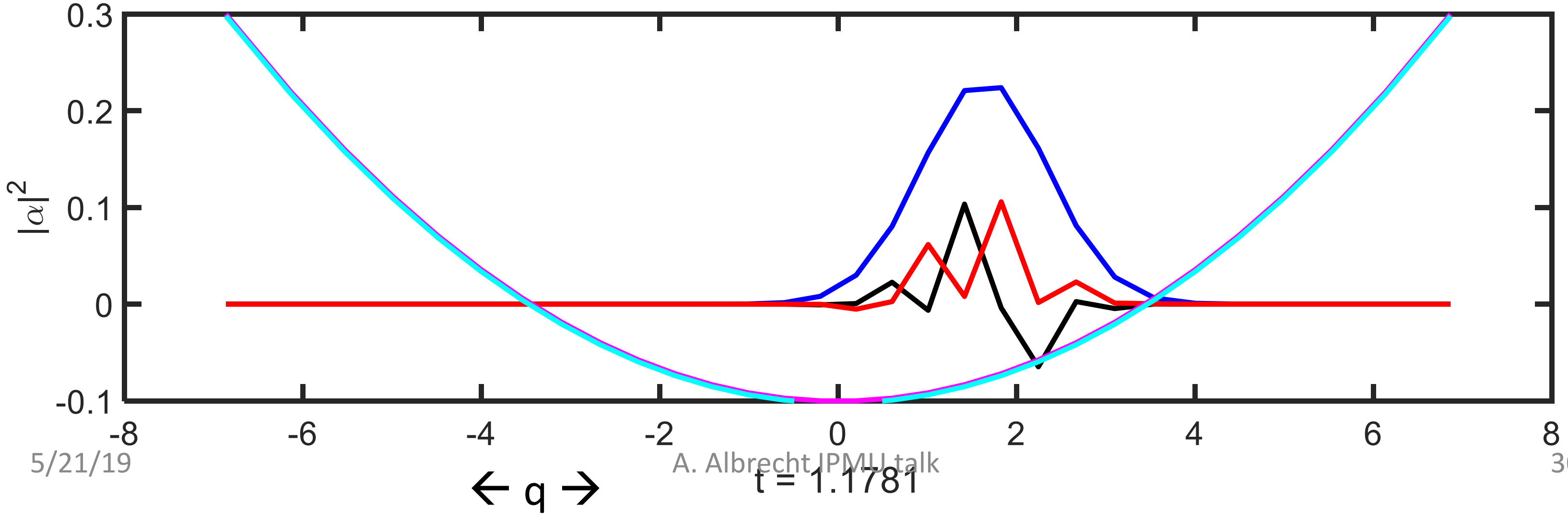

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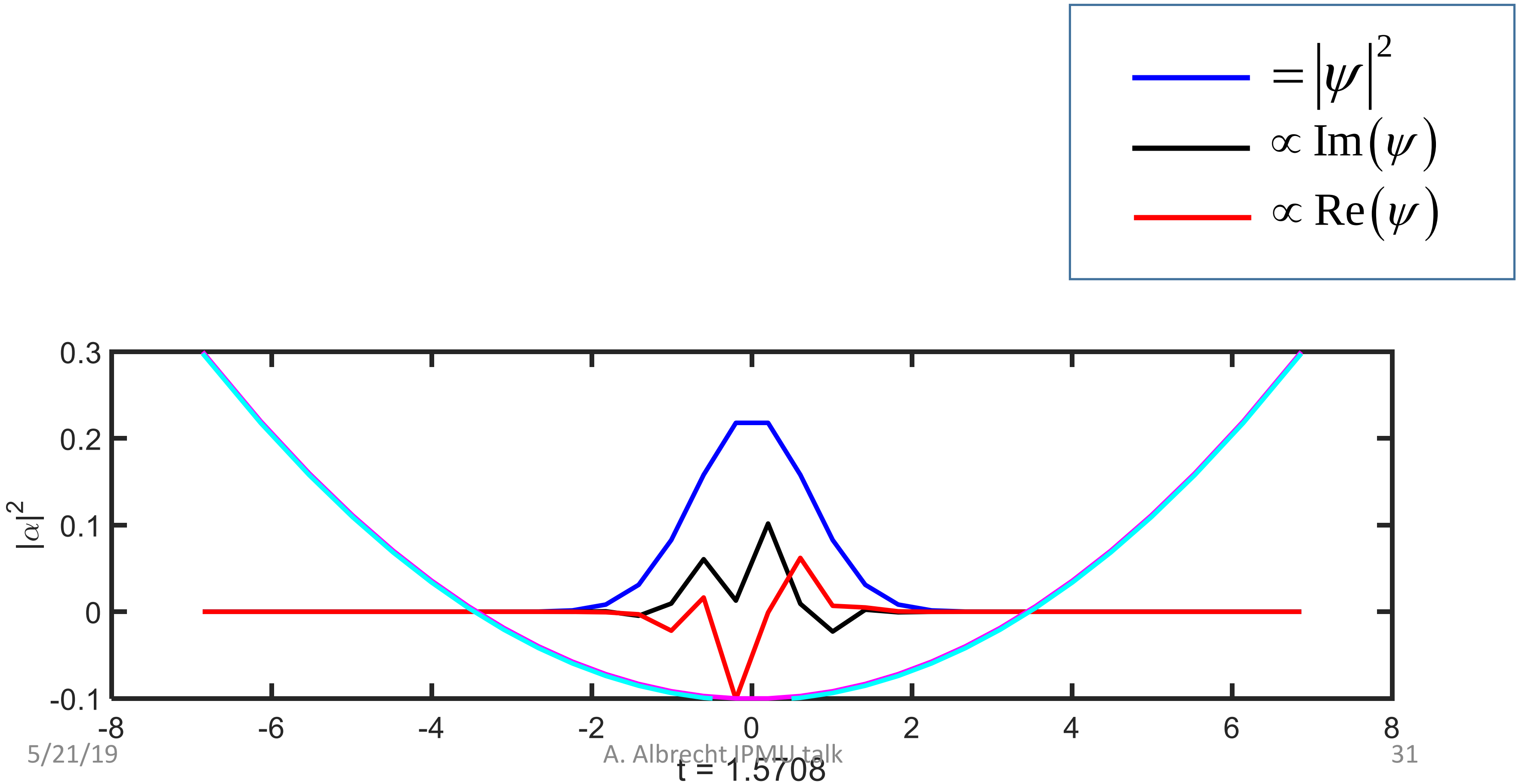

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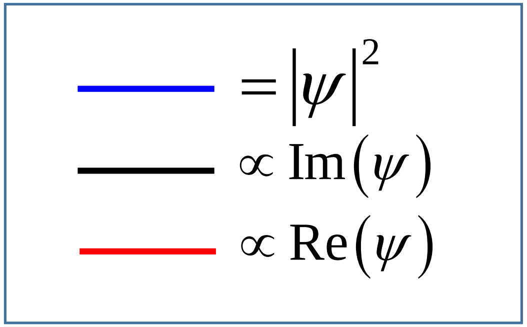

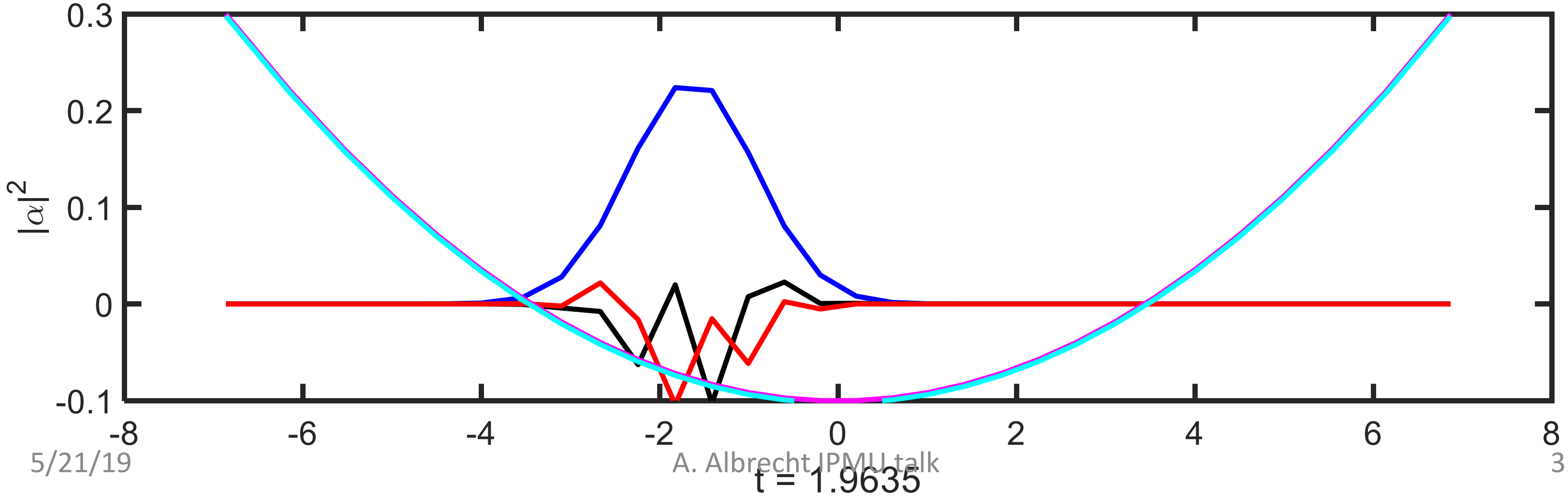

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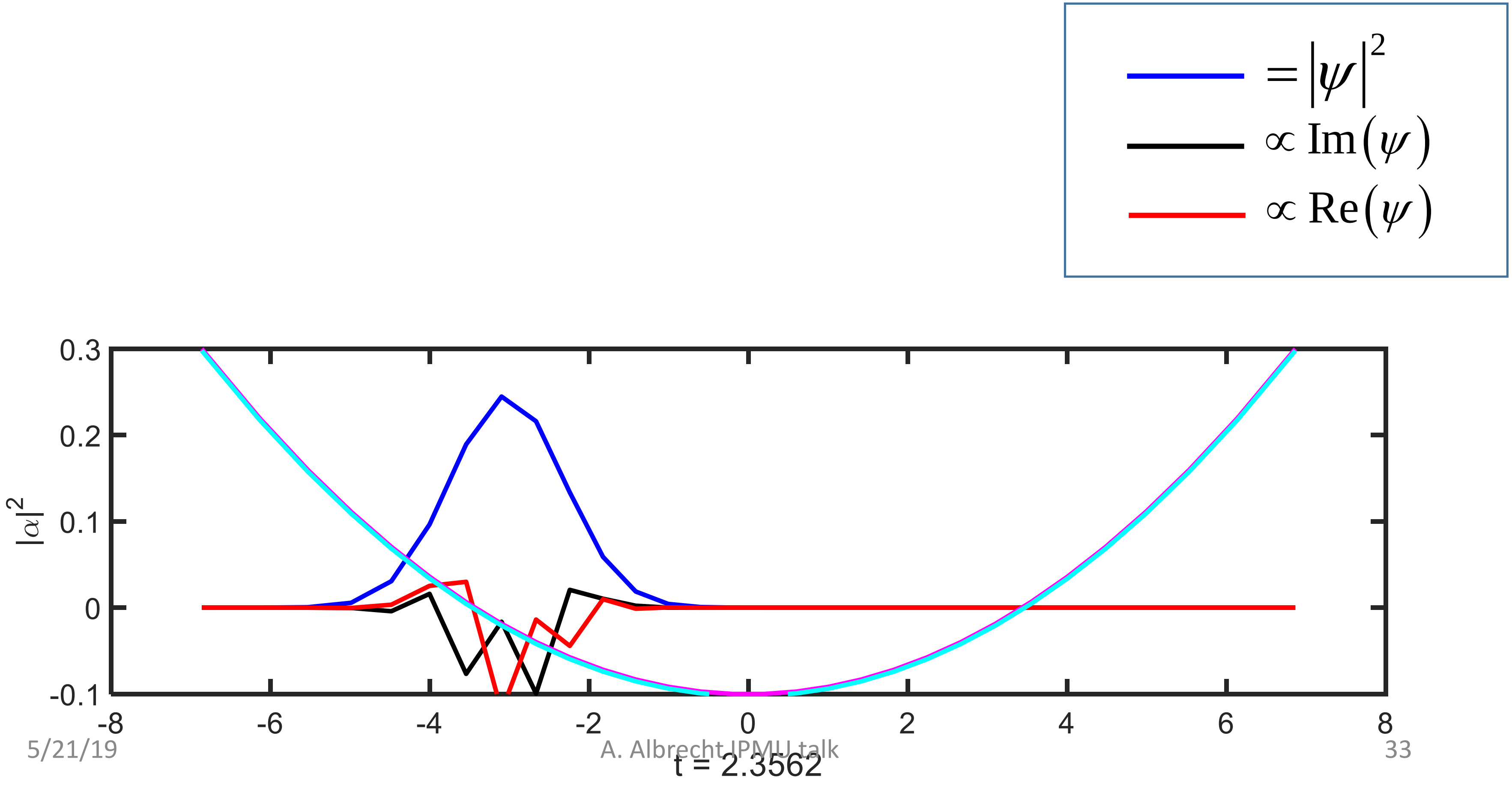

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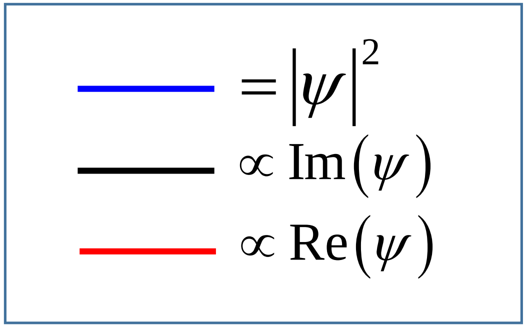
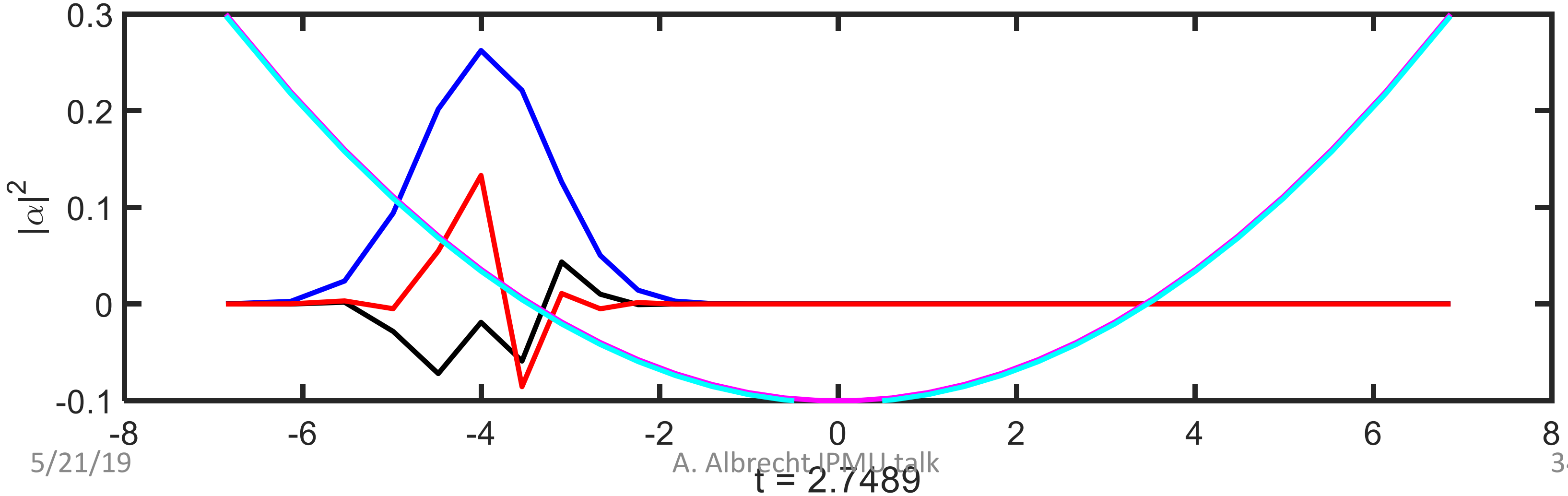


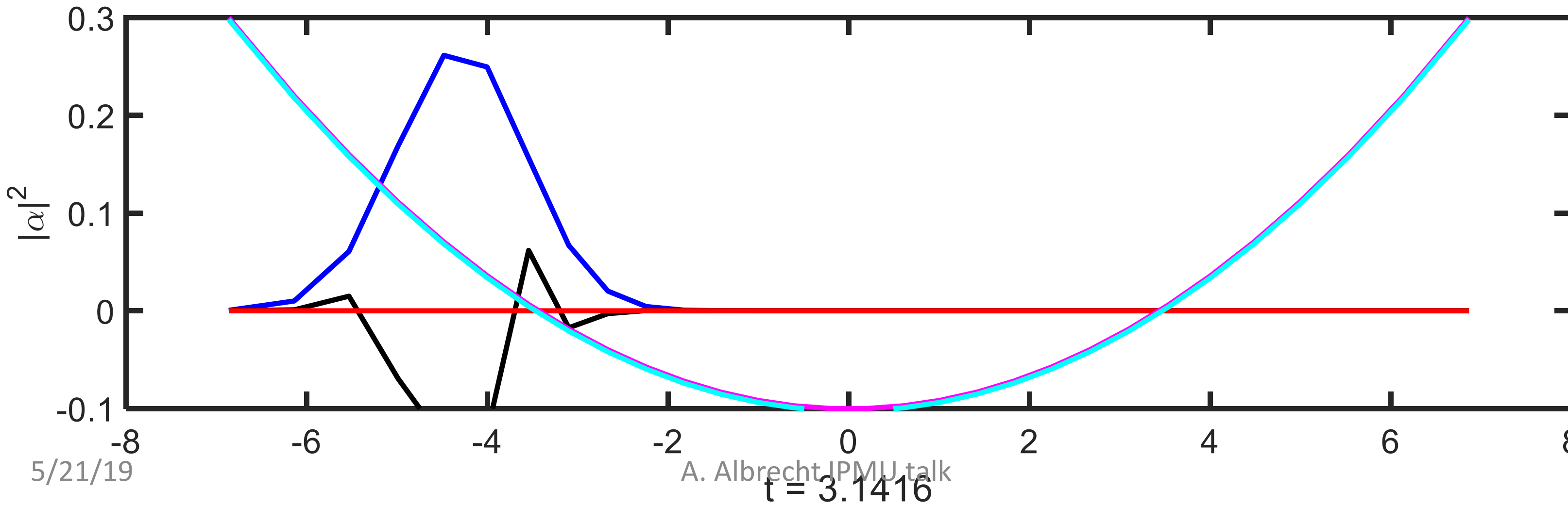


Isolated SHO

$= |\psi|^2$

$\propto \mathrm{Im}(\psi)$

$\propto \mathrm{Re}(\psi)$



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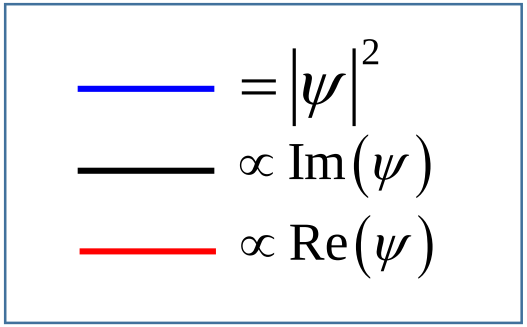

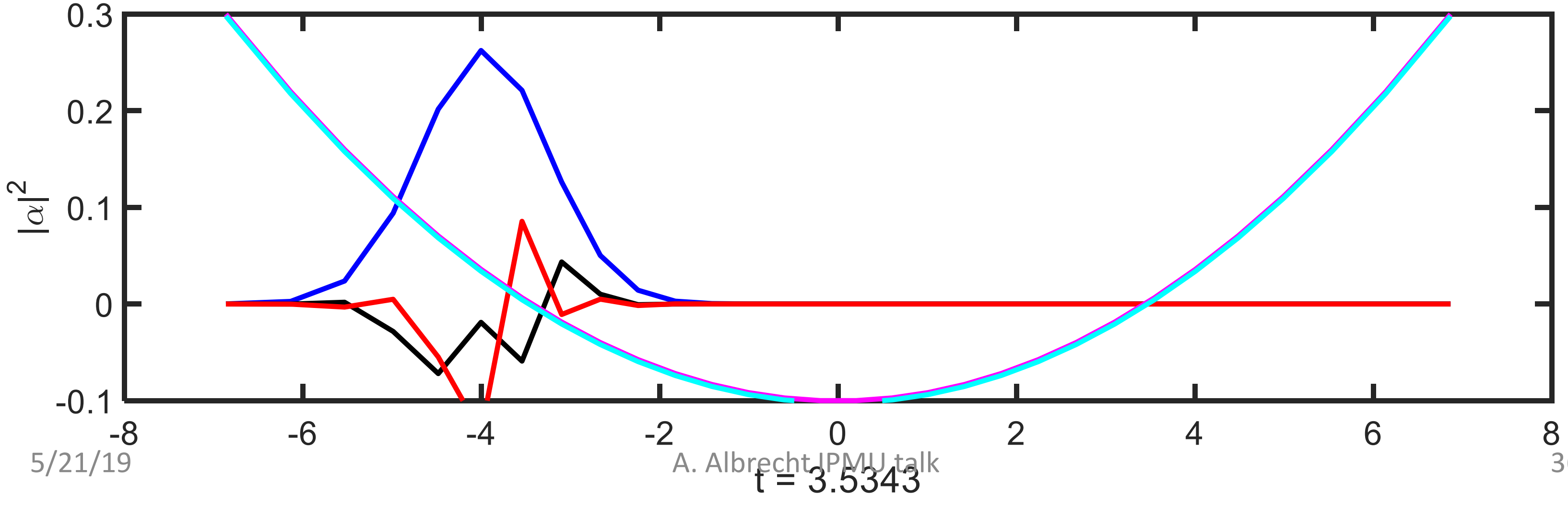

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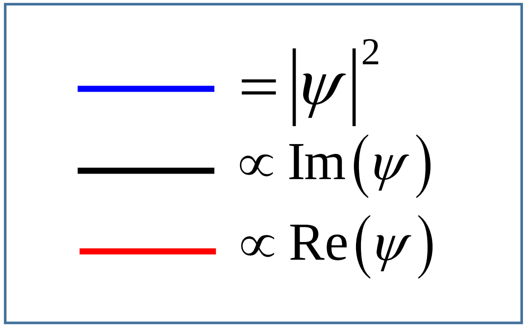

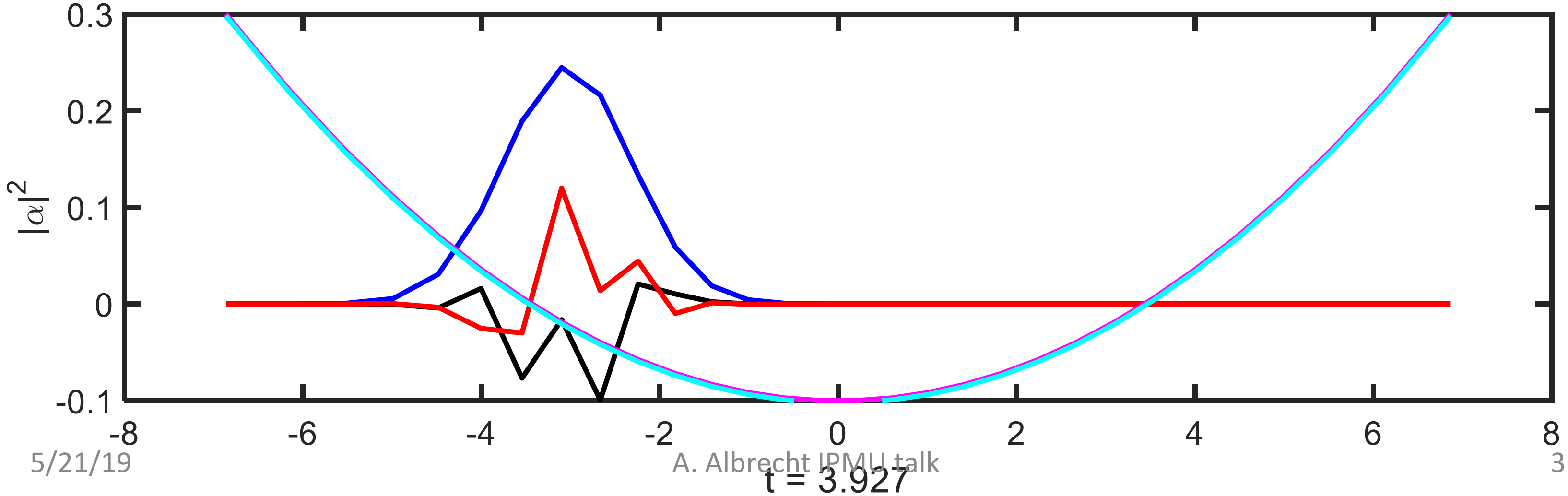

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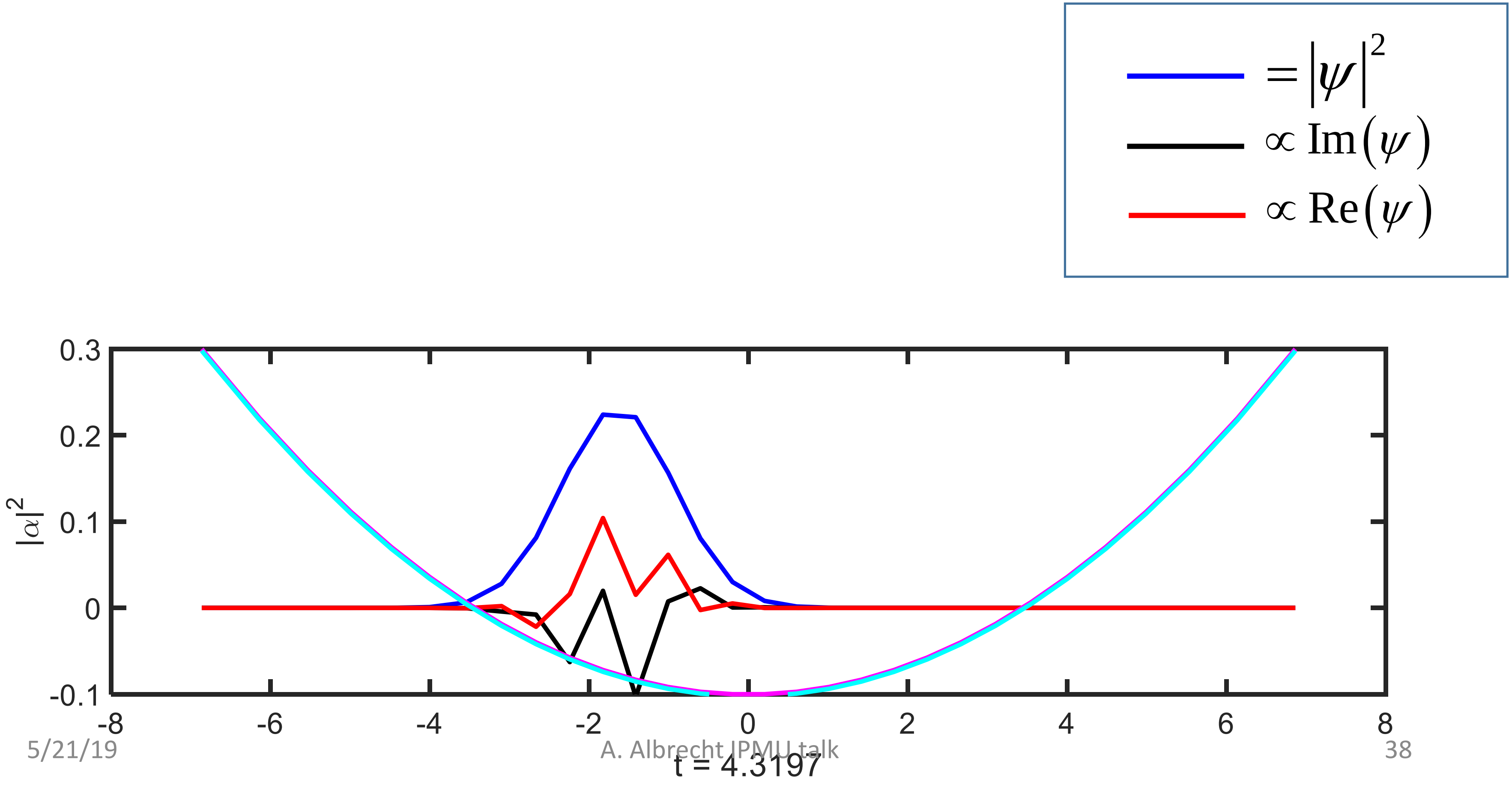

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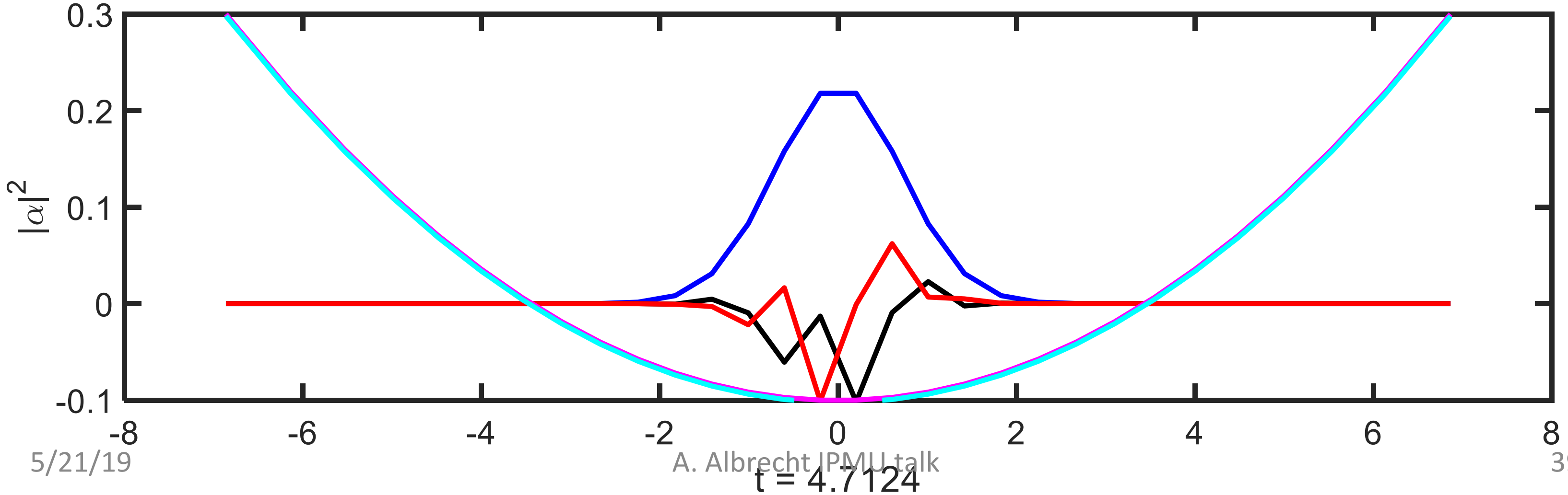

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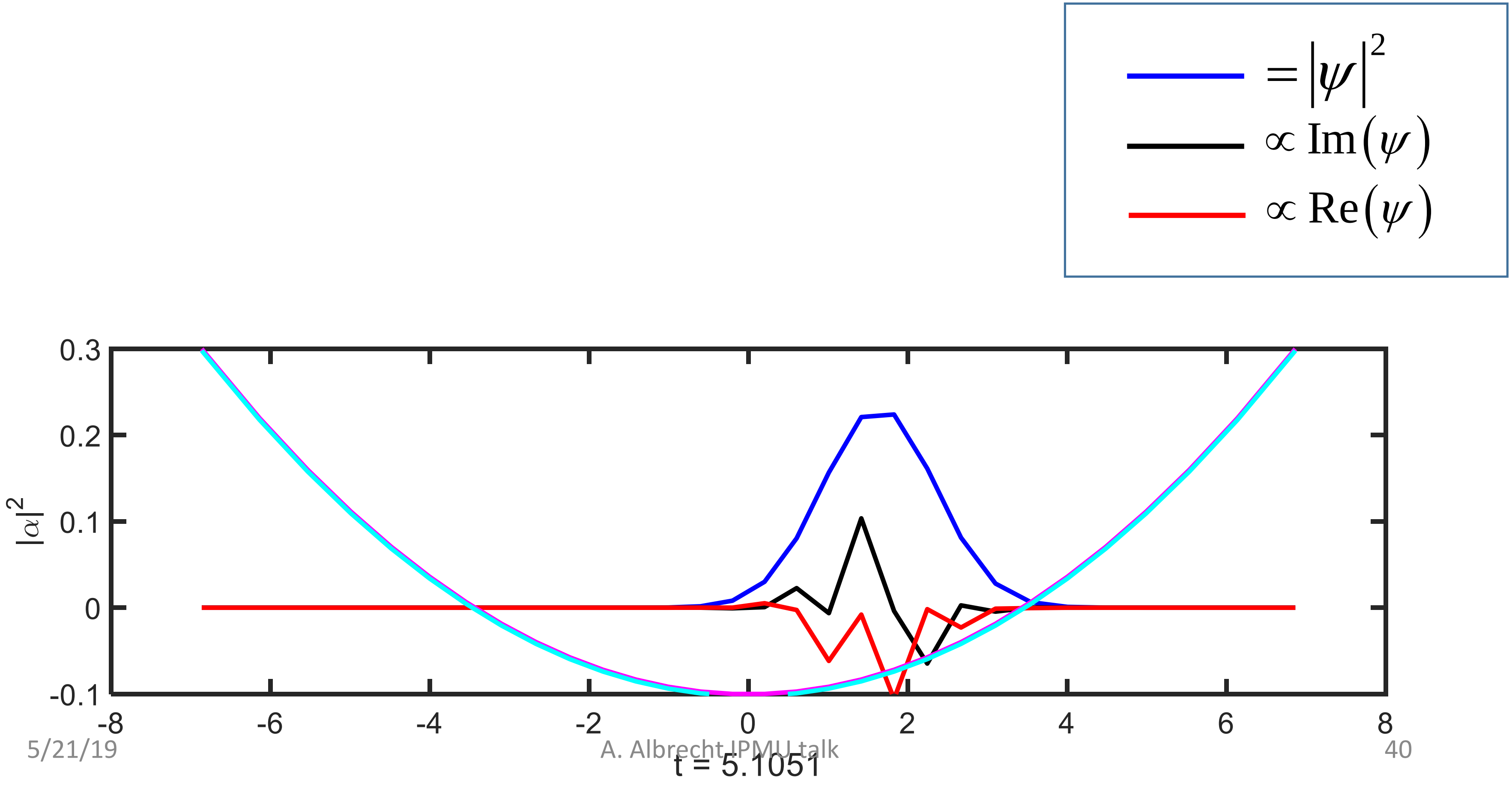

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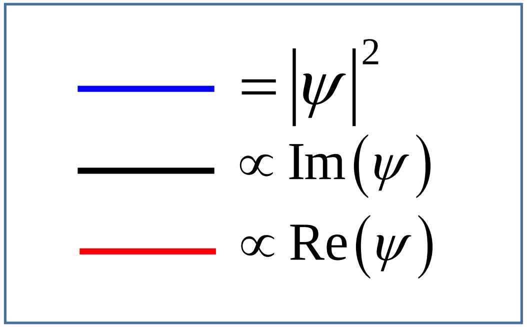

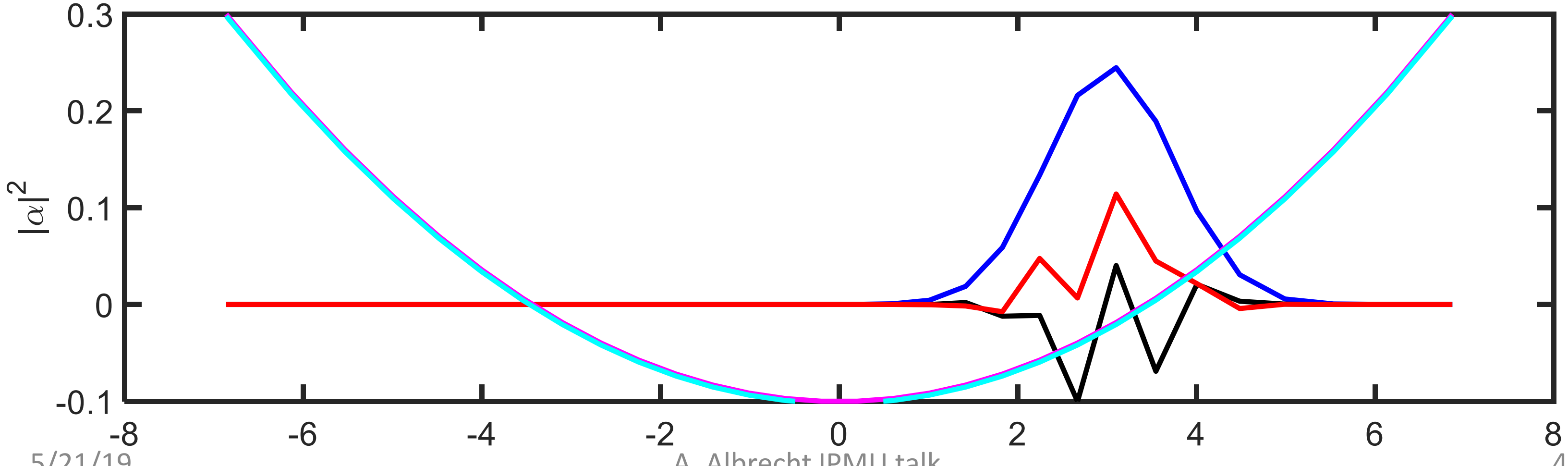

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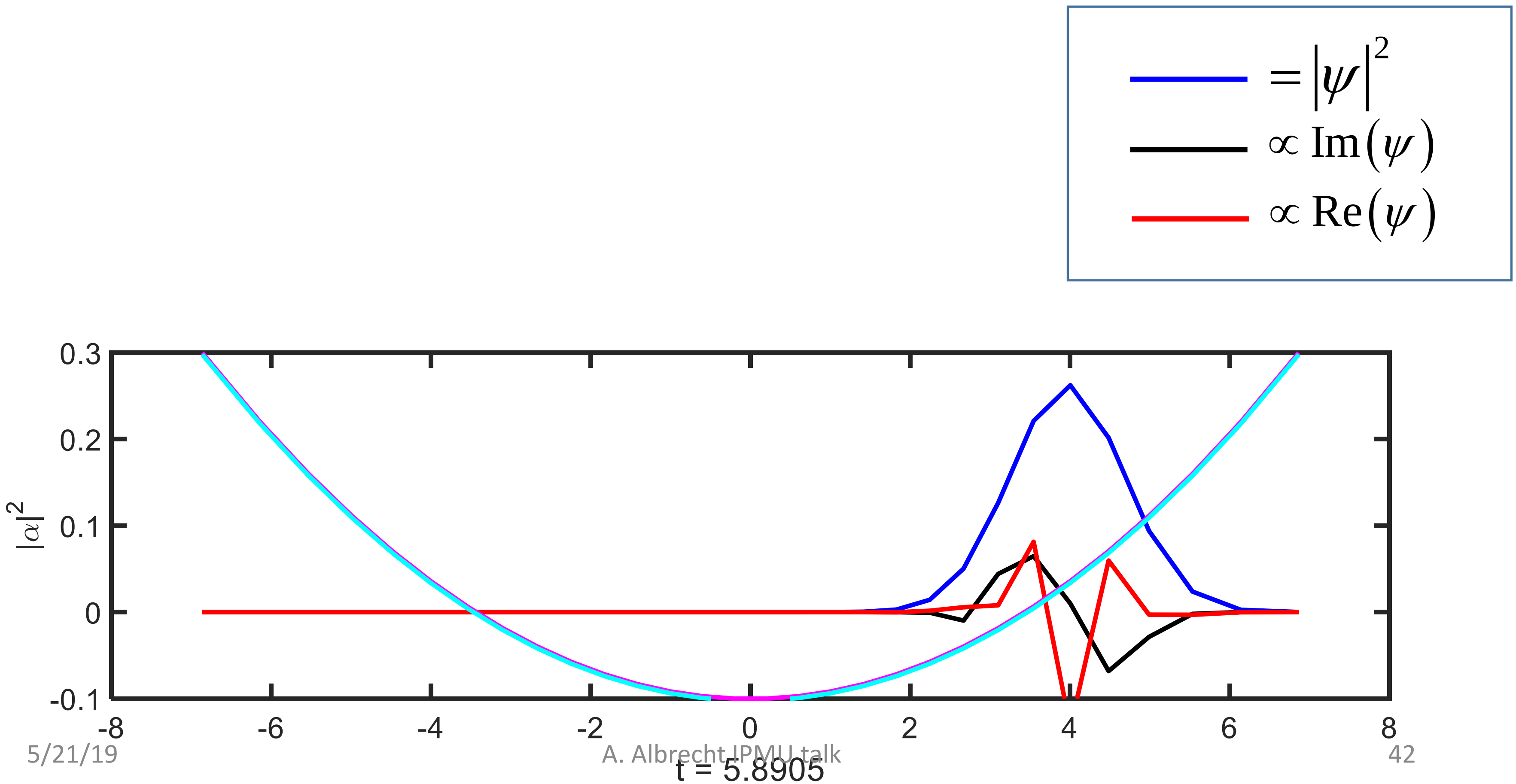

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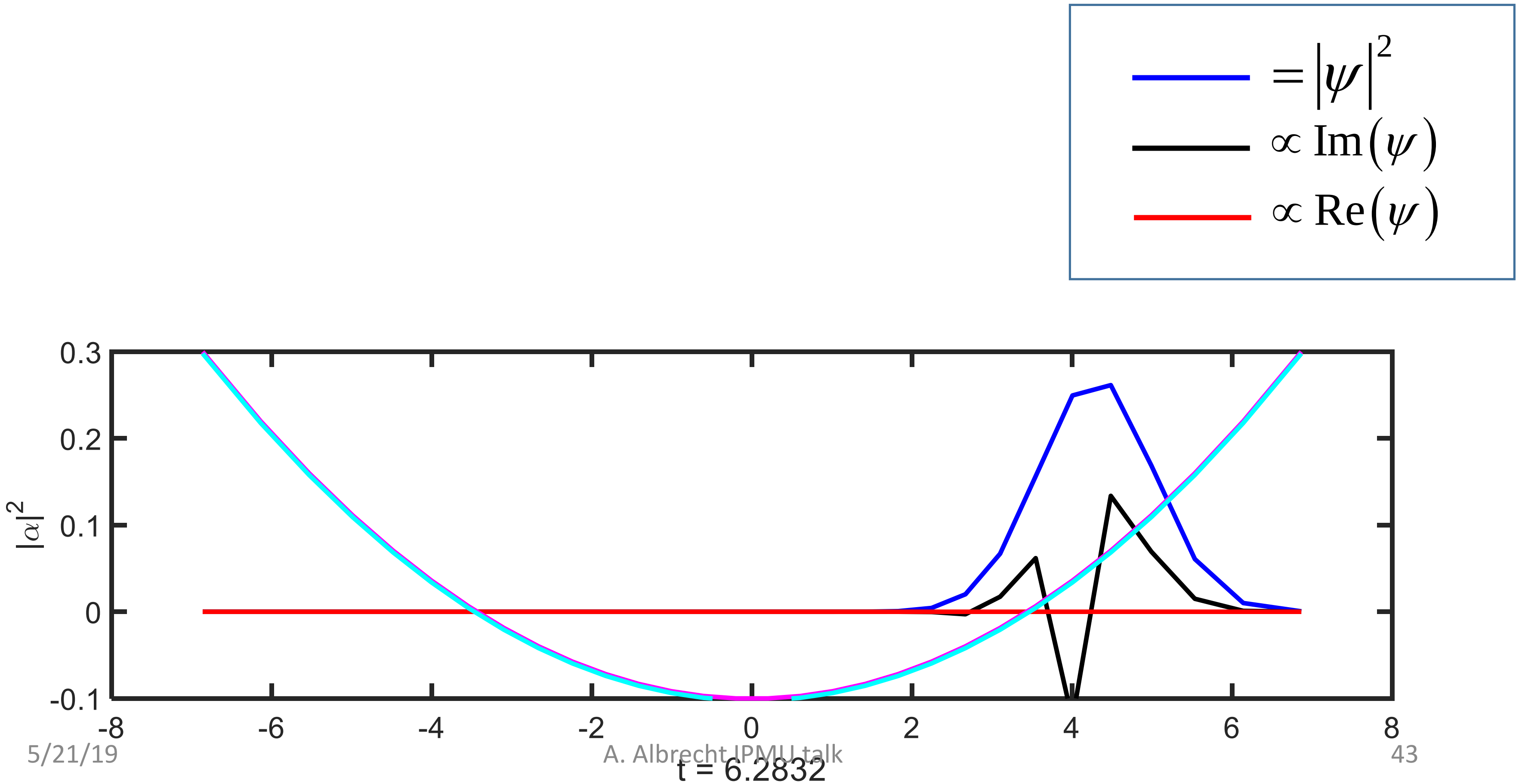

Introducing the toy model

- No interaction case ($H_I^E = \mathbf{0}$)
- Model SHO with d=30 Hilbert space

Nice stable behavior

Numerical noise not an issue

Introducing the Schrödinger cat

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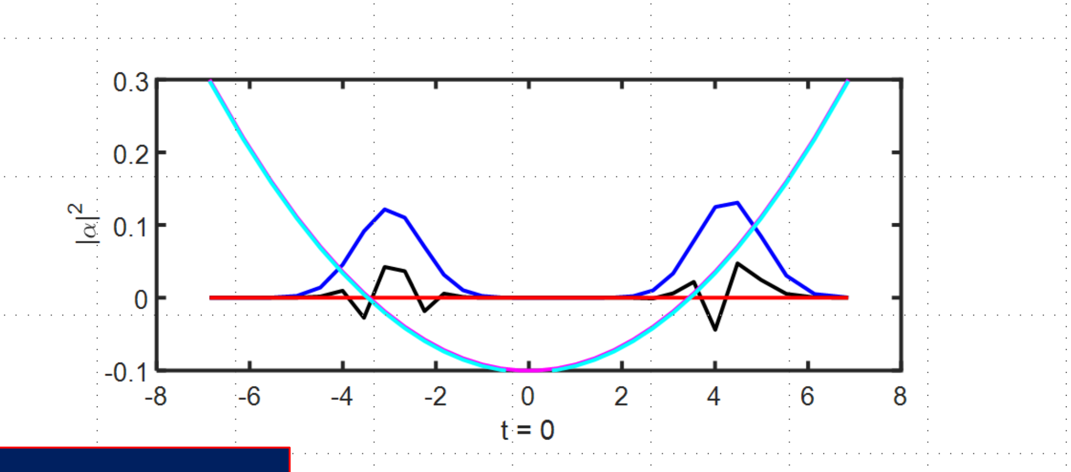
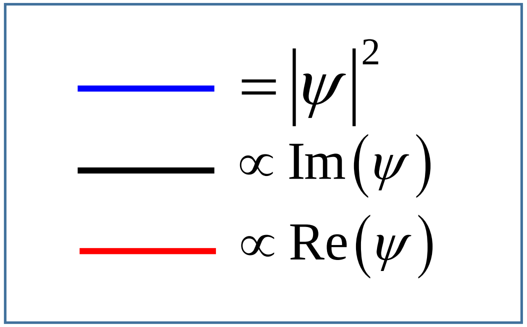
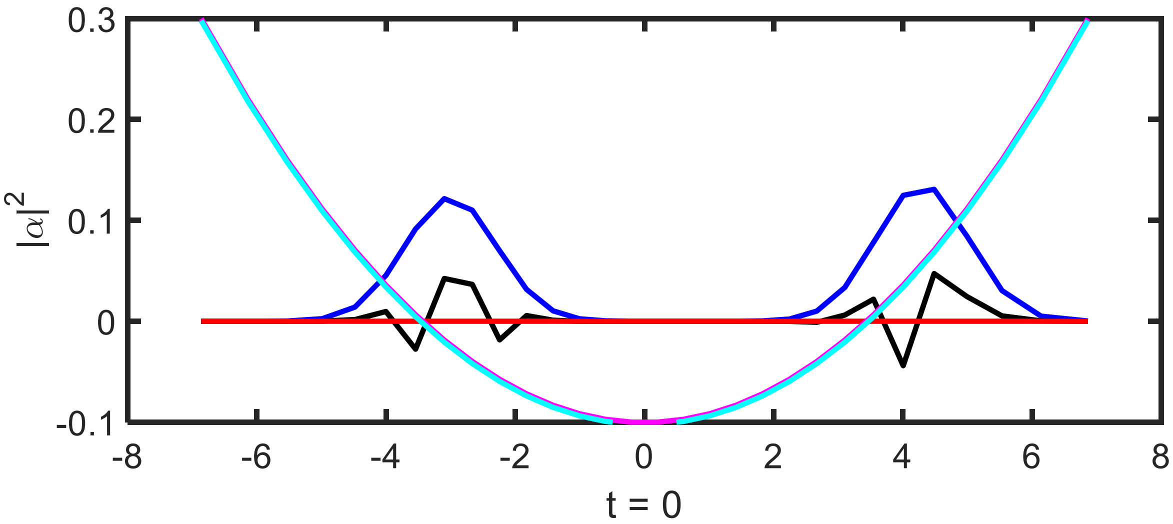


Show Movie B

Isolated SHO





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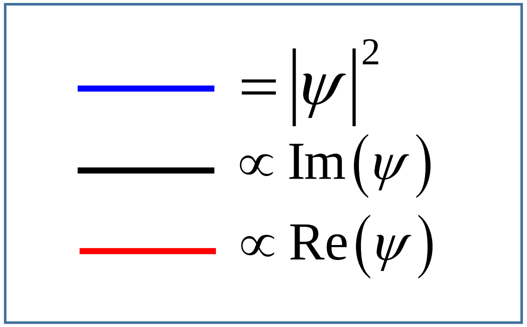

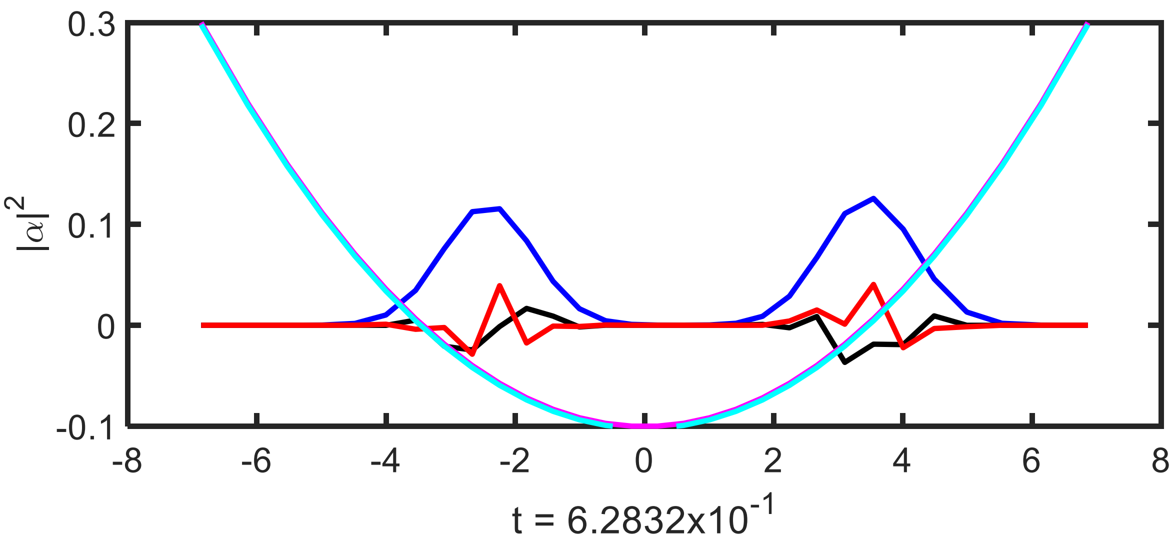

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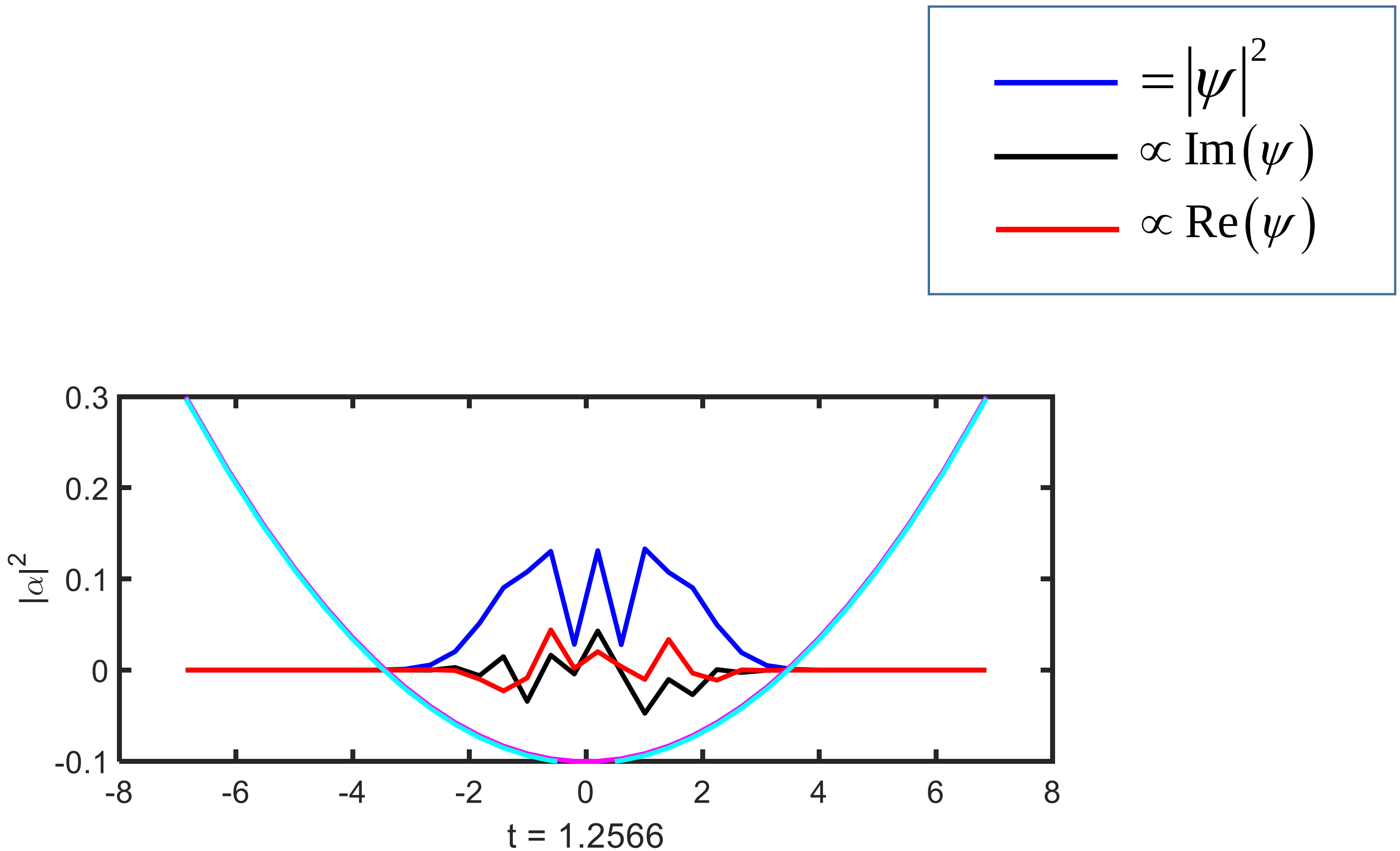

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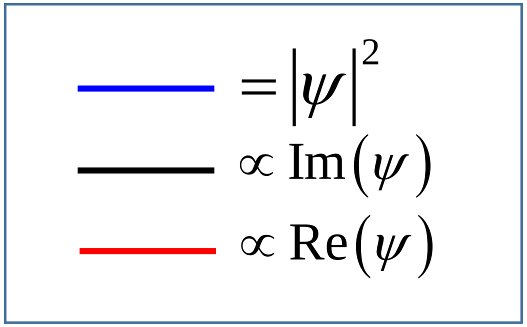

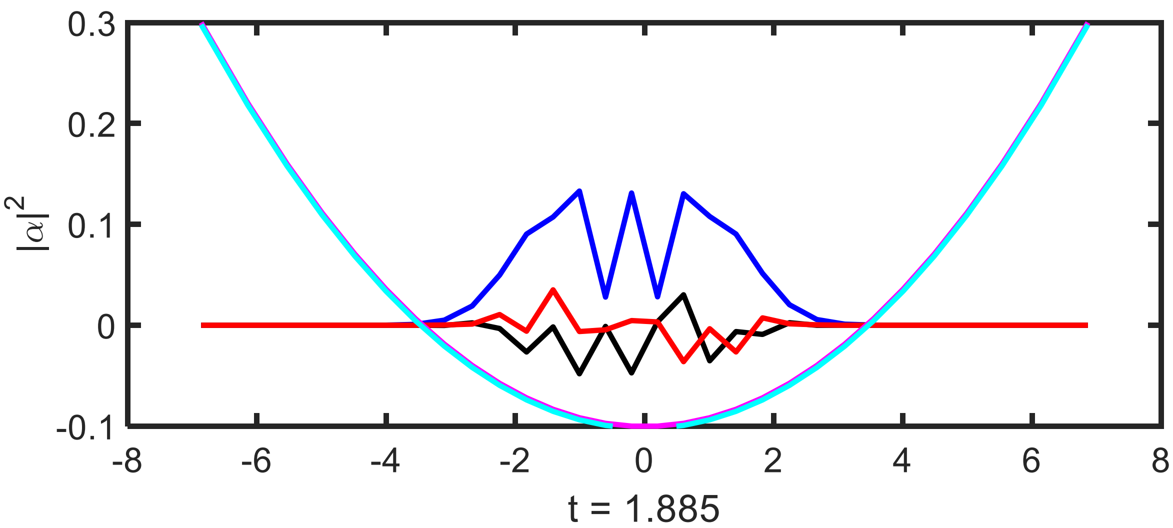

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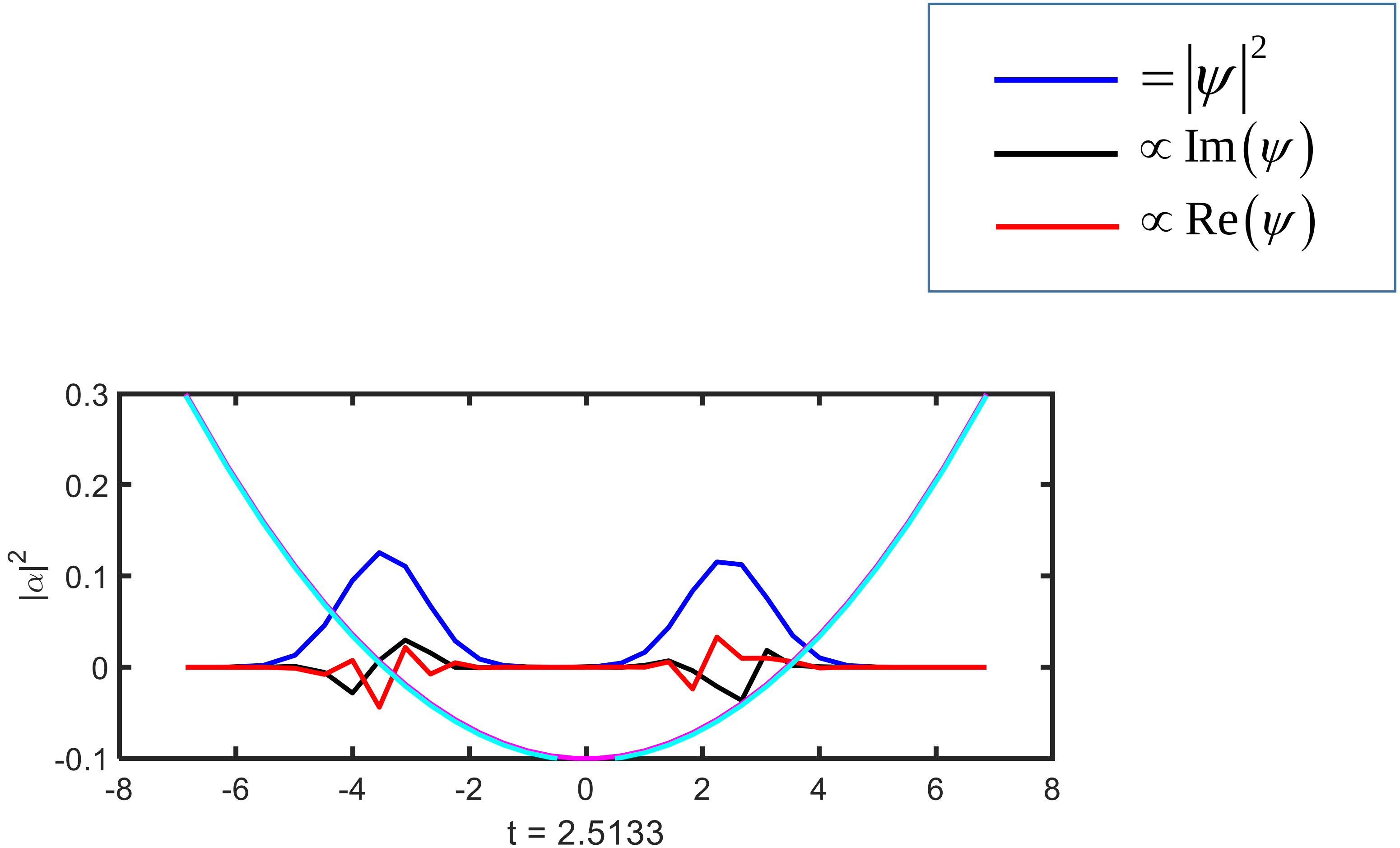

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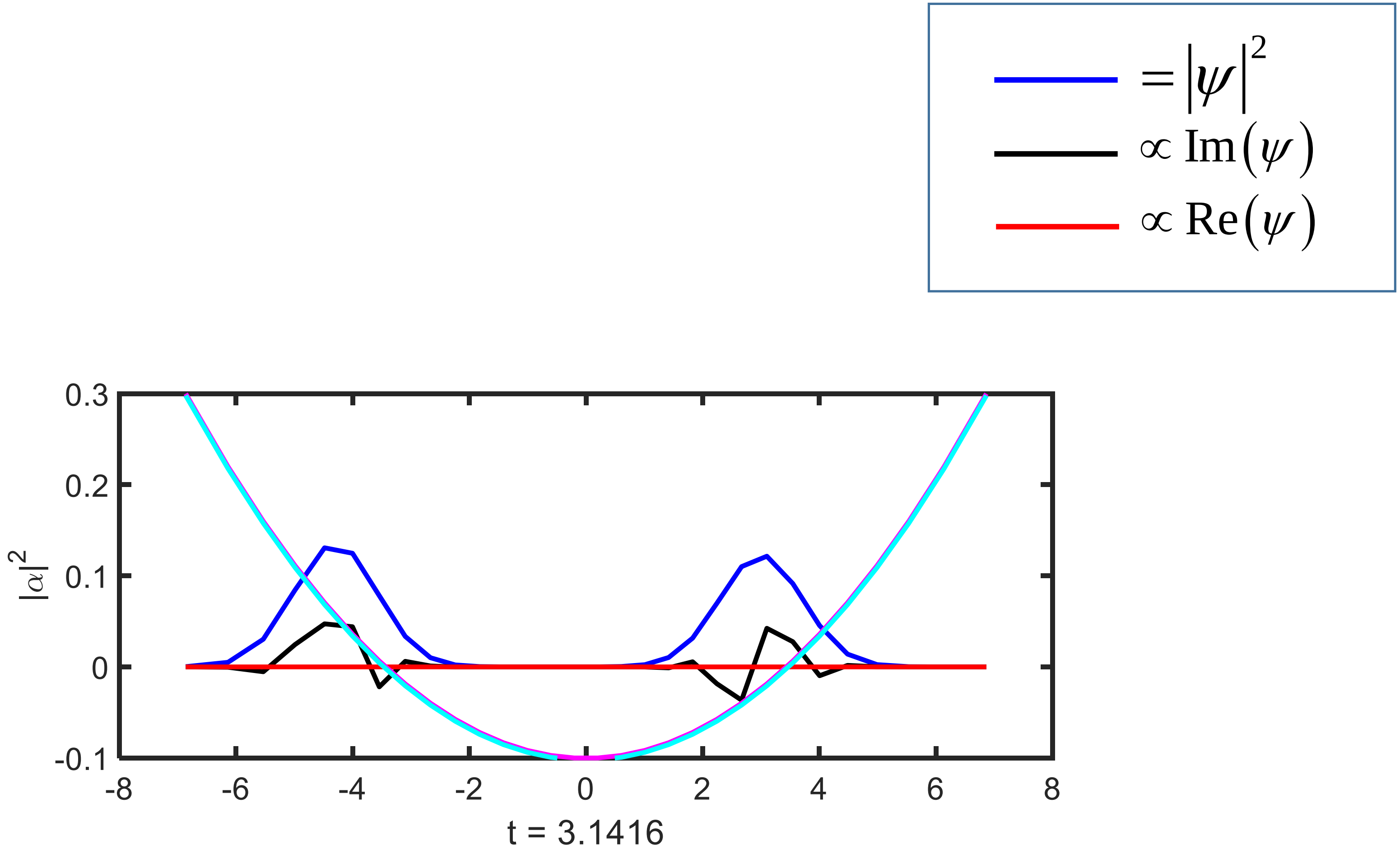

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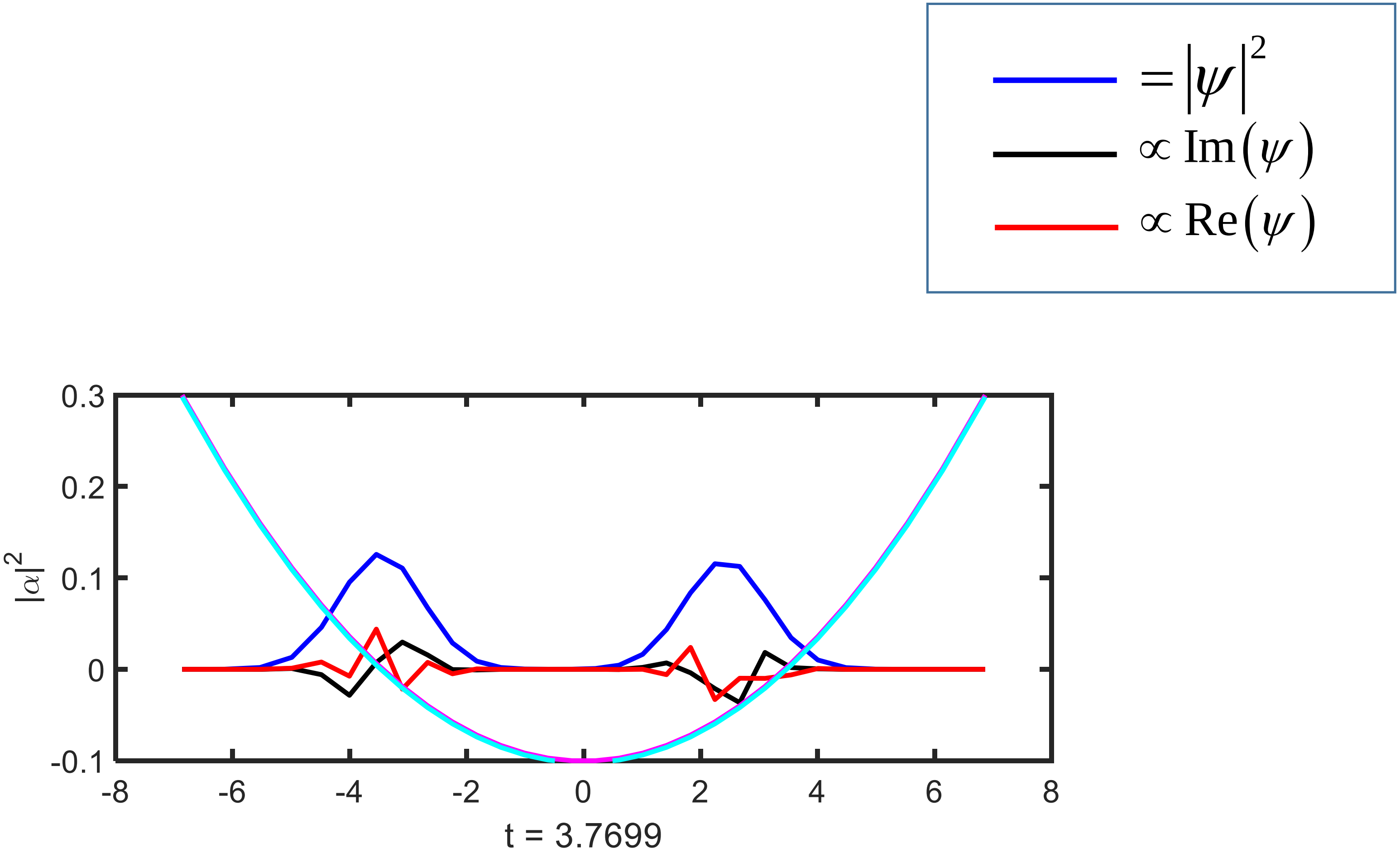

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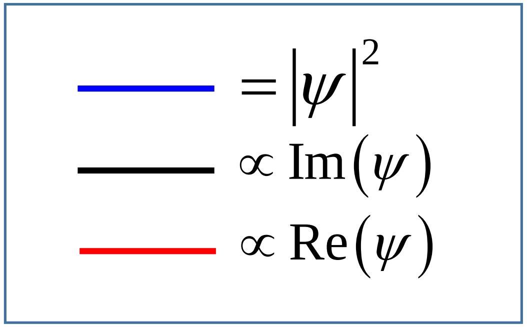

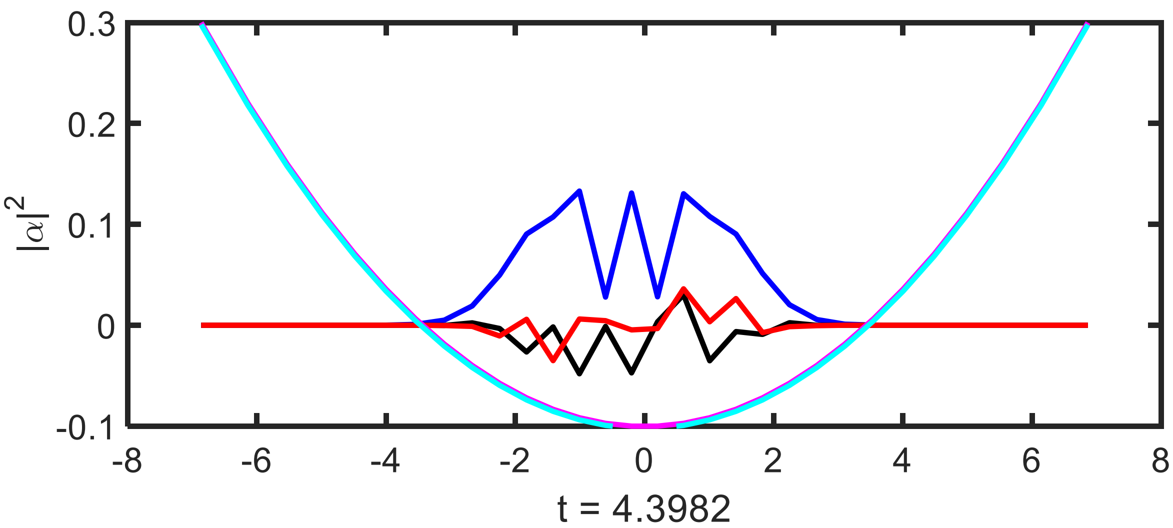

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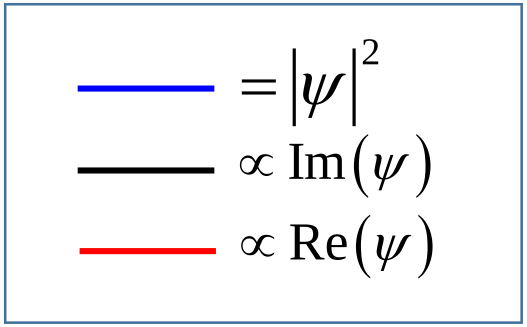

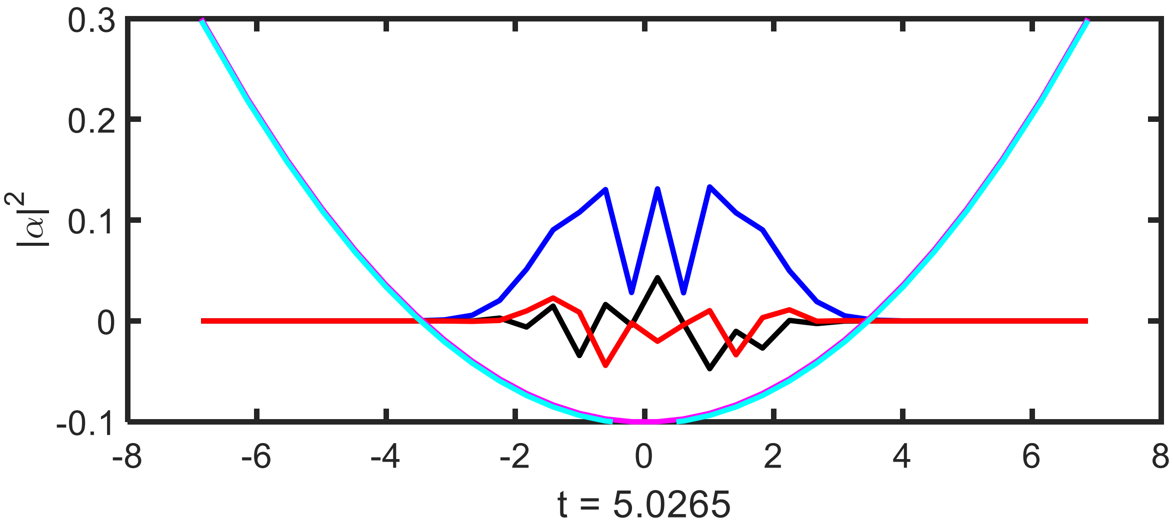

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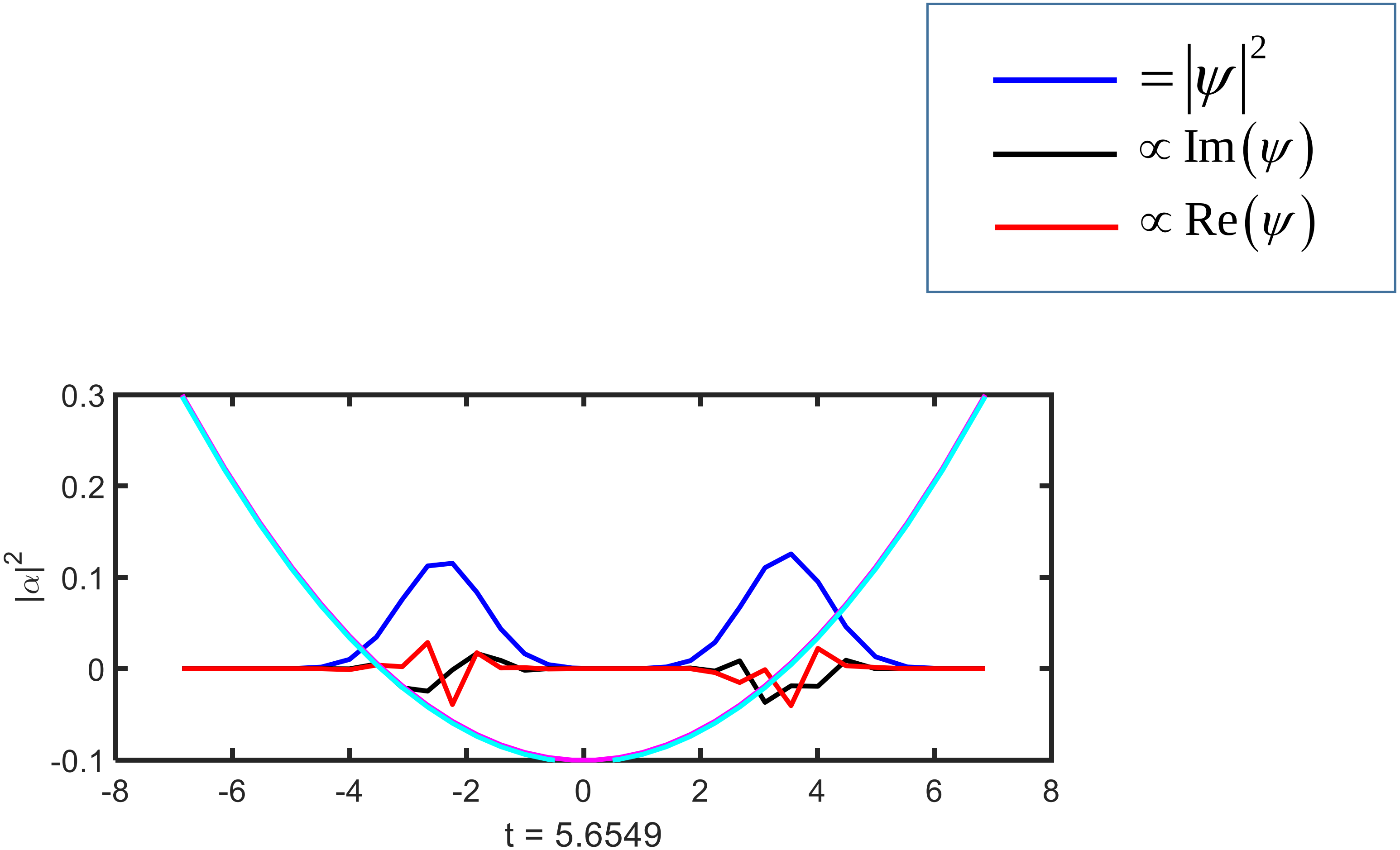

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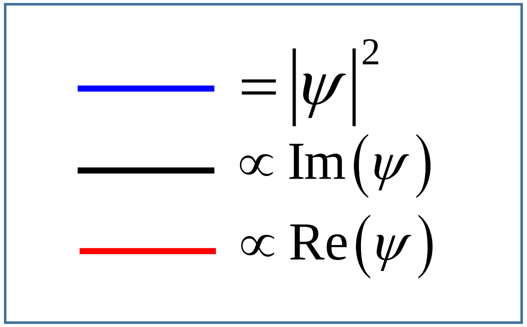

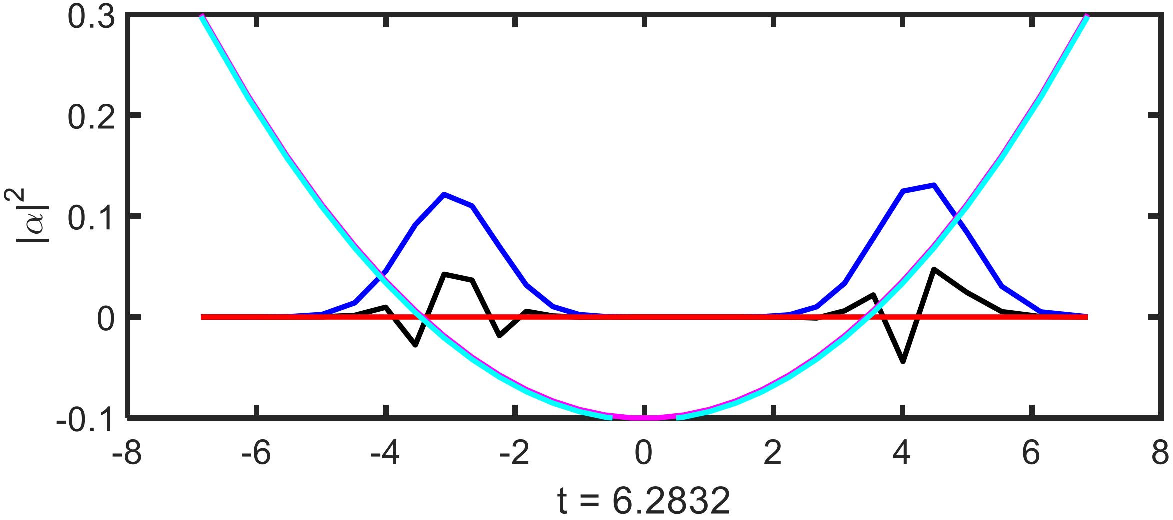

Schrödinger cat interacting with the environment:

- Interactions turned on $(H_I^E \neq \mathbf{0})$

$$H = H_{SHO}^S \otimes \mathbf{1}^E + q_{SHO} H_I^E + \mathbf{1}^S \otimes H^E$$

This evolution will take an initial product state into a mixed state:

$$|\psi\rangle_W = |\psi\rangle_S |\psi\rangle_E \rightarrow \sum_{i,j} \alpha_{ij} |i\rangle_S |j\rangle_E$$

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Pure (product)

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$$|\psi\rangle_W = |\psi\rangle_S |\psi\rangle_E \Rightarrow \sum_{i,j} \alpha_{ij} |i\rangle_S |j\rangle_E$$

$$\rho_S \equiv Tr_E\left(|\psi\rangle_{W\ W}\langle\psi|\right) = |\psi\rangle_{S\ S}\langle\psi| \Rightarrow$$ more general ρ_S

Some comments on entangled states

$$W = A \otimes B$$

Inclined to think:

$$|\psi\rangle_W = |\psi\rangle_A |\psi\rangle_B$$

A state for each subsystem

$$W = A \otimes B$$

But the general case is:

$$\left|\psi\right\rangle_W = \sum_{i,j} \alpha_{ij} \left|i\right\rangle_A \left|j\right\rangle_B$$

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$$\left|\psi\right\rangle_W = \sum_{i,j} \alpha_{ij} \left|i\right\rangle_A \left|j\right\rangle_B$$

Which gives:

$$\rho_A \equiv Tr_B\left(\left|\psi\right\rangle_{W\ W}\left\langle\psi\right|\right)$$

$$\rho_B \equiv Tr_A\left(\left|\psi\right\rangle_{W\ W}\left\langle\psi\right|\right)$$

A density matrix for each subsystem

The expectation value of an observable which lives only in A can be written:

$$\langle O_A \rangle \equiv tr\left(\rho_A O_A\right) = \sum_i p_i \left\langle p_i \left| \hat{O} \right| p_i \right\rangle$$

Eigenvalues and eigenstates of ρ_A

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Eigenvalues and eigenstates of ρ_A

("Schmidt states")

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A "classical mixture" of the eigenstates (no cross terms → no "quantum coherence")

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Eigenvalues and eigenstates of ρ_A

A "classical mixture" of the eigenstates (no cross terms → no "quantum coherence")

Onset of entanglement → decoherence

$$S \equiv tr\left(\rho \ln \rho\right)$$

von Neumann entropy

$S > 0$

$S = 0$

$$\left|\psi\right\rangle_W = \left|\psi\right\rangle_A \left|\psi\right\rangle_B \rightarrow \sum_{i,j} \alpha_{ij} \left|i\right\rangle_A \left|j\right\rangle_B$$

Decoherence ➔ increasing S
➔ arrow of time

- In general, the density matrix eigenstates might vary significantly from one moment to the next, producing a "classical mixture of random stuff"

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Discuss pendulum interacting with the air, leading to localized wave packed pointer states.

Schrödinger cat interacting with the environment:

- Interactions turned on $(H_I^E \neq \mathbf{0})$

$$H = H_{SHO}^S \otimes \mathbf{1}^E + q_{SHO} H_I^E + \mathbf{1}^S \otimes H^E$$

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An illustration of Einselection

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This evolution will take an initial product state into a mixed state:

$$|\psi\rangle_W = |\psi\rangle_S |\psi\rangle_E \rightarrow \sum_{i,j} \alpha_{ij} |i\rangle_S |j\rangle_E$$

$$\rho_S \equiv Tr_E\left(|\psi\rangle_{W\ W}\langle\psi|\right) = |\psi\rangle_{S\ S}\langle\psi| \rightarrow \text{ more general } \rho_S$$

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Show eigenstates and eigenvalues

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Show eigenstates and eigenvalues

First 2

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Show eigenstates and eigenvalues

First 2

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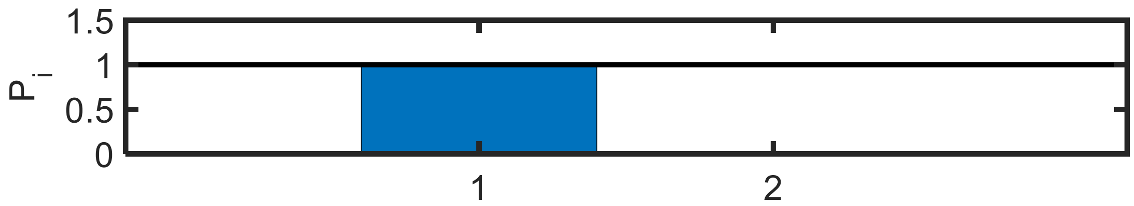
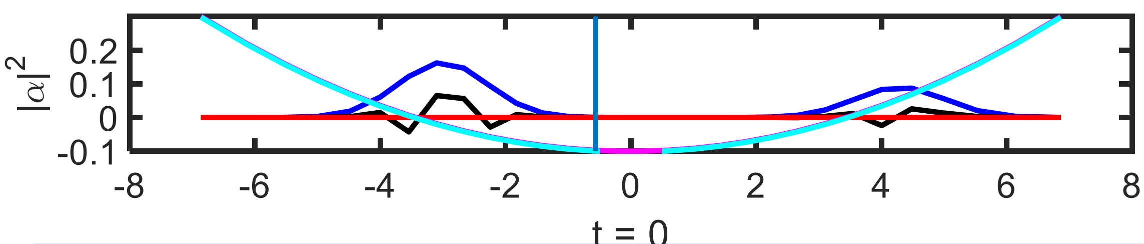
Show Movie C

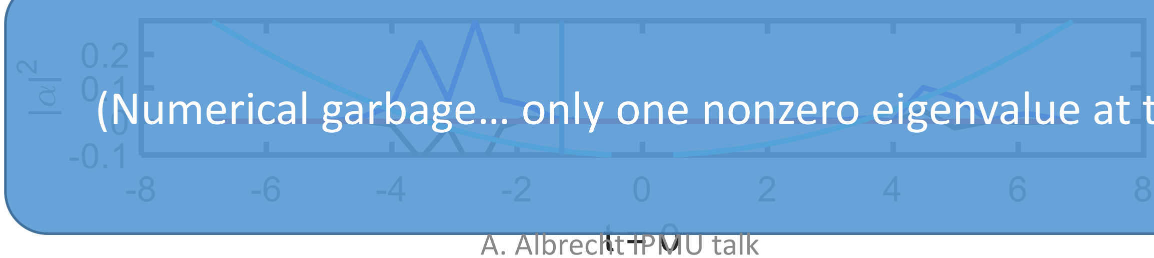
Eigenvalues



First 2

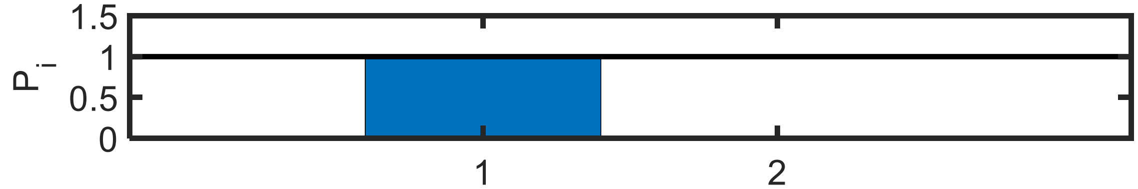


Eigenstates

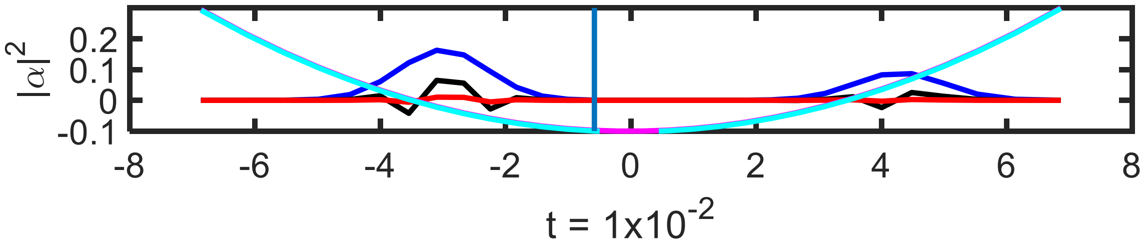


(Numerical garbage… only one nonzero eigenvalue at t=0)

Eigenvalues



First 2



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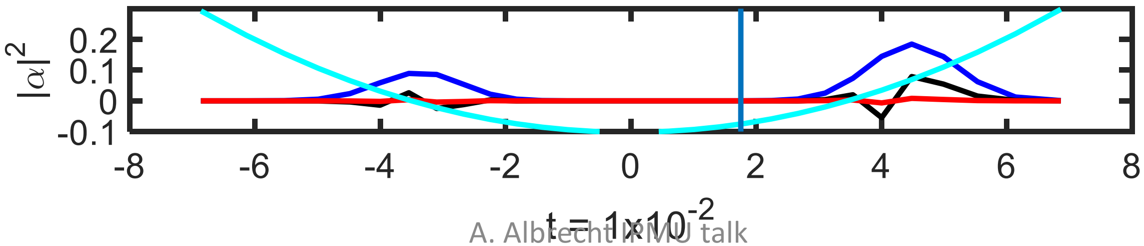

Eigenvalues

First 2

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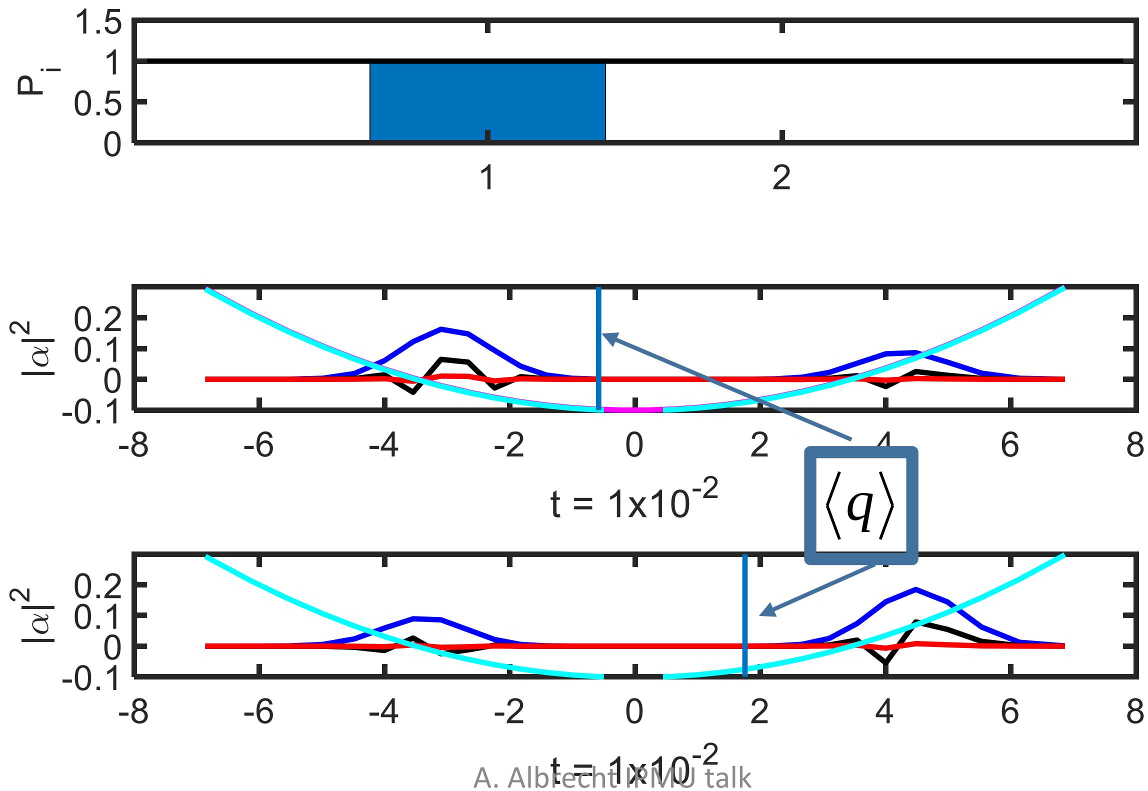

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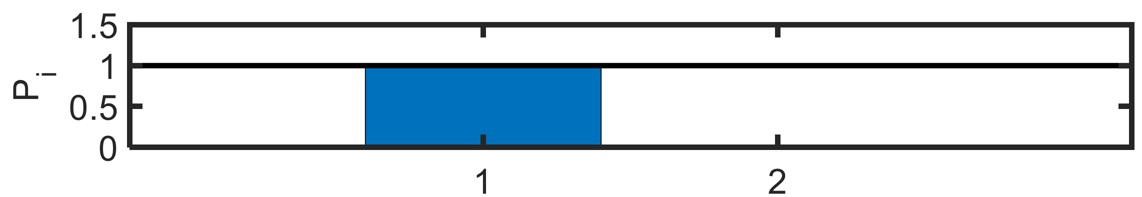
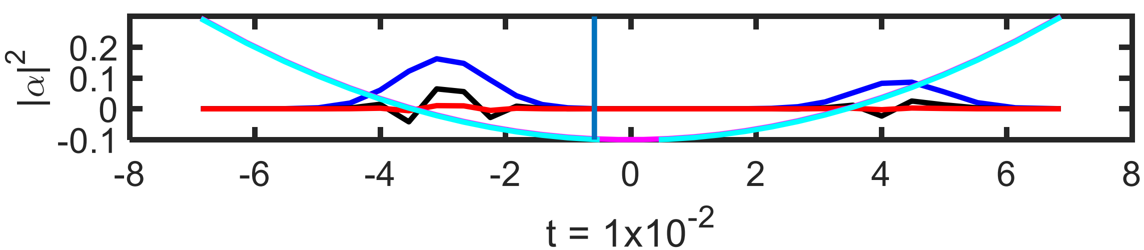
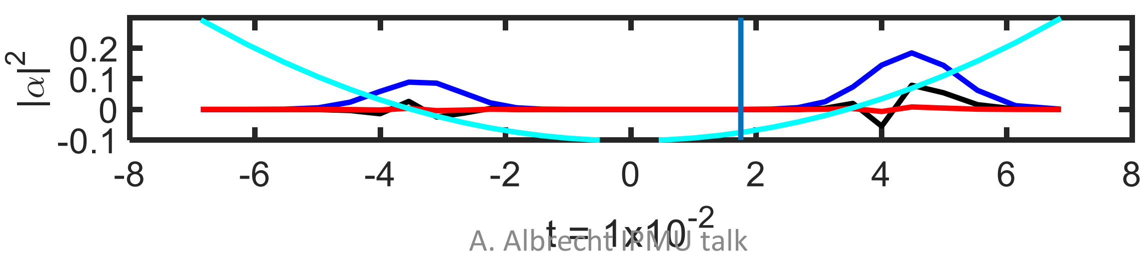


First 2

Eigenstates

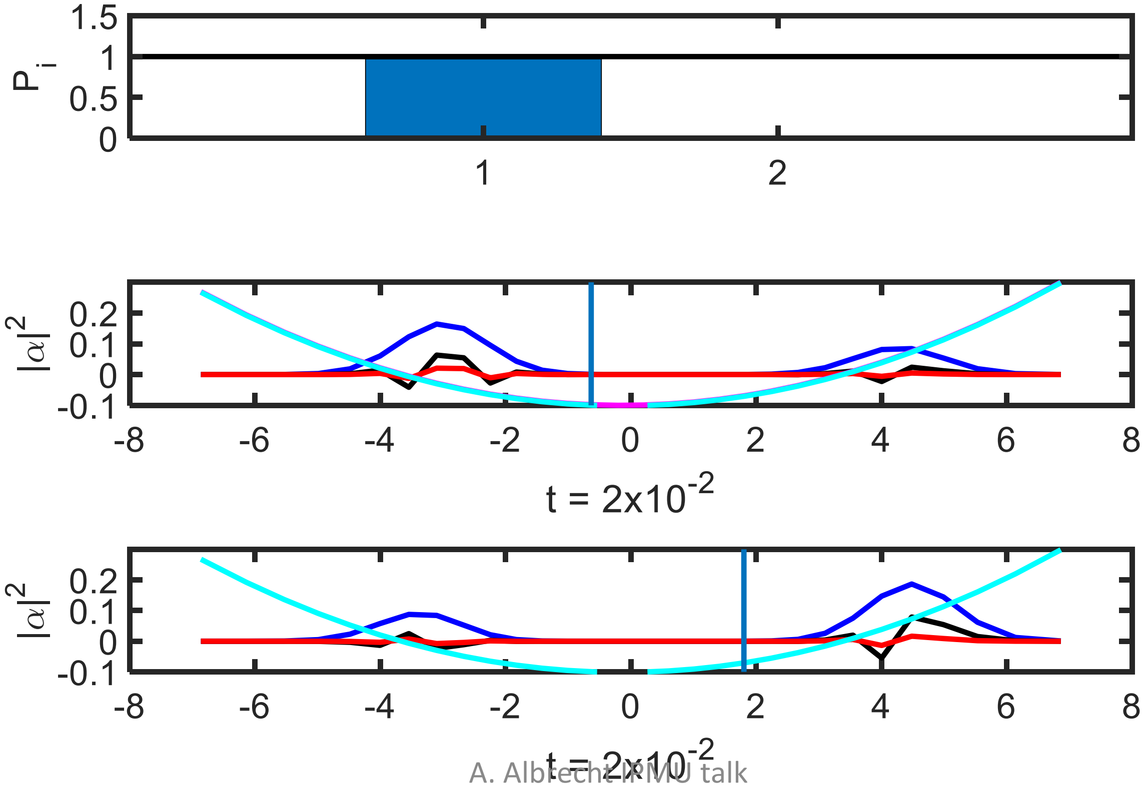




Eigenvalues

First 2

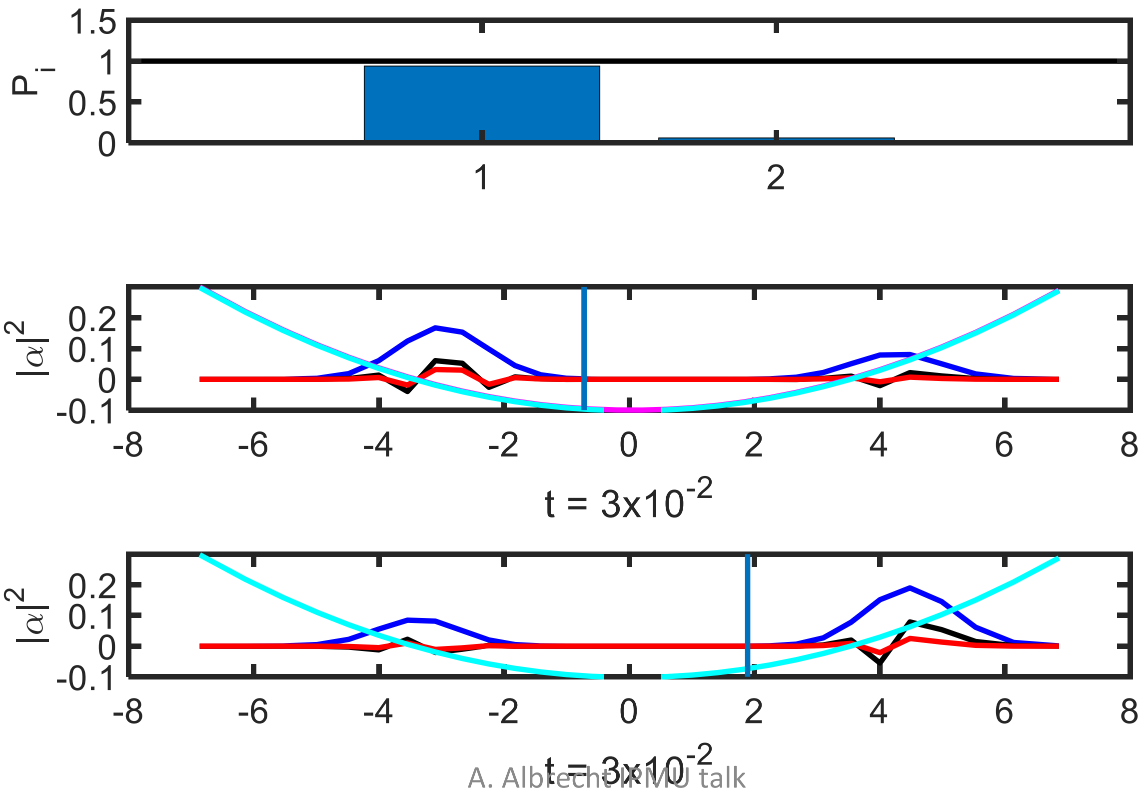
Eigenstates



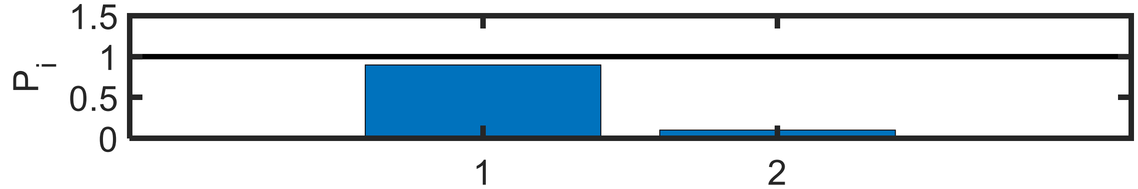
Eigenvalues

First 2

Eigenstates

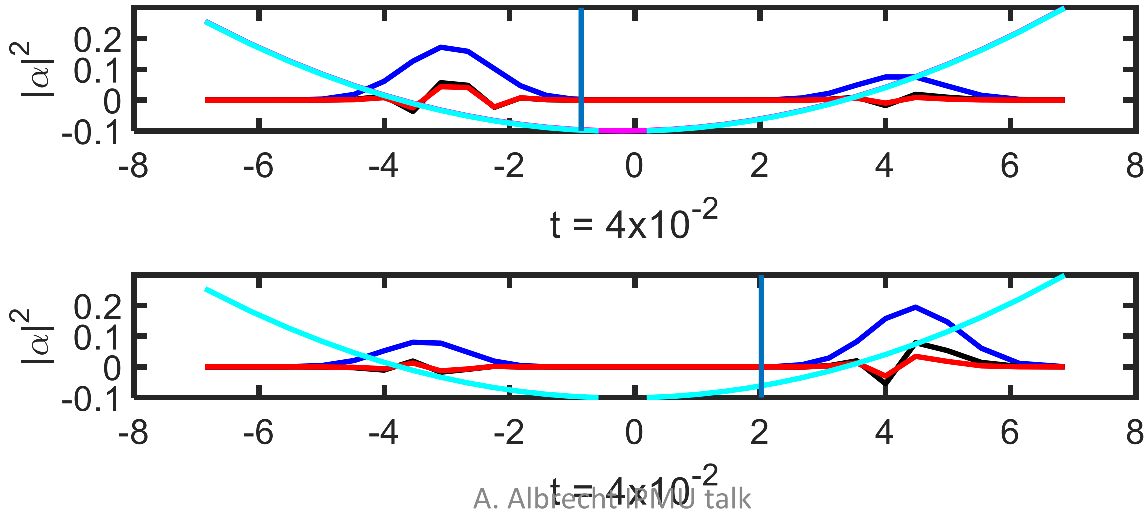


Eigenvalues



First 2

Eigenstates



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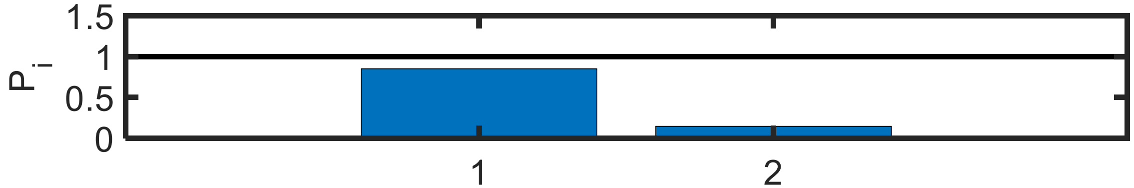
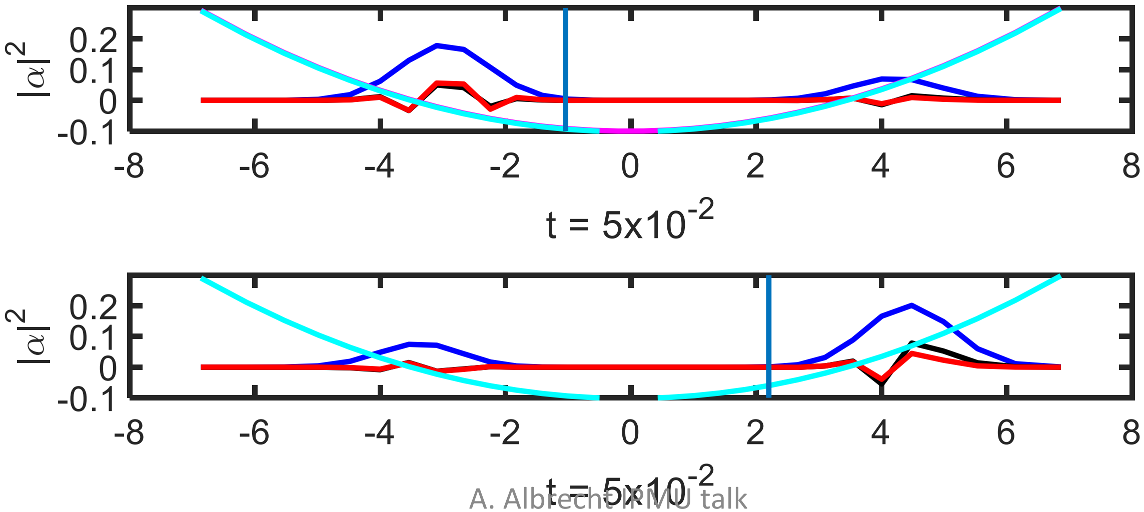


First 2

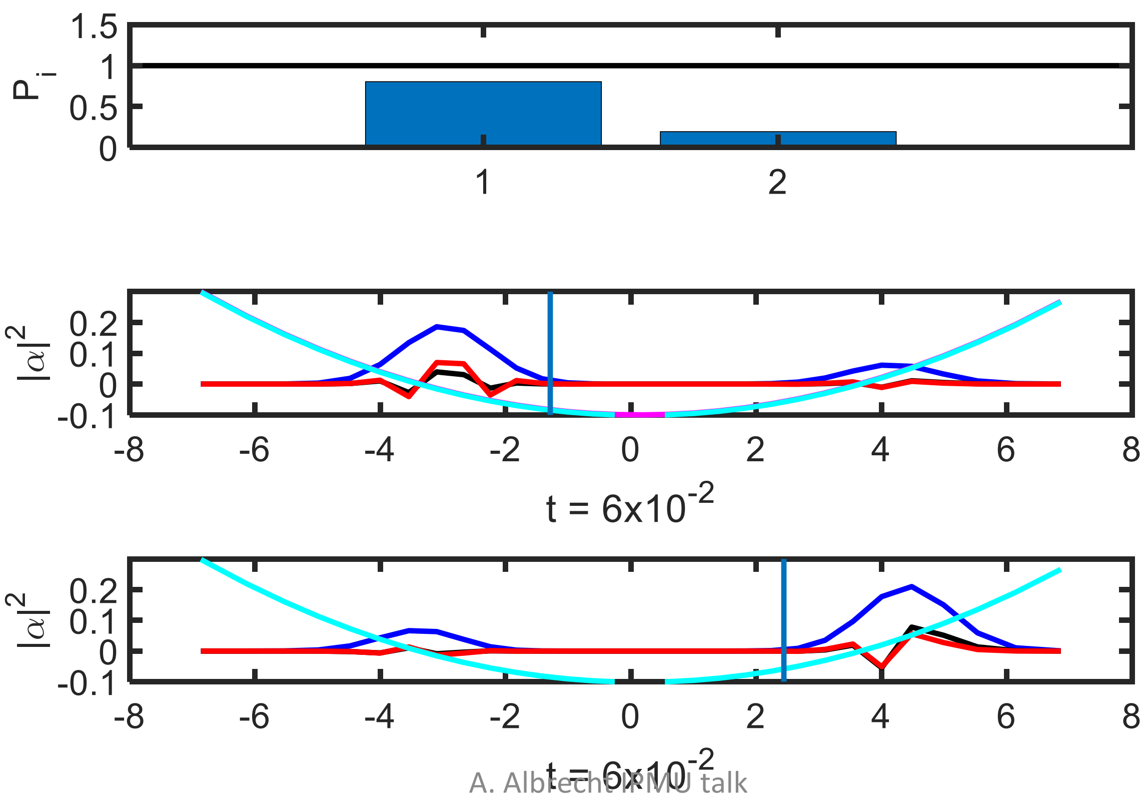
Eigenstates



Eigenvalues

First 2

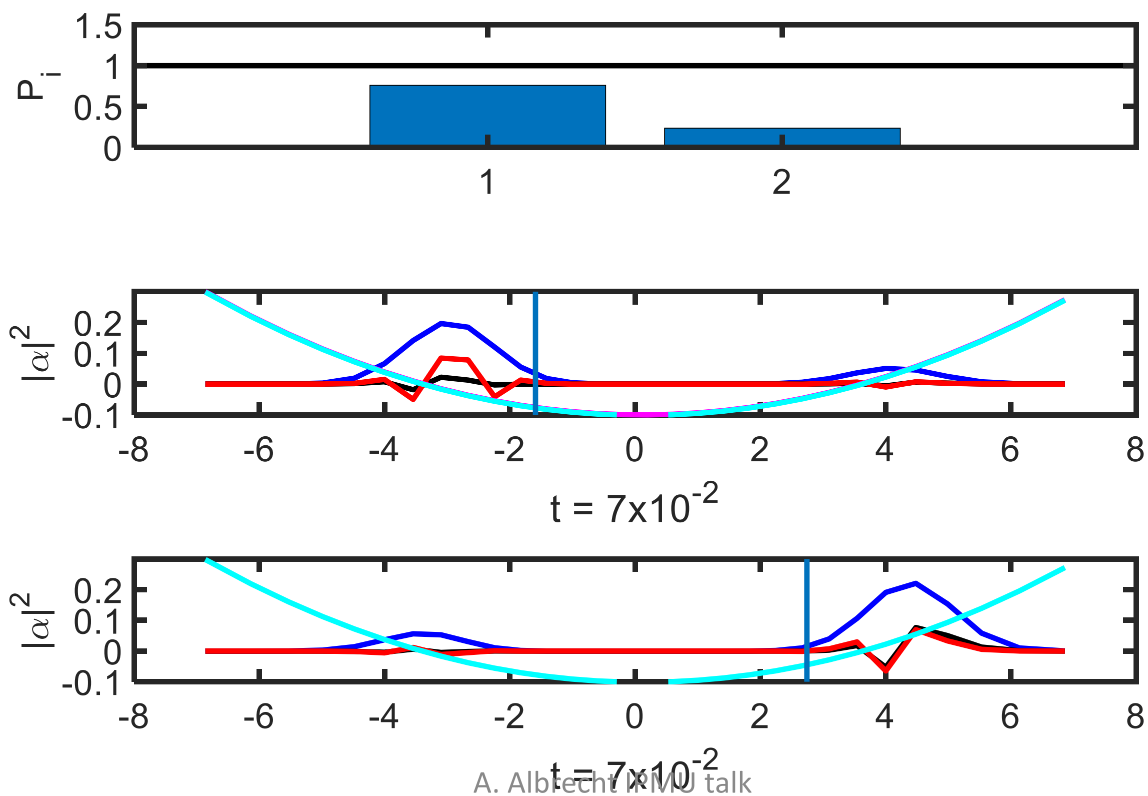
Eigenstates



Eigenvalues

First 2

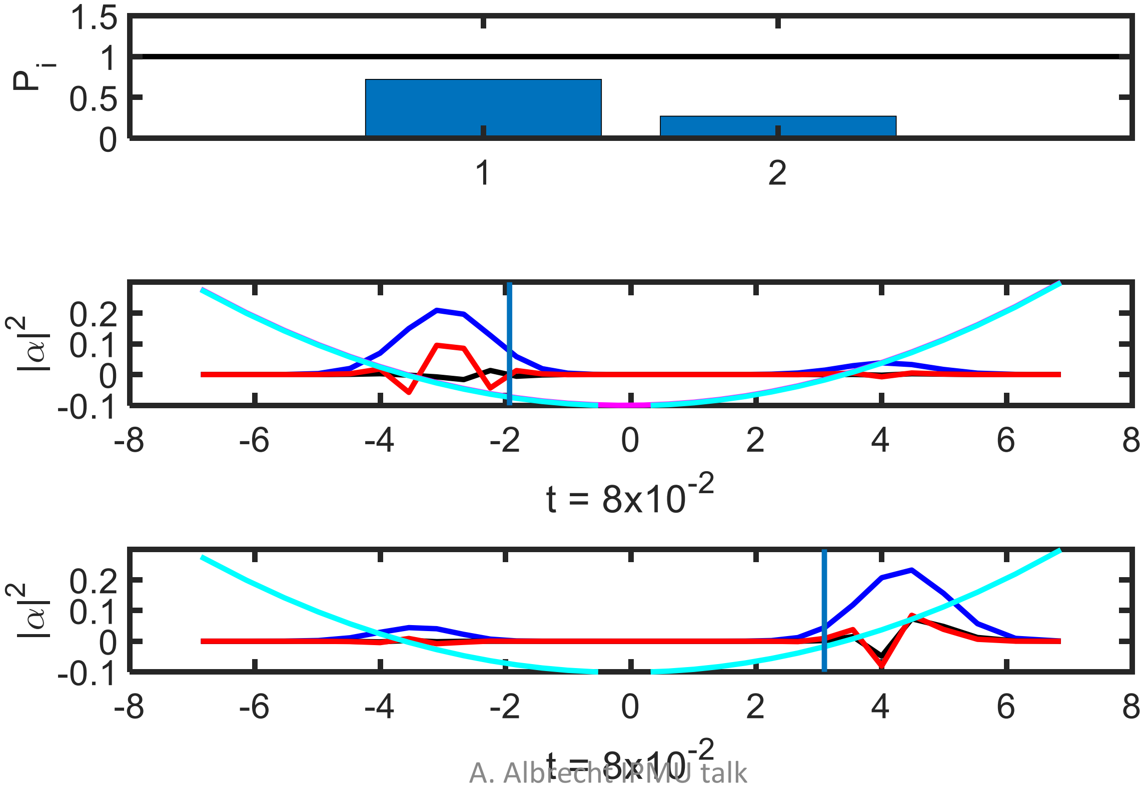
Eigenstates



Eigenvalues

First 2

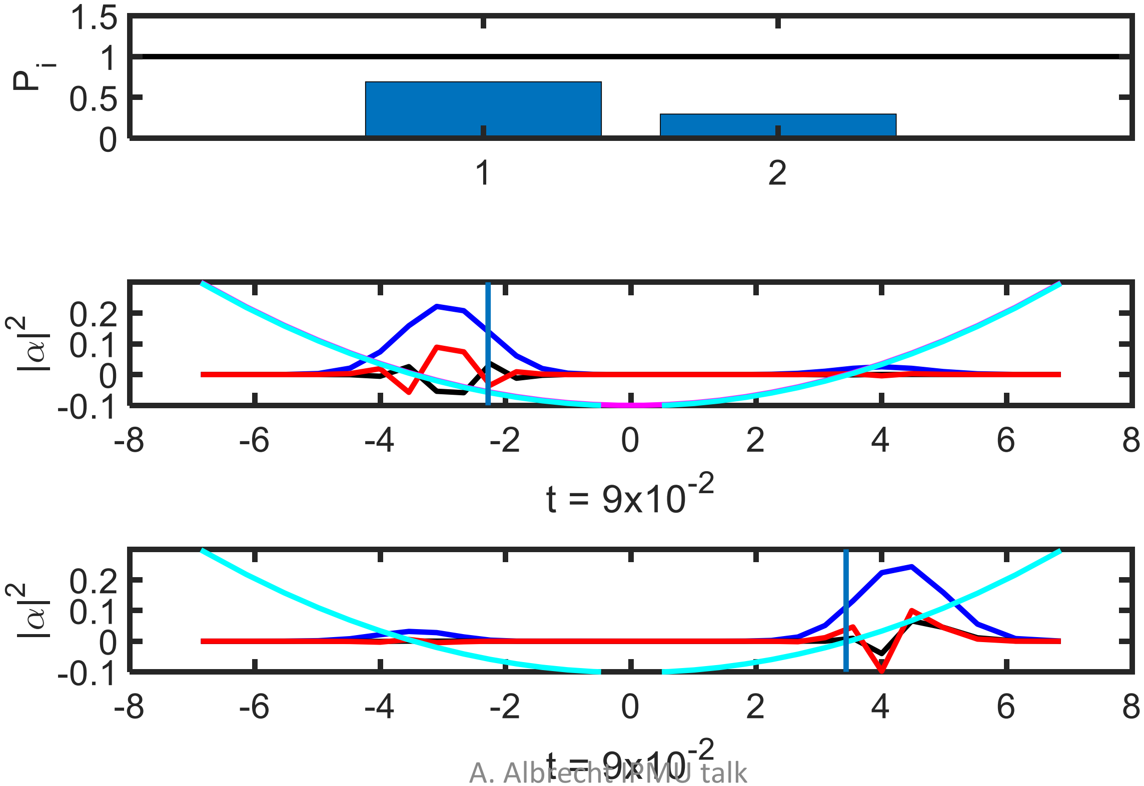
Eigenstates



Eigenvalues

First 2

Eigenstates



Eigenvalues

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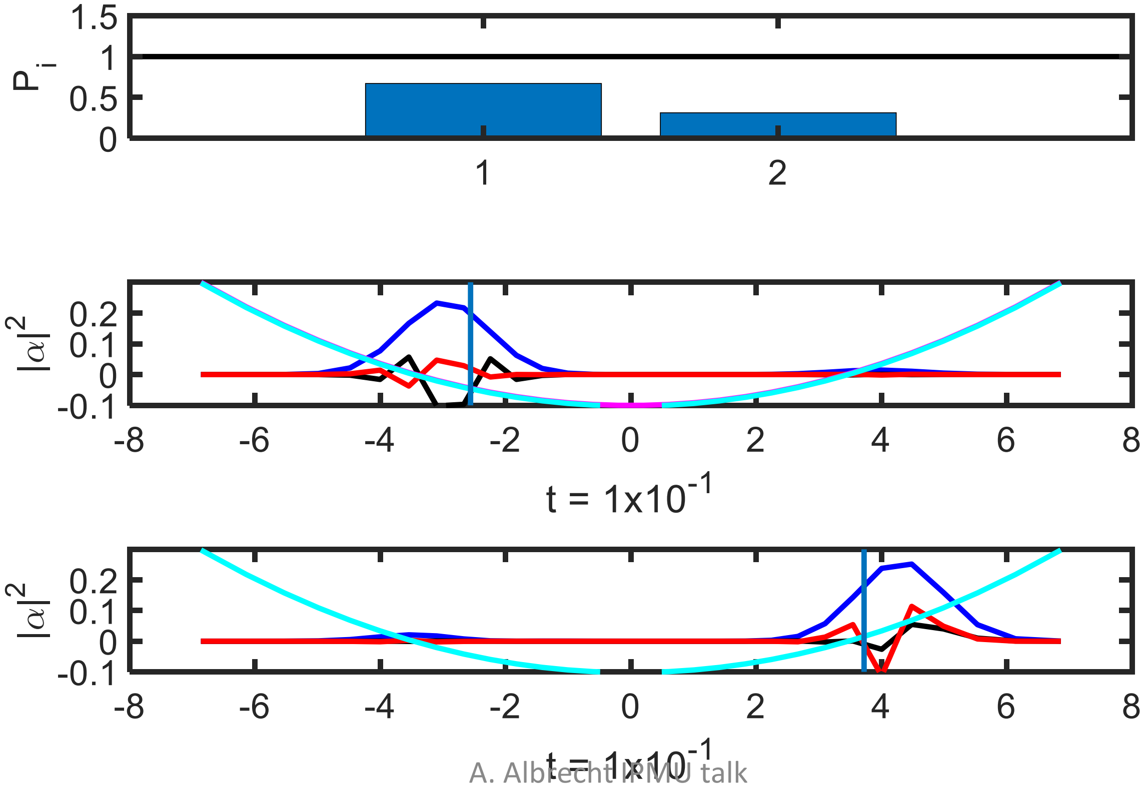
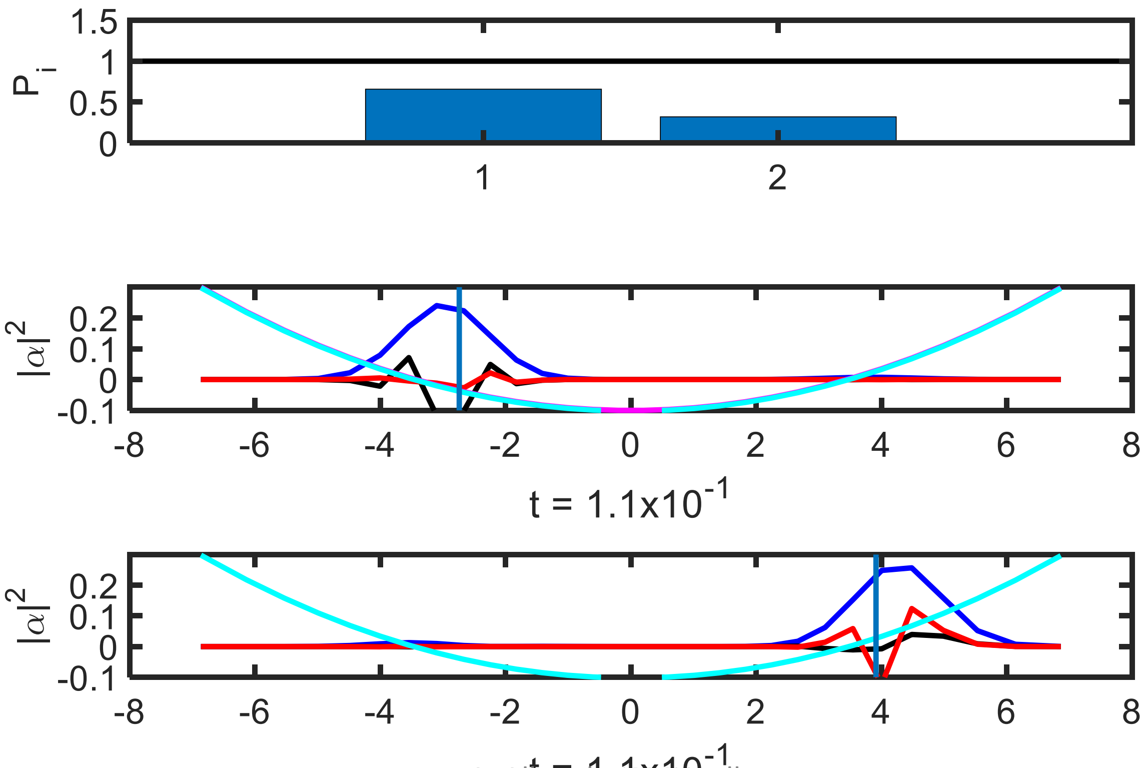
Eigenstates



Eigenvalues

First 2

Eigenstates



Eigenvalues

First 2

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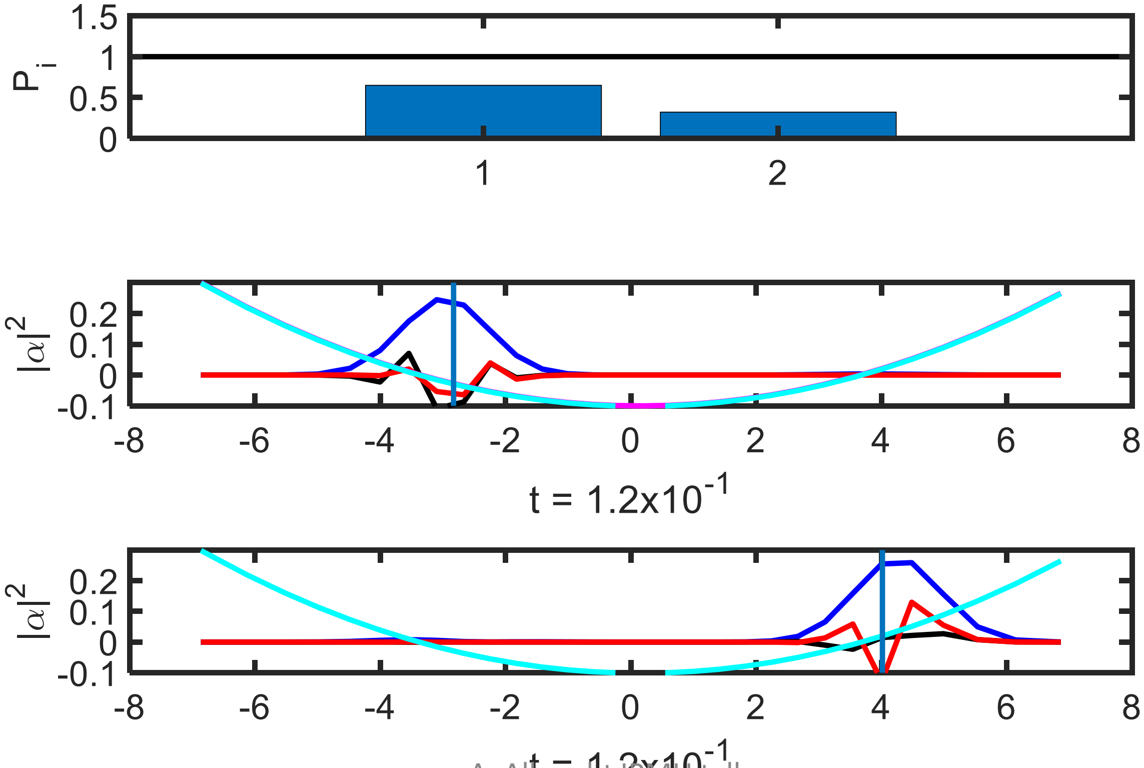

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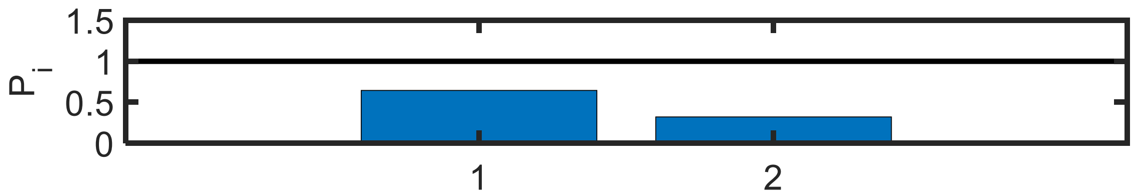
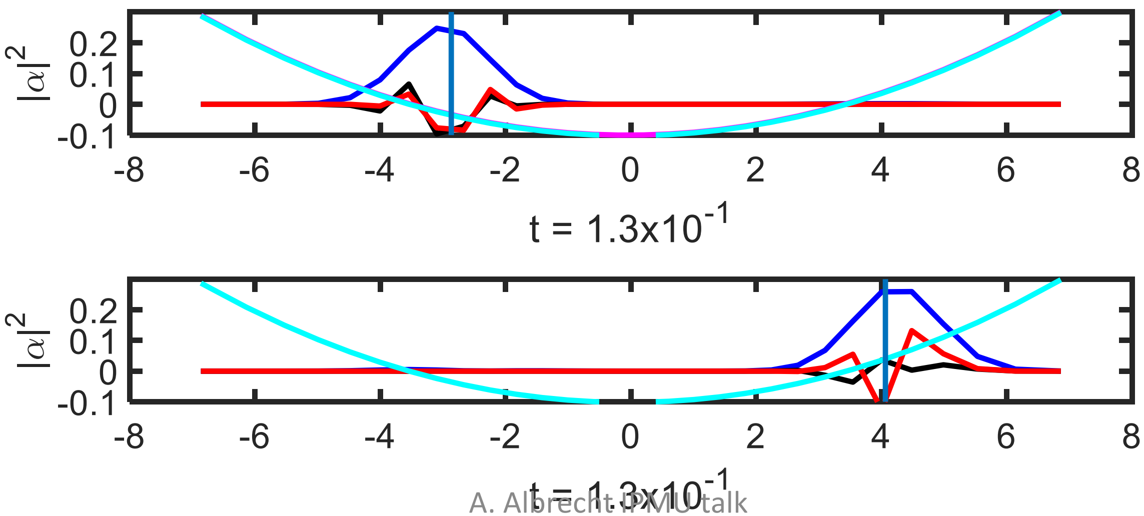


First 2

Eigenstates



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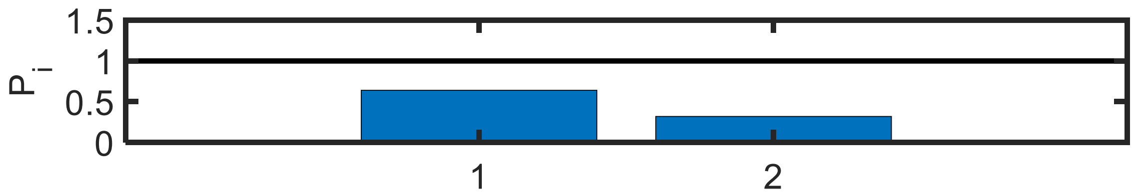
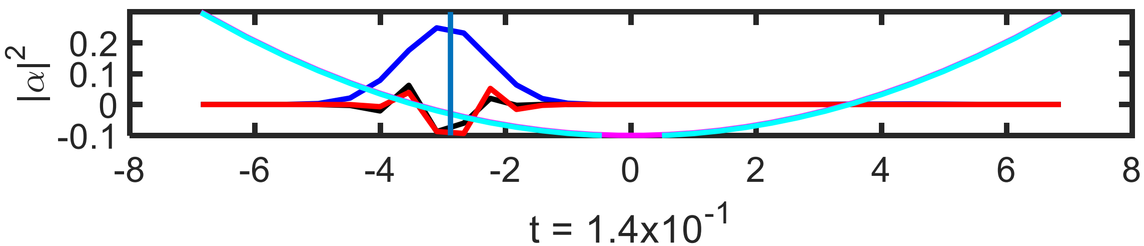
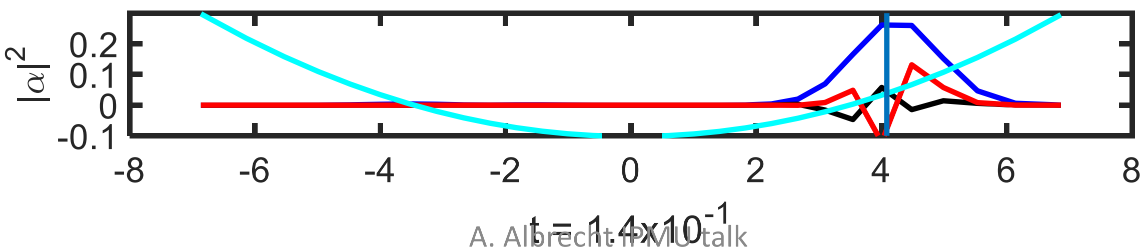


First 2



Eigenstates



Schrödinger cat interacting with the environment:

- Interactions turned on $(H_I^E \neq \mathbf{0})$

$$H = H^S \otimes \mathbf{1}^E + a \quad H^E + \mathbf{1}^S \otimes H^E$$

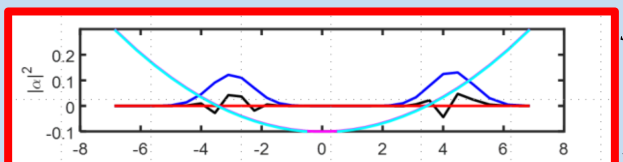
This ev
mixed

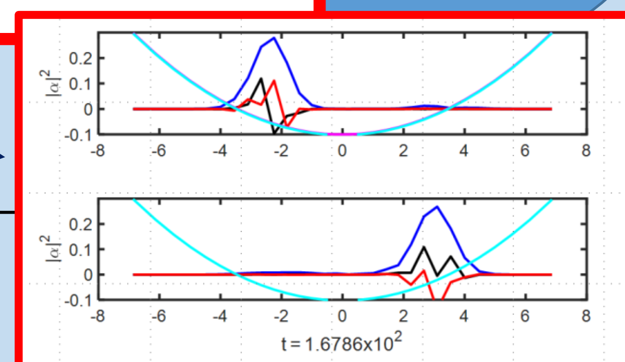
UPSHOT:

- The toy model successfully "einselects" the "classical" wave packets from a Schrödinger cat superposition

Show
genstates
and
envalues

First 2





$$\rho_S = Tr_E\left(|\psi\rangle_W \, {}_W\langle\psi|\right) \quad |\psi\rangle_S \, {}_S\langle\psi| -$$

Show Movie C

Outline

1. Motivations
2. Introduction to einselection and the toy model
3. Einselection in equilibrium (technical explorations and overall assessment)
4. Eigenstate Einselection Hypothesis (if there is time)
5. Conclusions

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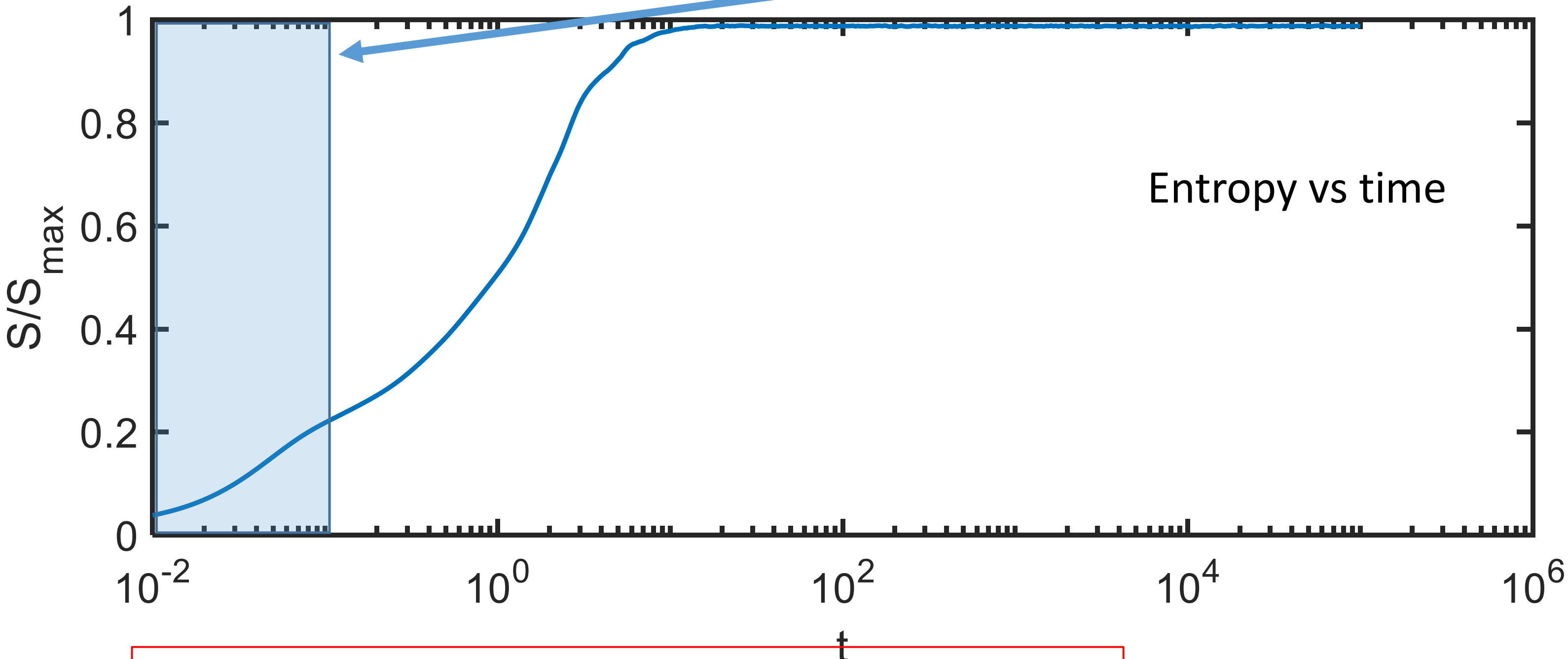
The collapsing Schrödinger cat (Movie C) was in this time window



- Einselection associated with increasing entropy

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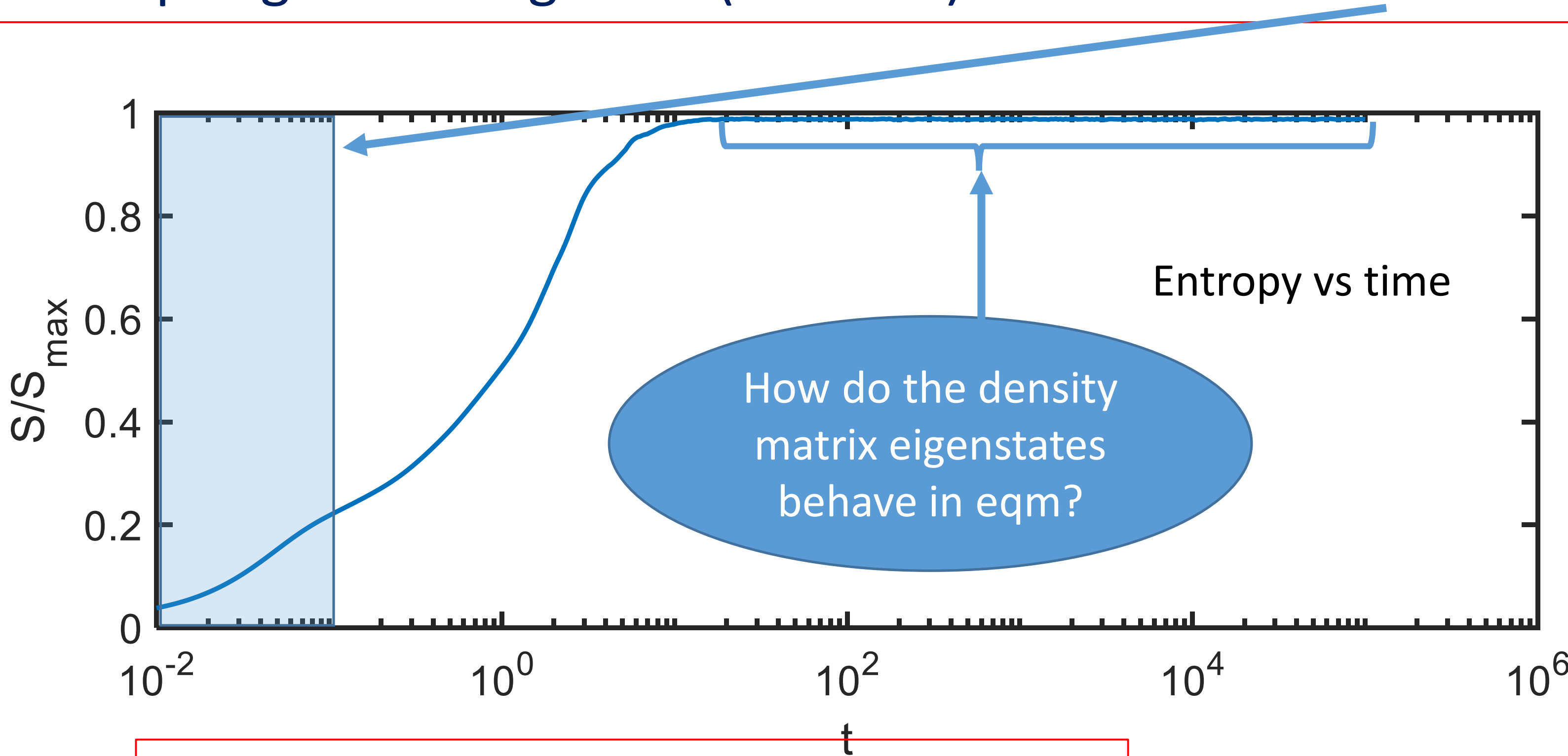

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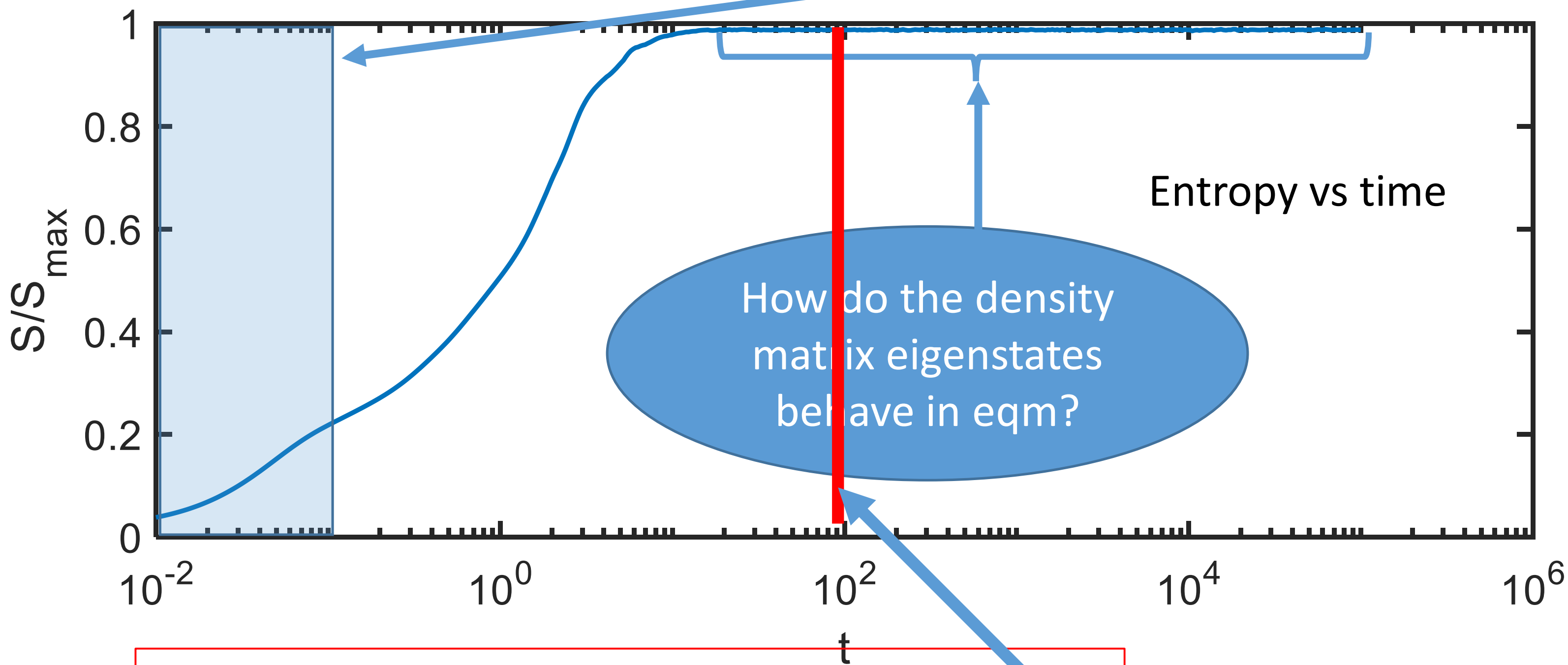


- Einselection associated with increasing entropy

Movie D starts here

Show Movie D

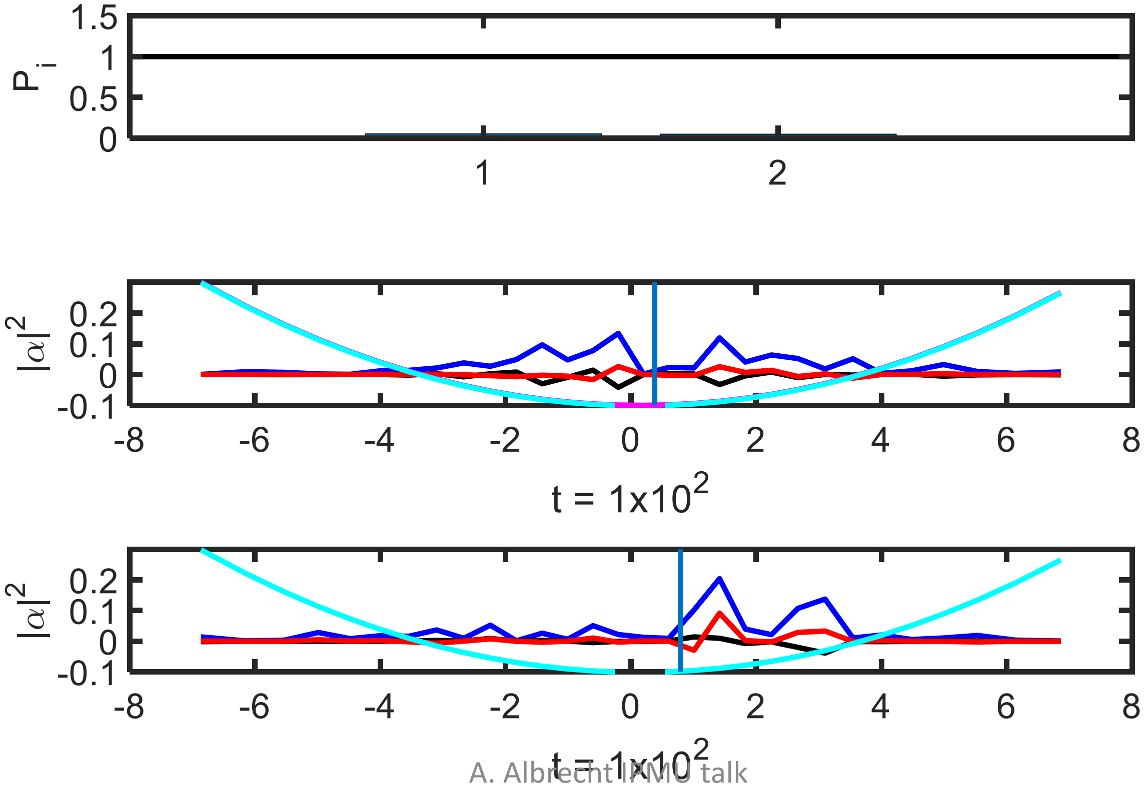
Discuss “detailed balance” (wallowing) of everett worlds at board

SHO density matrix in eqm

Eigenvalues

First 2

Eigenstates



SHO density matrix in eqm

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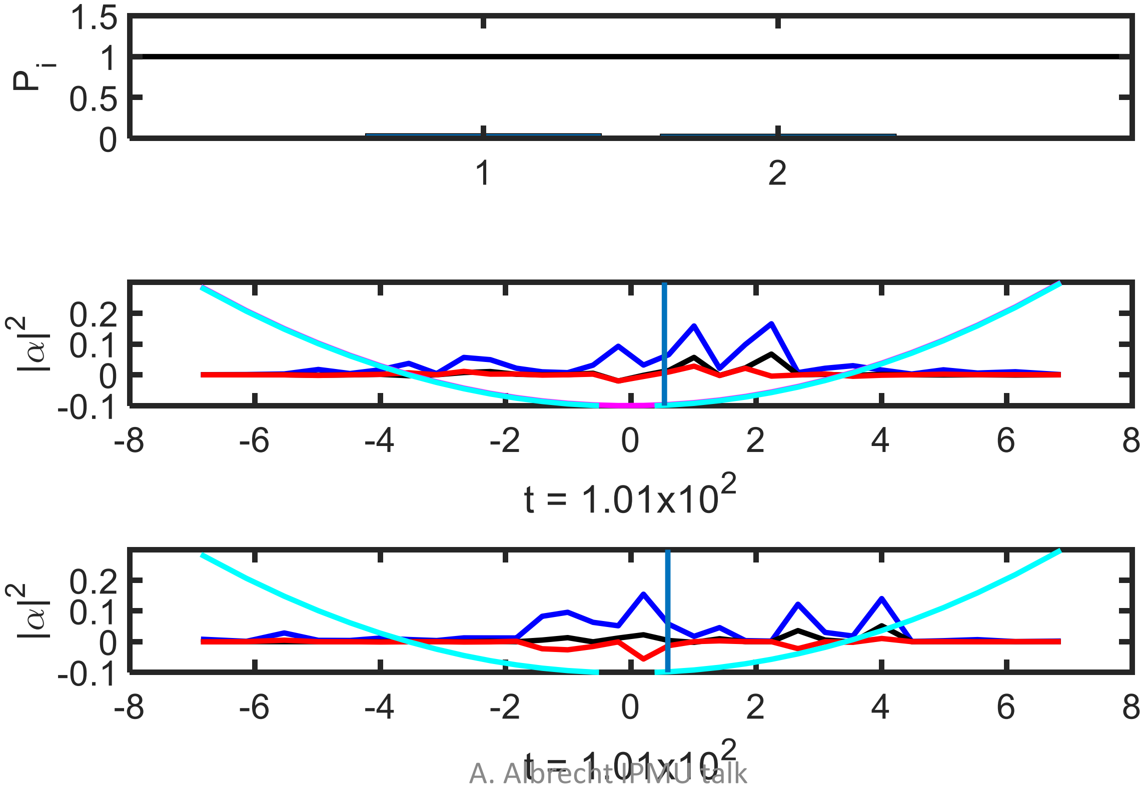

SHO density matrix in eqm

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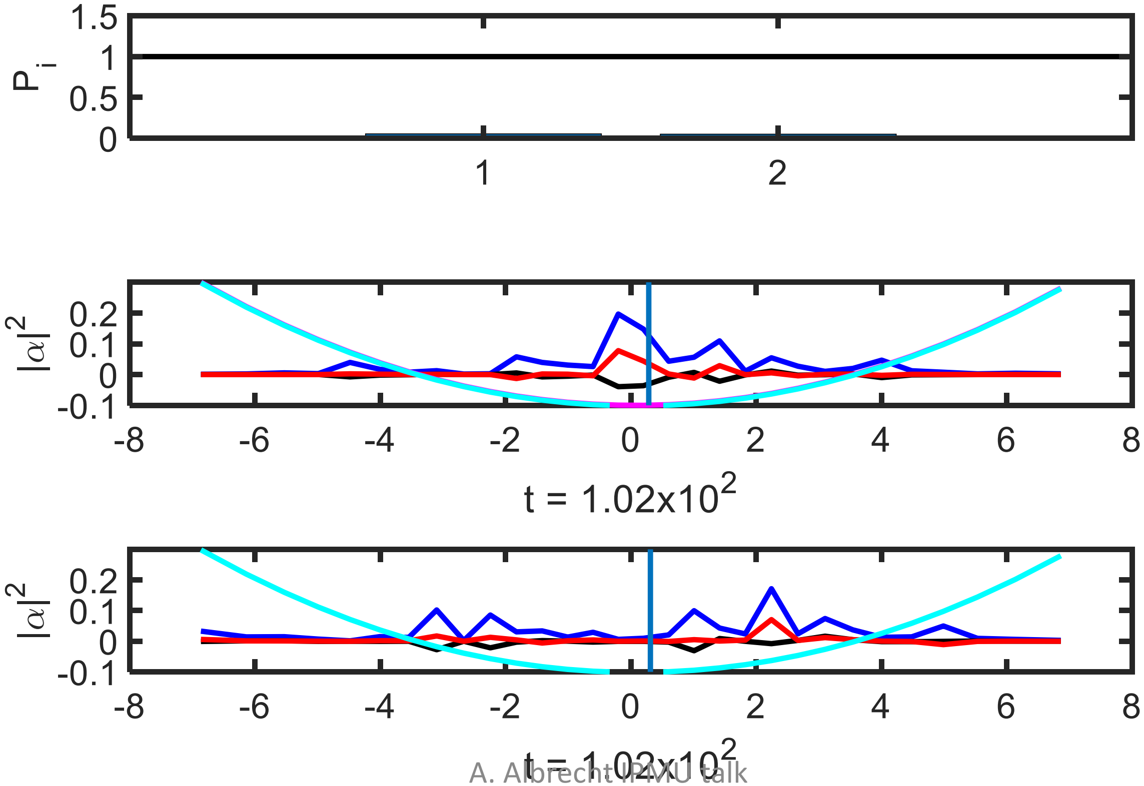

SHO density matrix in eqm

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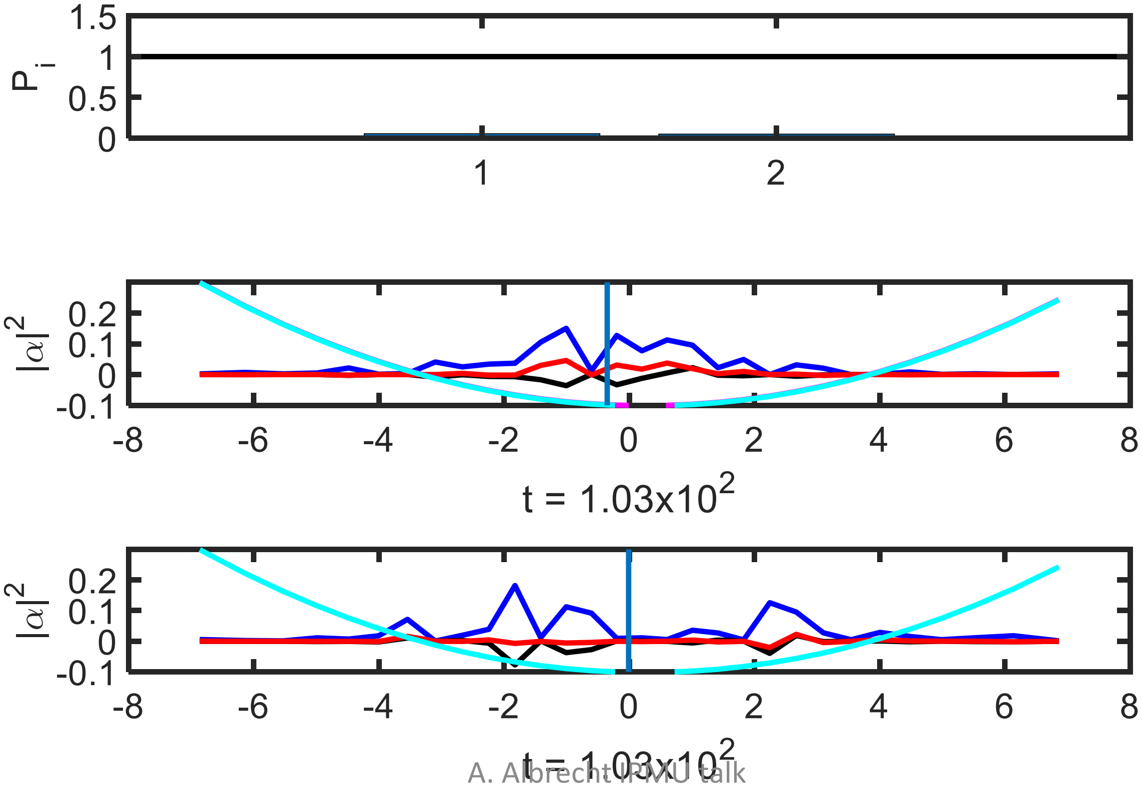

SHO density matrix in eqm

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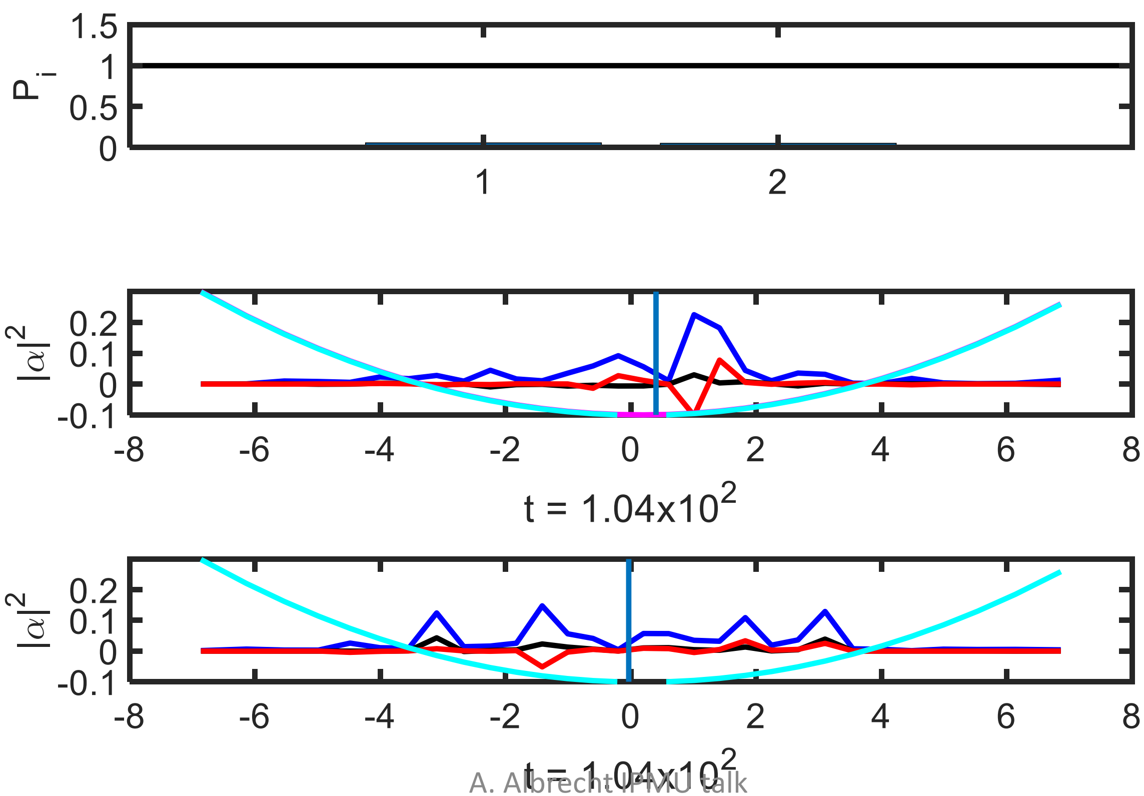

SHO density matrix in eqm

Eigenvalues

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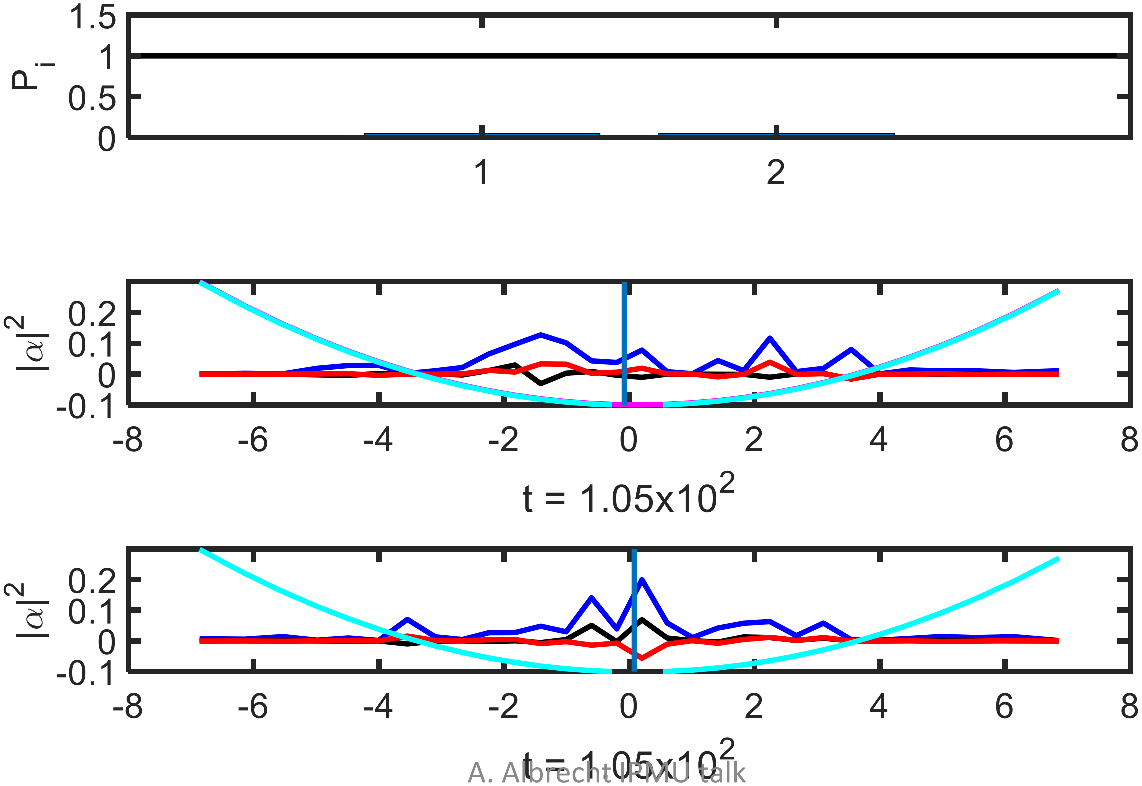
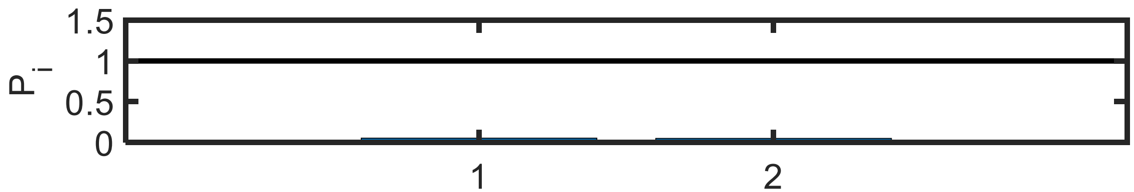


SHO density matrix in eqm

Eigenvalues



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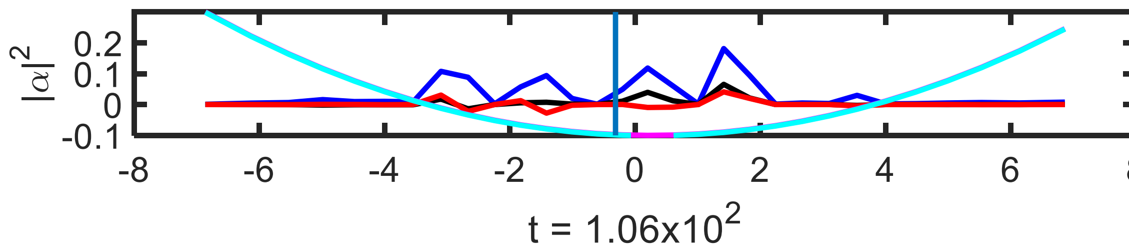
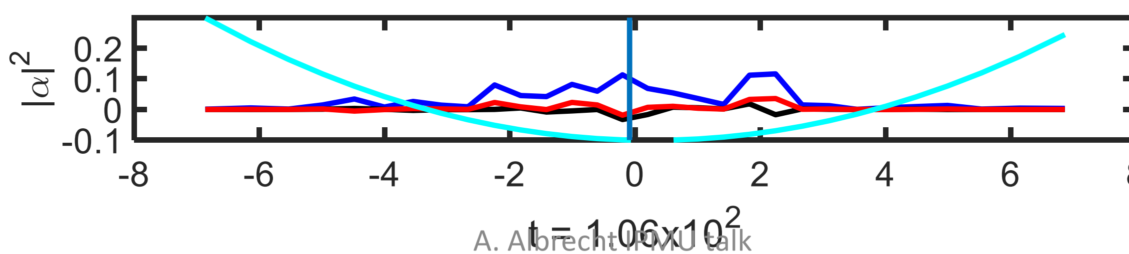


Eigenstates



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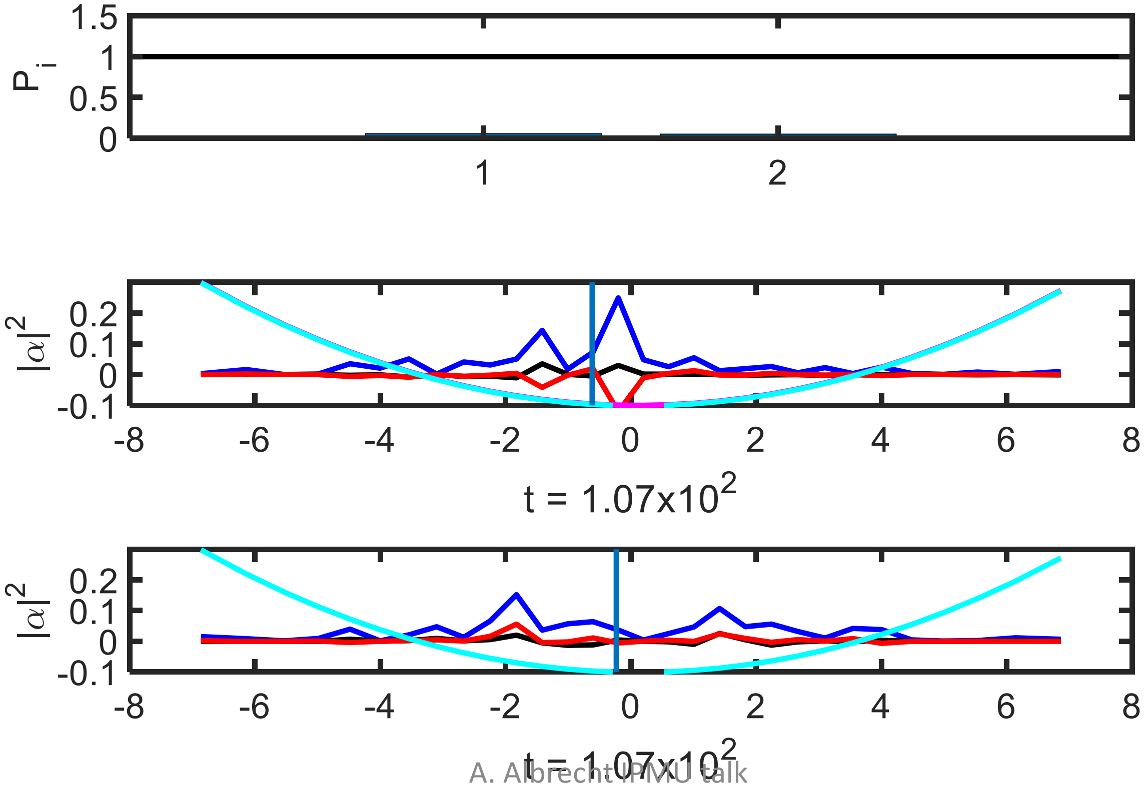

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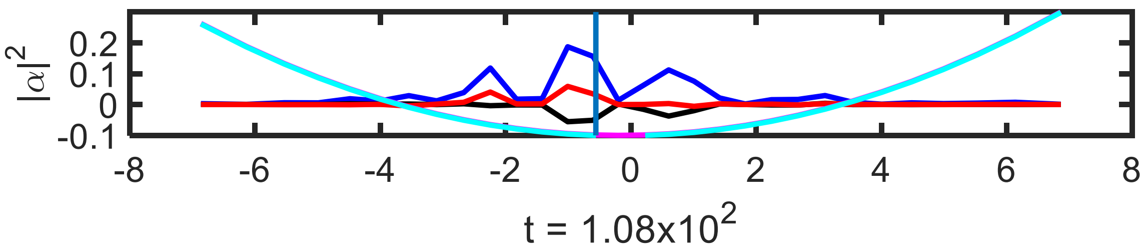

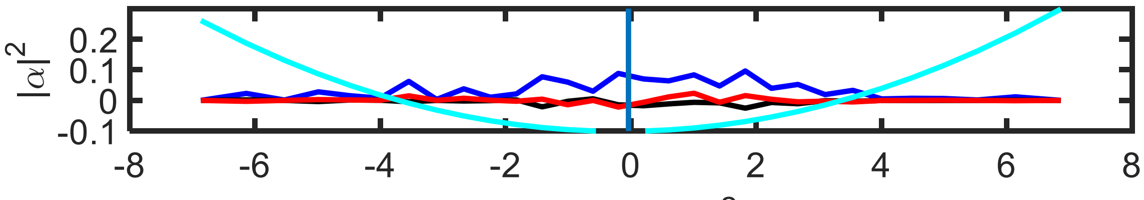

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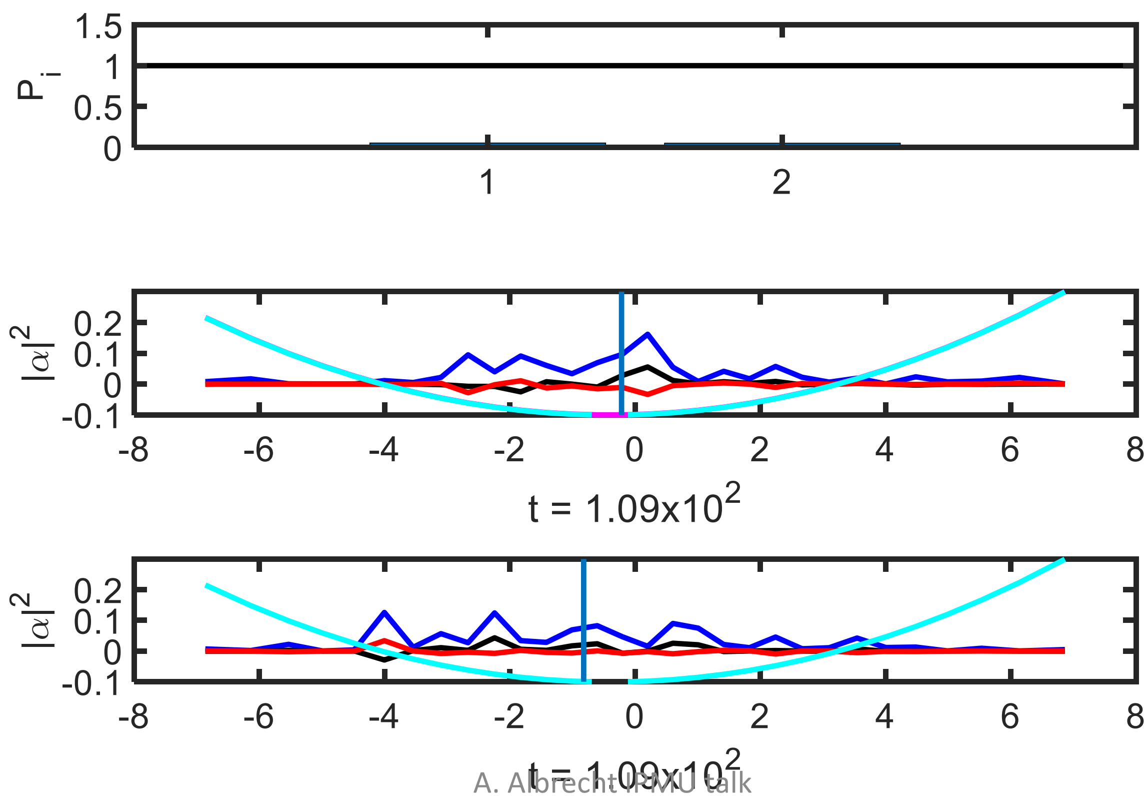

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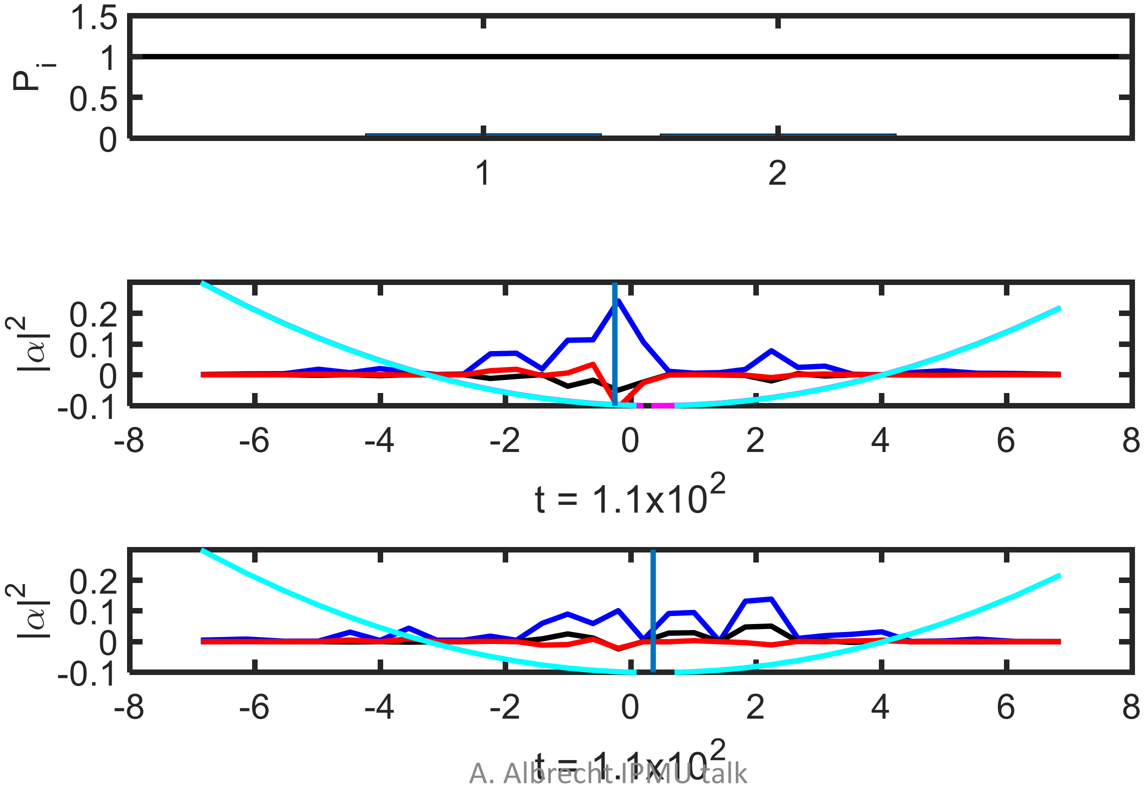

SHO density matrix in eqm

Eigenvalues

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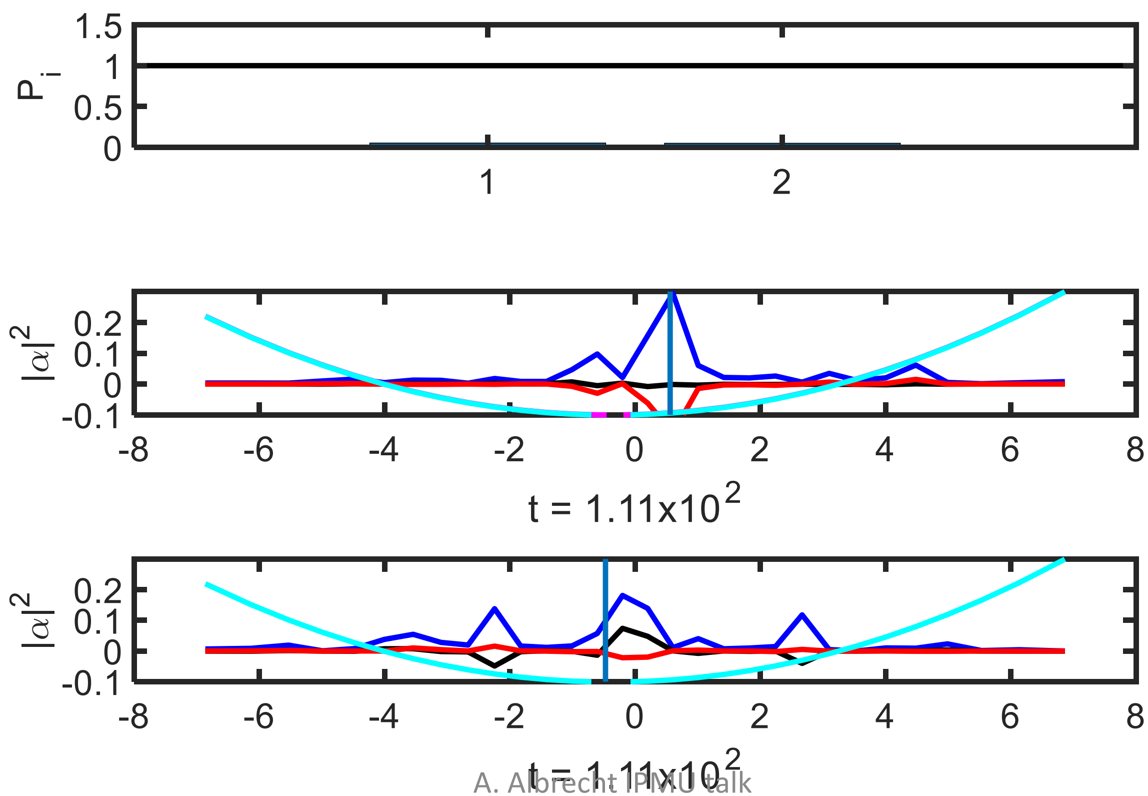

SHO density matrix in eqm

Eigenvalues

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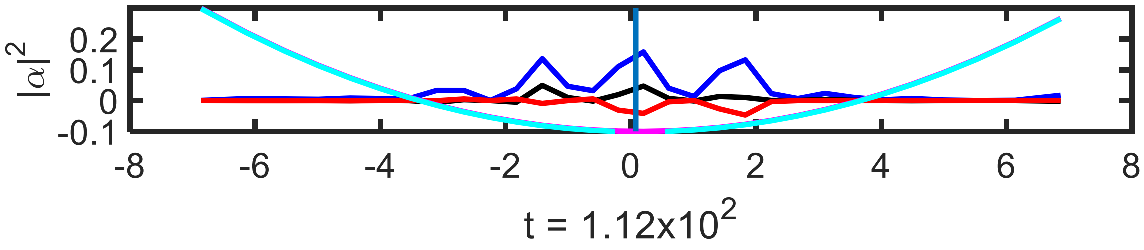
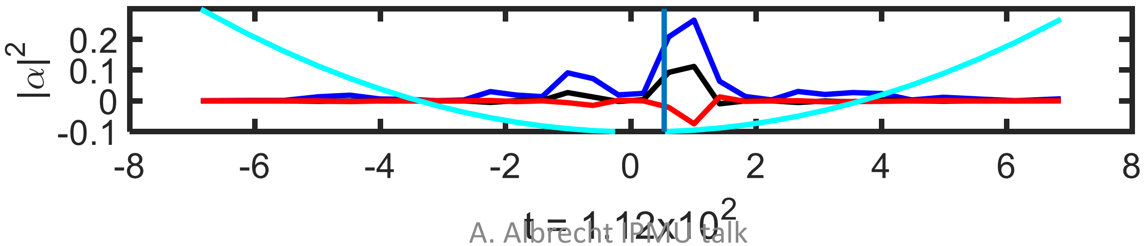


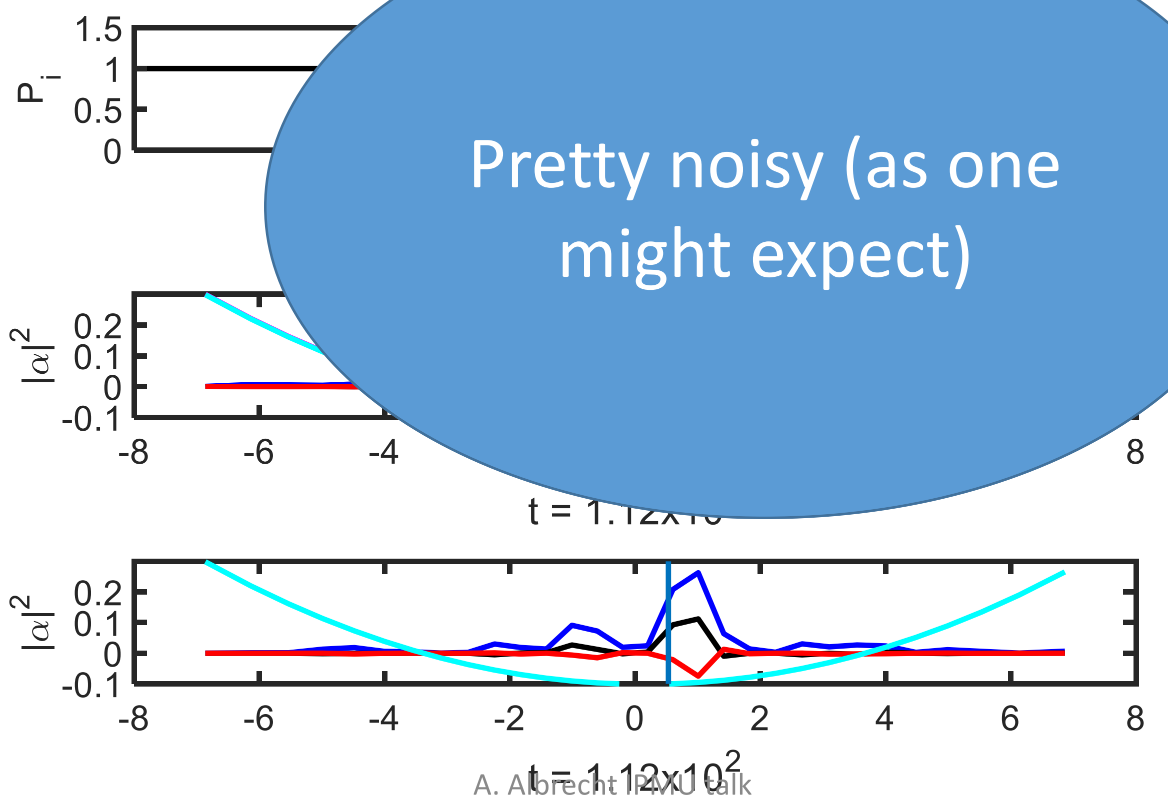


SHO density matrix in eqm

Eigenvalues

First 2

Eigenstates



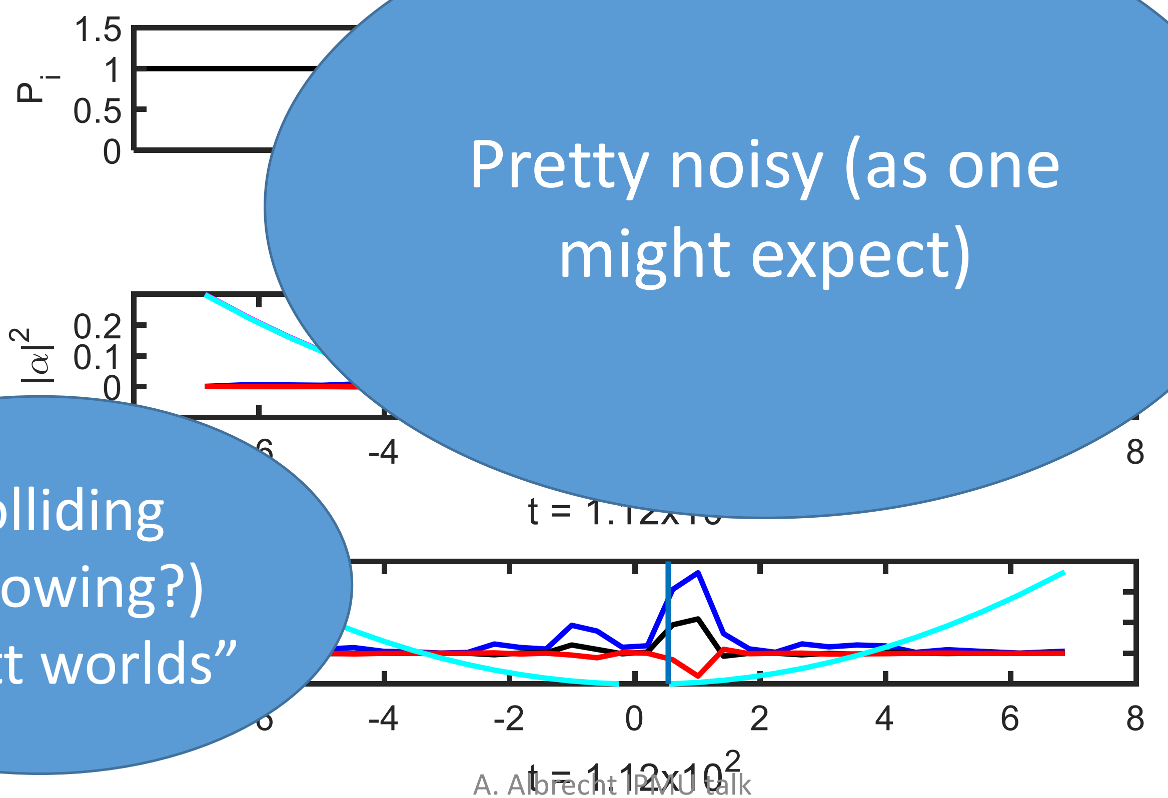
Pretty noisy (as one might expect)

SHO density matrix in eqm

Eigenvalues

First 2

Eige



Pretty noisy (as one might expect)

“Colliding (wallowing?) Everett worlds”

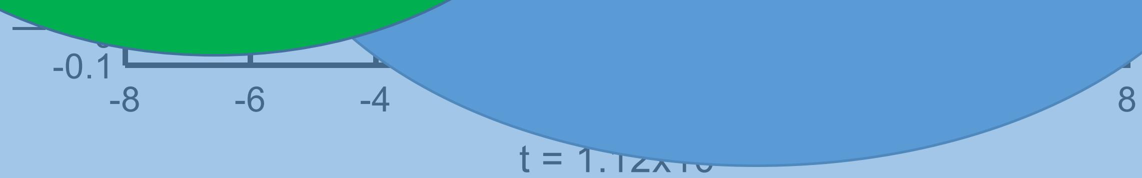
SHO density matrix in eqm

Eigen

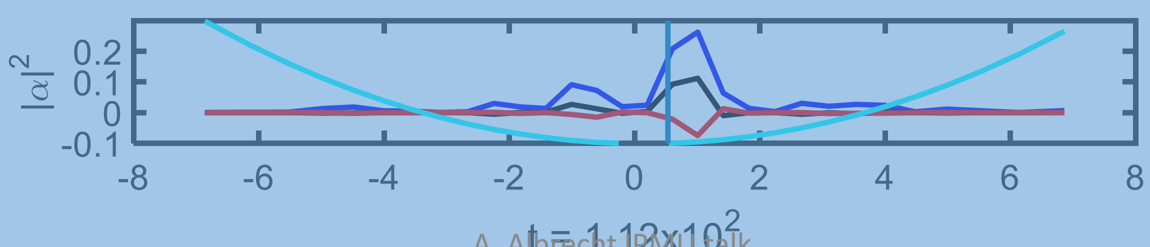
First 2

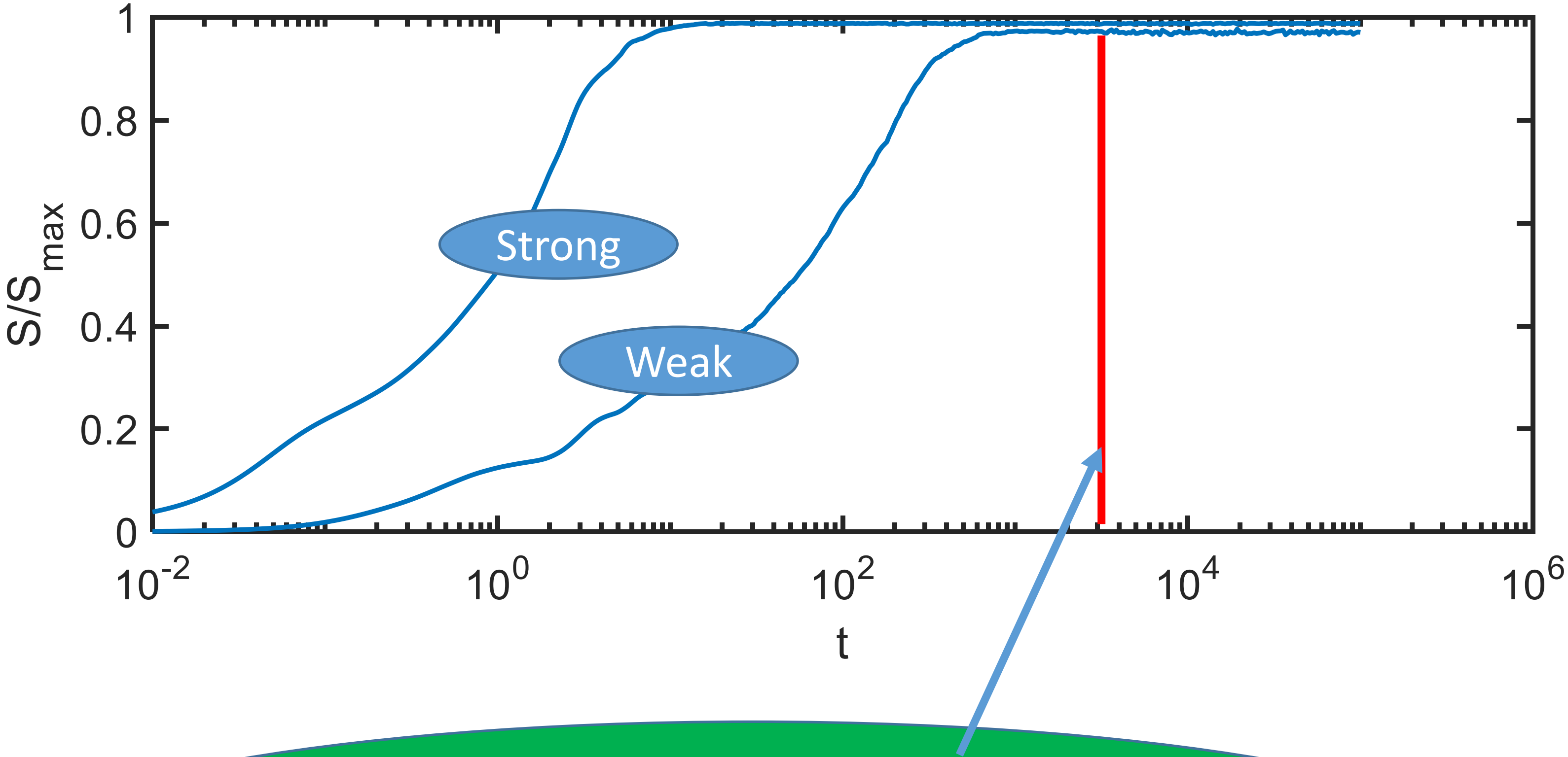
ty noisy (as one might expect)

However, when the coupling strength is reduced, things get more interesting



Eigenstates





Next movie shows weak coupling case, starting here

Show Movie E

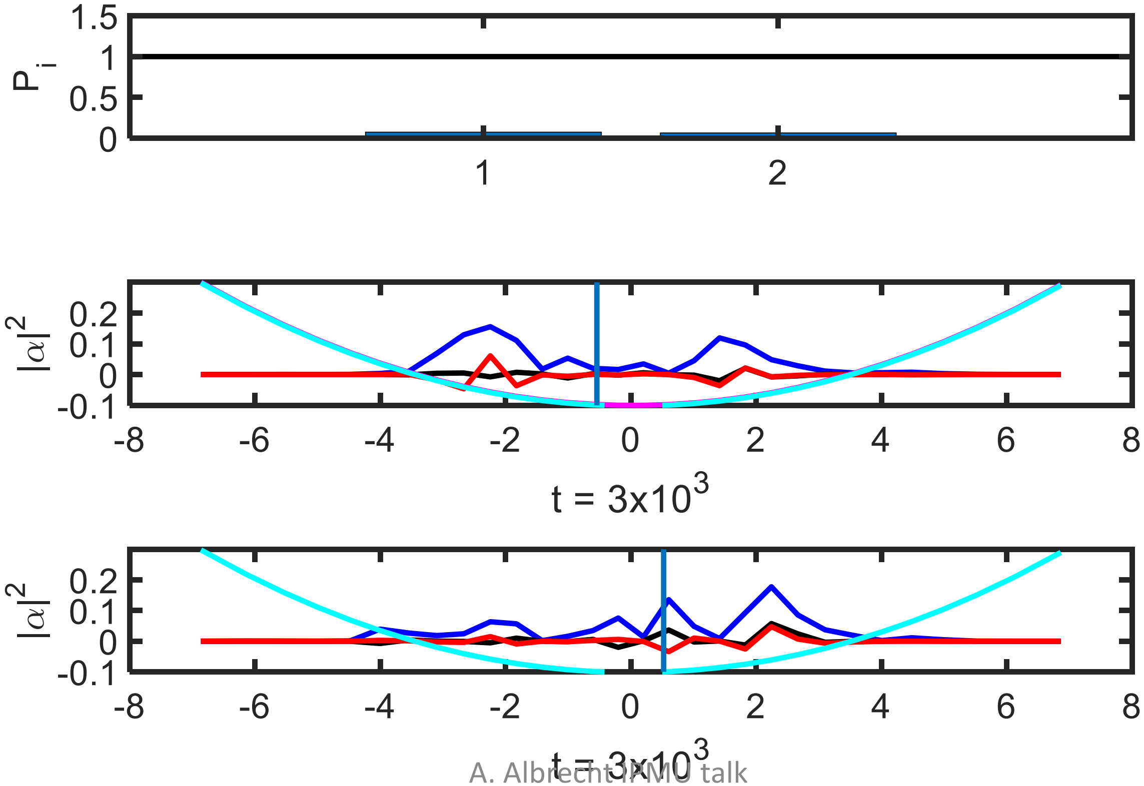
SHO density matrix in eqm

Weakly coupled case

Eigenvalues

First 2

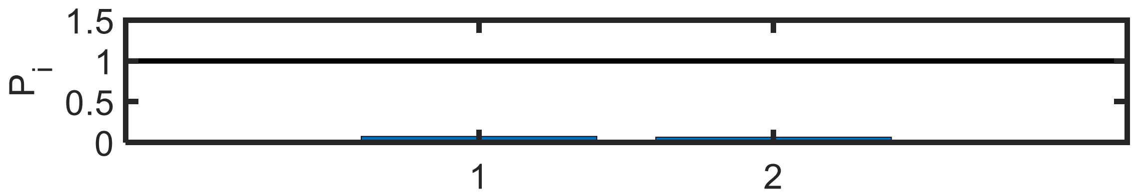
Eigenstates



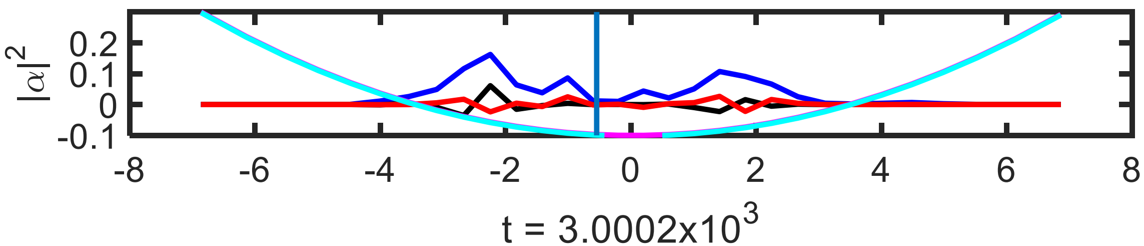
SHO density matrix in eqm

Weakly coupled case

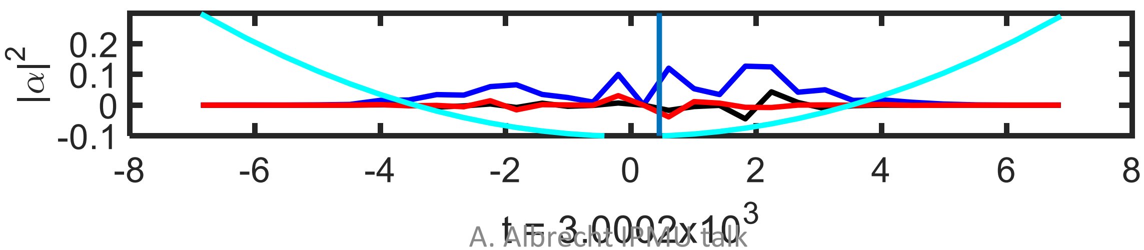
Eigenvalues



First 2



Eigenstates



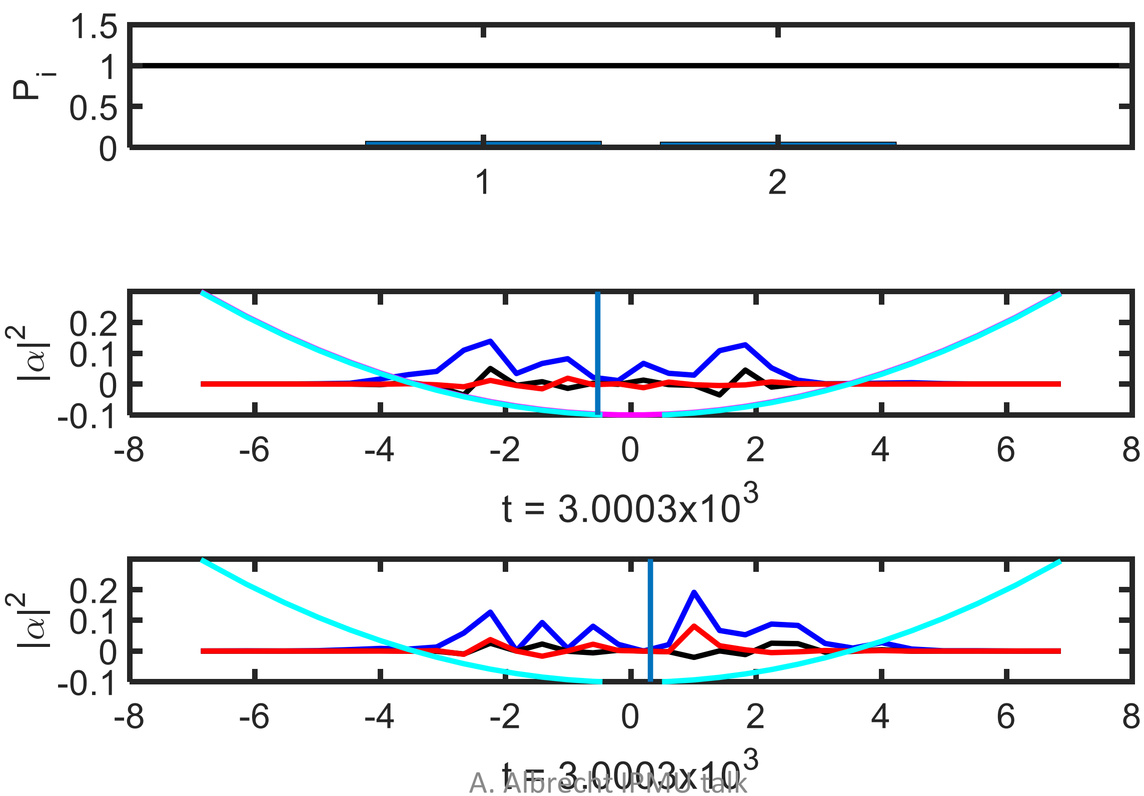
SHO density matrix in eqm

Weakly coupled case

Eigenvalues

First 2

Eigenstates



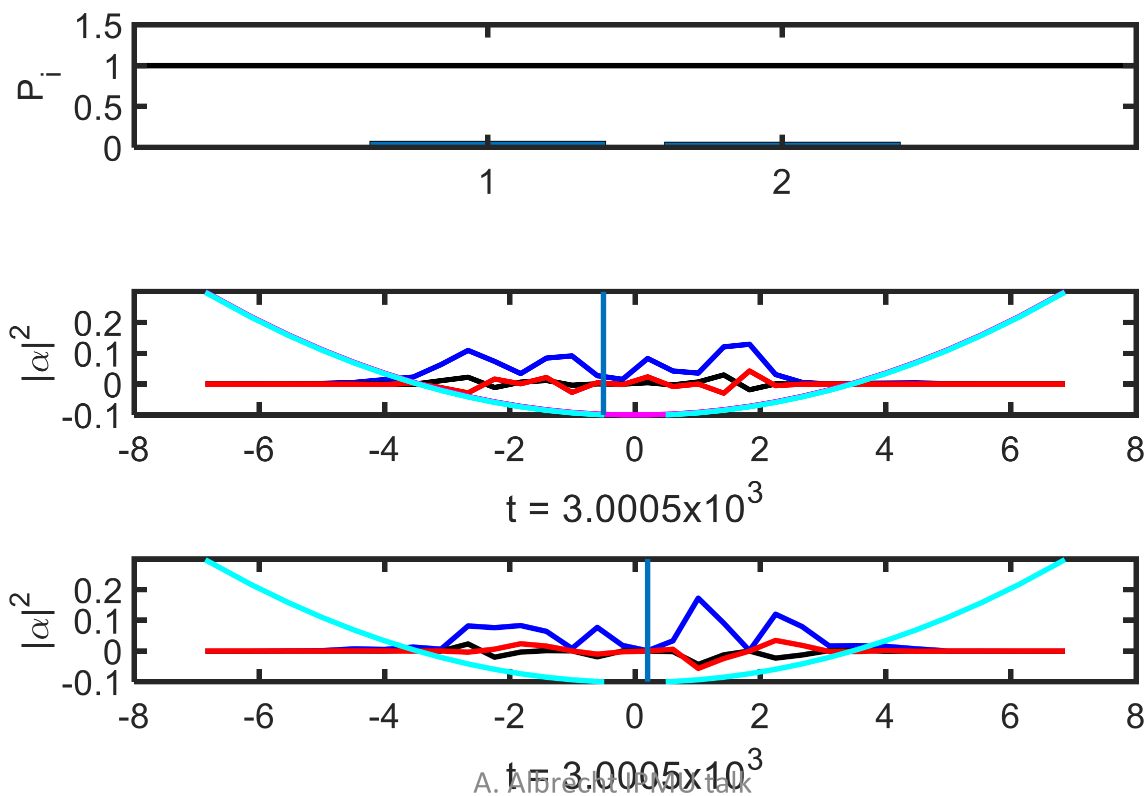
SHO density matrix in eqm

Weakly coupled case

Eigenvalues

First 2

Eigenstates



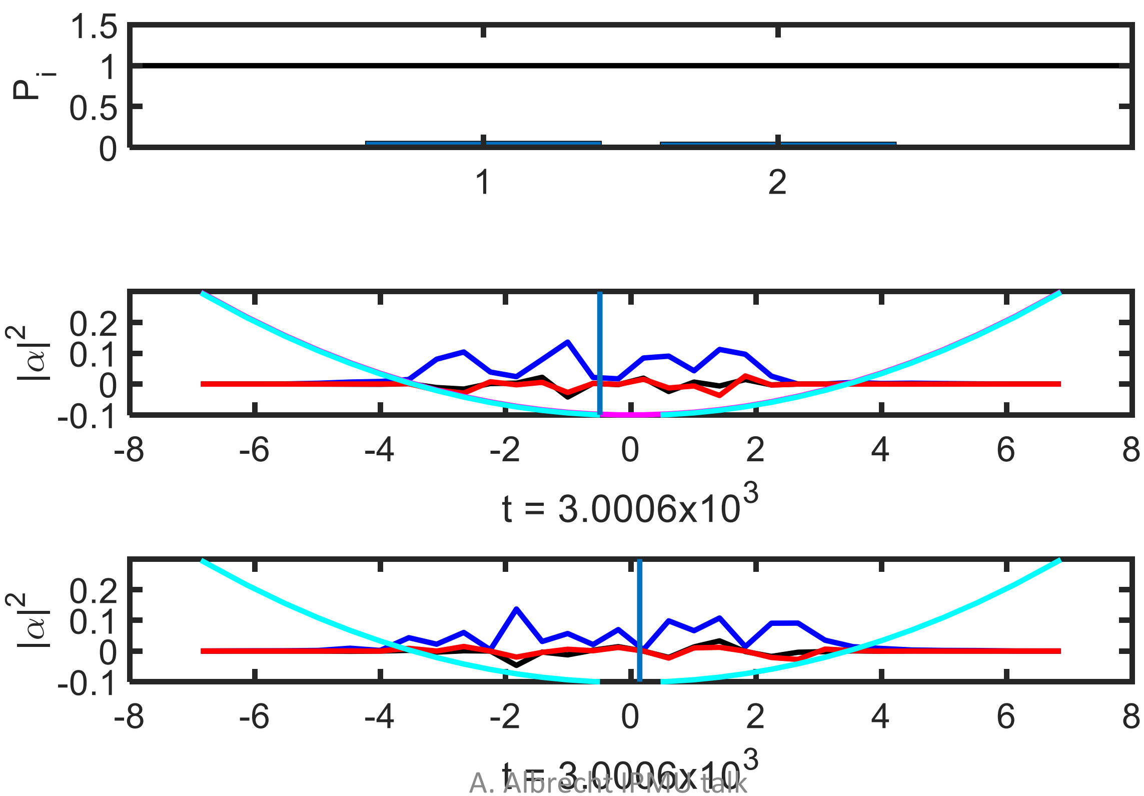
SHO density matrix in eqm

Weakly coupled case

Eigenvalues

First 2

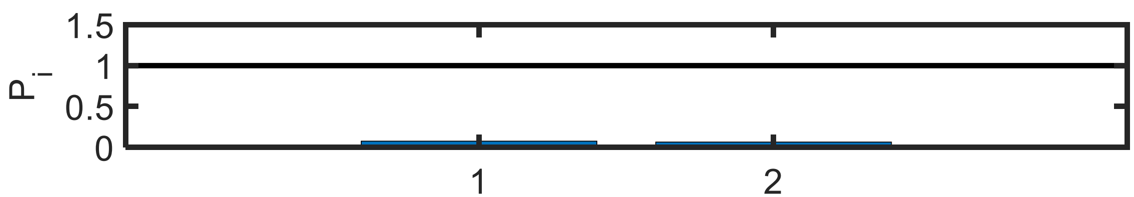
Eigenstates



SHO density matrix in eqm

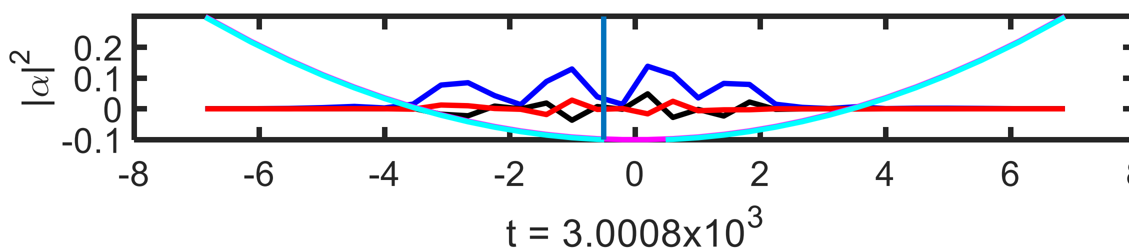
Weakly coupled case

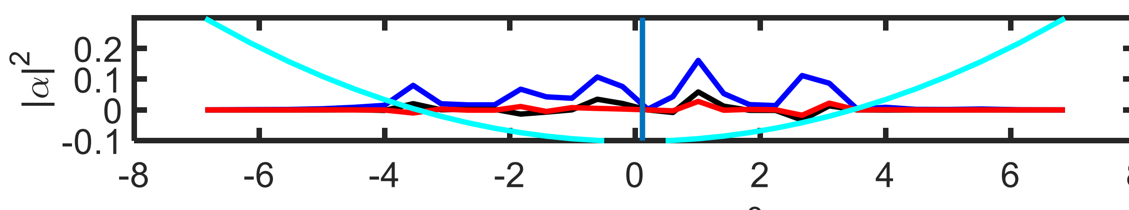
Eigenvalues



First 2

Eigenstates





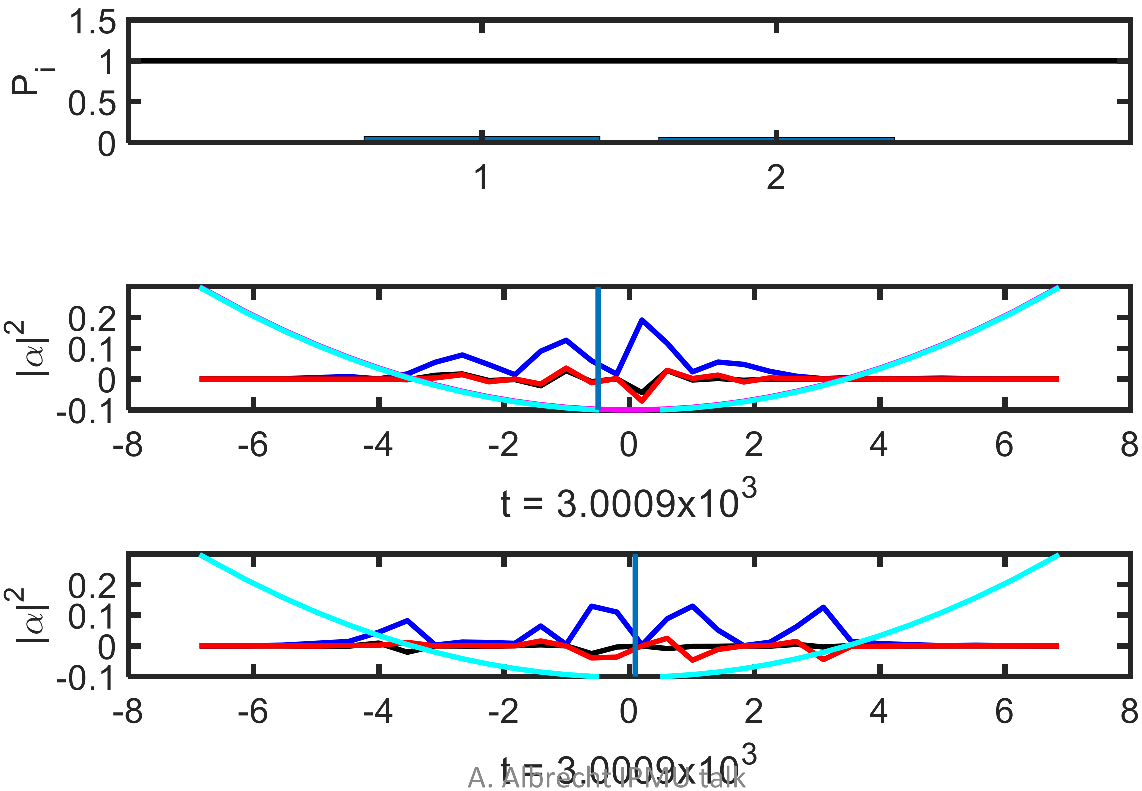
SHO density matrix in eqm

Weakly coupled case

Eigenvalues

First 2

Eigenstates



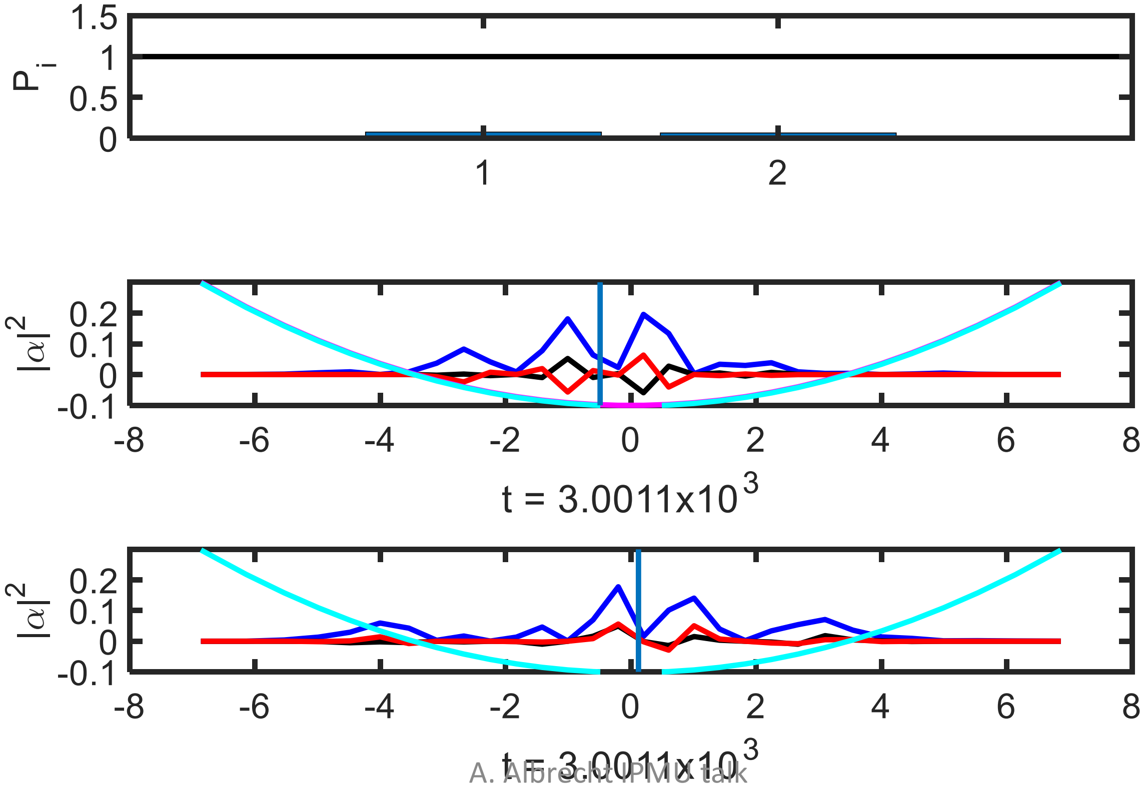
SHO density matrix in eqm

Weakly coupled case

Eigenvalues

First 2

Eigenstates



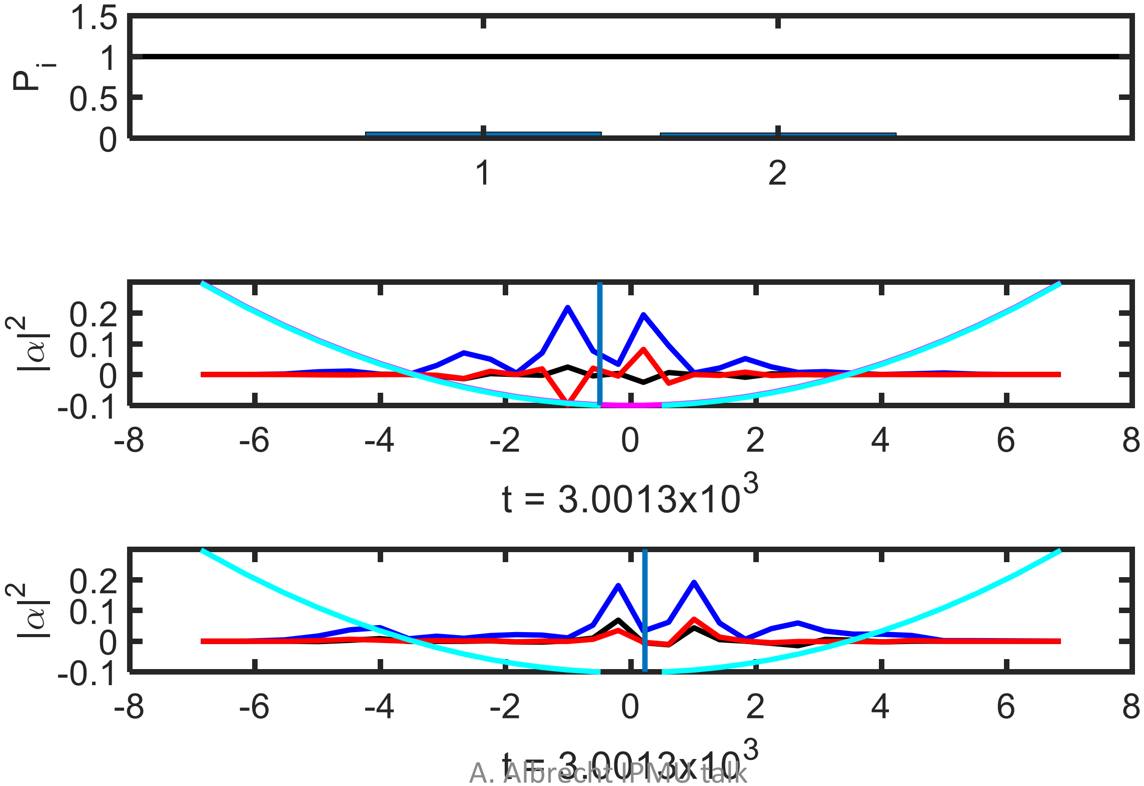
SHO density matrix in eqm

Weakly coupled case

Eigenvalues

First 2

Eigenstates



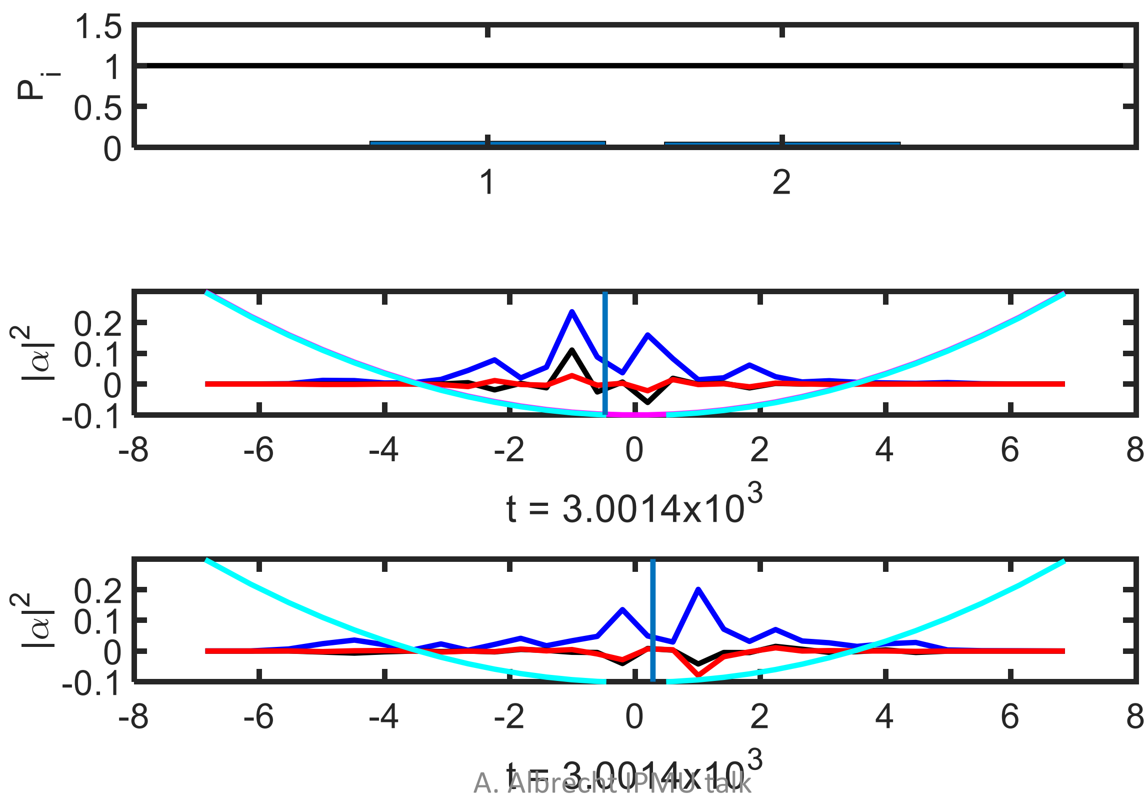
SHO density matrix in eqm

Weakly coupled case

Eigenvalues

First 2

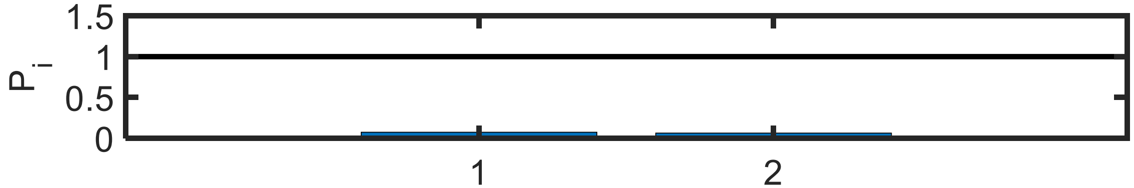
Eigenstates



SHO density matrix in eqm

Weakly coupled case

Eigenvalues



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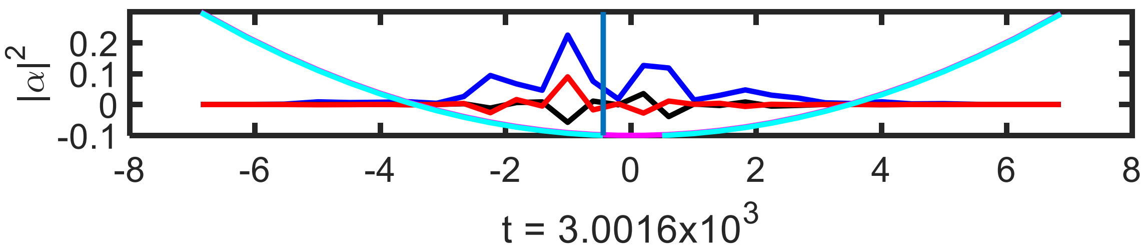

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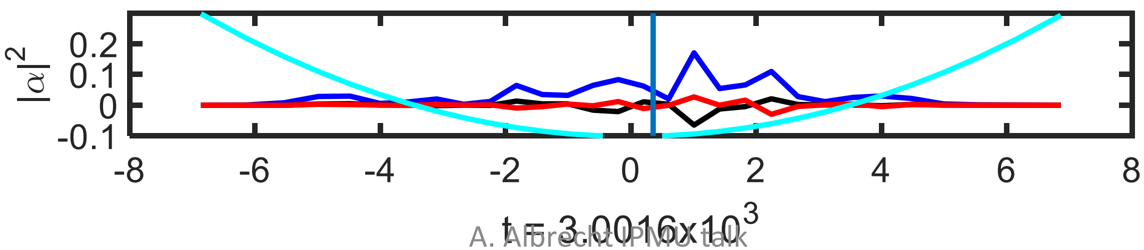


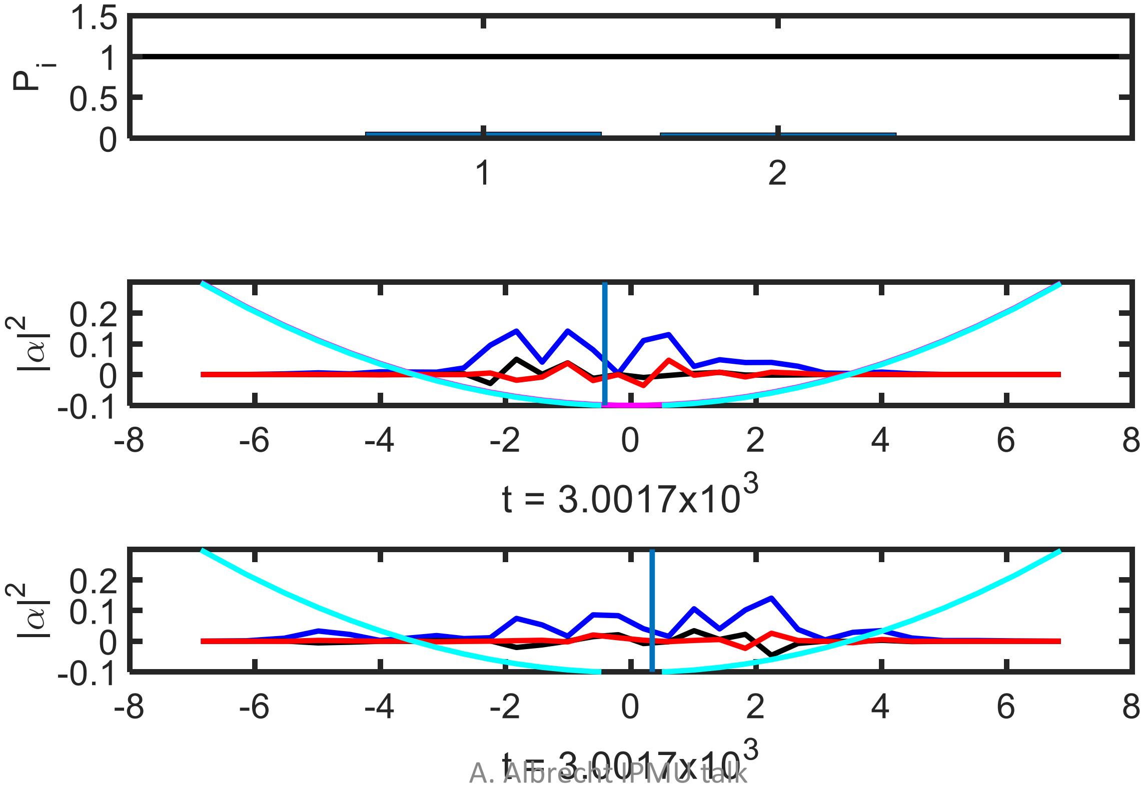
SHO density matrix in eqm

Weakly coupled case

Eigenvalues

First 2

Eigenstates



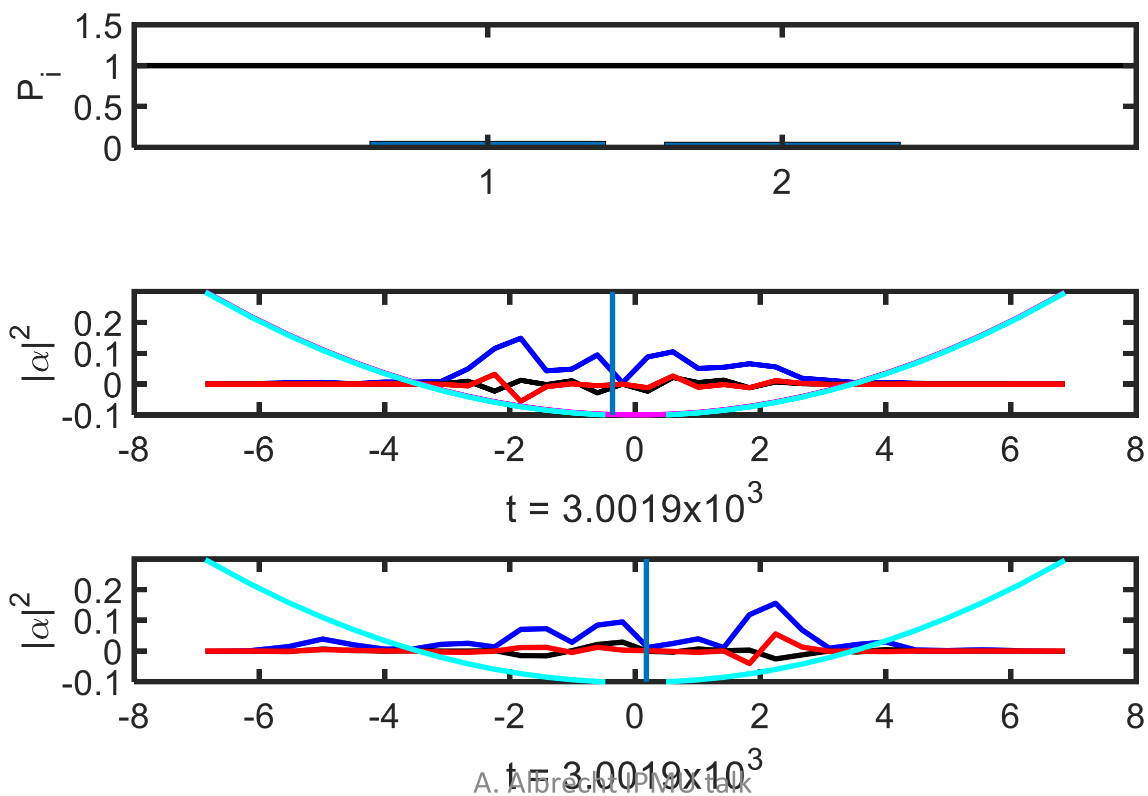
SHO density matrix in eqm

Weakly coupled case

Eigenvalues

First 2

Eigenstates



SHO density matrix in eqm

Weakly coupled case

Eigenvalues

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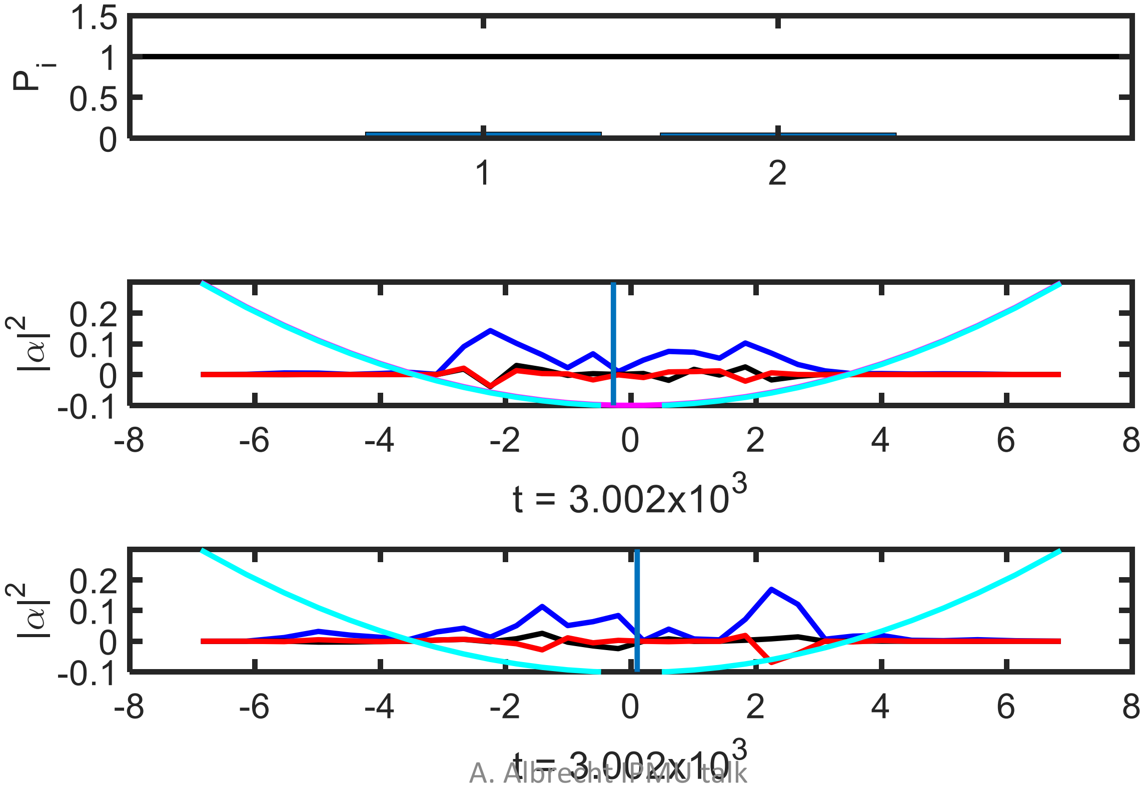
Eigenstates



SHO density matrix in eqm

Weakly coupled case

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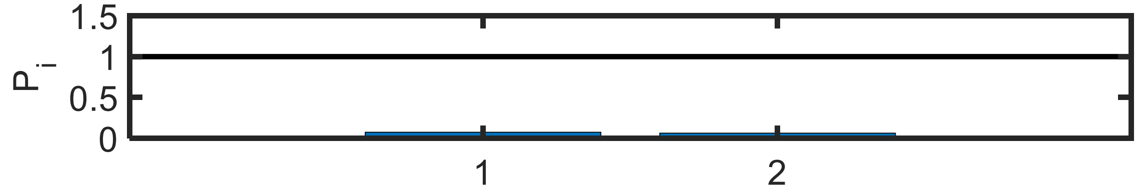
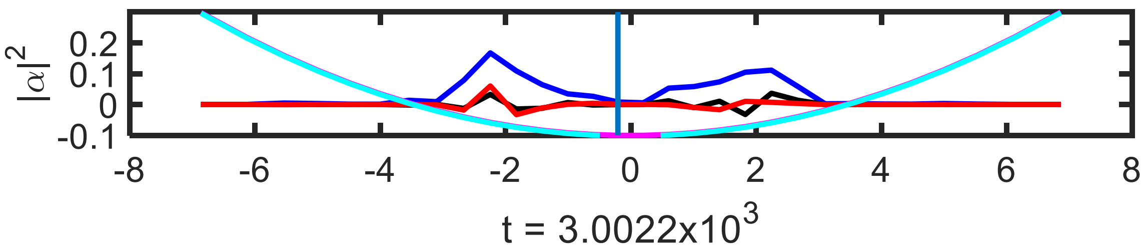
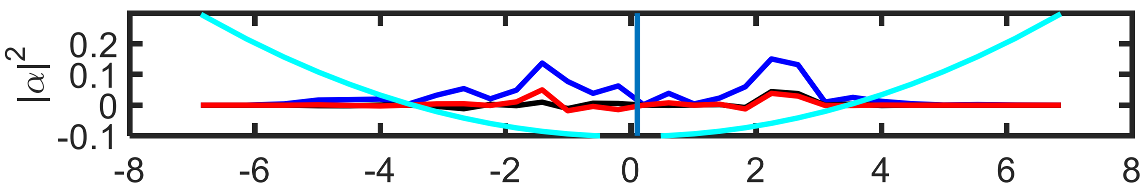


First 2

Eigenstates

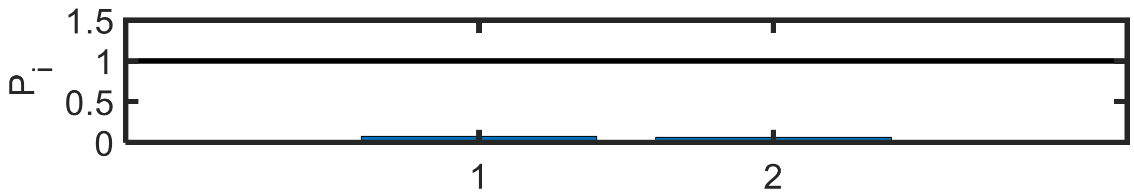




SHO density matrix in eqm

Weakly coupled case

Eigenvalues



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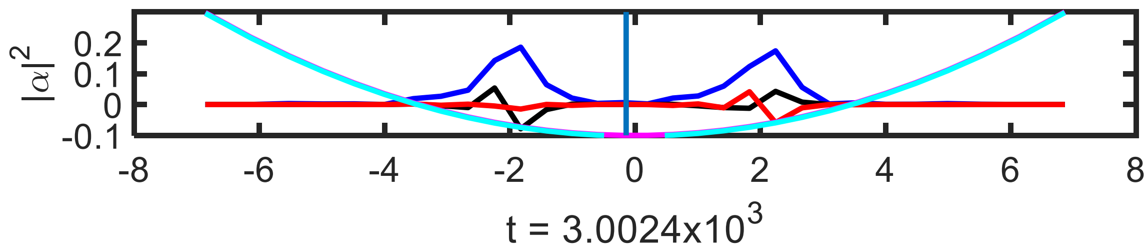
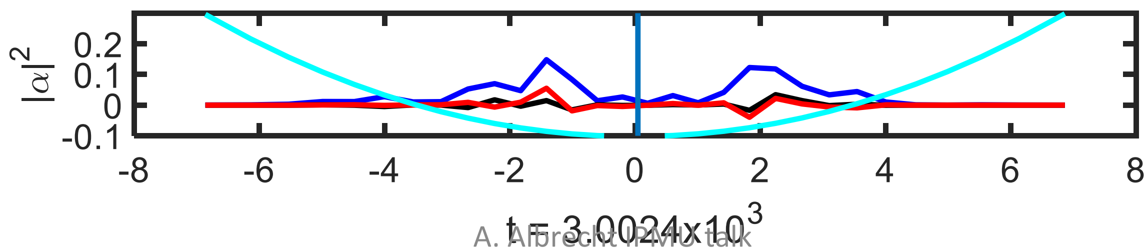


Eigenstates



SHO density matrix in eqm

Weakly coupled case

Eigenvalues

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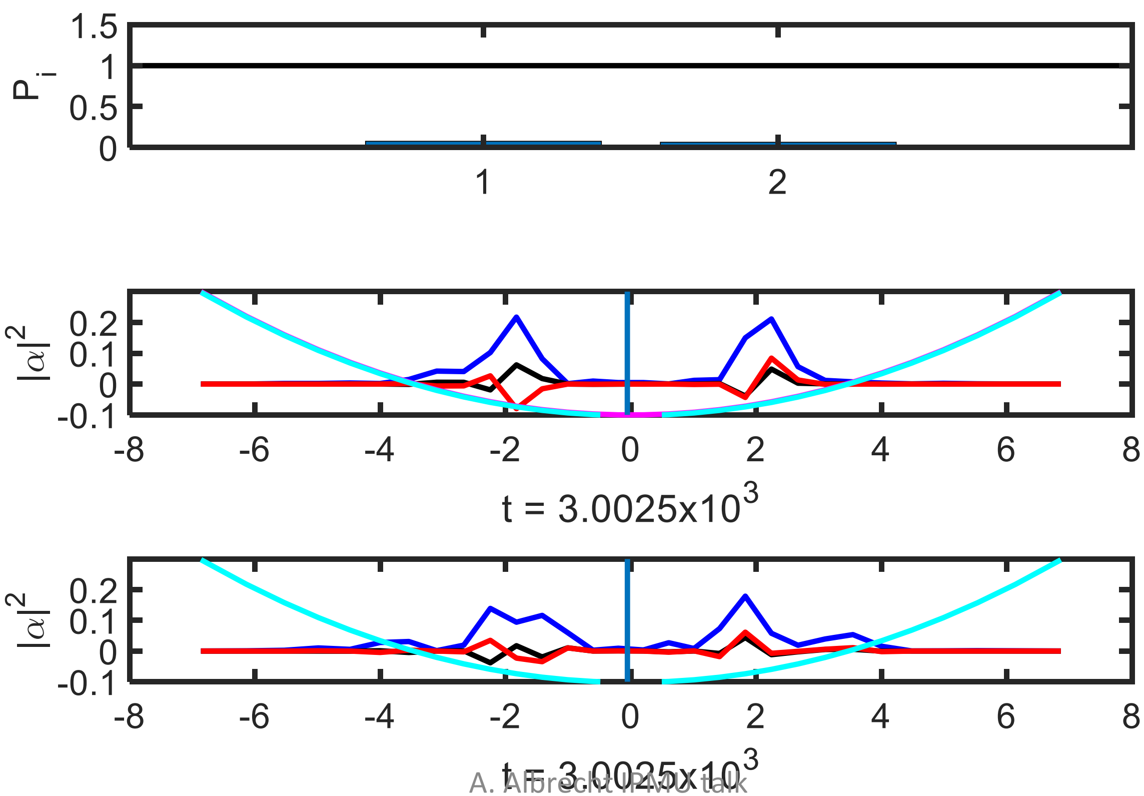

SHO density matrix in eqm

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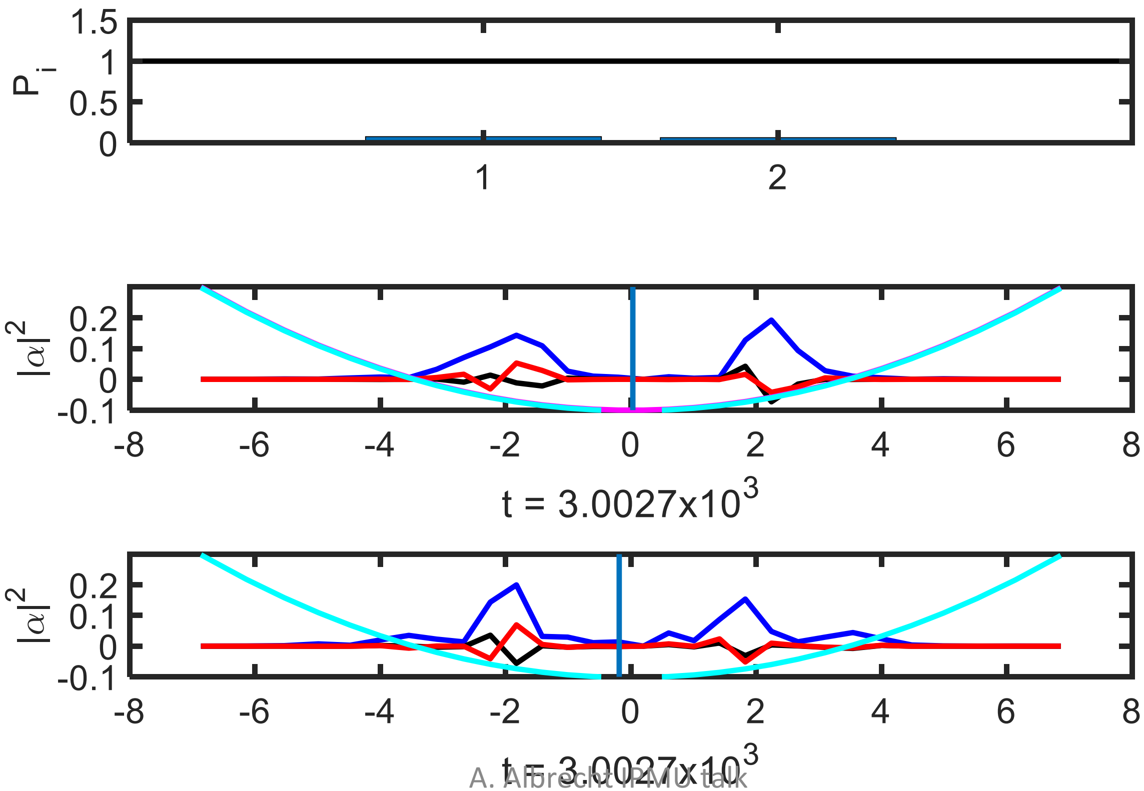

SHO density matrix in eqm

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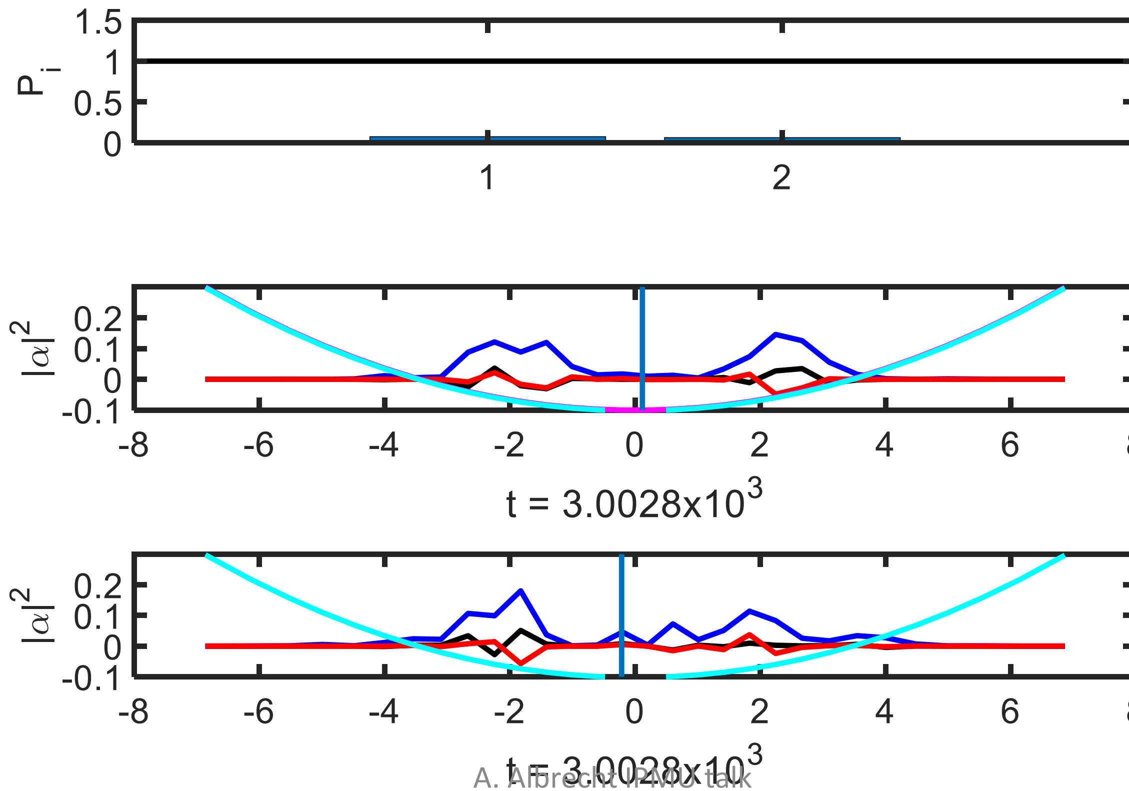

SHO density matrix in eqm

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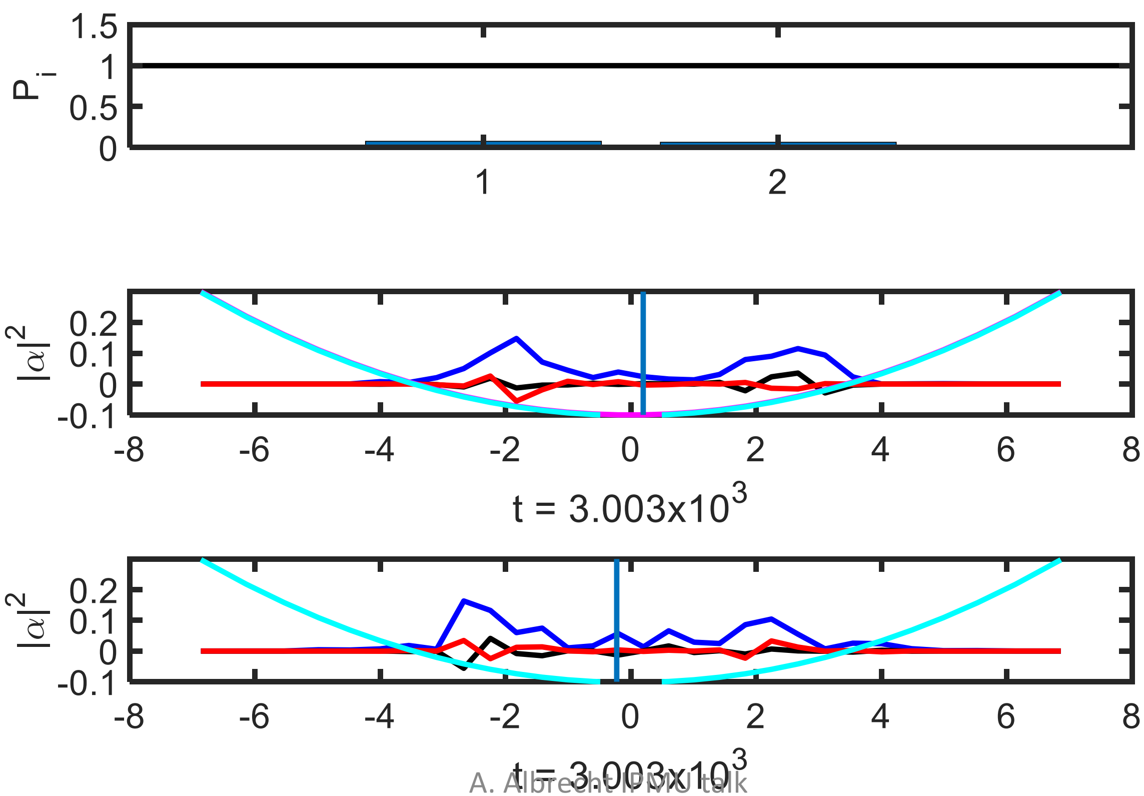
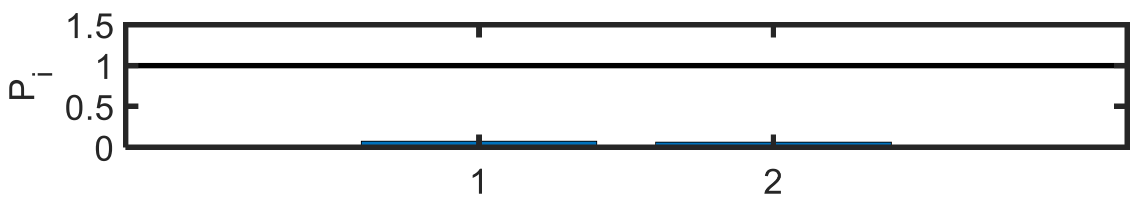


SHO density matrix in eqm

Weakly coupled case

Eigenvalues



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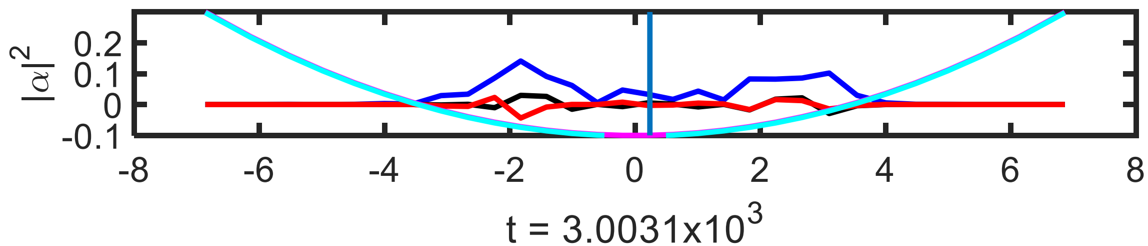

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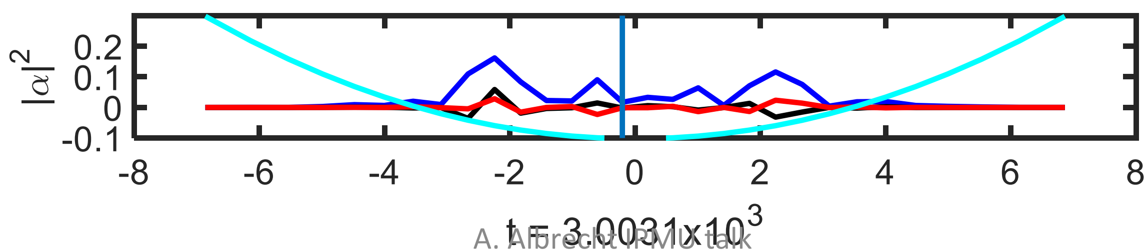

SHO density matrix in eqm

Weakly coupled case

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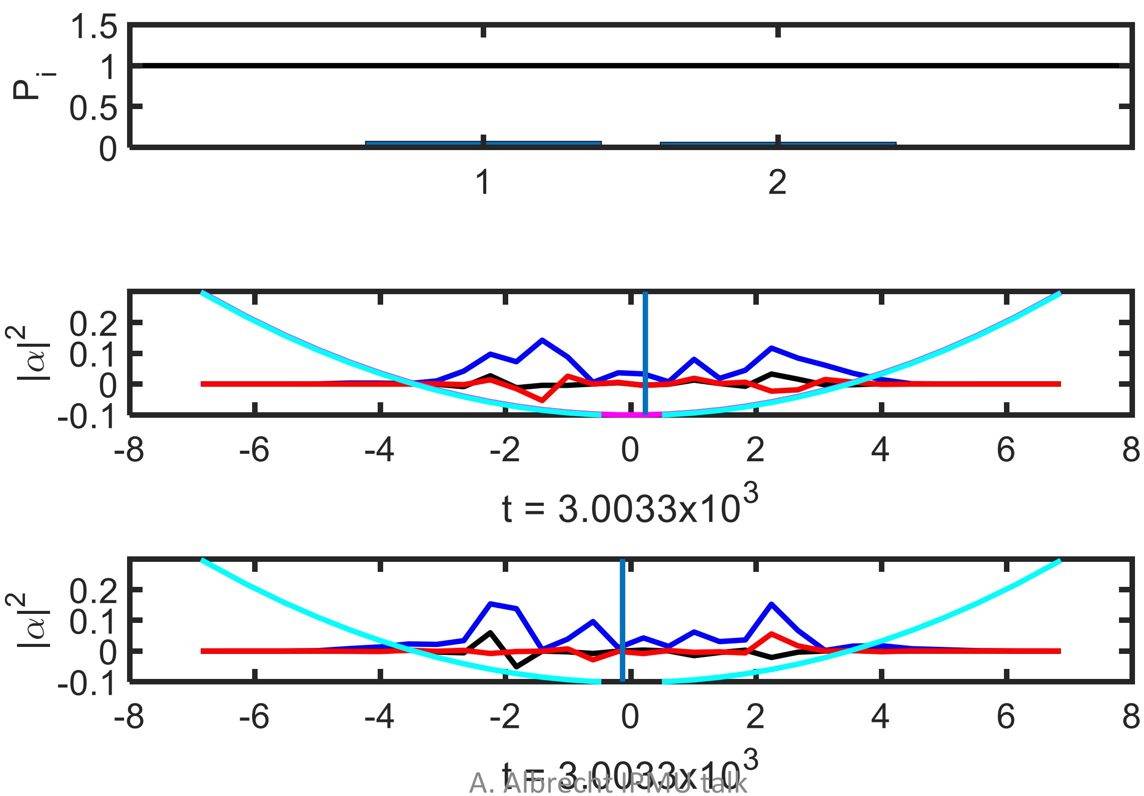

SHO density matrix in eqm

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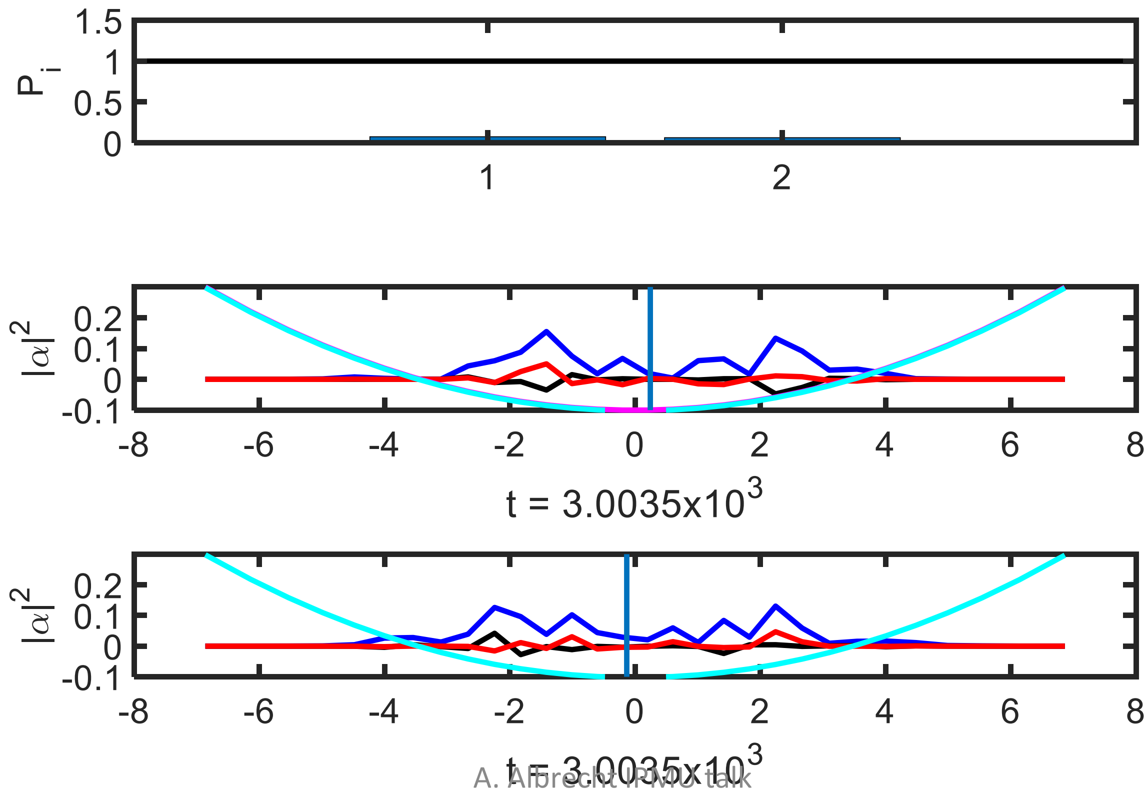

SHO density matrix in eqm

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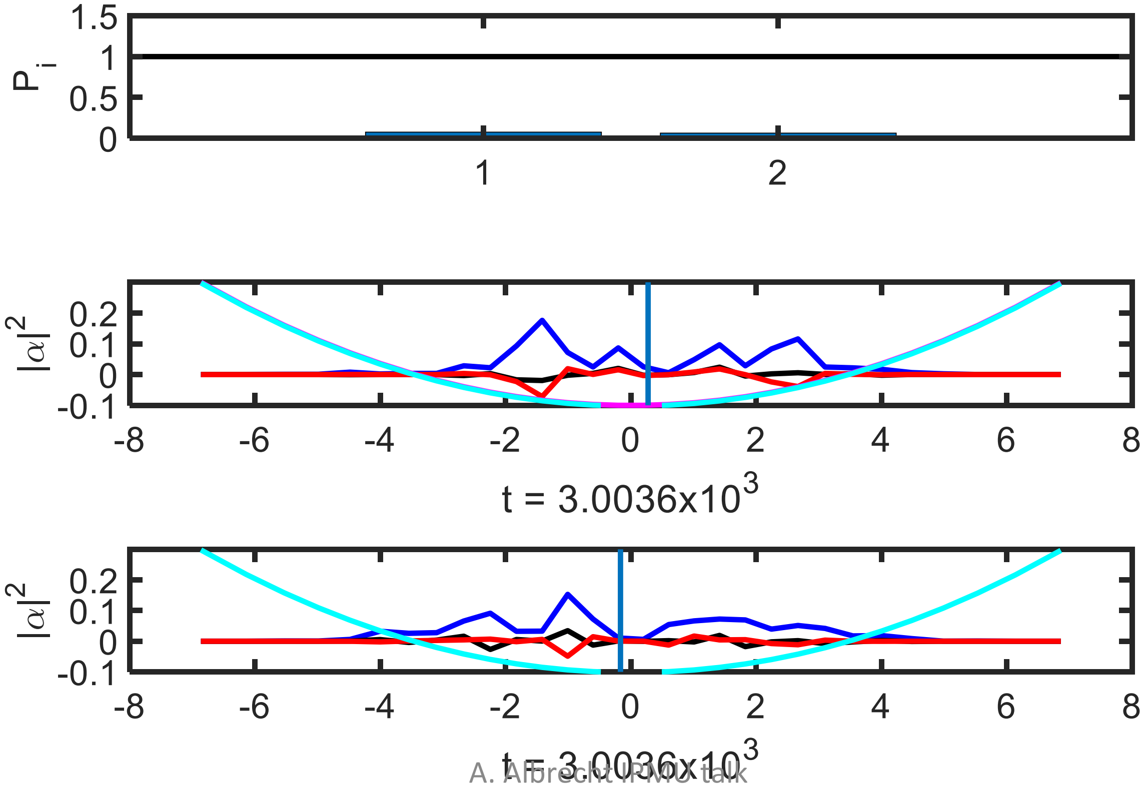

SHO density matrix in eqm

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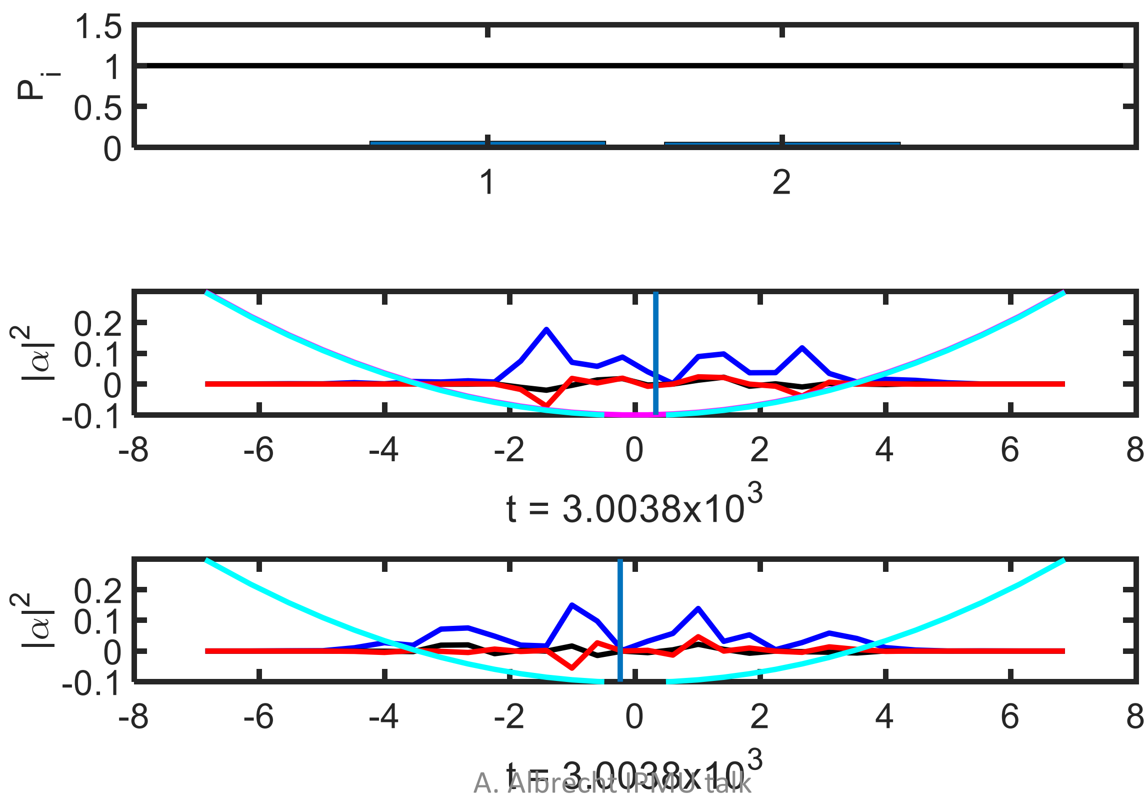

SHO density matrix in eqm

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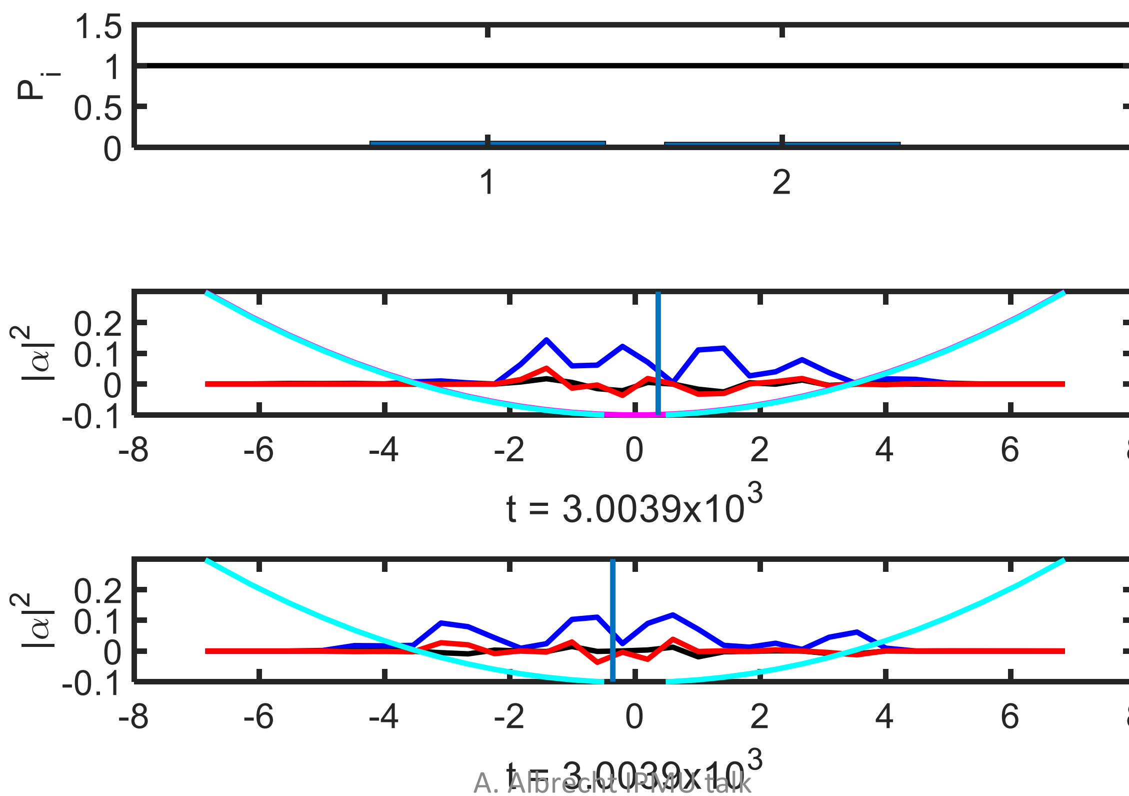

SHO density matrix in eqm

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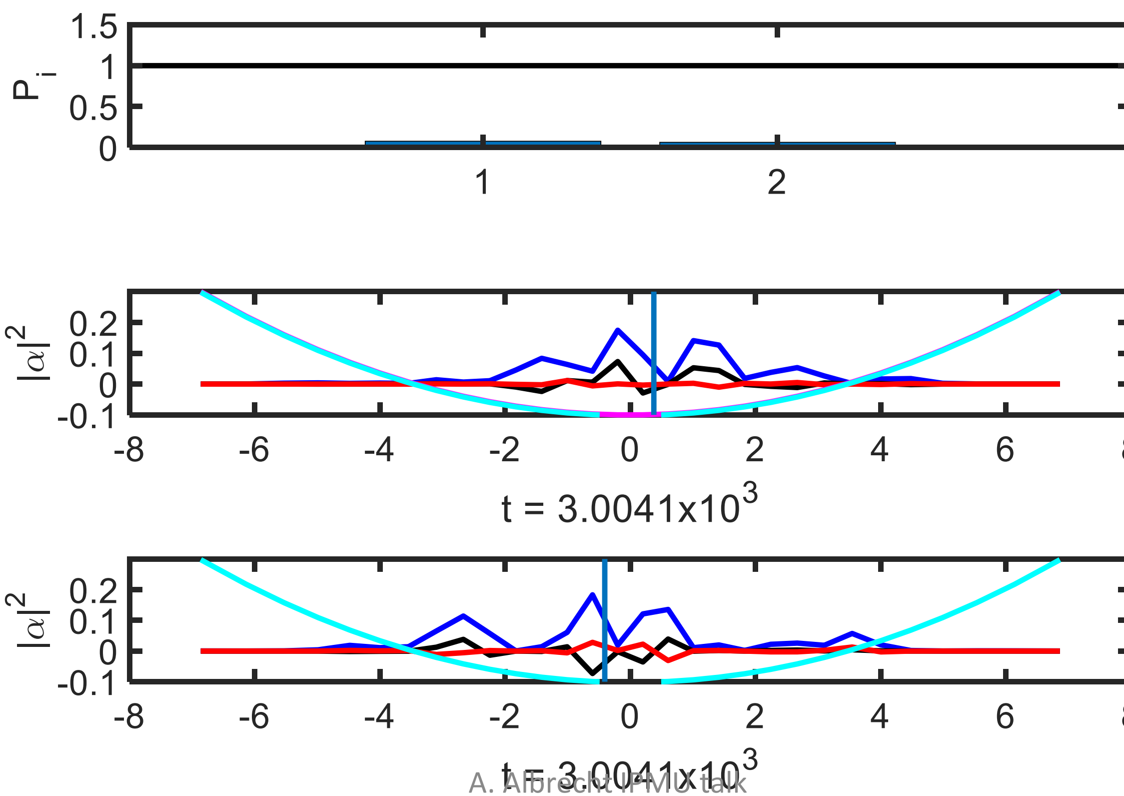

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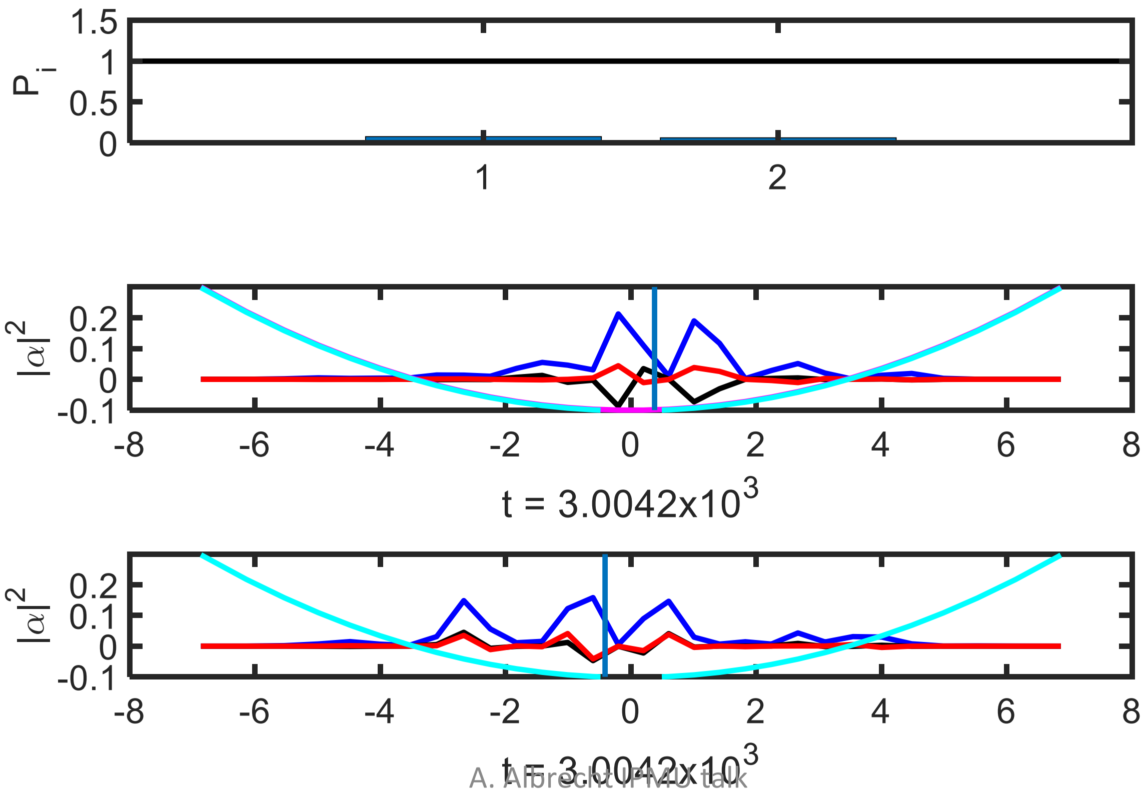

SHO density matrix in eqm

Weakly coupled case

Eigenvalues

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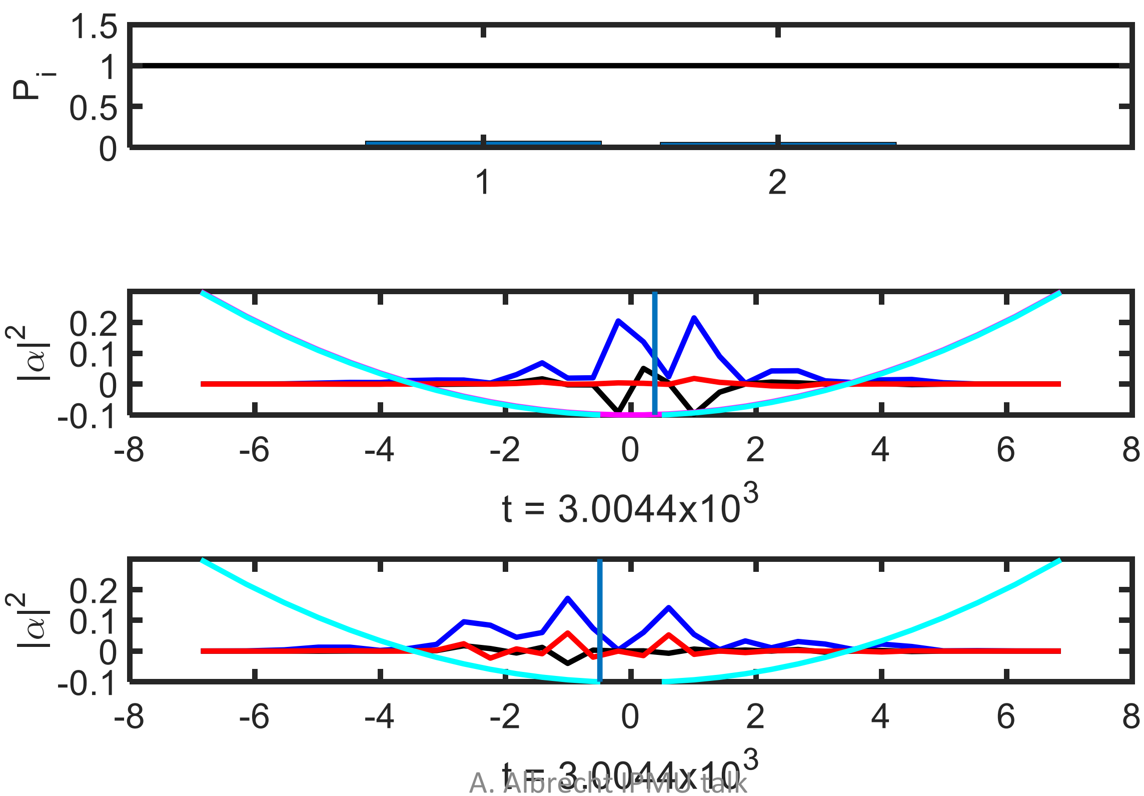


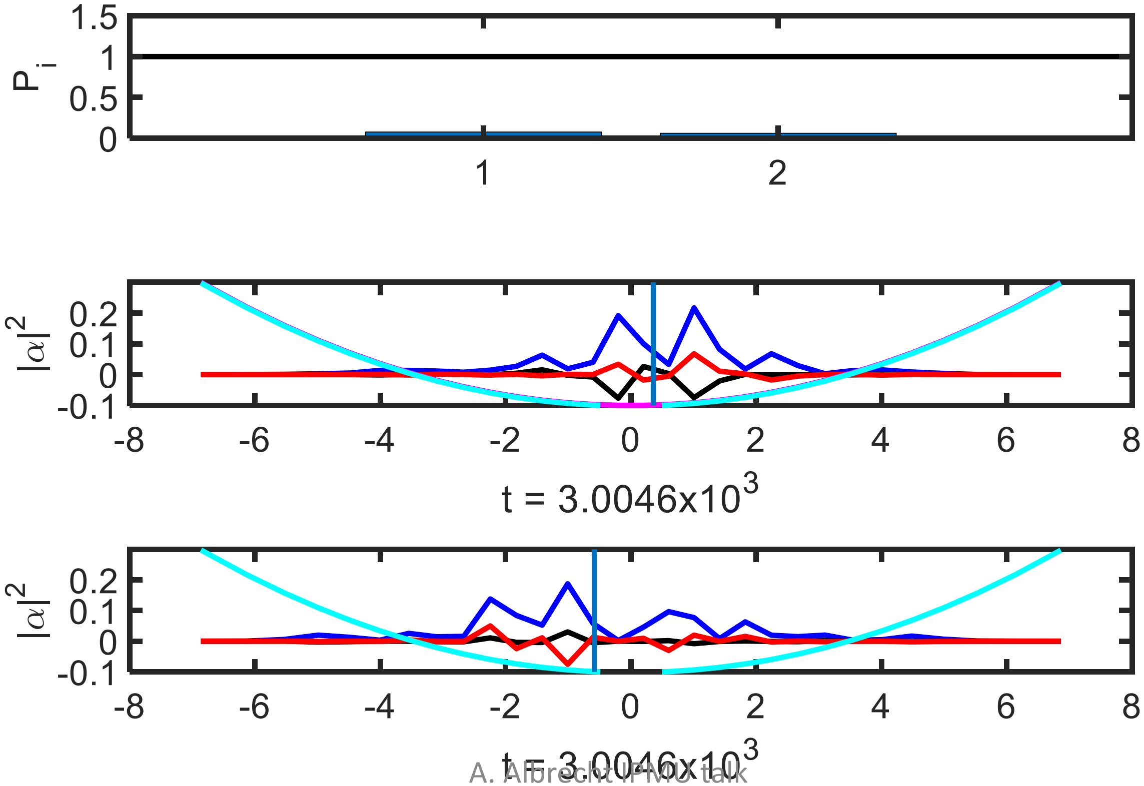
Weakly coupled case

SHO density matrix in eqm

Eigenvalues

First 2

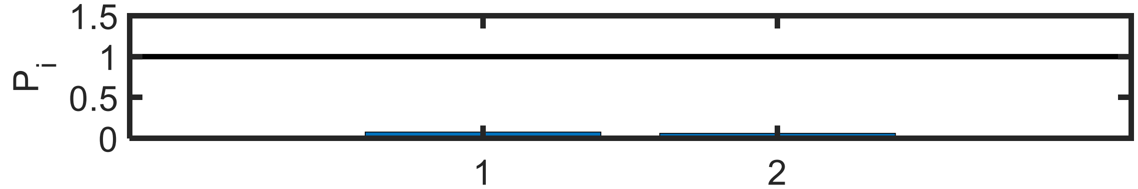
Eigenstates



SHO density matrix in eqm

Weakly coupled case

Eigenvalues



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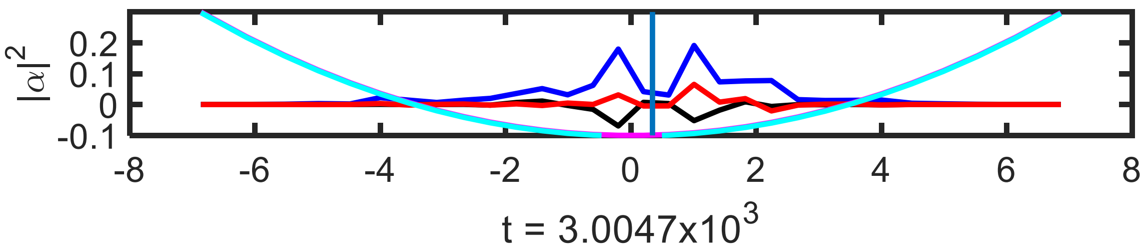
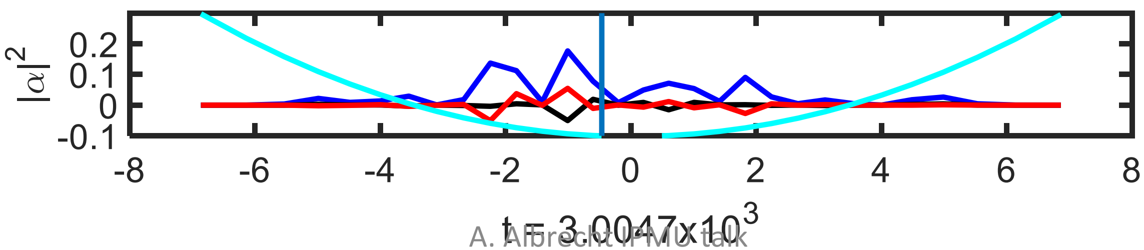
Eigenstates





SHO density matrix in eqm

Weakly coupled case

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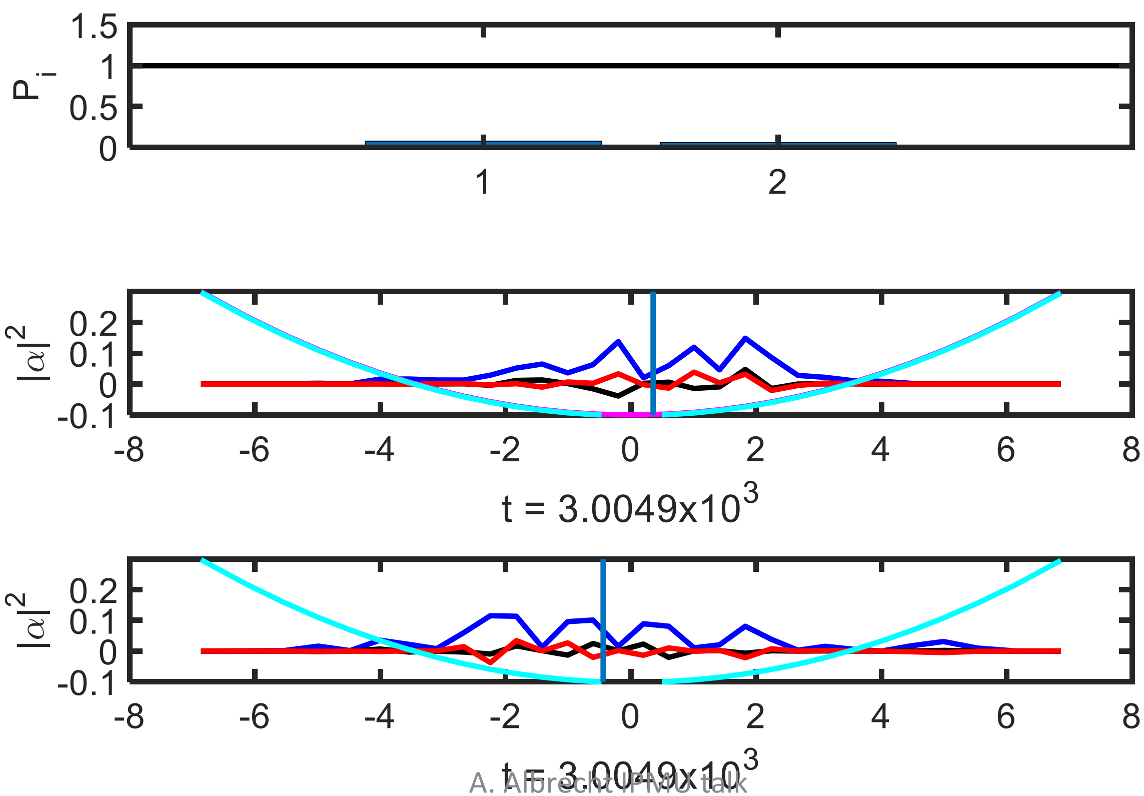

SHO density matrix in eqm

Weakly coupled case

Eigenvalues

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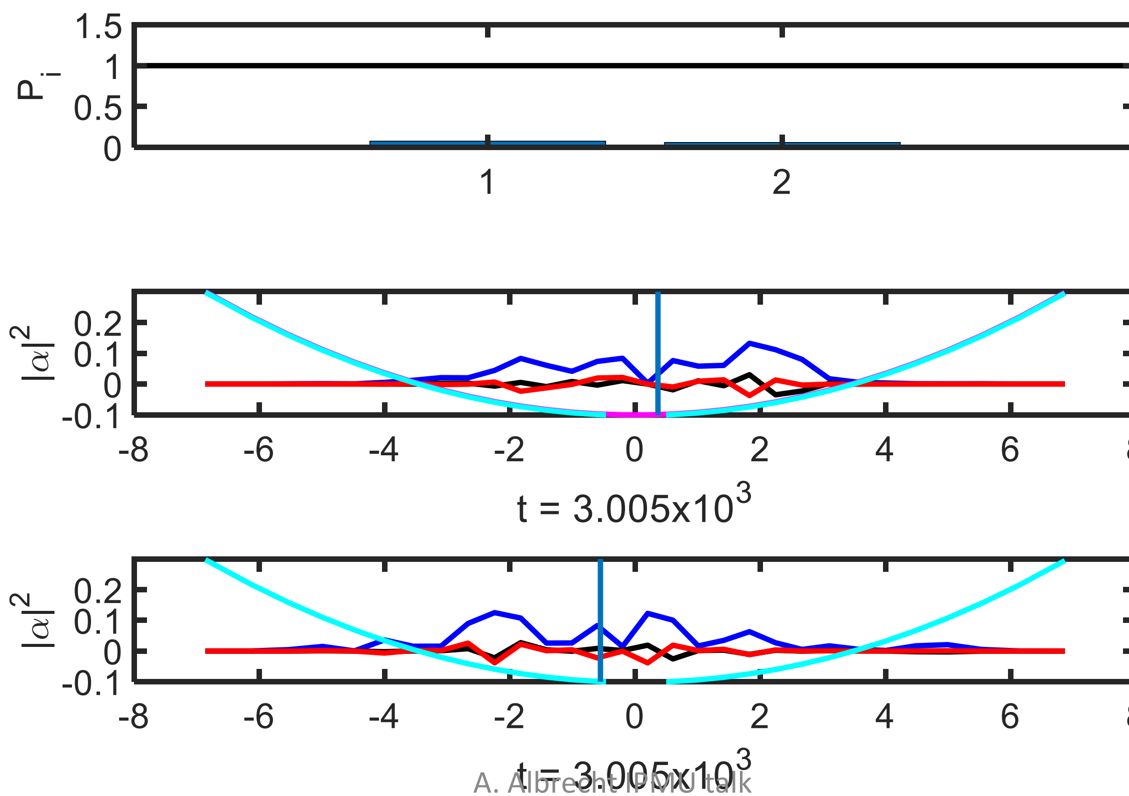
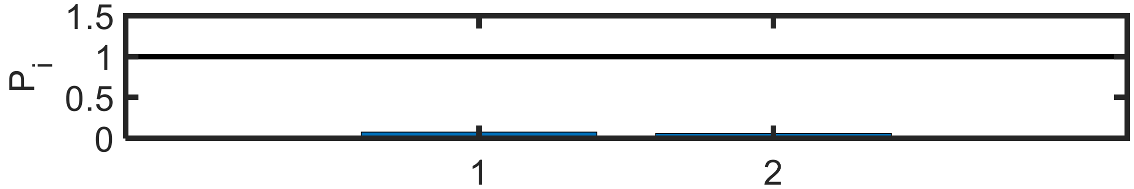


Weakly coupled case

SHO density matrix in eqm

Eigenvalues



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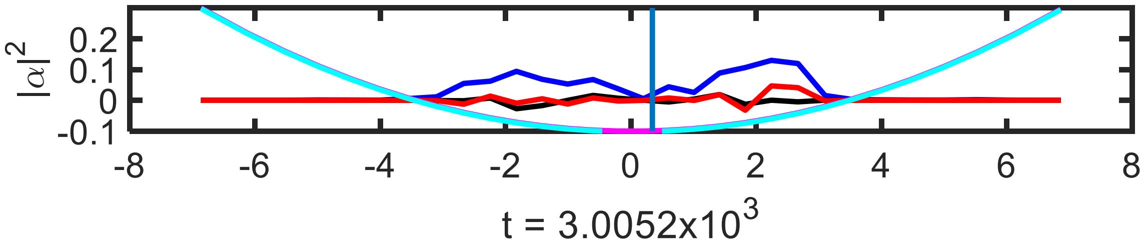

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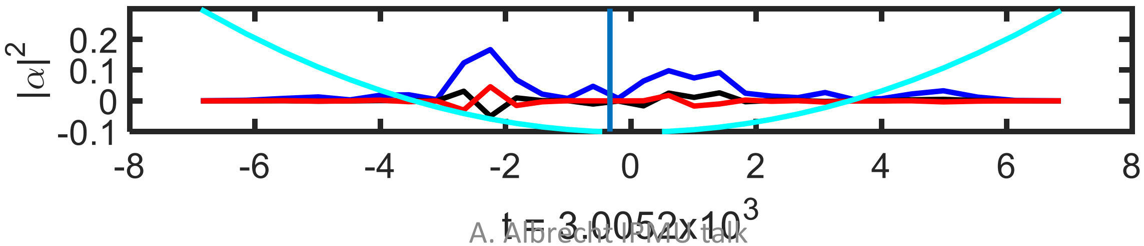
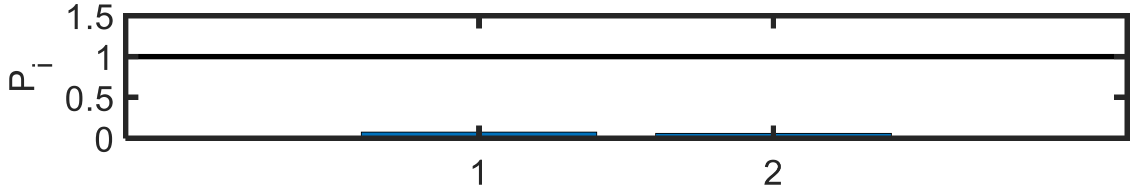


SHO density matrix in eqm

Weakly coupled case

Eigenvalues



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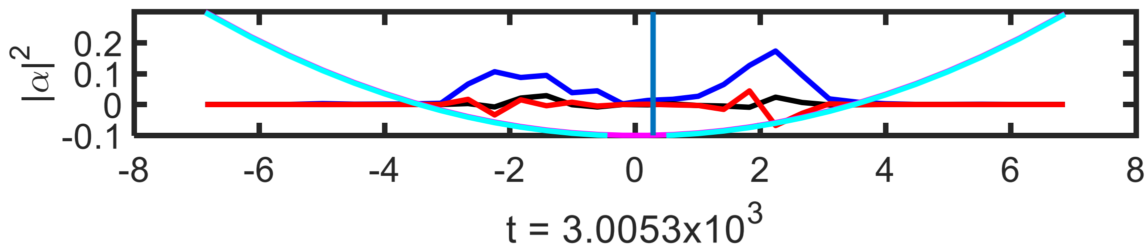

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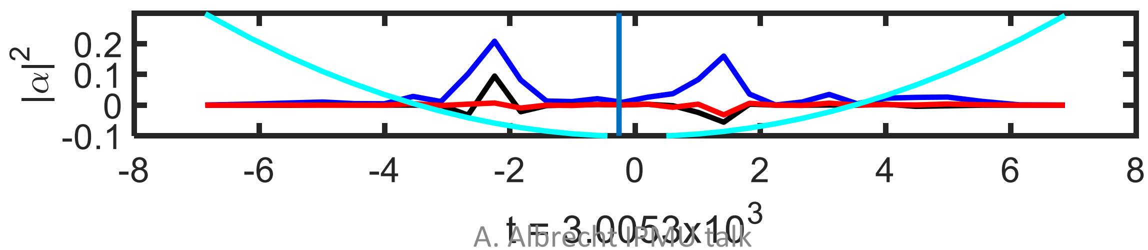
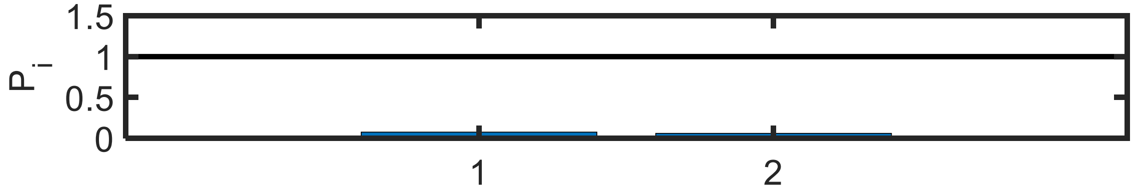


SHO density matrix in eqm

Weakly coupled case

Eigenvalues



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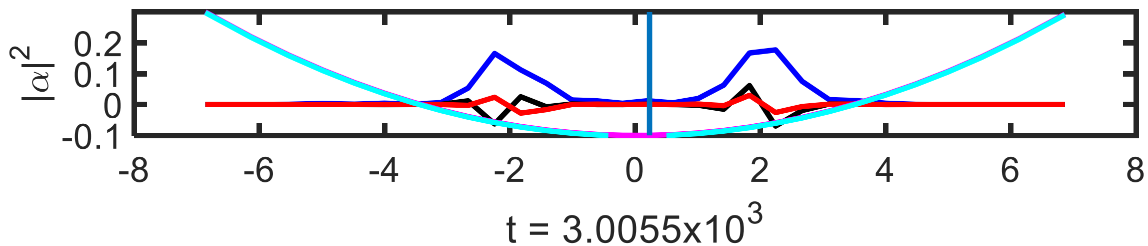
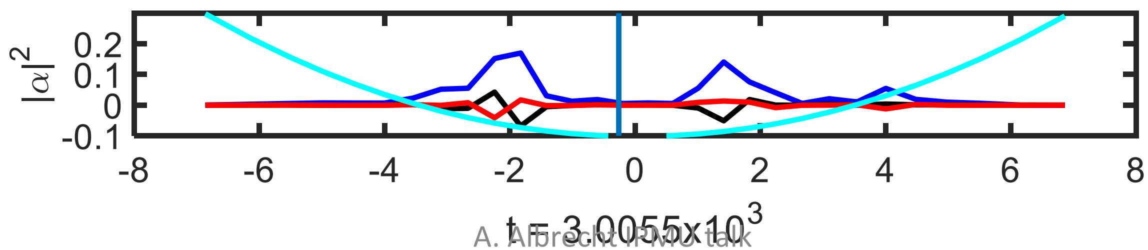
Eigenstates





SHO density matrix in eqm

Weakly coupled case

Eigenvalues

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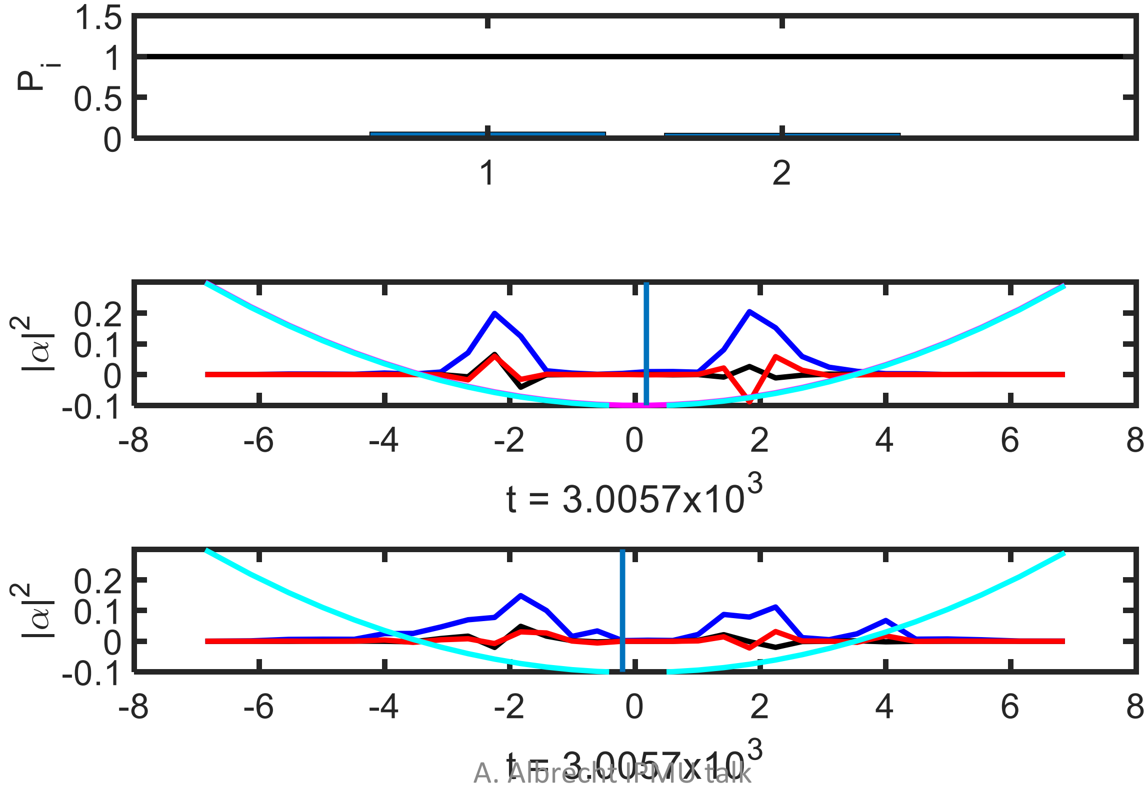

SHO density matrix in eqm

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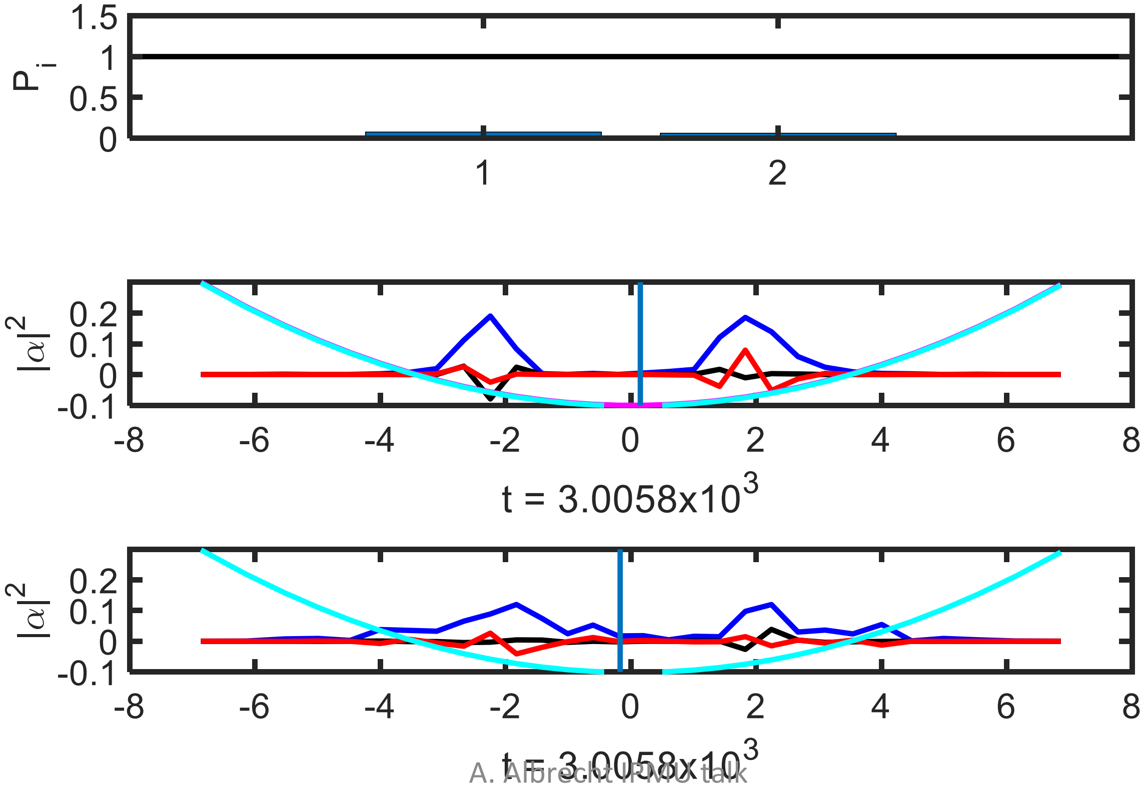

SHO density matrix in eqm

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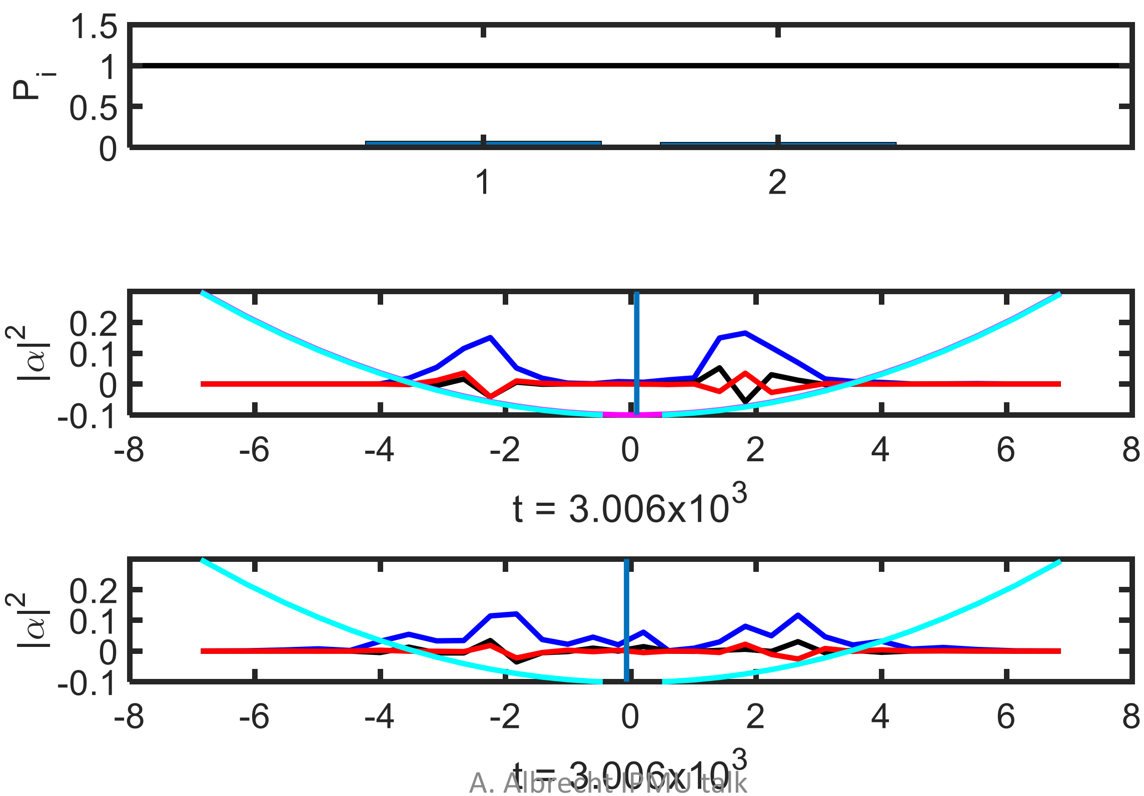

SHO density matrix in eqm

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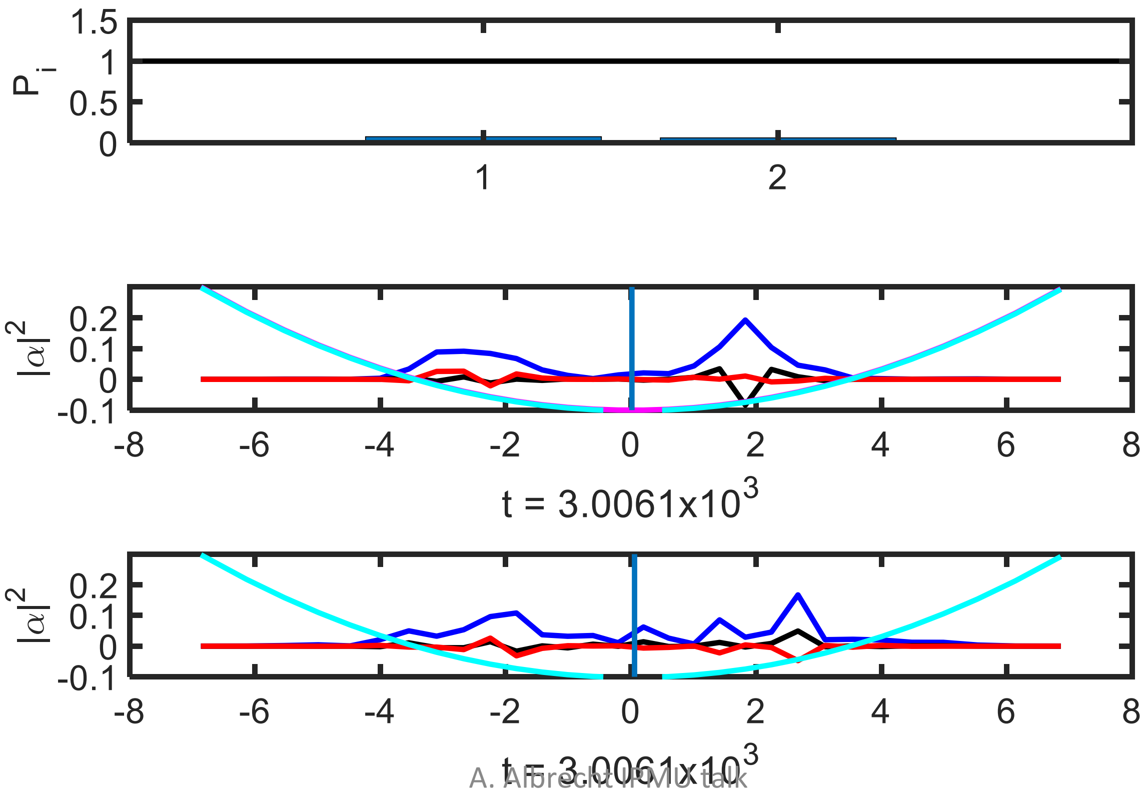
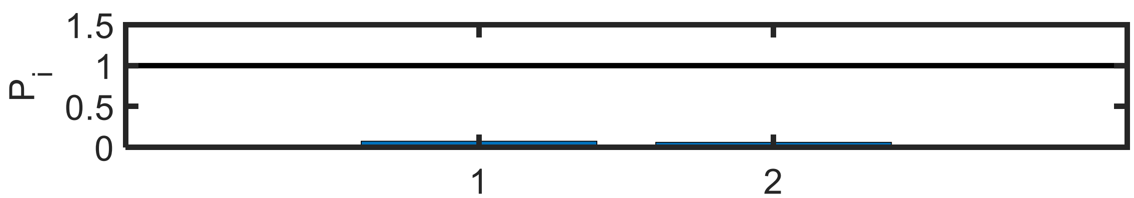


SHO density matrix in eqm

Weakly coupled case

Eigenvalues



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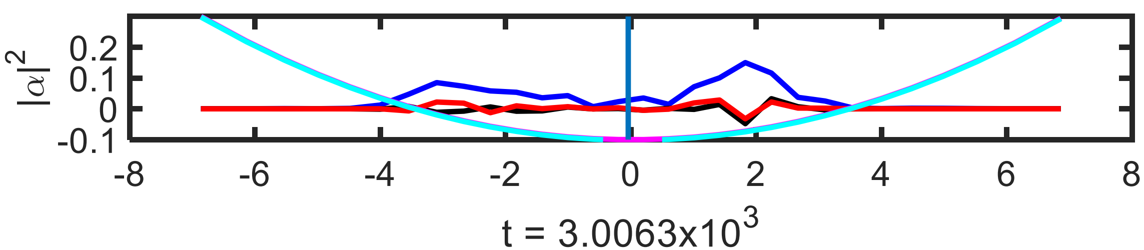
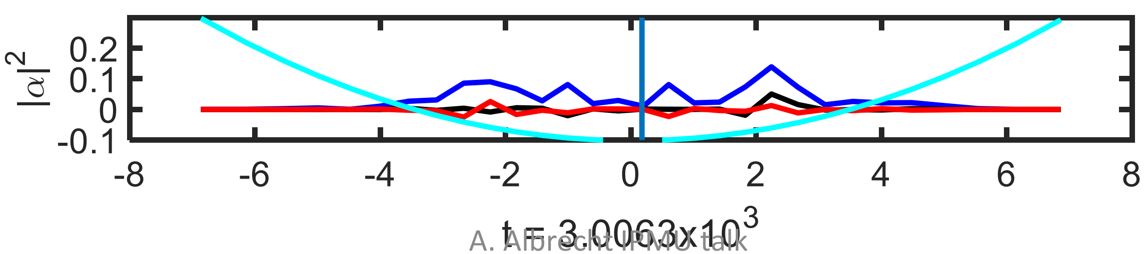


Eigenstates



SHO density matrix in eqm

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Eigenvalues

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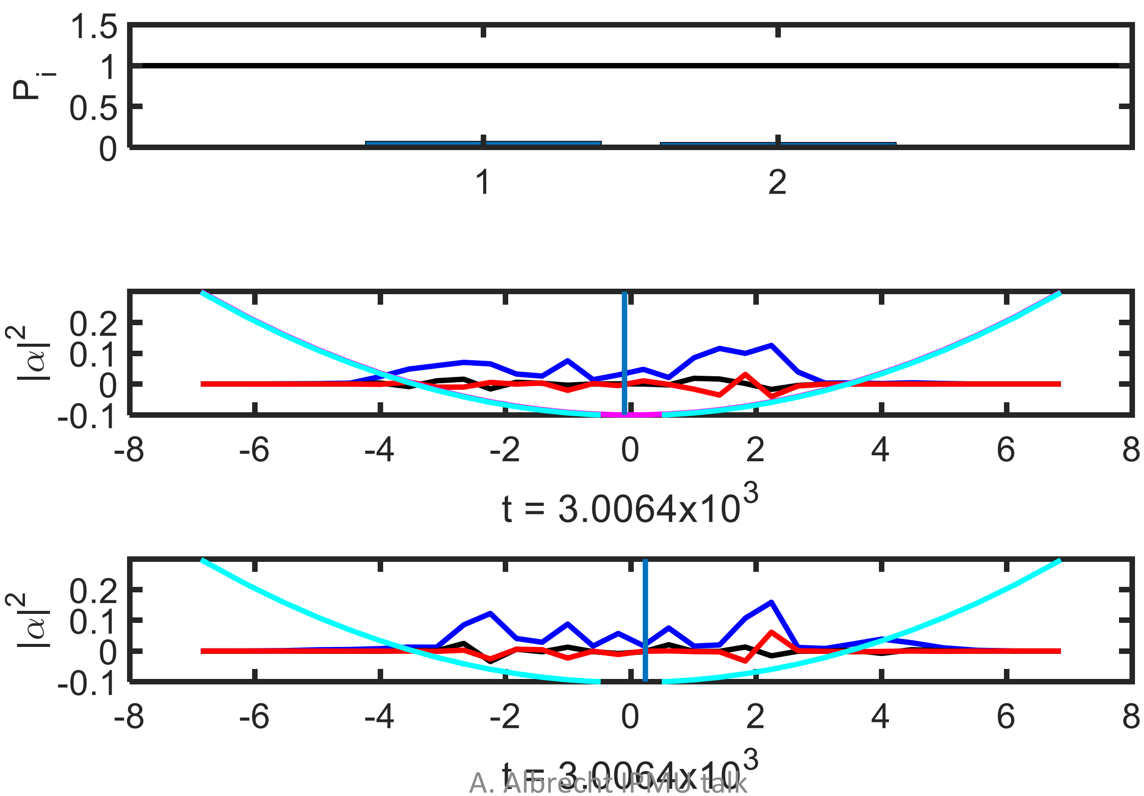
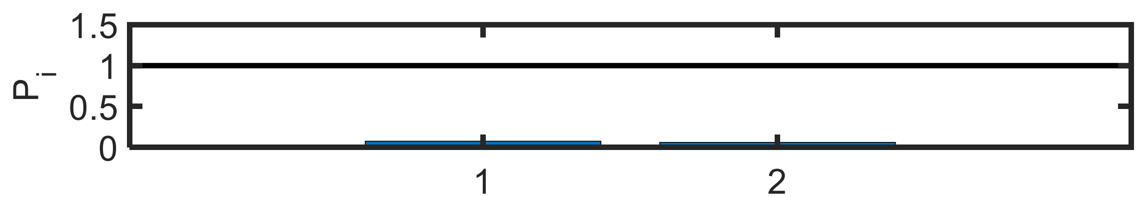


SHO density matrix in eqm

Weakly coupled case

Eigenvalues



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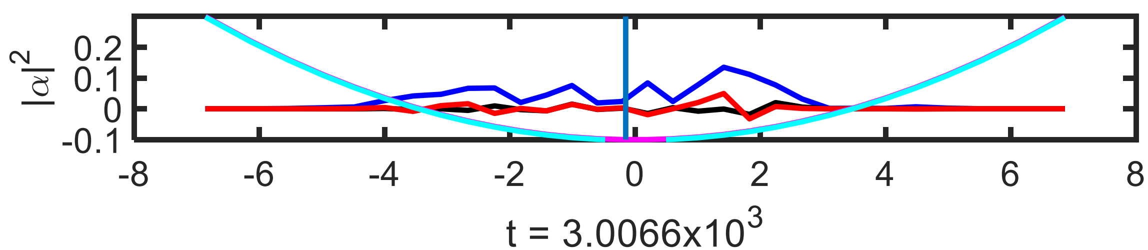
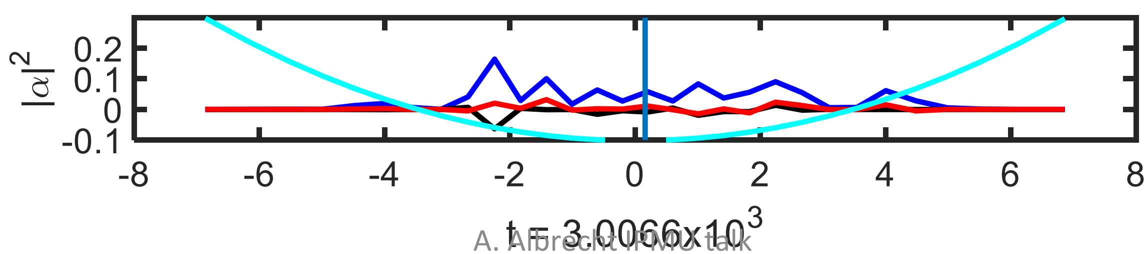


Eigenstates



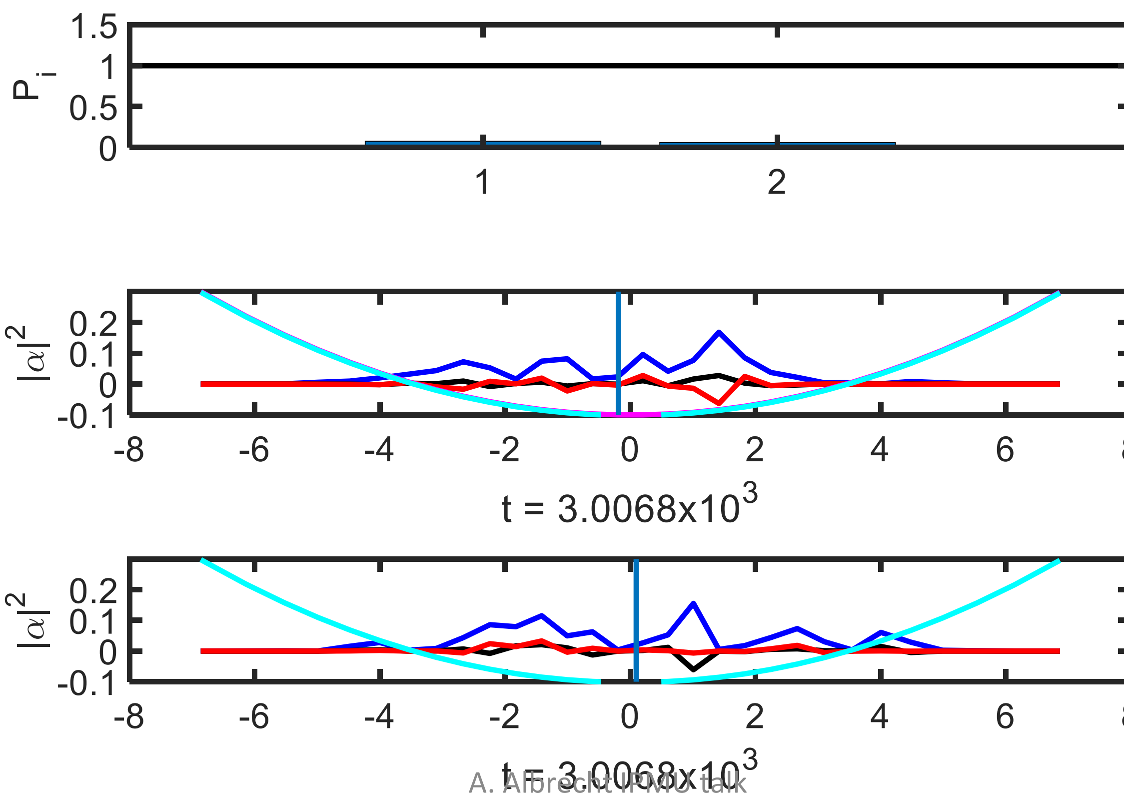
SHO density matrix in eqm

Weakly coupled case

Eigenvalues

First 2

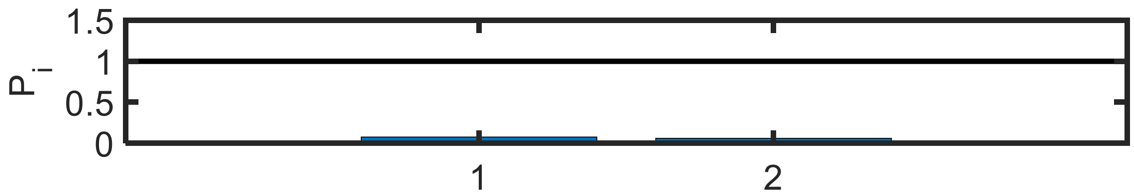
Eigenstates



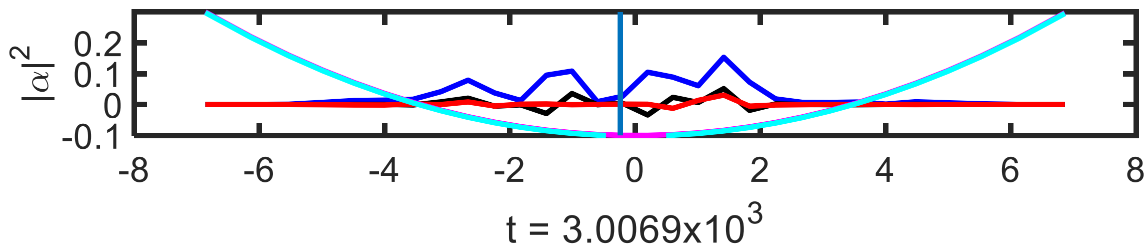
SHO density matrix in eqm

Weakly coupled case

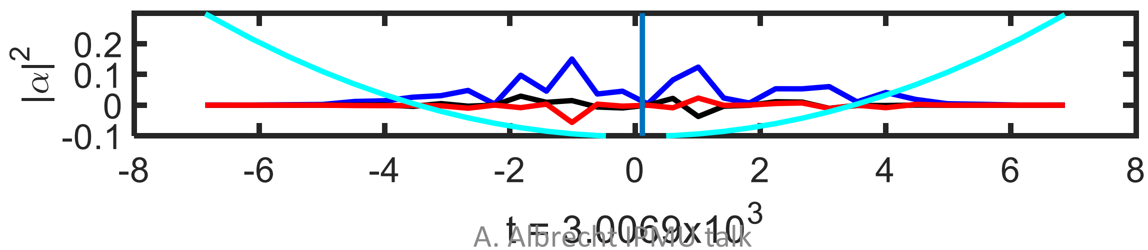
Eigenvalues



First 2



Eigenstates



SHO density matrix in eqm

Weakly coupled case

Eigenvalues

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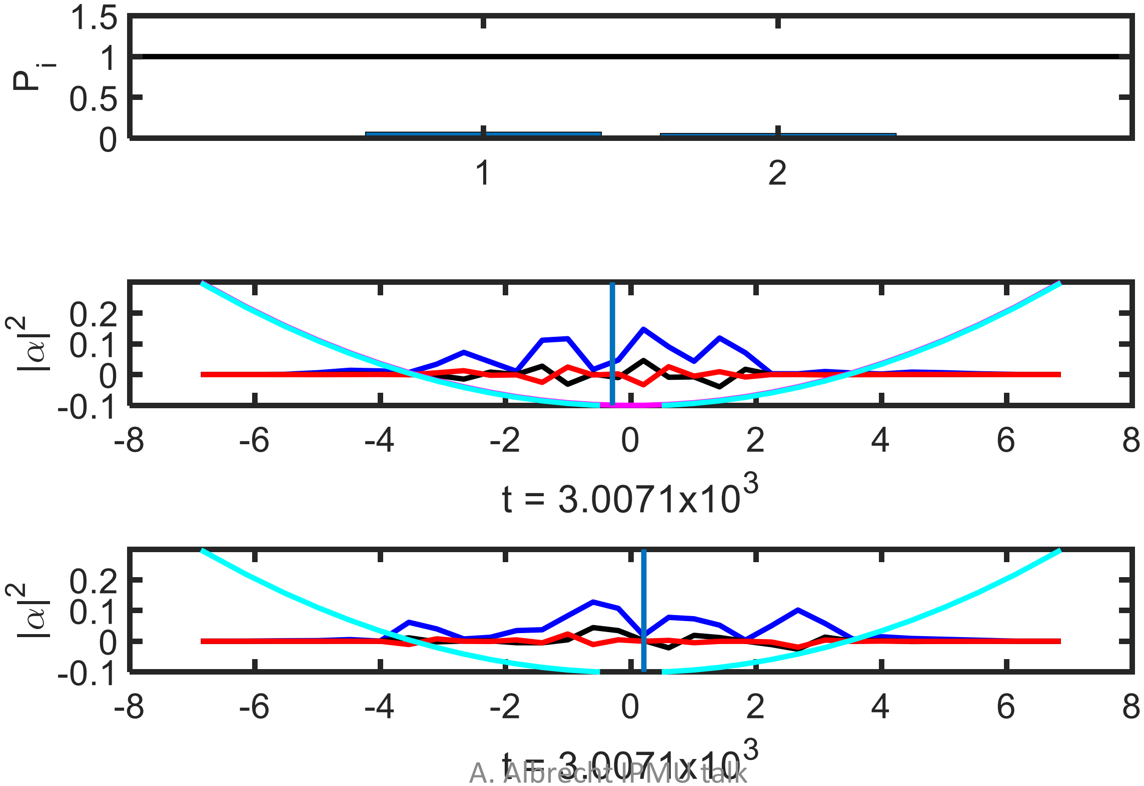

SHO density matrix in eqm

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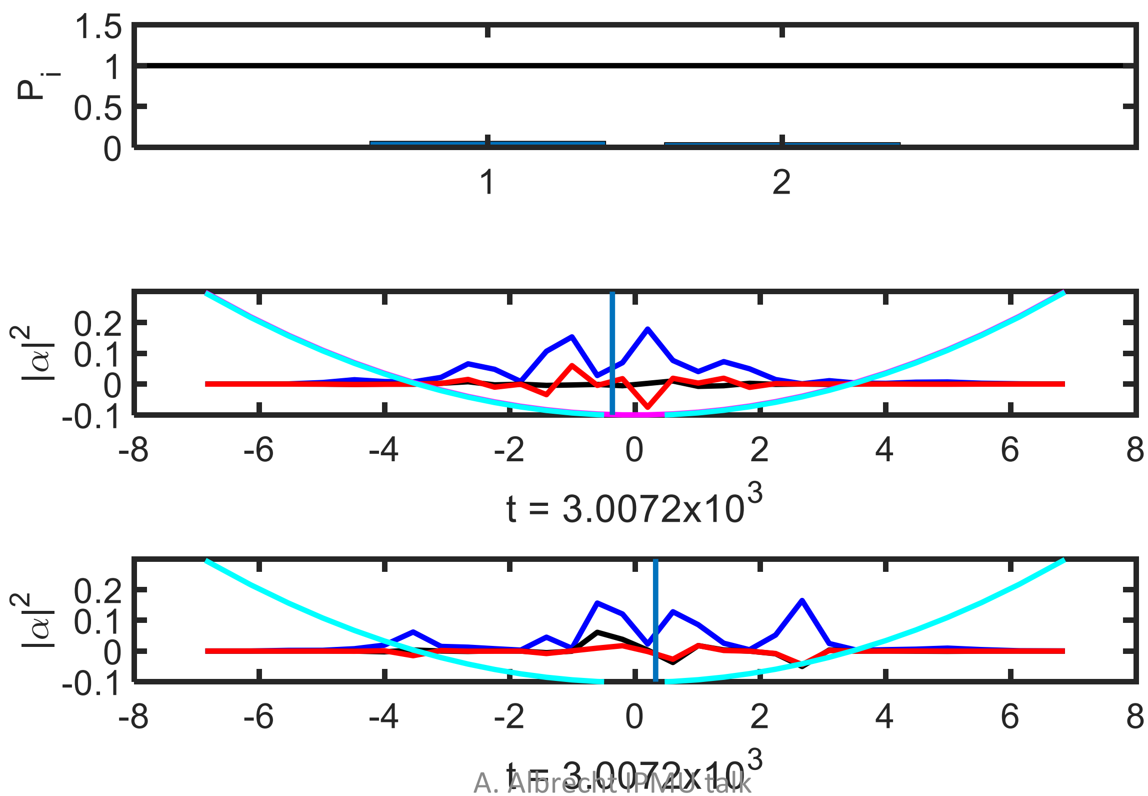

SHO density matrix in eqm

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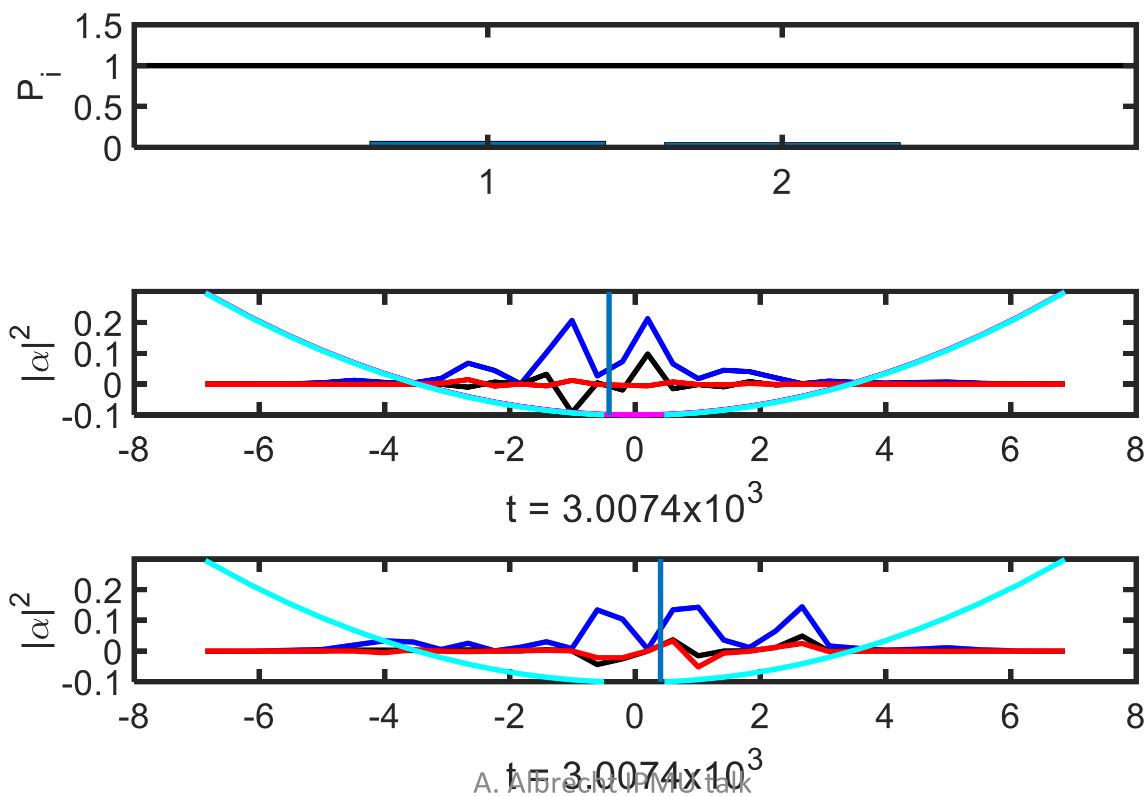

SHO density matrix in eqm

Weakly coupled case

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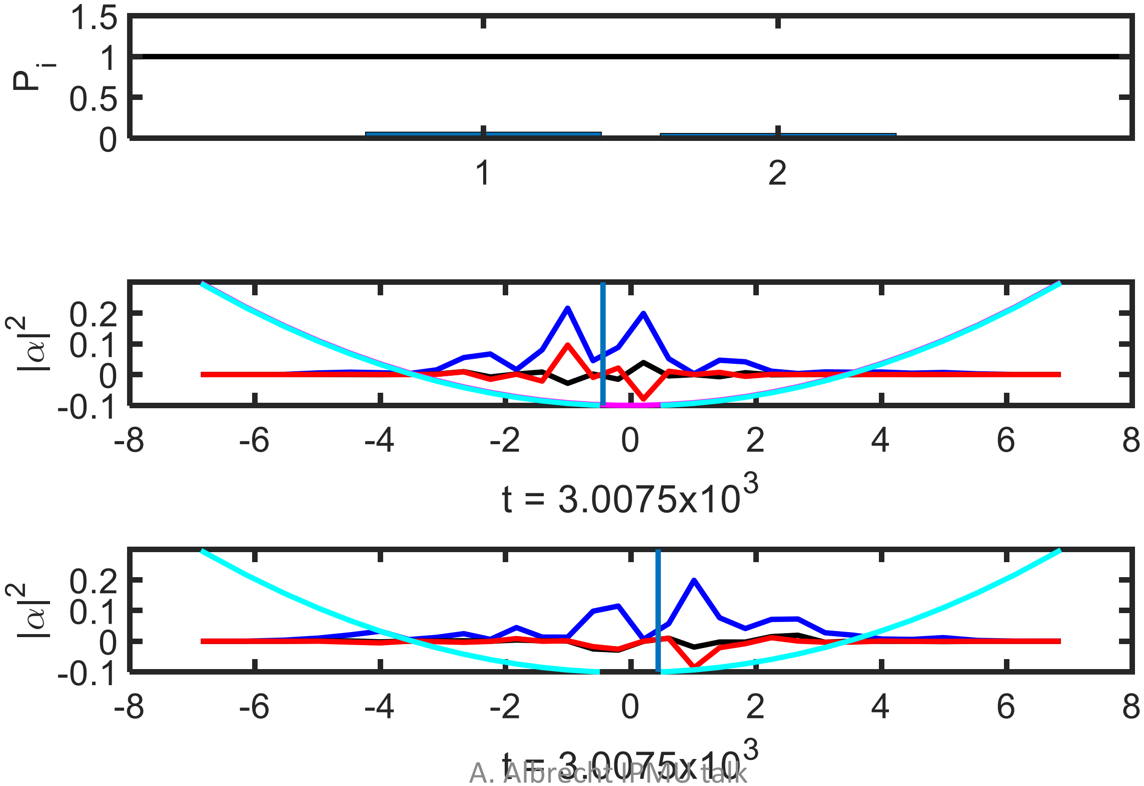

SHO density matrix in eqm

Weakly coupled case

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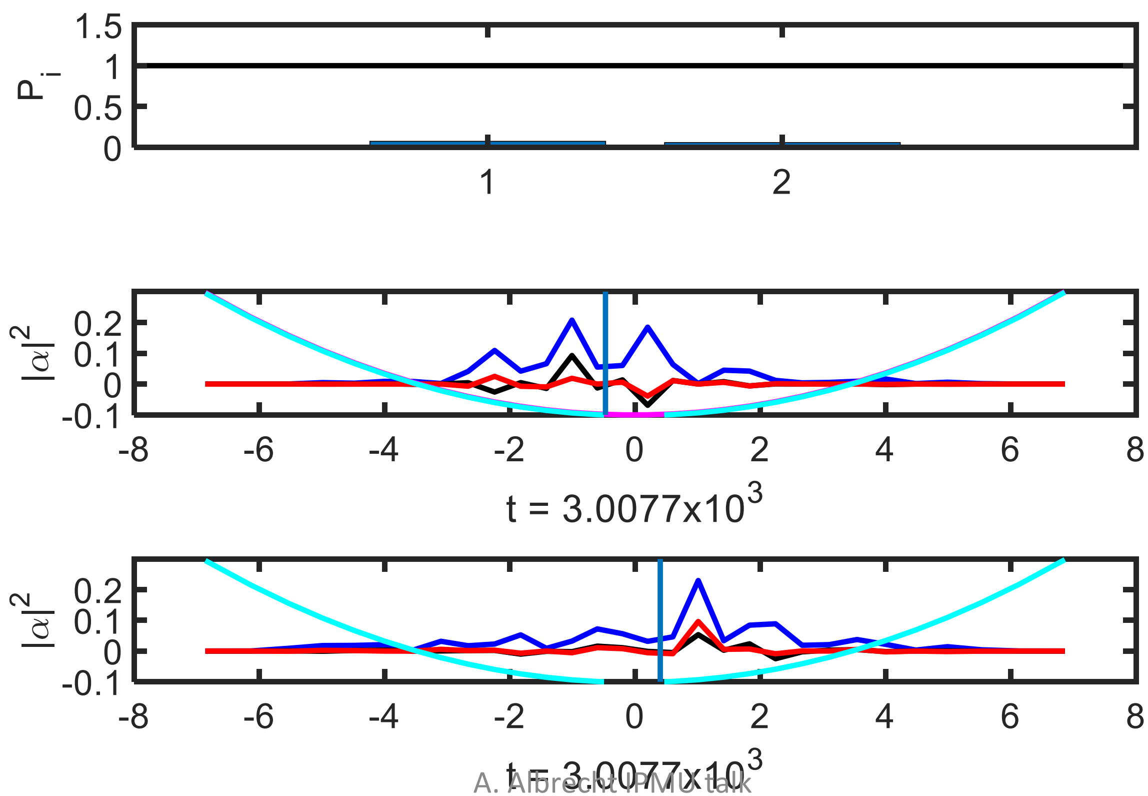

SHO density matrix in eqm

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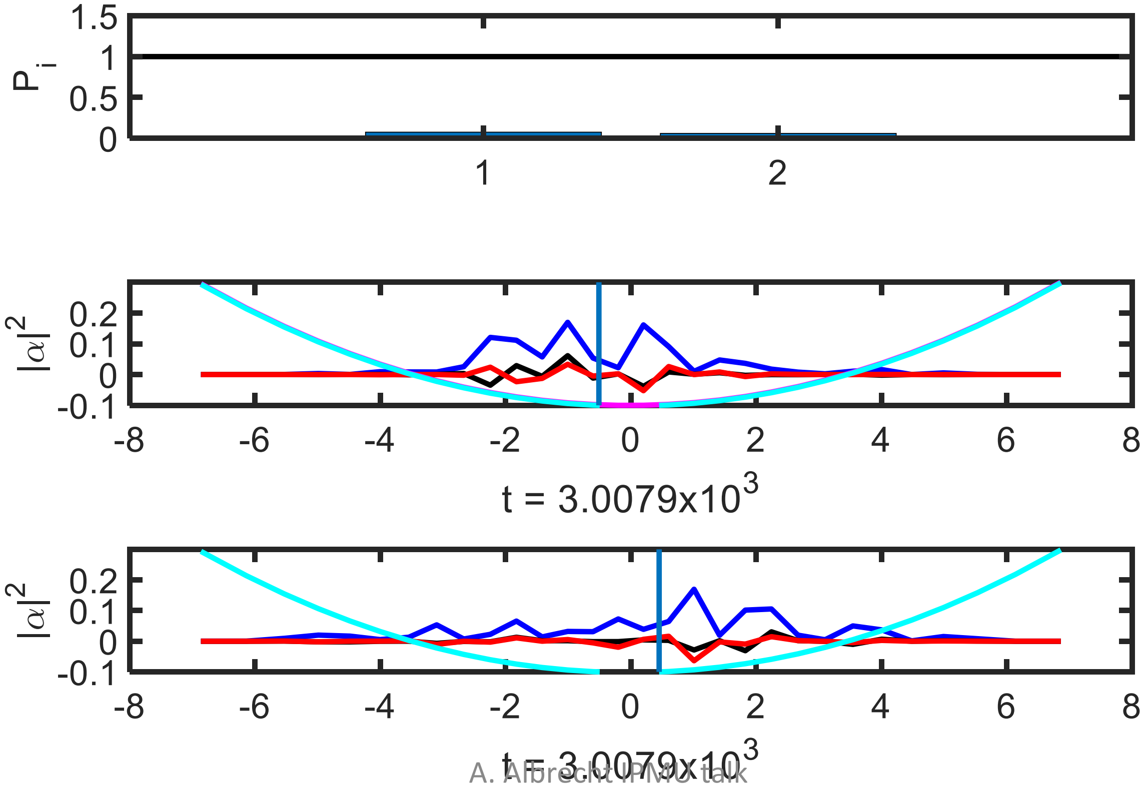

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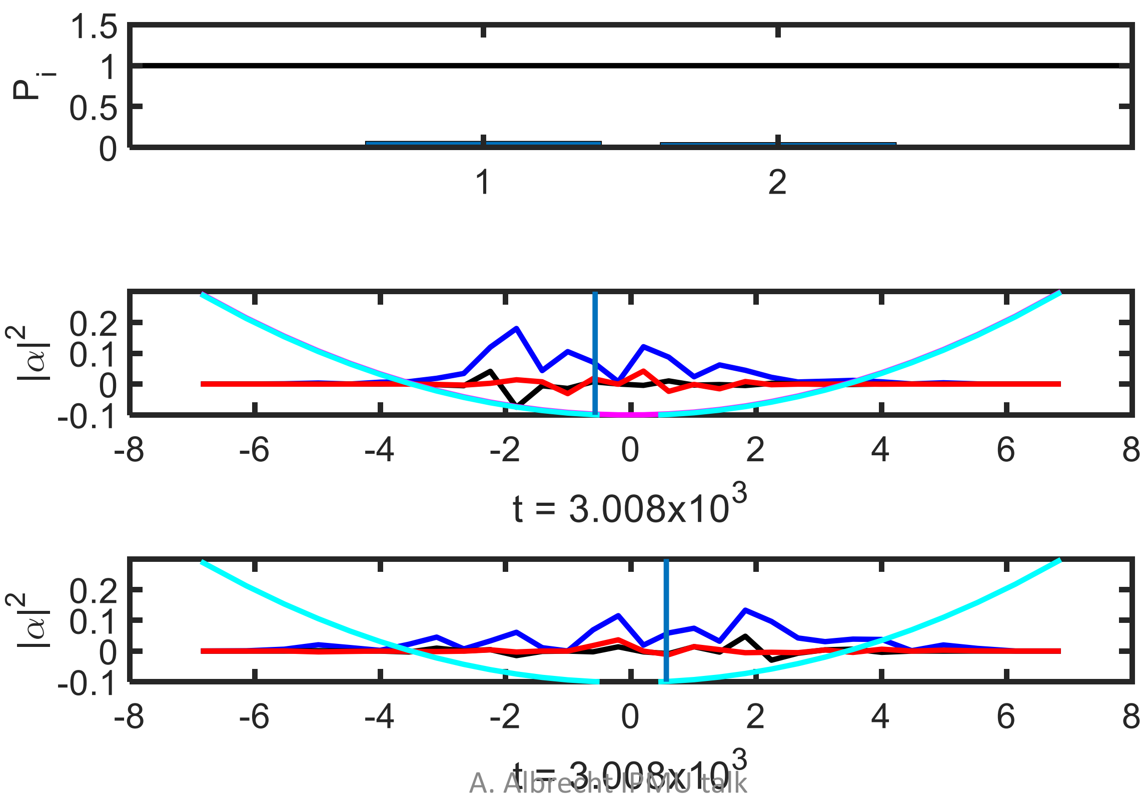

SHO density matrix in eqm

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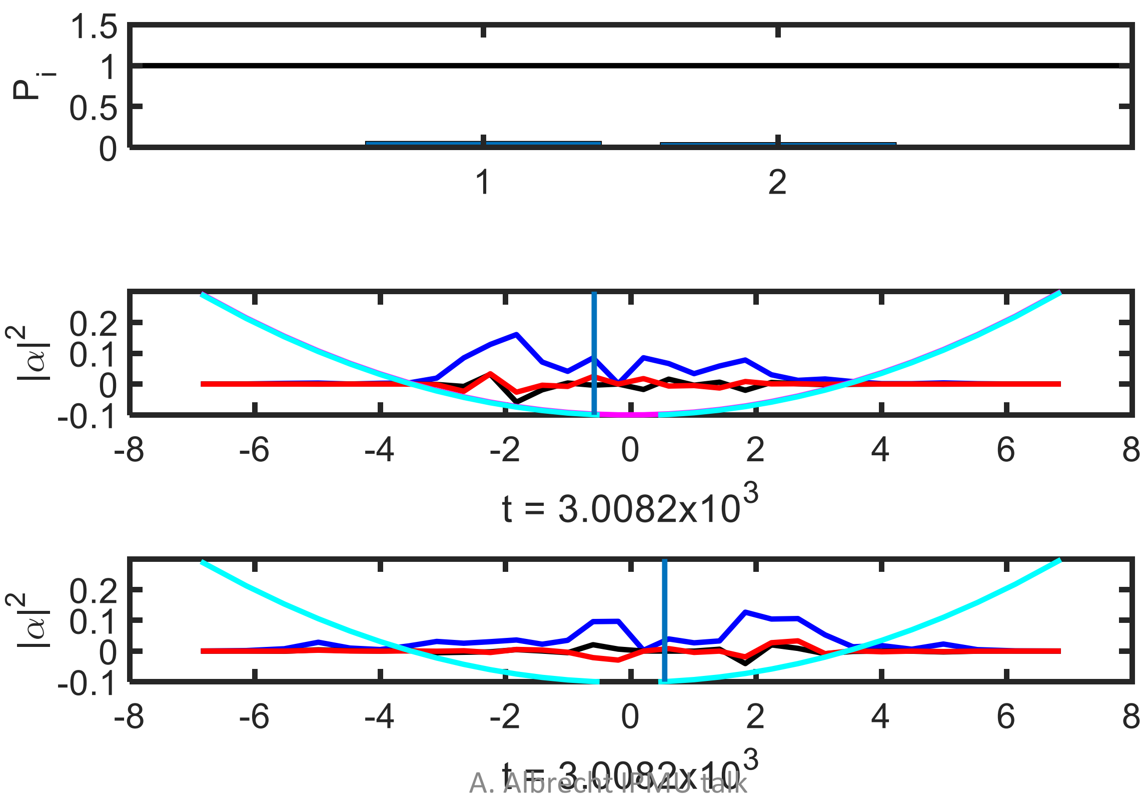

SHO density matrix in eqm

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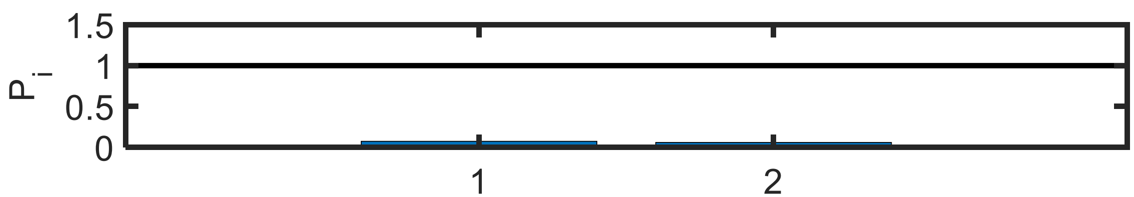
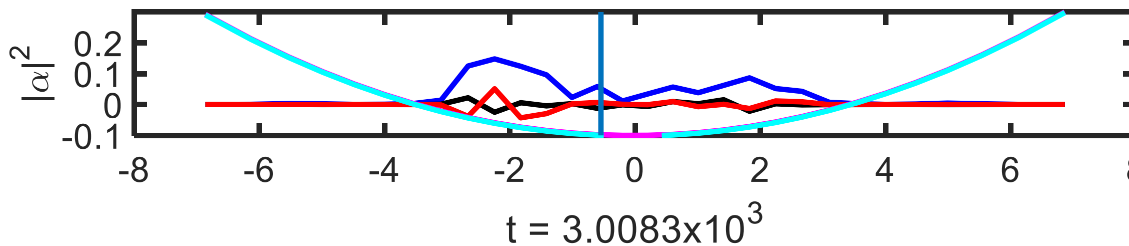
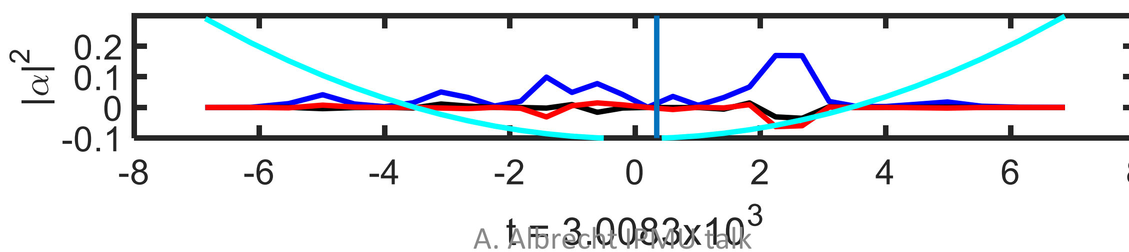


First 2

Eigenstates





SHO density matrix in eqm

Weakly coupled case

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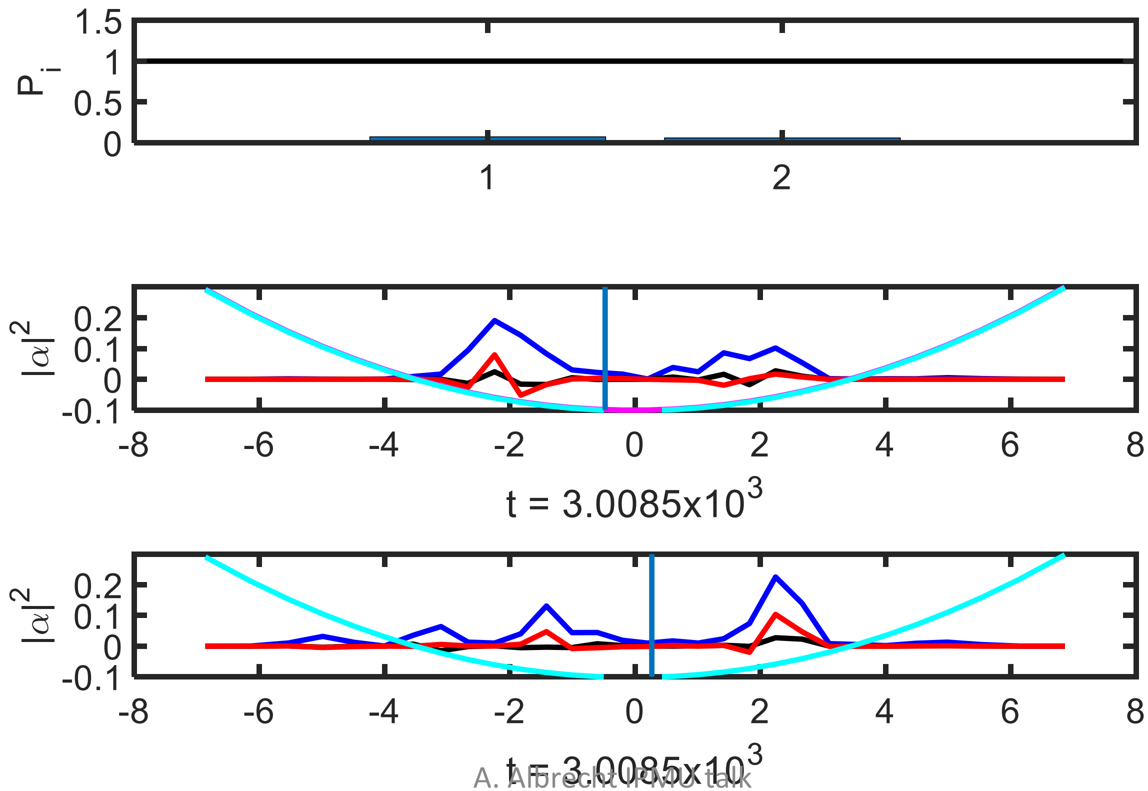

SHO density matrix in eqm

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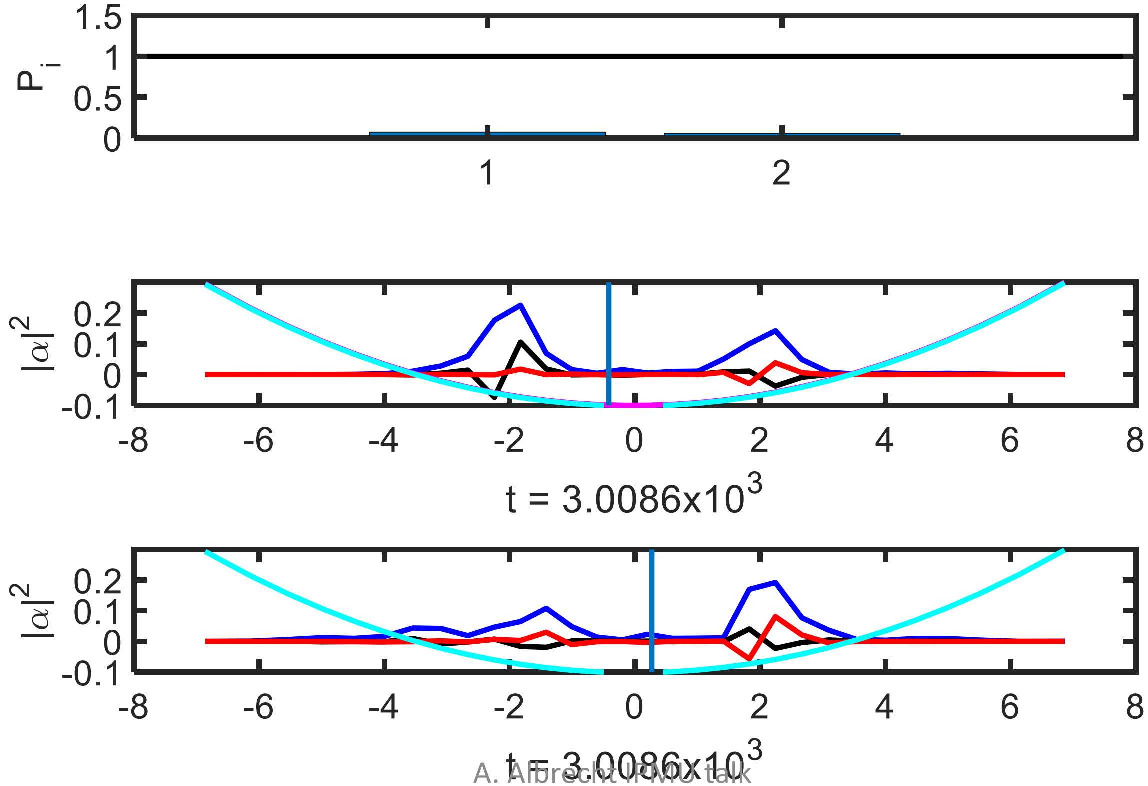

SHO density matrix in eqm

Weakly coupled case

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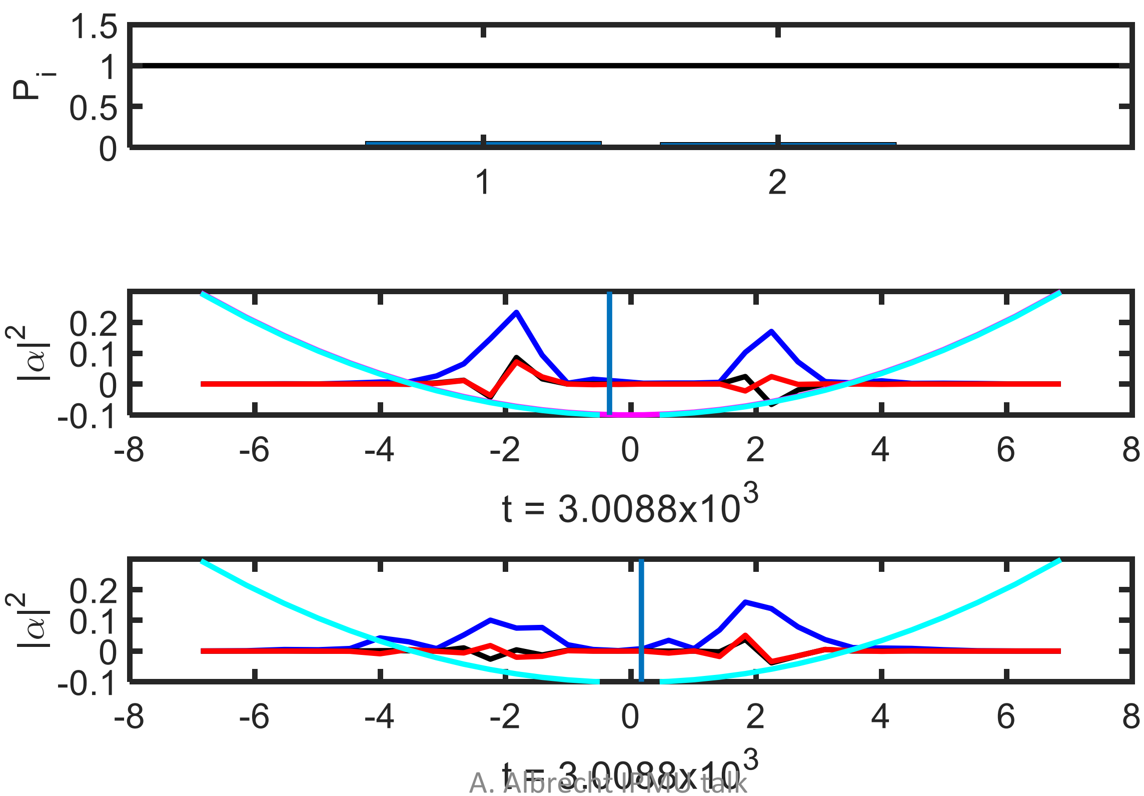

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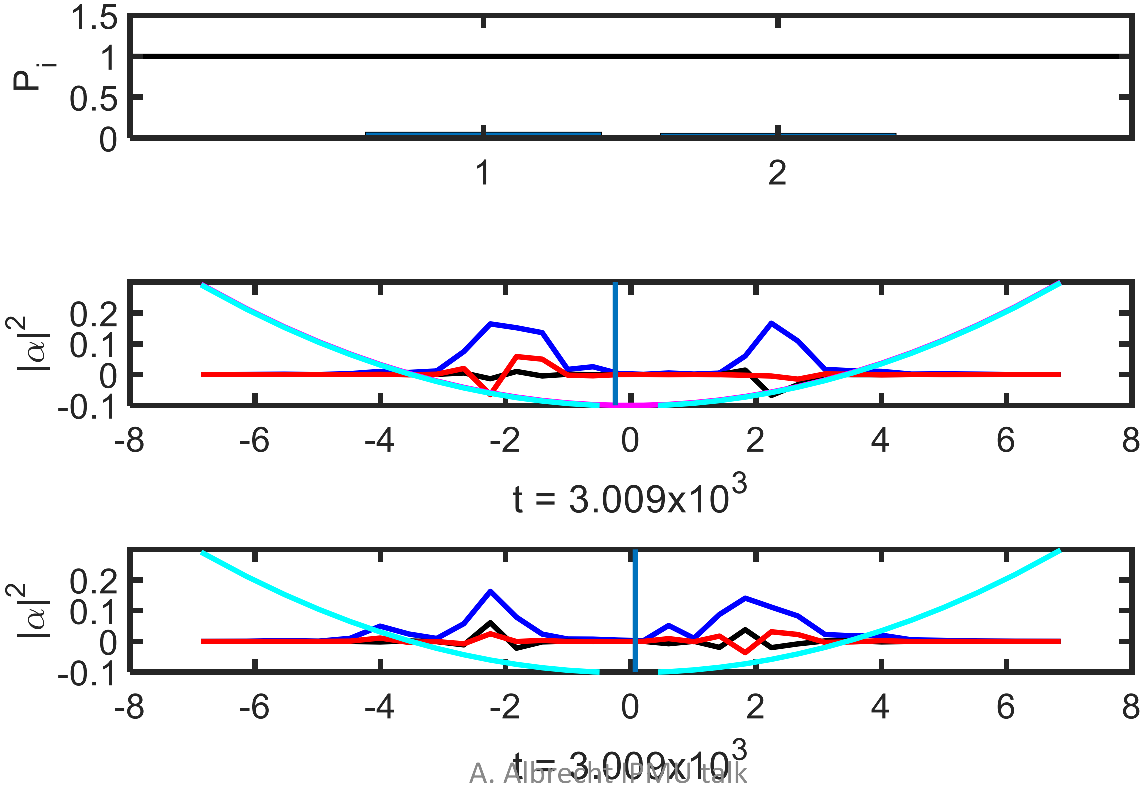

SHO density matrix in eqm

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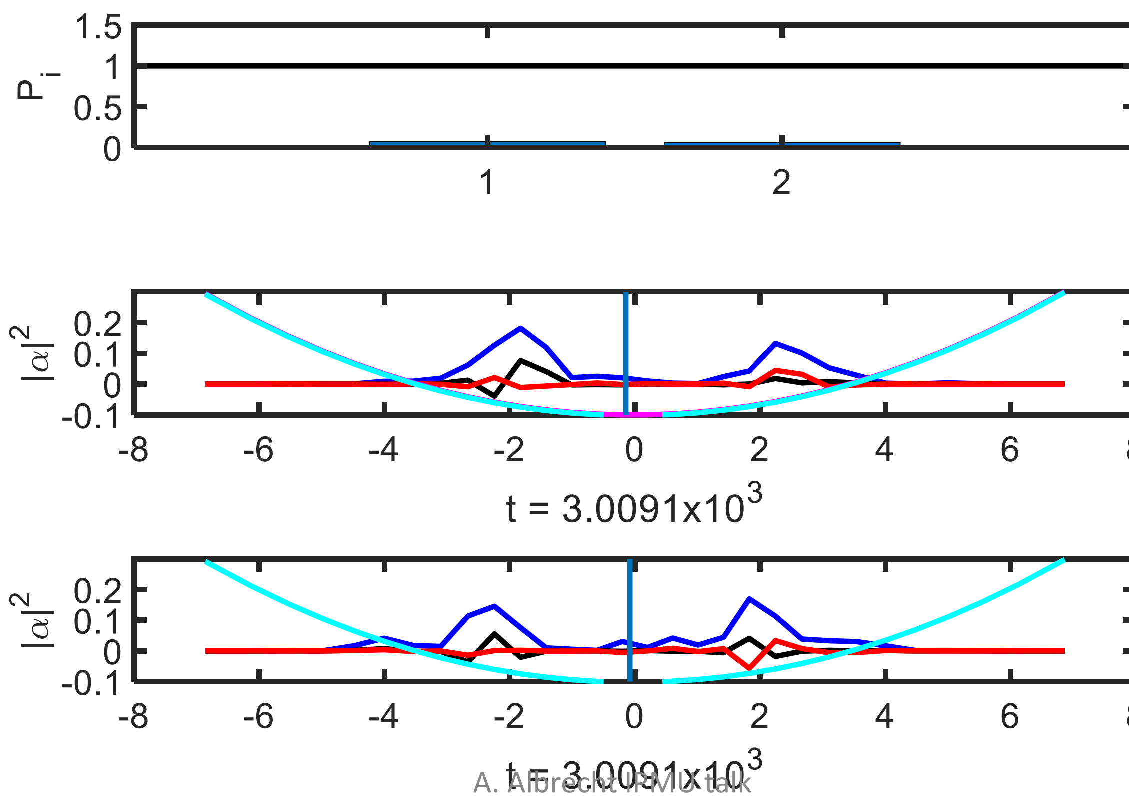

SHO density matrix in eqm

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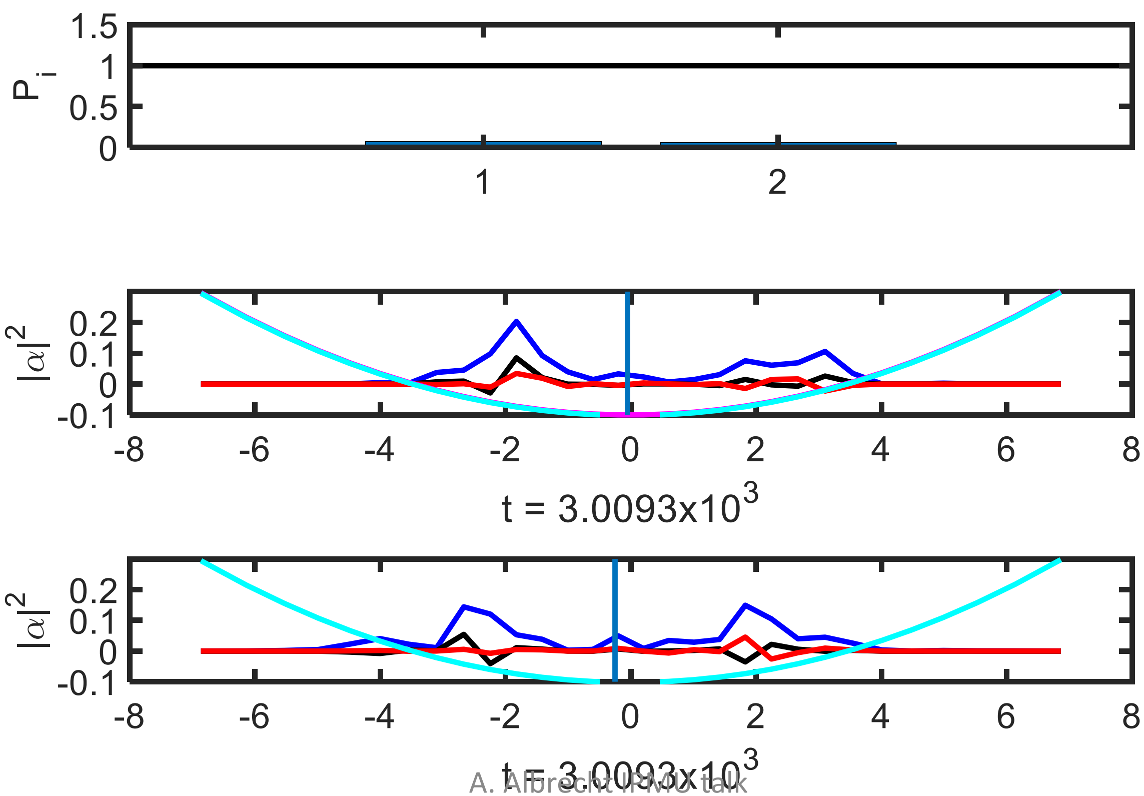

SHO density matrix in eqm

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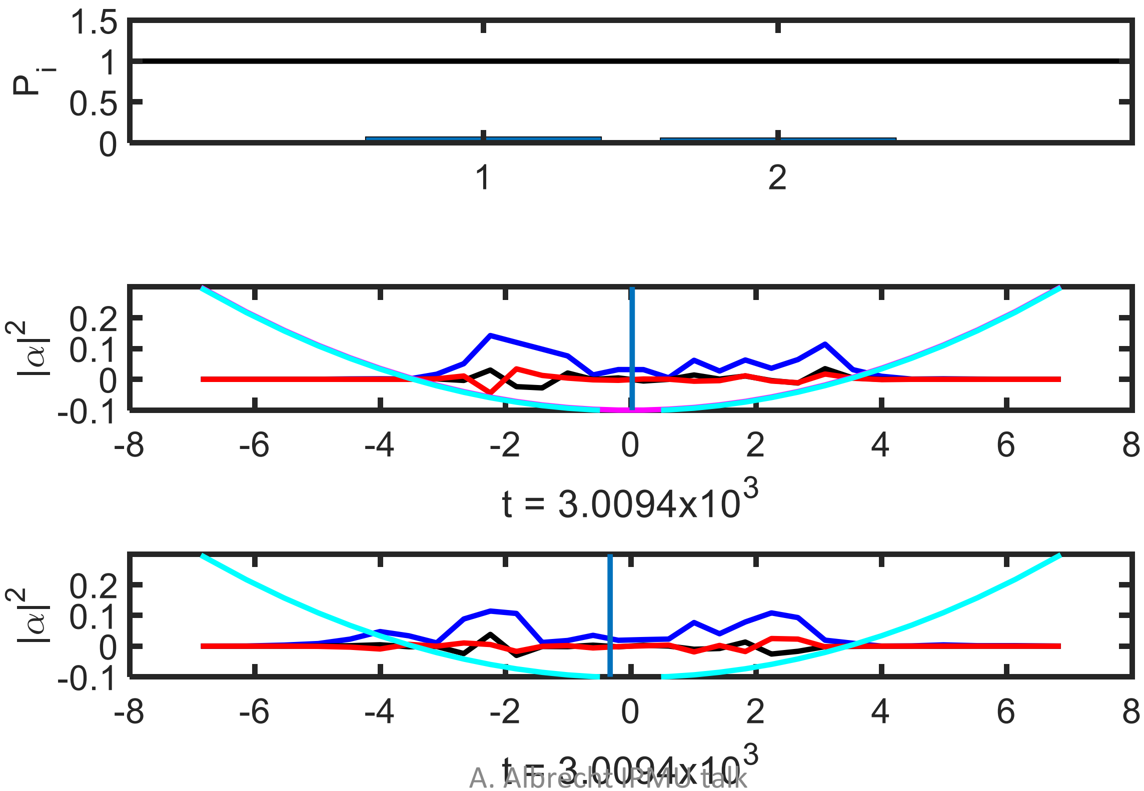

SHO density matrix in eqm

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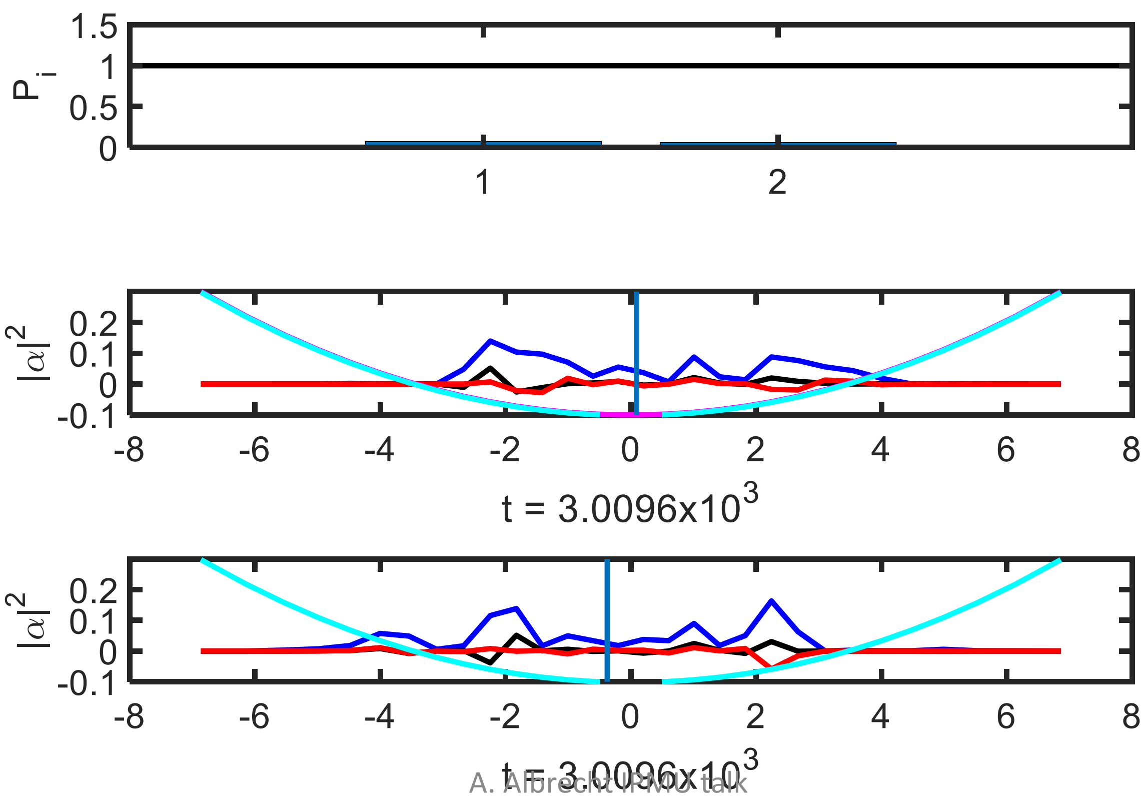

SHO density matrix in eqm

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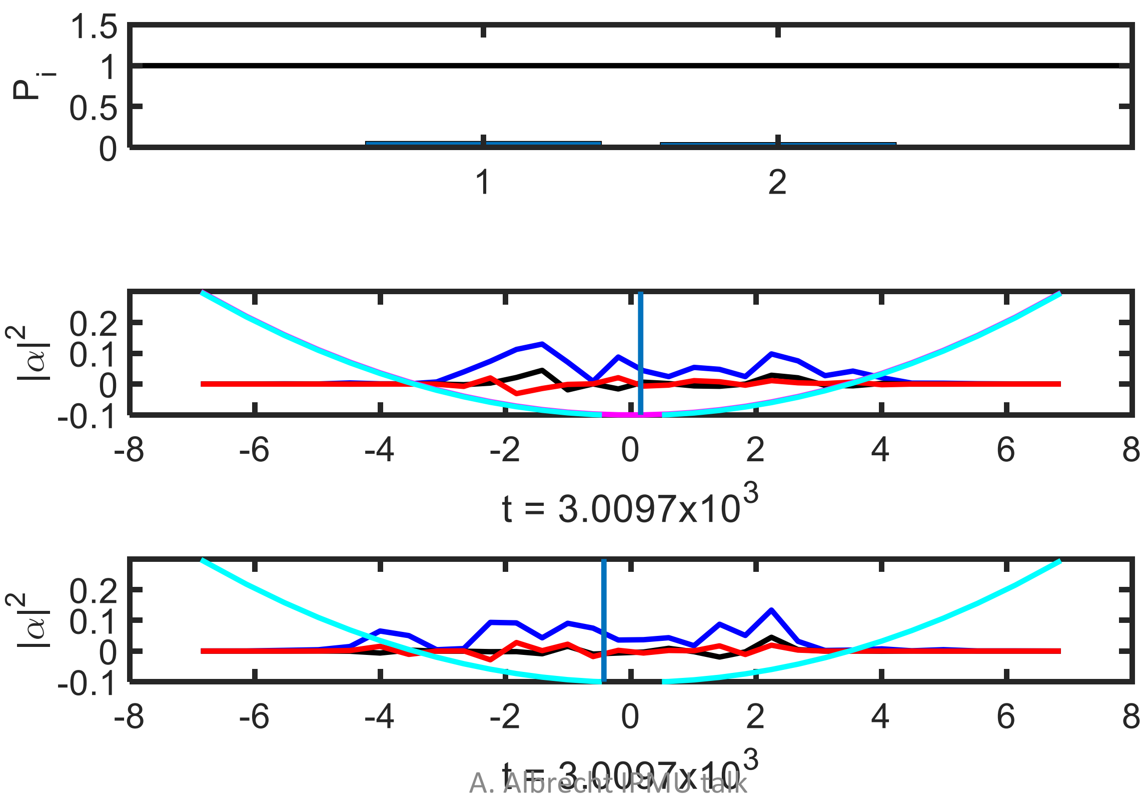

SHO density matrix in eqm

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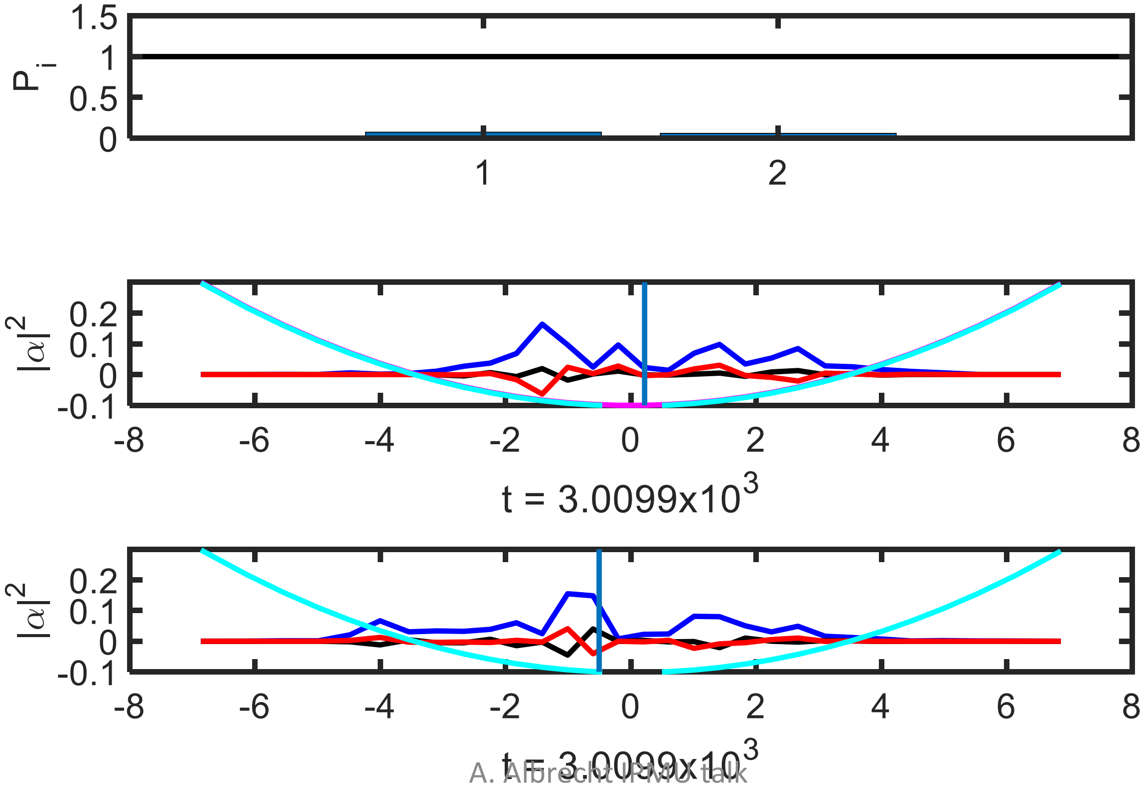

SHO density matrix in eqm

Weakly coupled case

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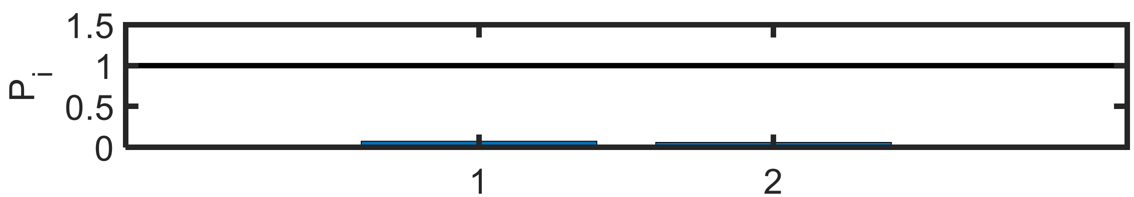
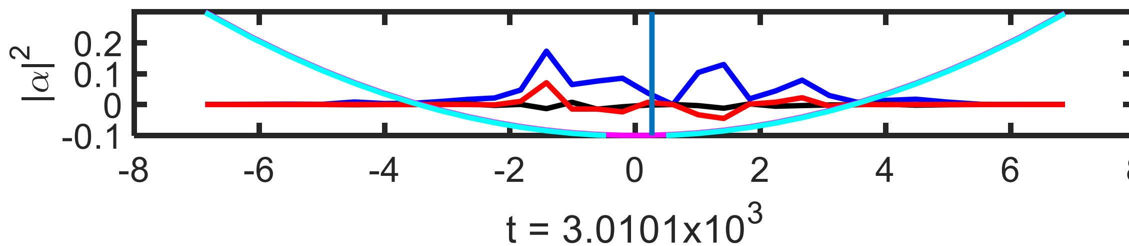
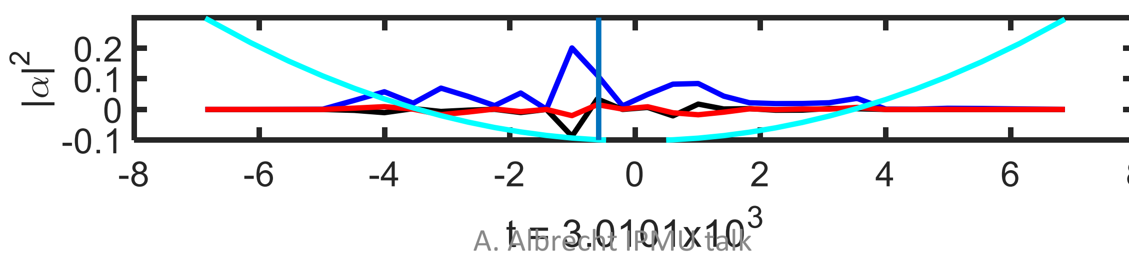


First 2



Eigenstates



SHO density matrix in eqm

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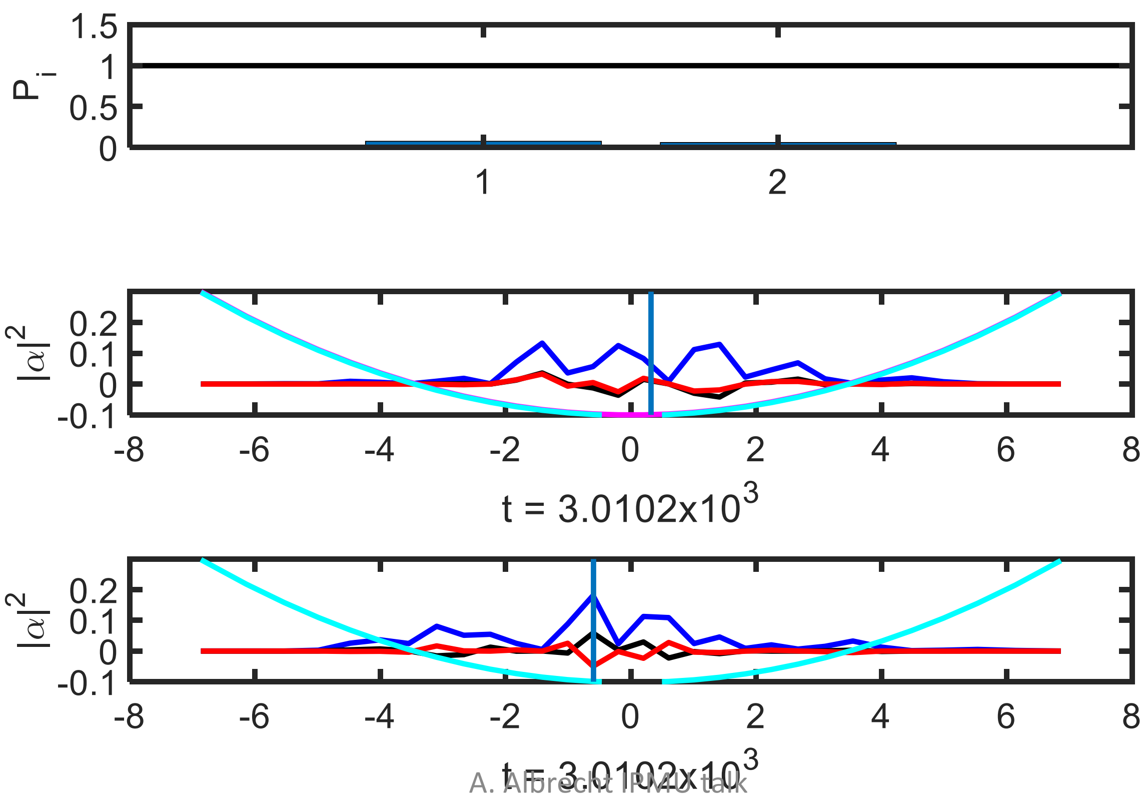

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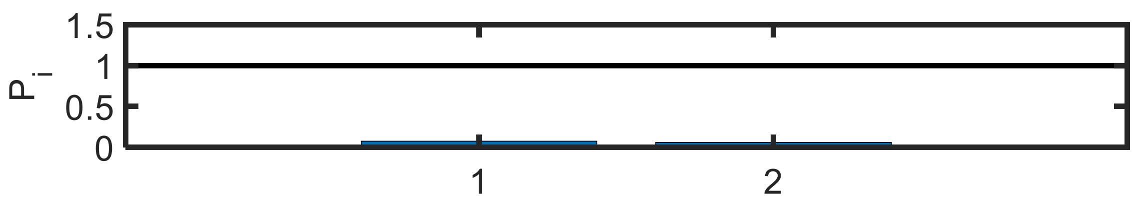

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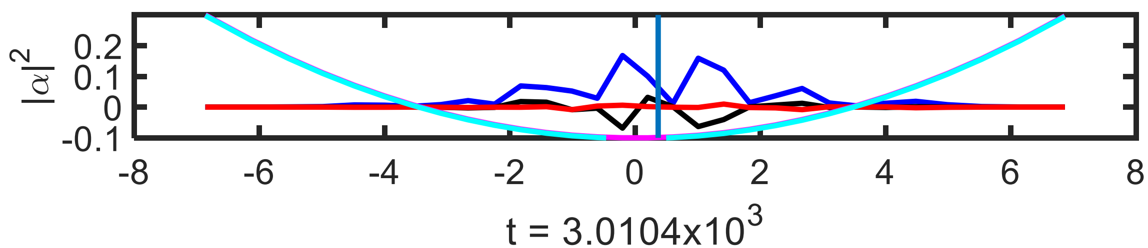

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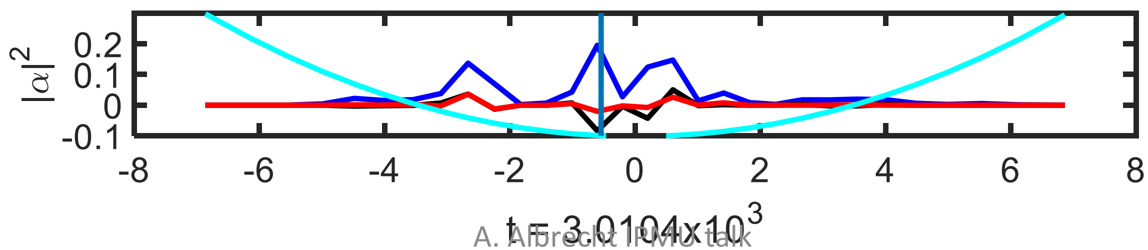

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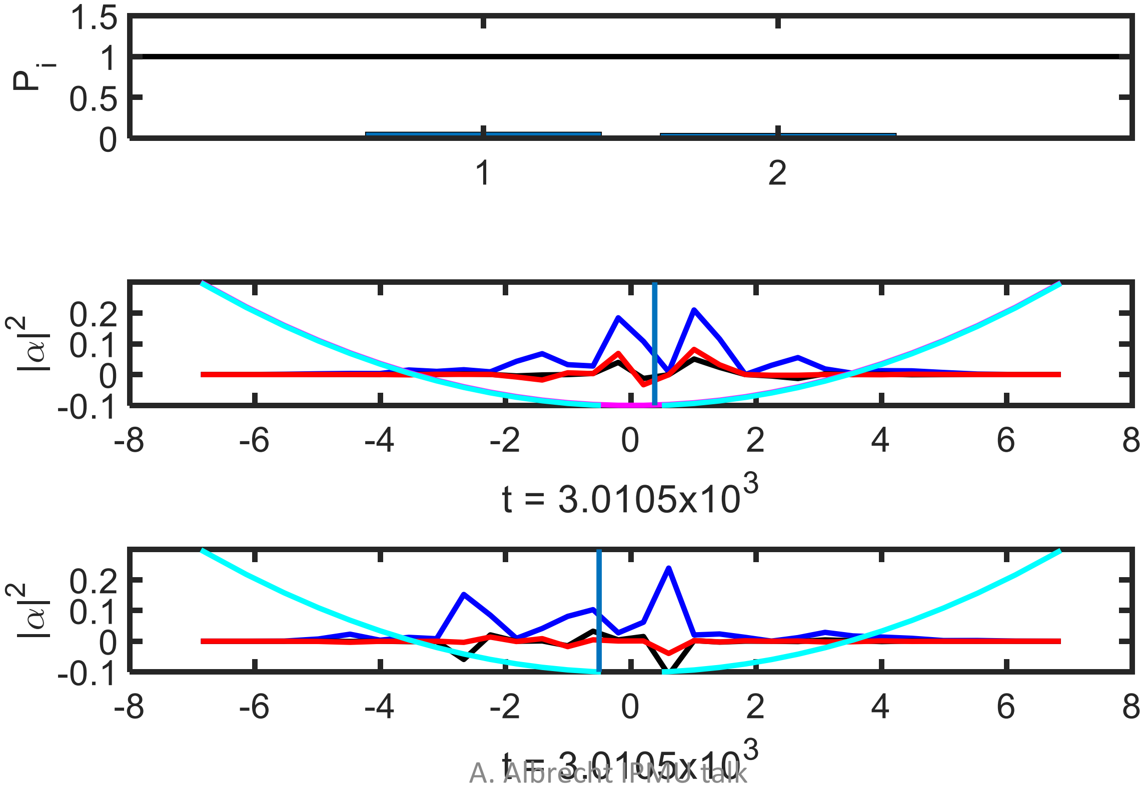

SHO density matrix in eqm

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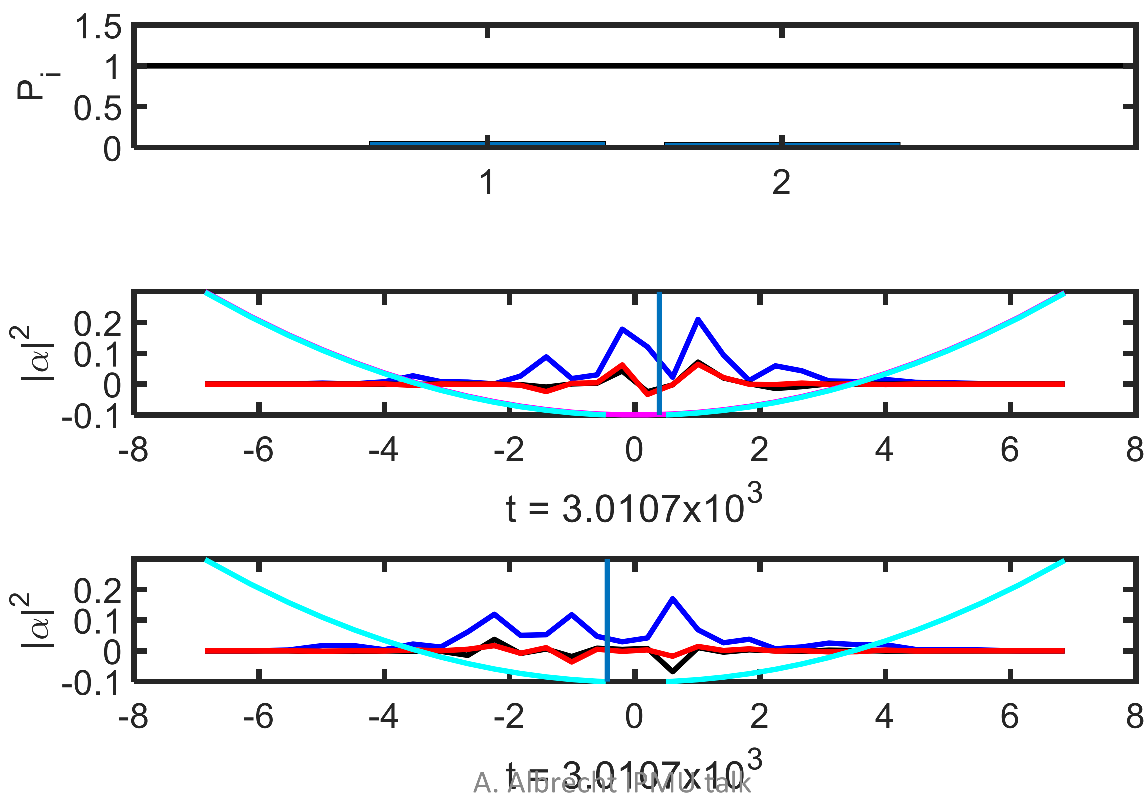

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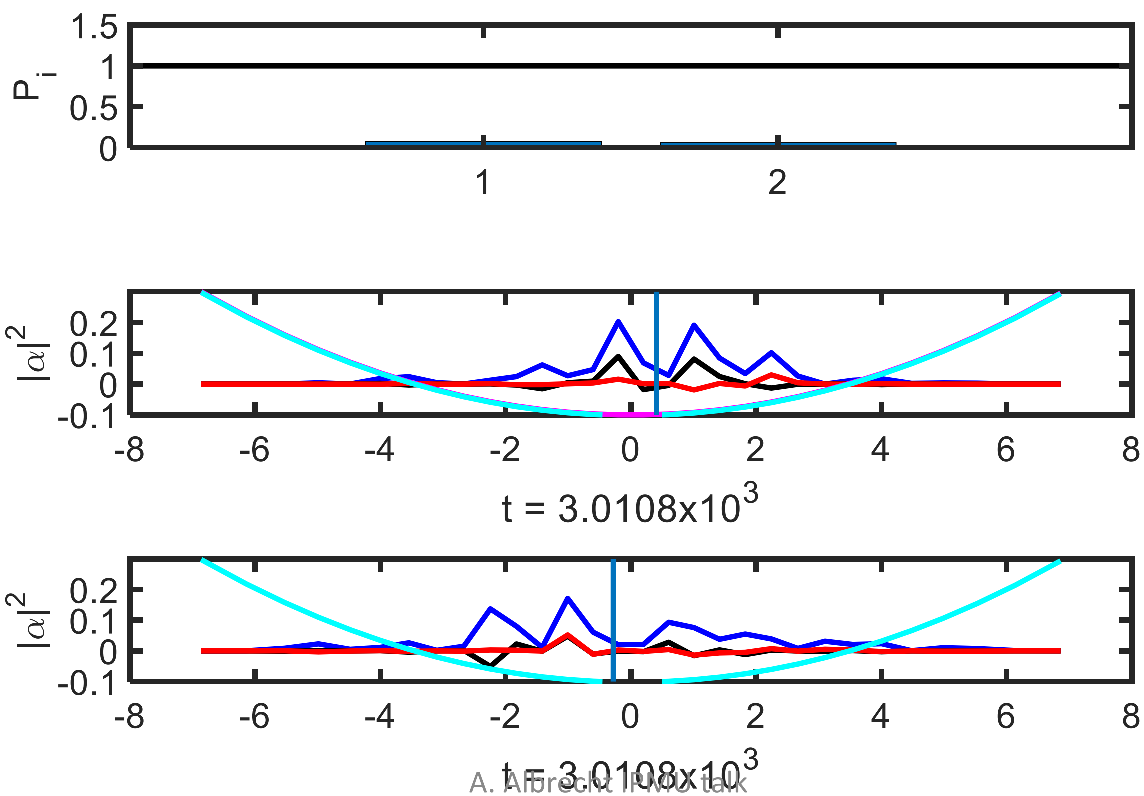

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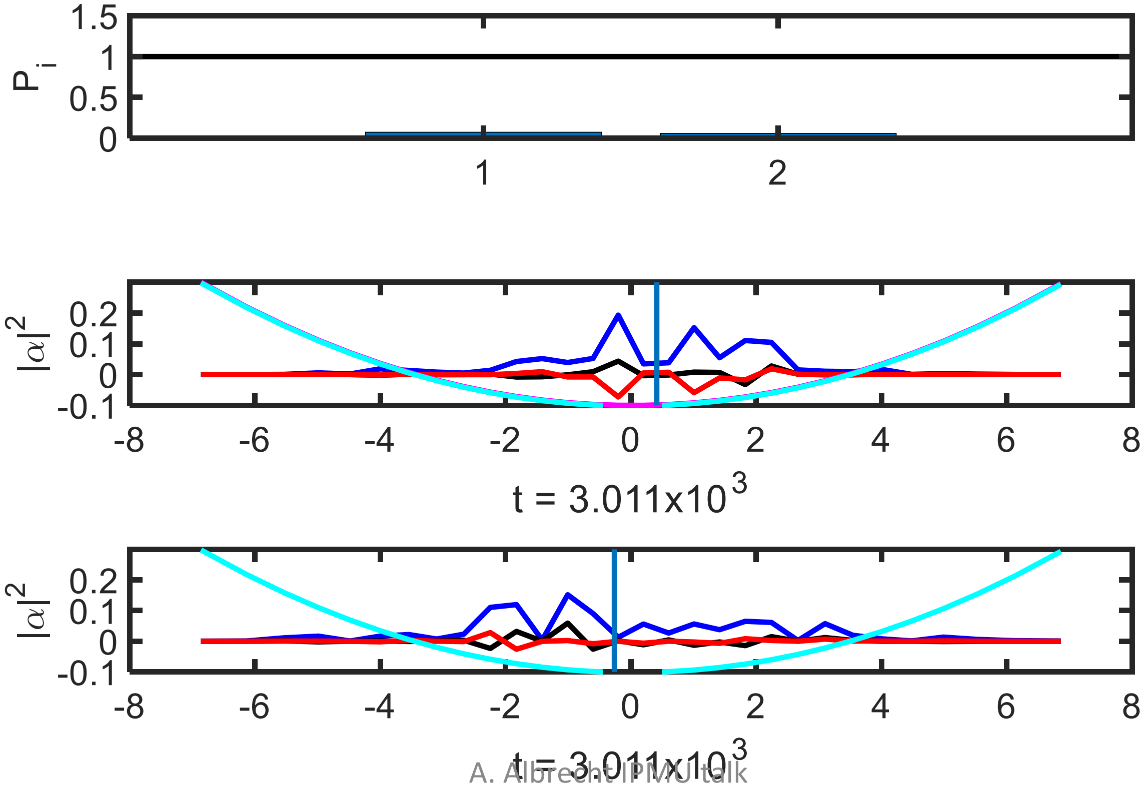

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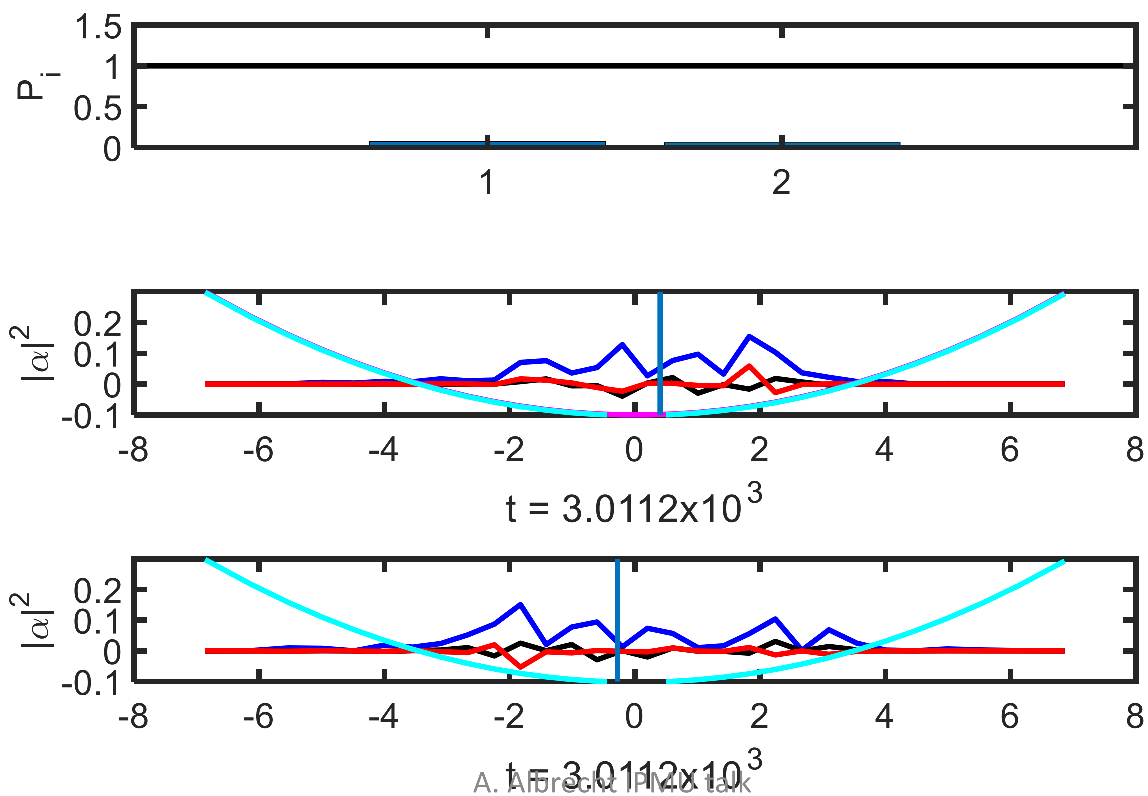

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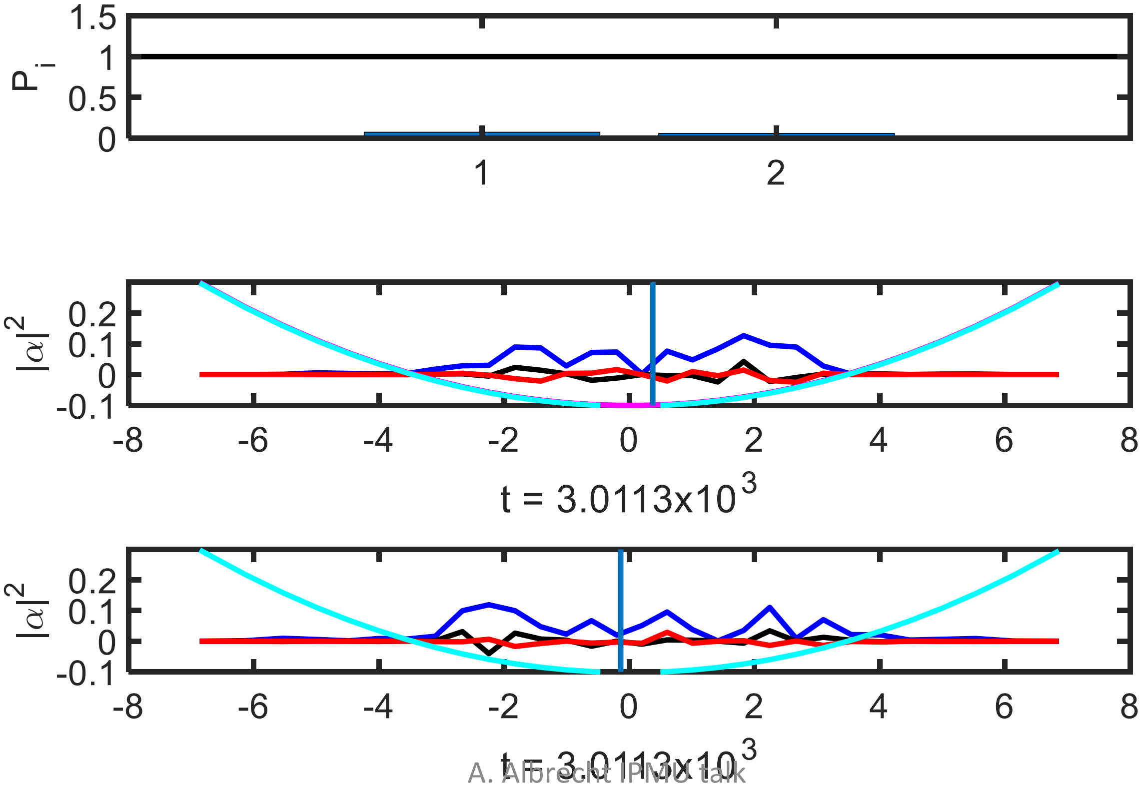

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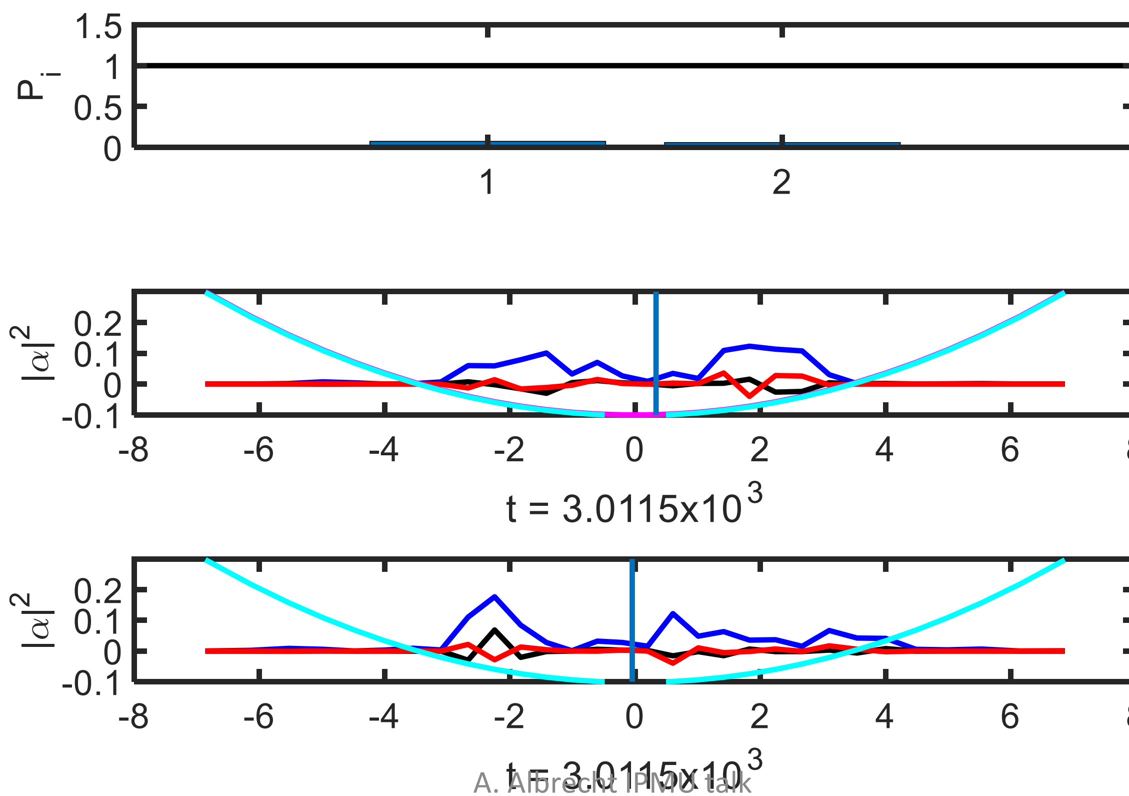

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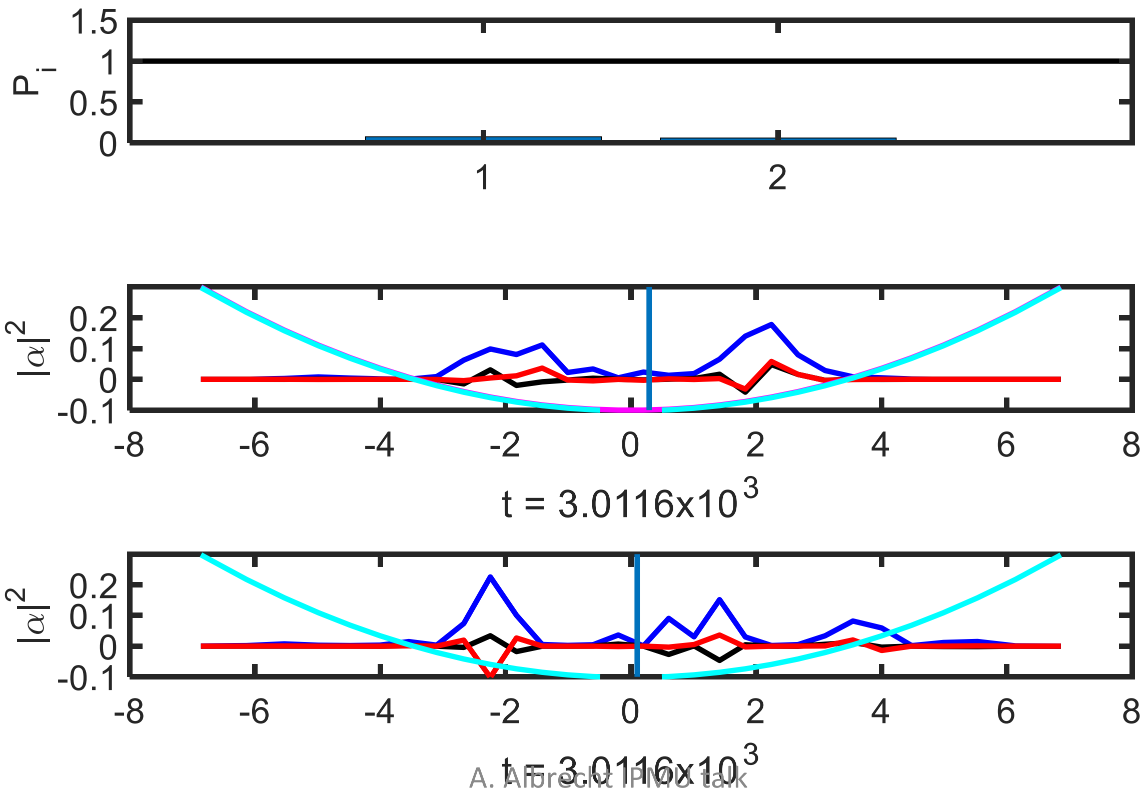

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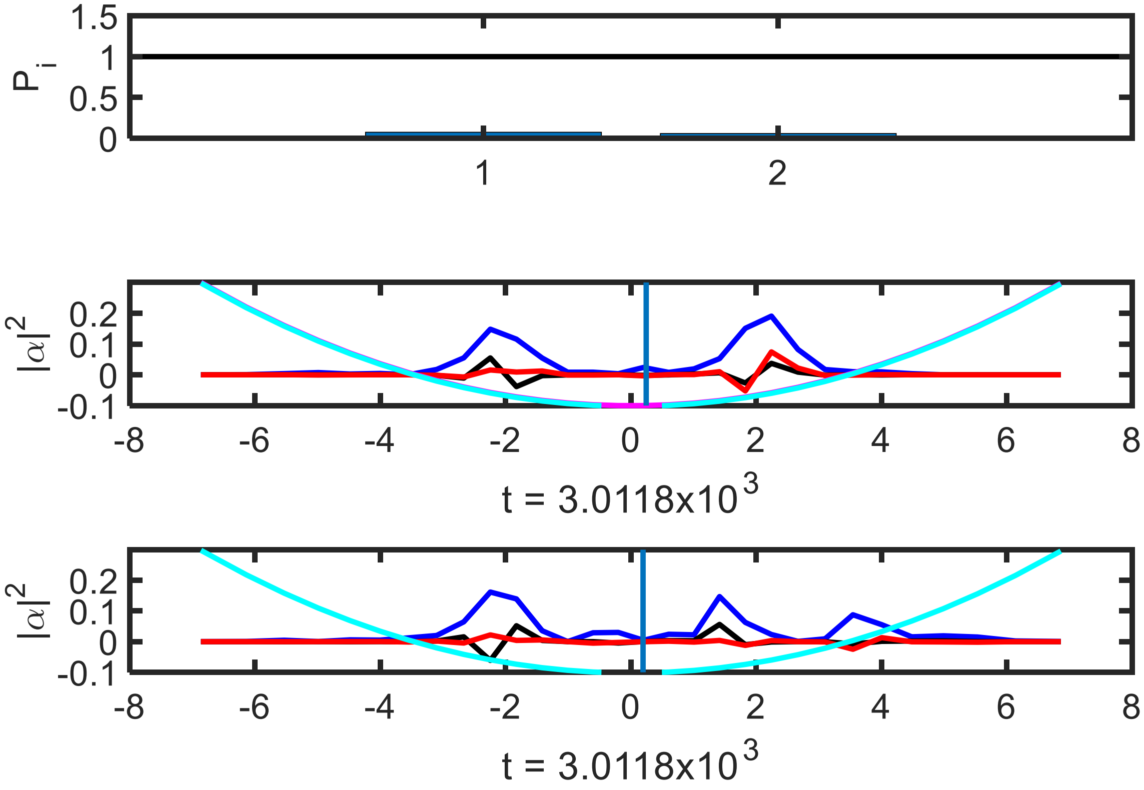

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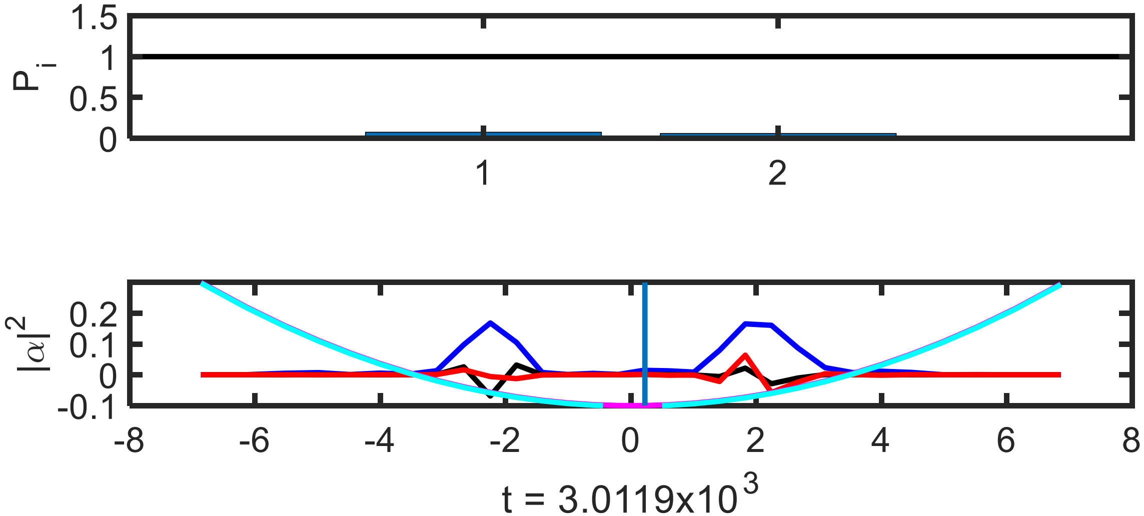

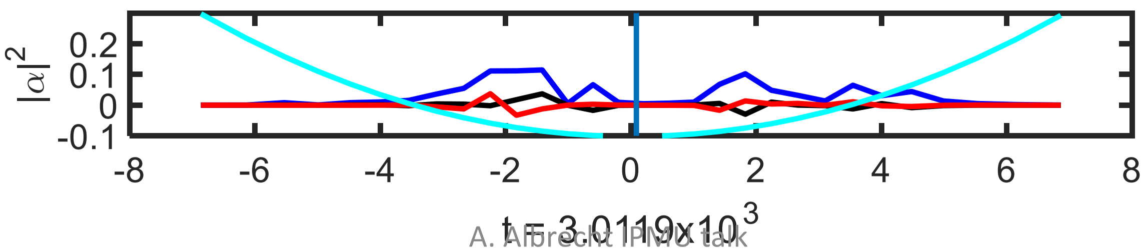

SHO density matrix in eqm

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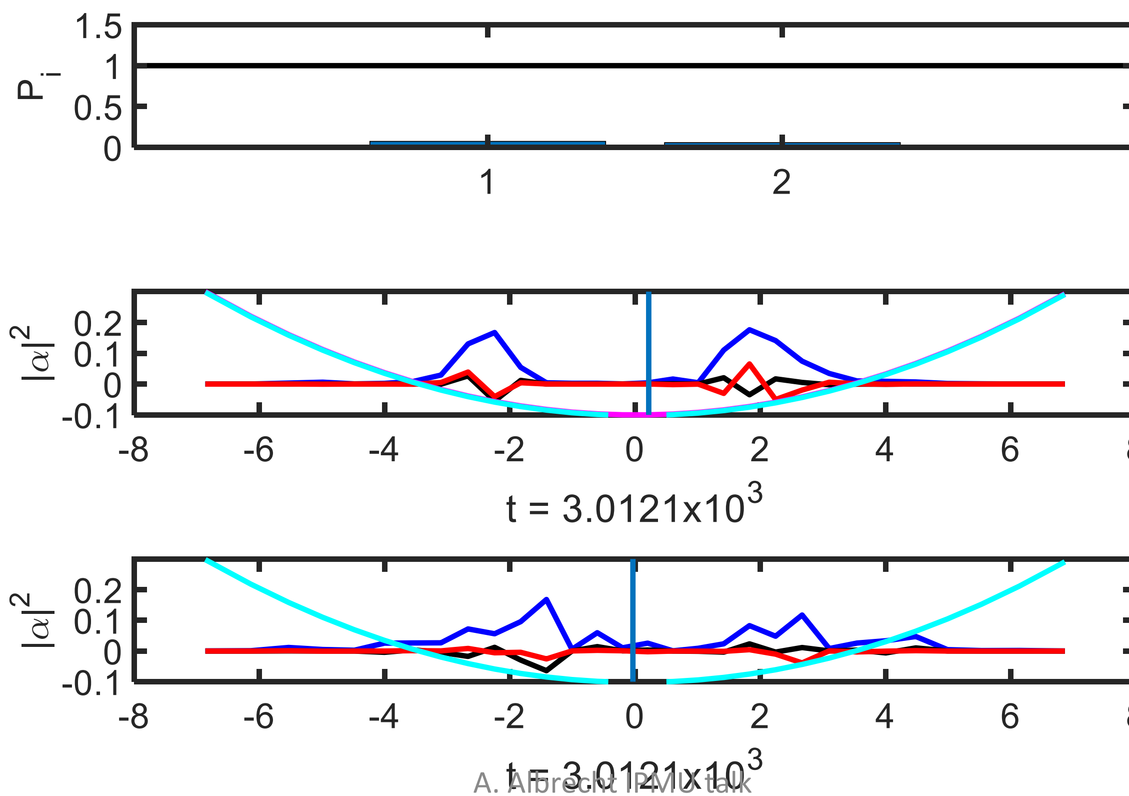

SHO density matrix in eqm

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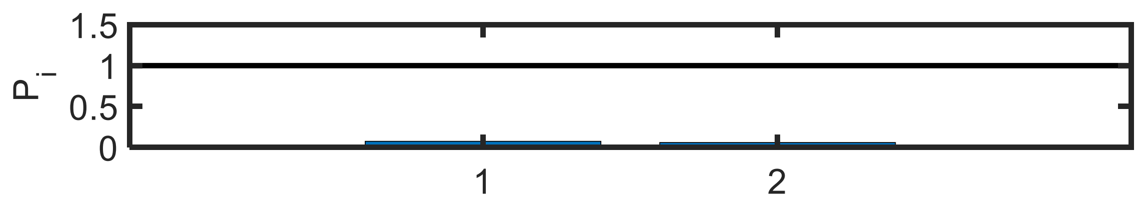

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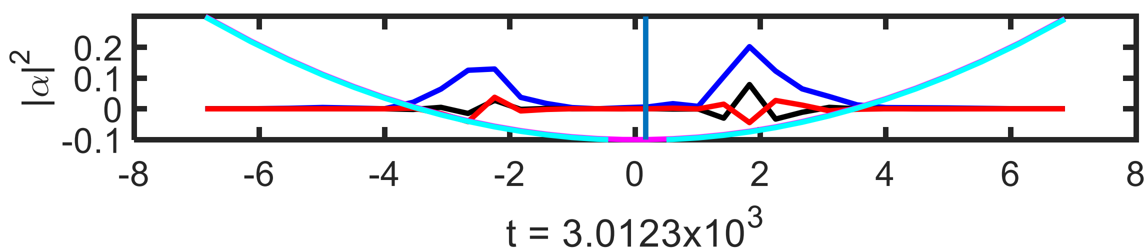
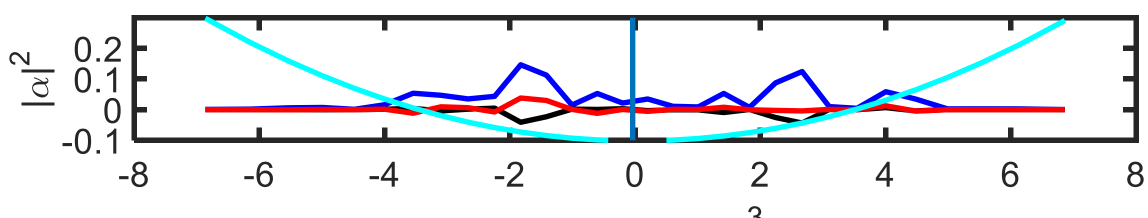


Eigenstates



SHO density matrix in eqm

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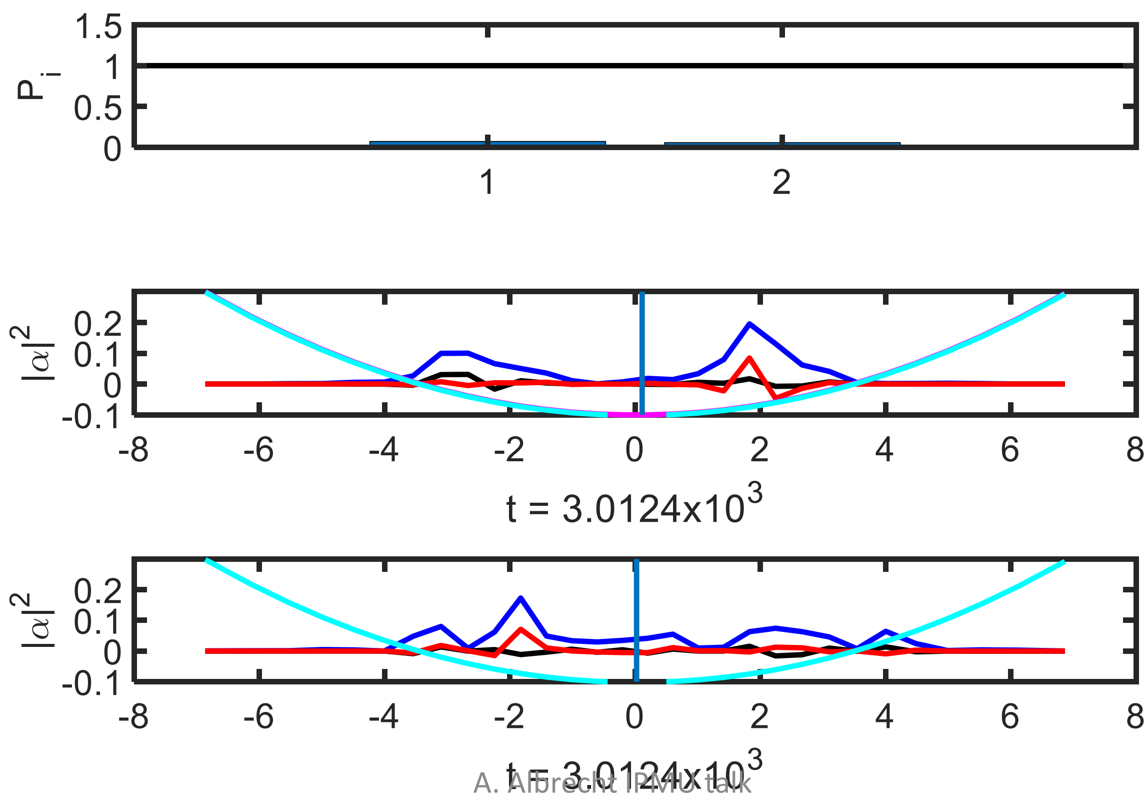

SHO density matrix in eqm

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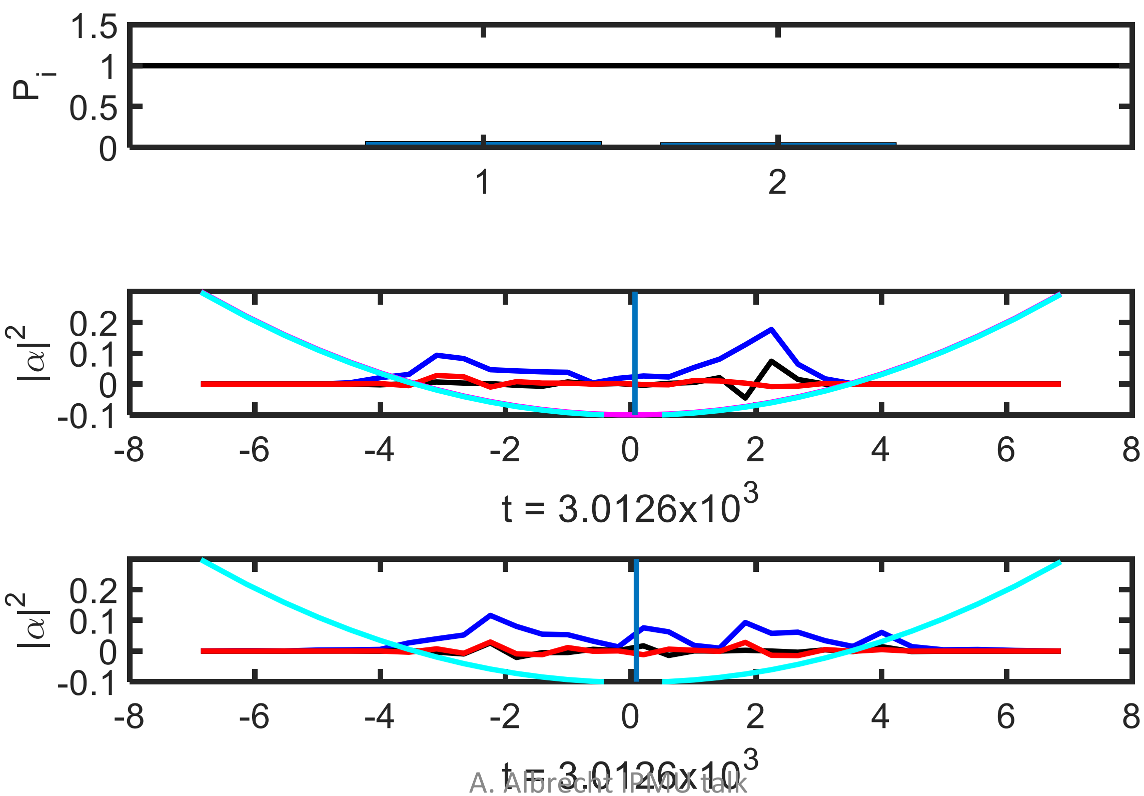
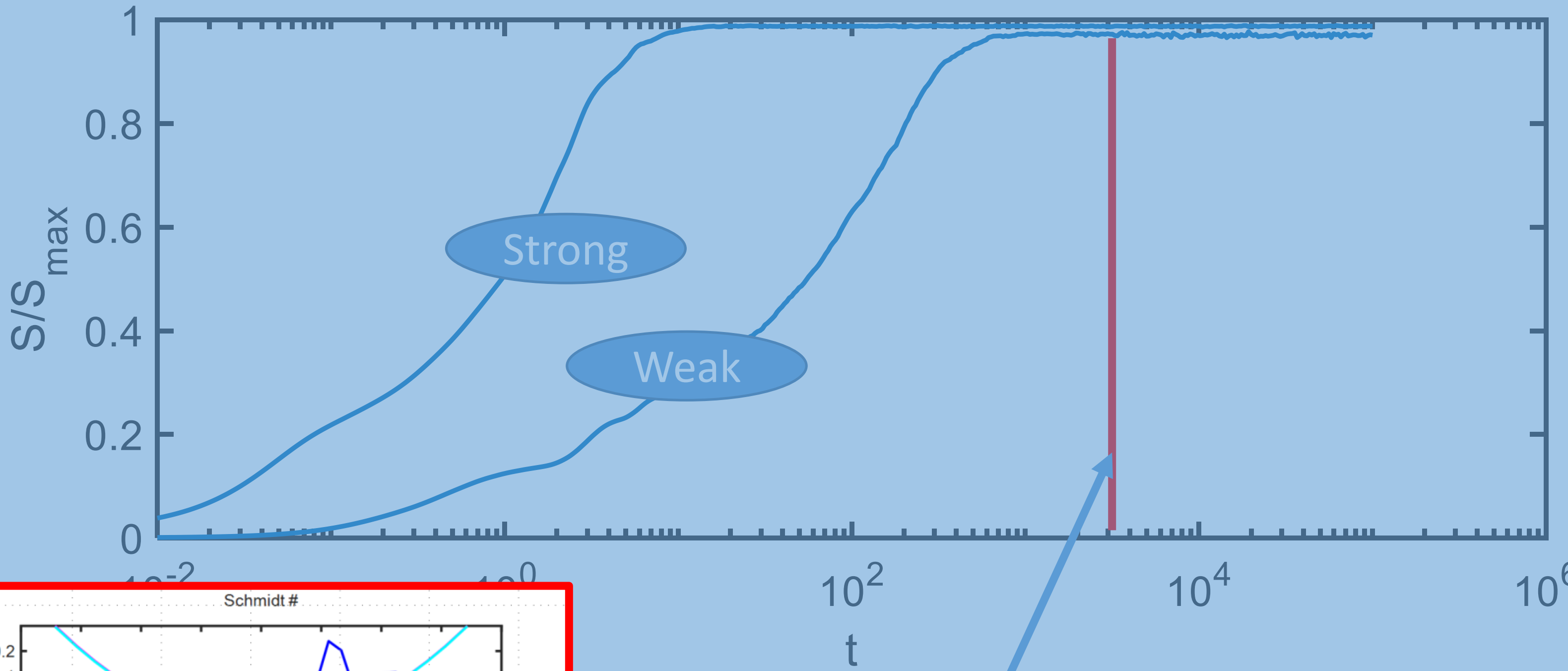
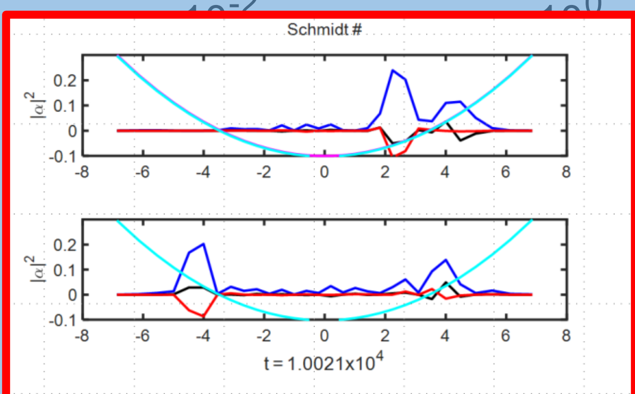


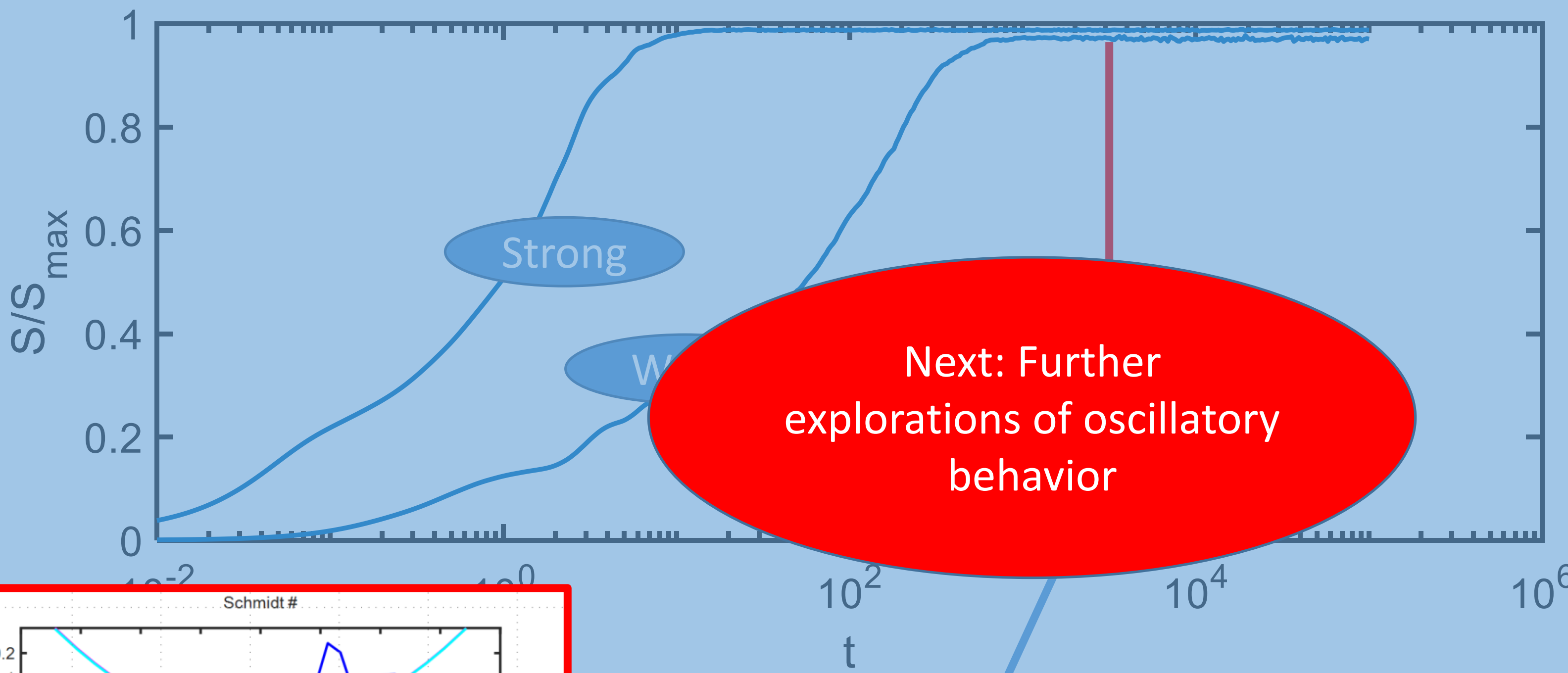




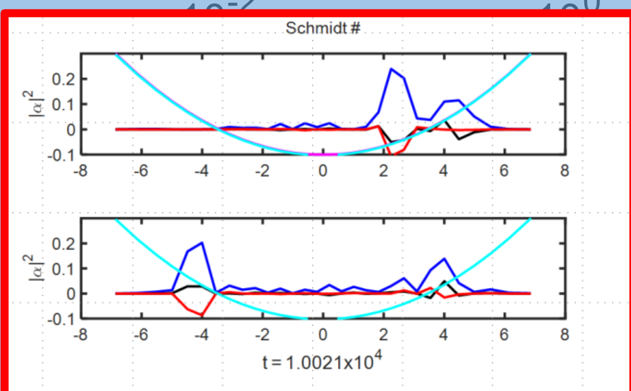
Movie E shows the weakly interacting toy model in eqm phase

➔ Some “noticeable” oscillatory behavior

Show Movie E



Next: Further explorations of oscillatory behavior



Show Movie E

Movie E shows the weakly interacting toy model in eqm phase

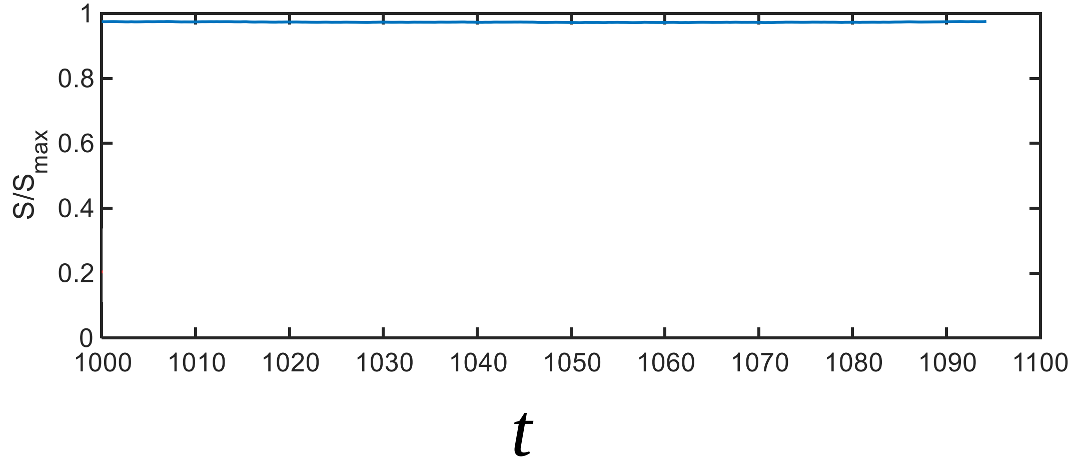
➔ Some "noticeable" oscillatory behavior

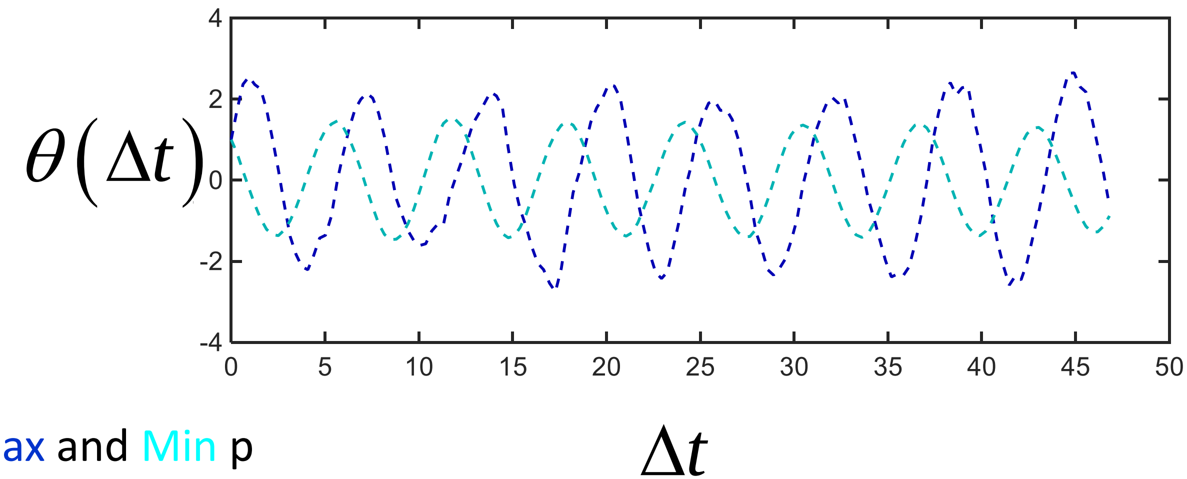
Further analysis:

Time-time correlation function

$$f(t) \equiv \langle \hat{q}_{SHO} \rangle_t$$

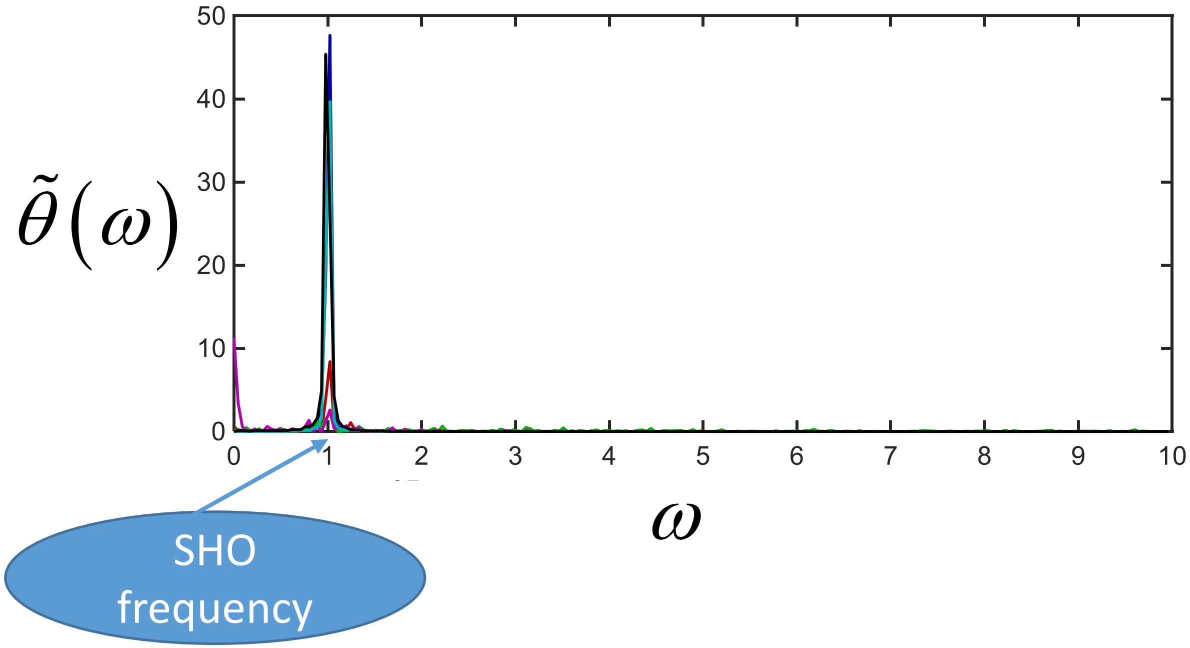
$$\theta(\Delta t) \equiv \int f(t)\, f(t+\Delta t)\, dt$$





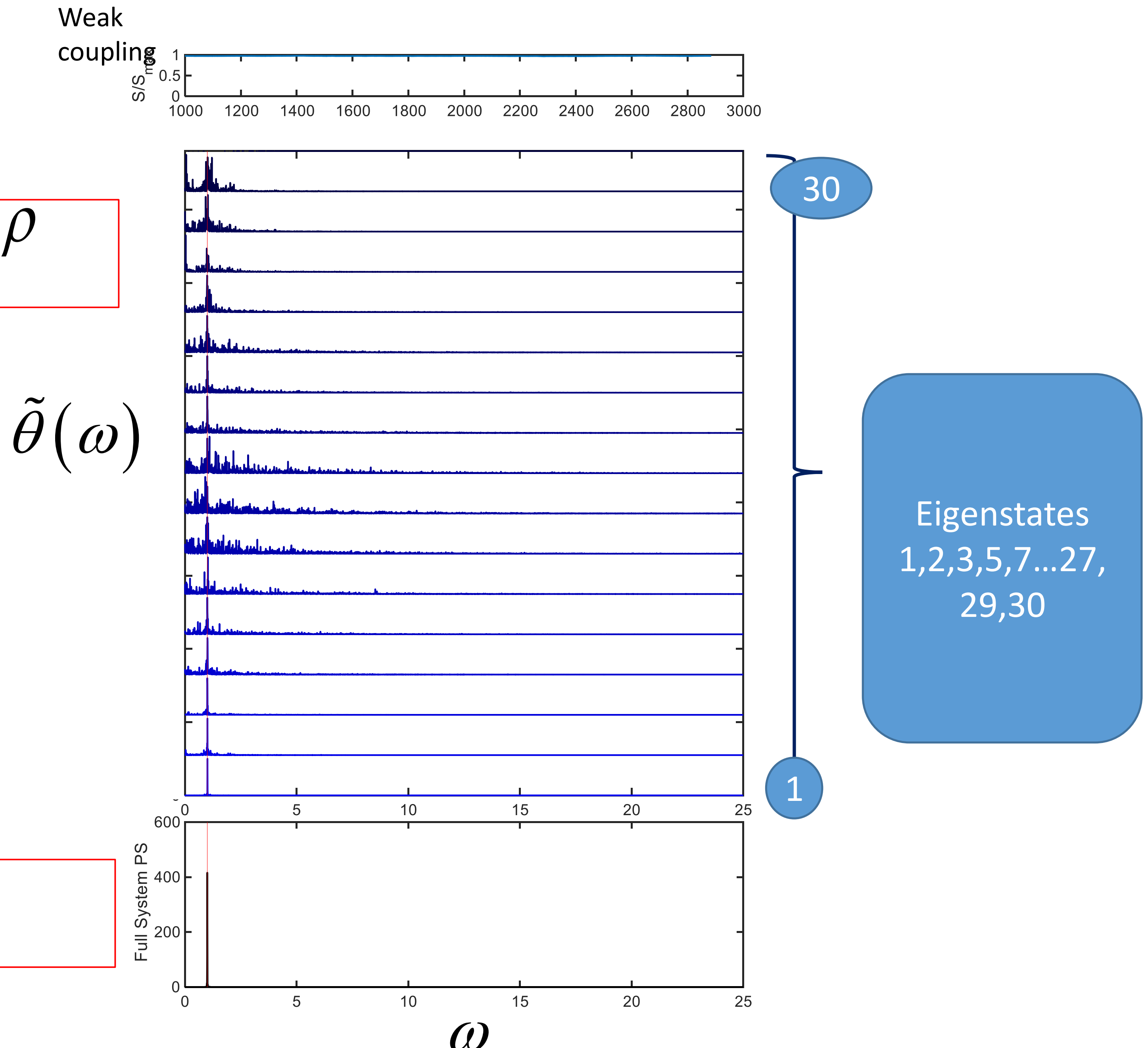
Max and Min p eigenvectors

Power spectrum

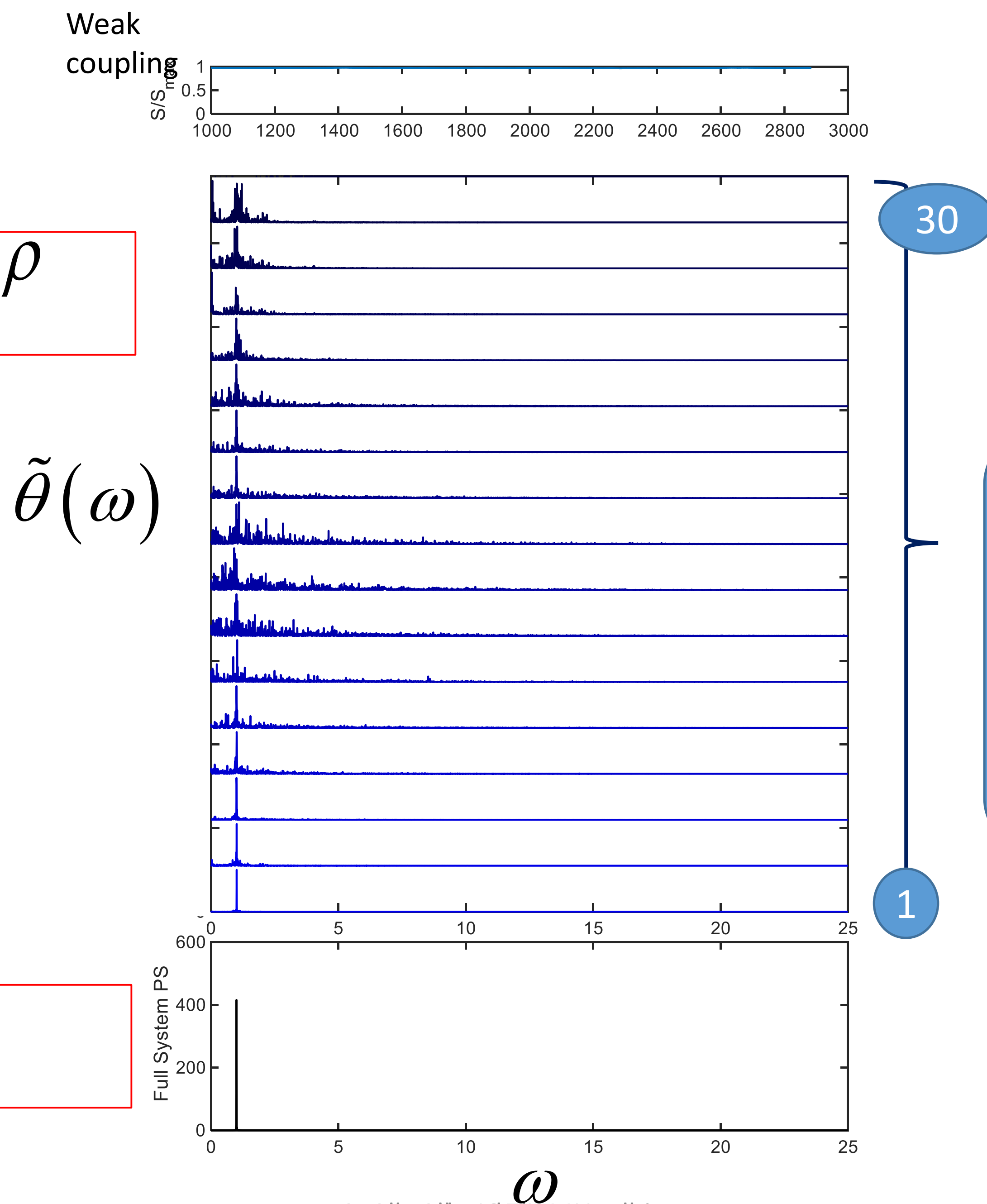


Power spectra by ρ eigenstate

Full system power spectra



Power spectra by ρ eigenstate

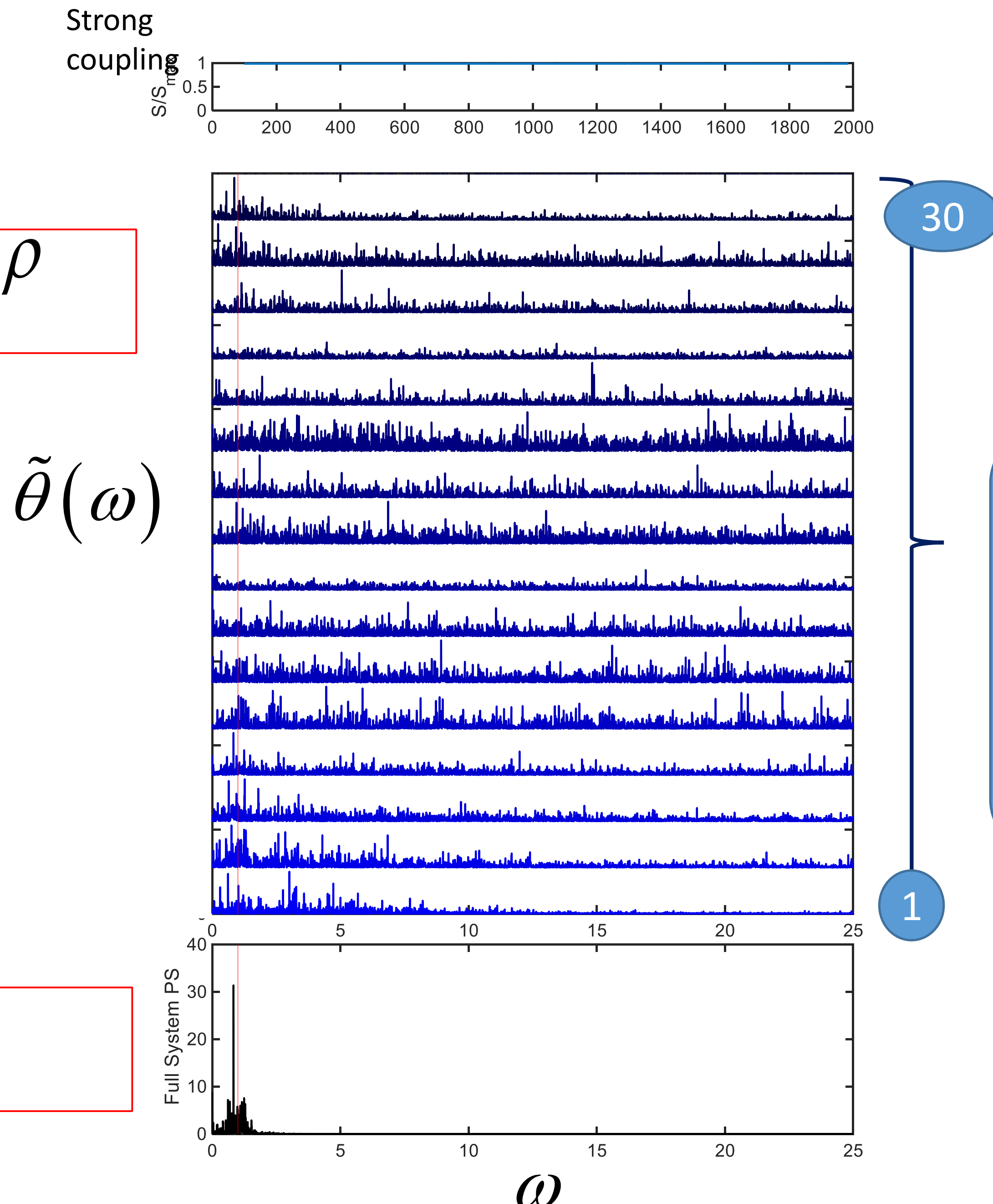


Eigenstates 1,2,3,5,7…27, 29,30

Full system power spectra

Now look at strong coupling, where Eqm seemed more noisy

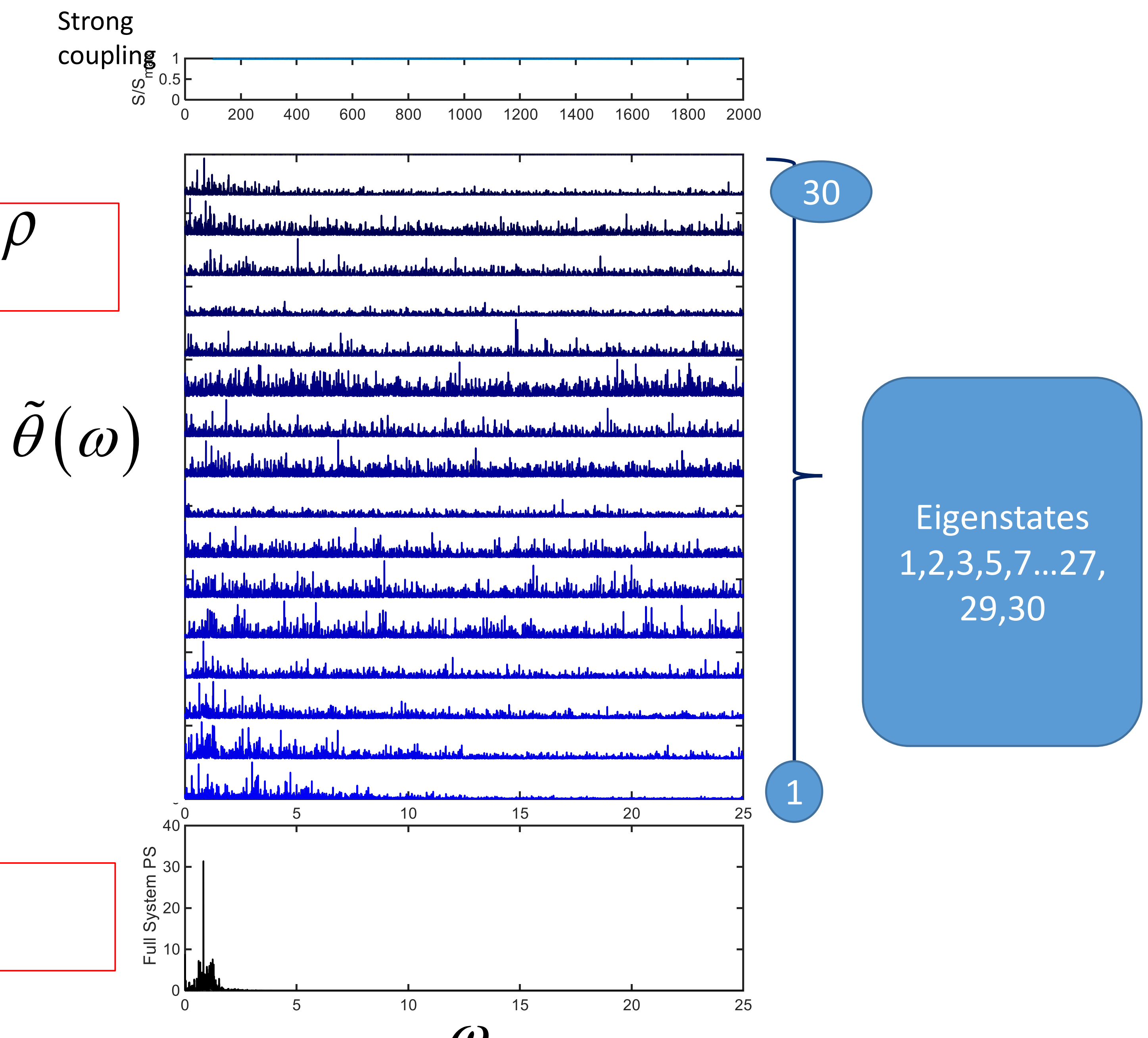
Power spectra by ρ eigenstate



Eigenstates 1,2,3,5,7…27, 29,30

Full system power spectra

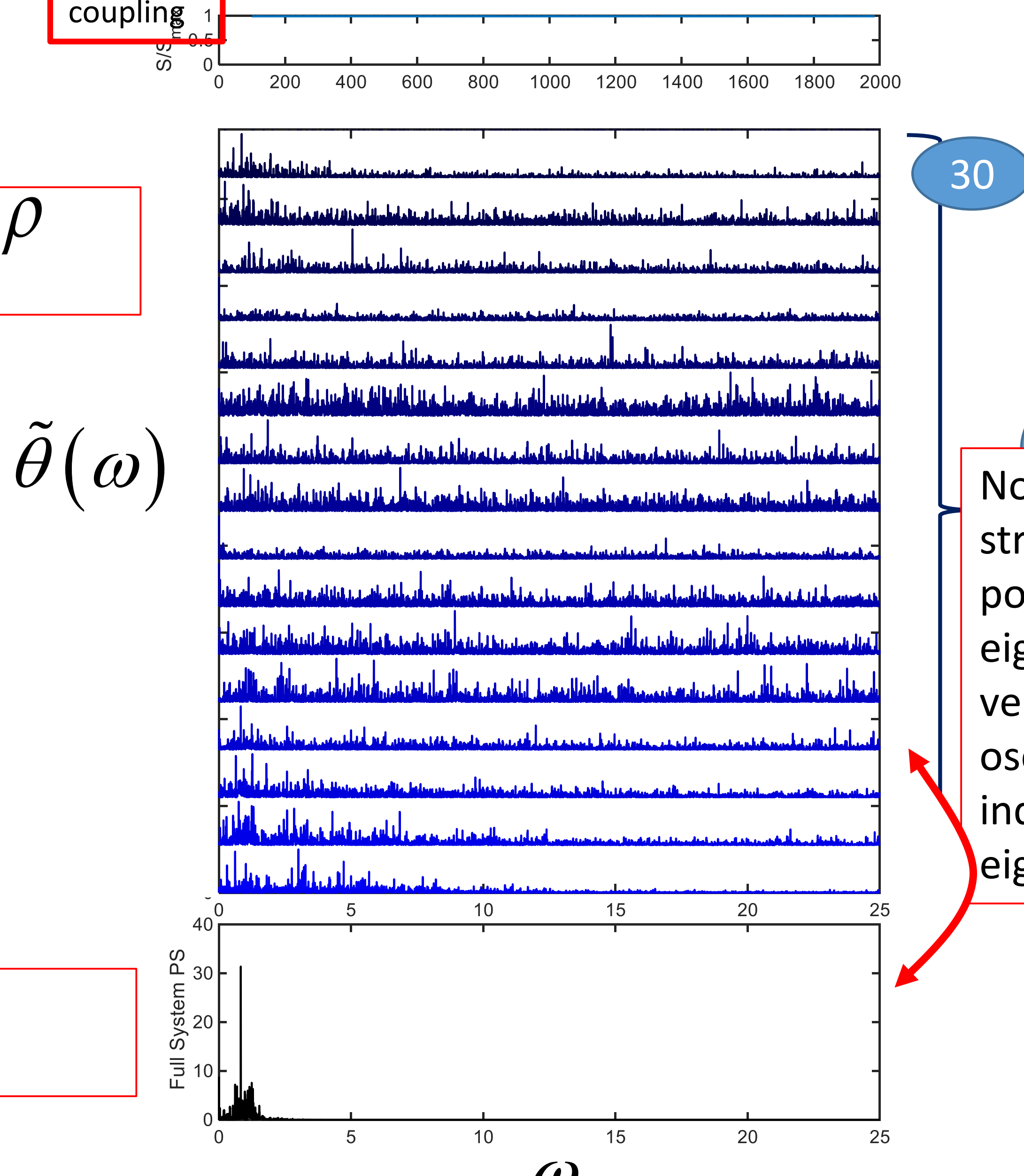
Power spectra by ρ eigenstate



Full system power spectra

Strong coupling

Power spectra by ρ eigenstate



Note: Relatively strong peak in total power spectrum (vs eigenstates), but very low amplitude oscillations (vs individual eigenstates).

Full system power spectra

Upshot:

- ➔ Strong oscillatory signal in <q> for ρ eigenstates for weakly coupled case (despite messy overall wavefunction shapes)

- ➔ No such signal for strongly coupled case

- ➔ Both cases show strong oscillatory signal for $\langle q\rho \rangle$ but amplitude is small.

Upshot:

- Strong oscillatory signal in <q> for ρ eigenstates for weakly coupled case (despite messy overall wavefunction shapes)
- No such signal for strongly coupled case
- Both cases show strong oscillatory signal for $\langle q\rho \rangle$ but amplitude is small.

NEXT: A consistent histories approach

Consistent histories (CH):

- → <u>Generally, in the path integral formulation of QM interference among paths plays an important role</u>

- → CH formalism identifies paths where interferences effects are NOT important. These are the paths to which probabilities can be assigned, and which are classical in that sense.

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(Define histories on a discrete time grid)

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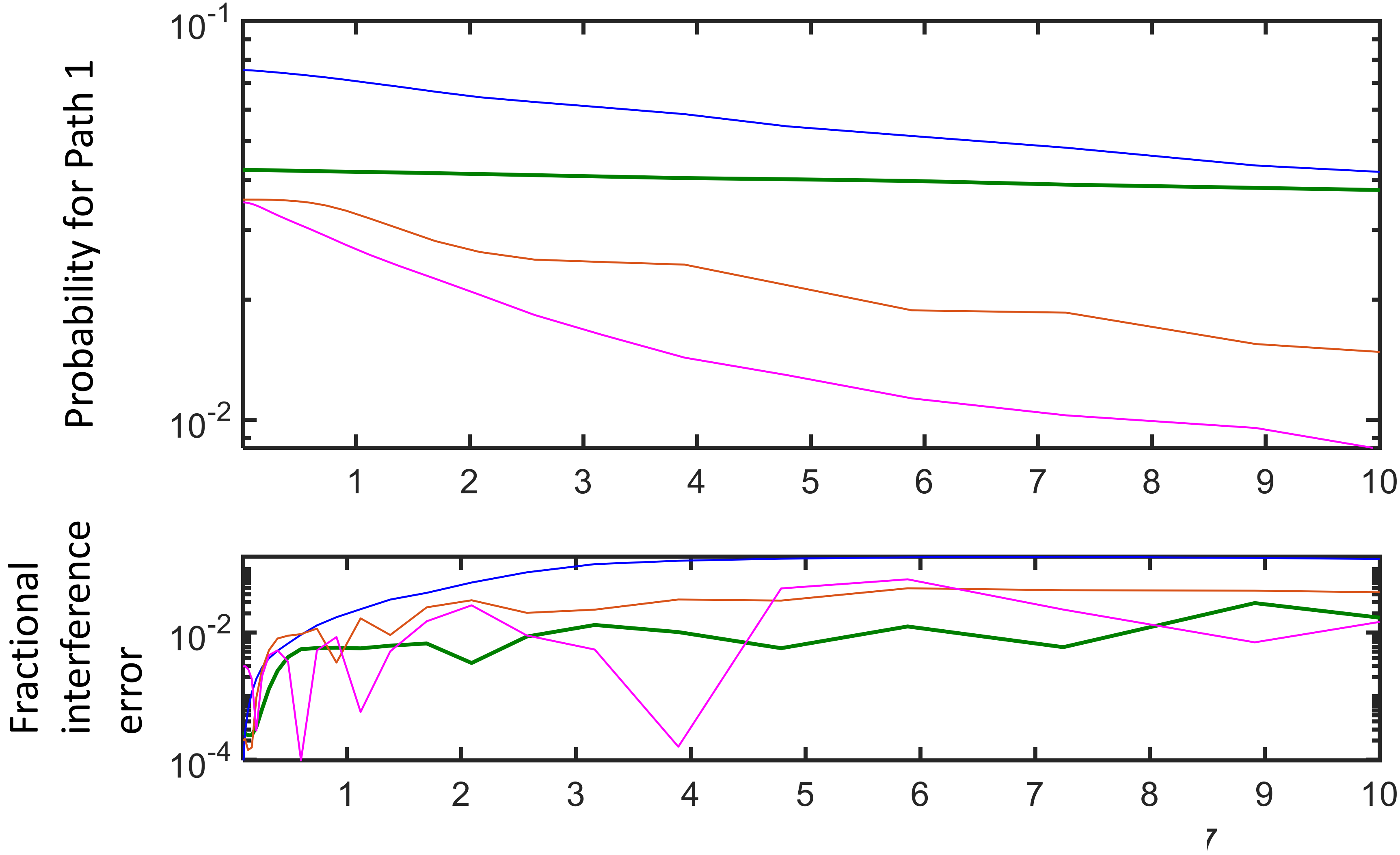
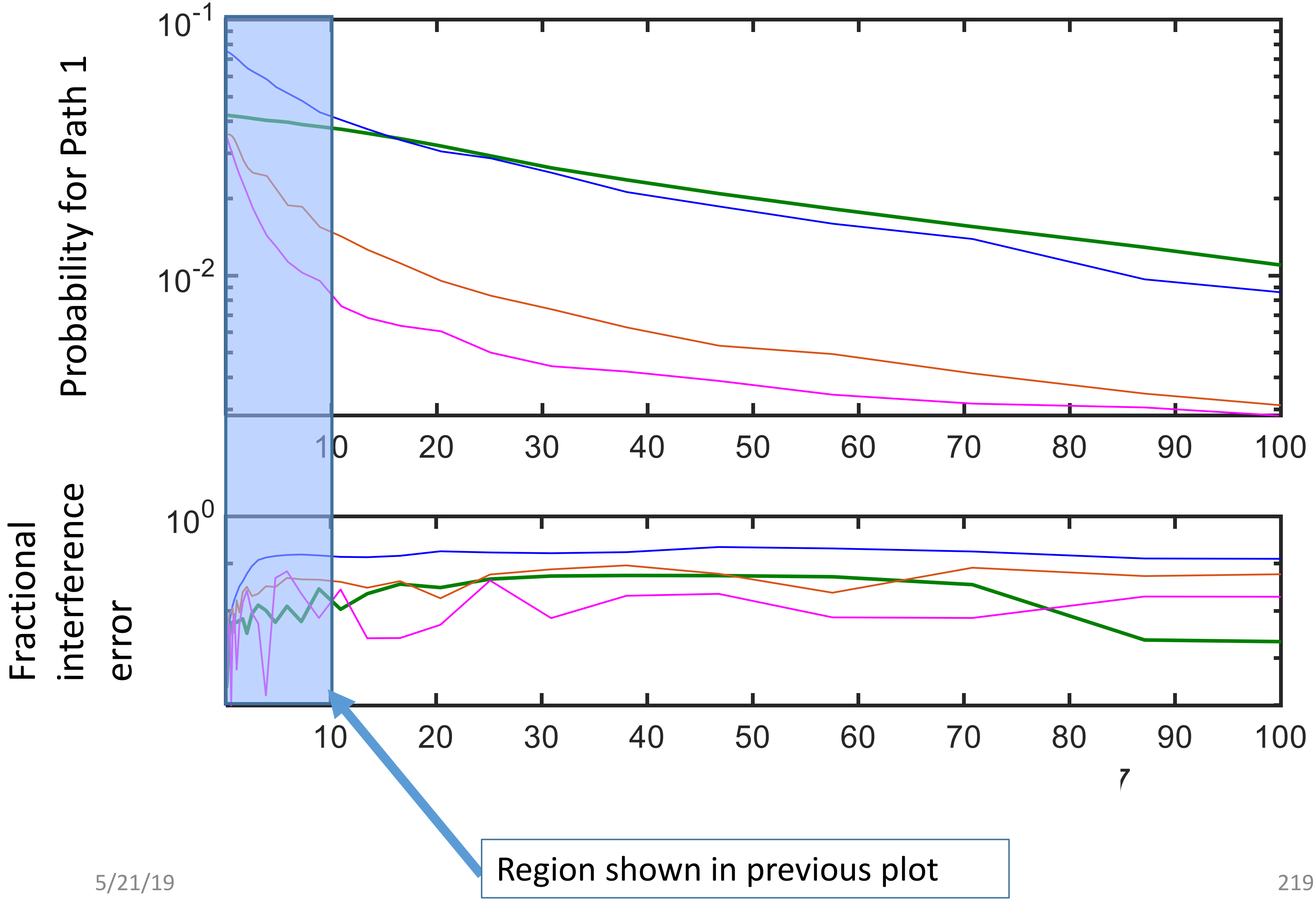
Histories built from coherent states **(green)** degrade more slowly than histories built from other states.



Histories built from coherent states **(green)** degrade more slowly than histories built from other states. But eventually the coherent state paths degrade too.



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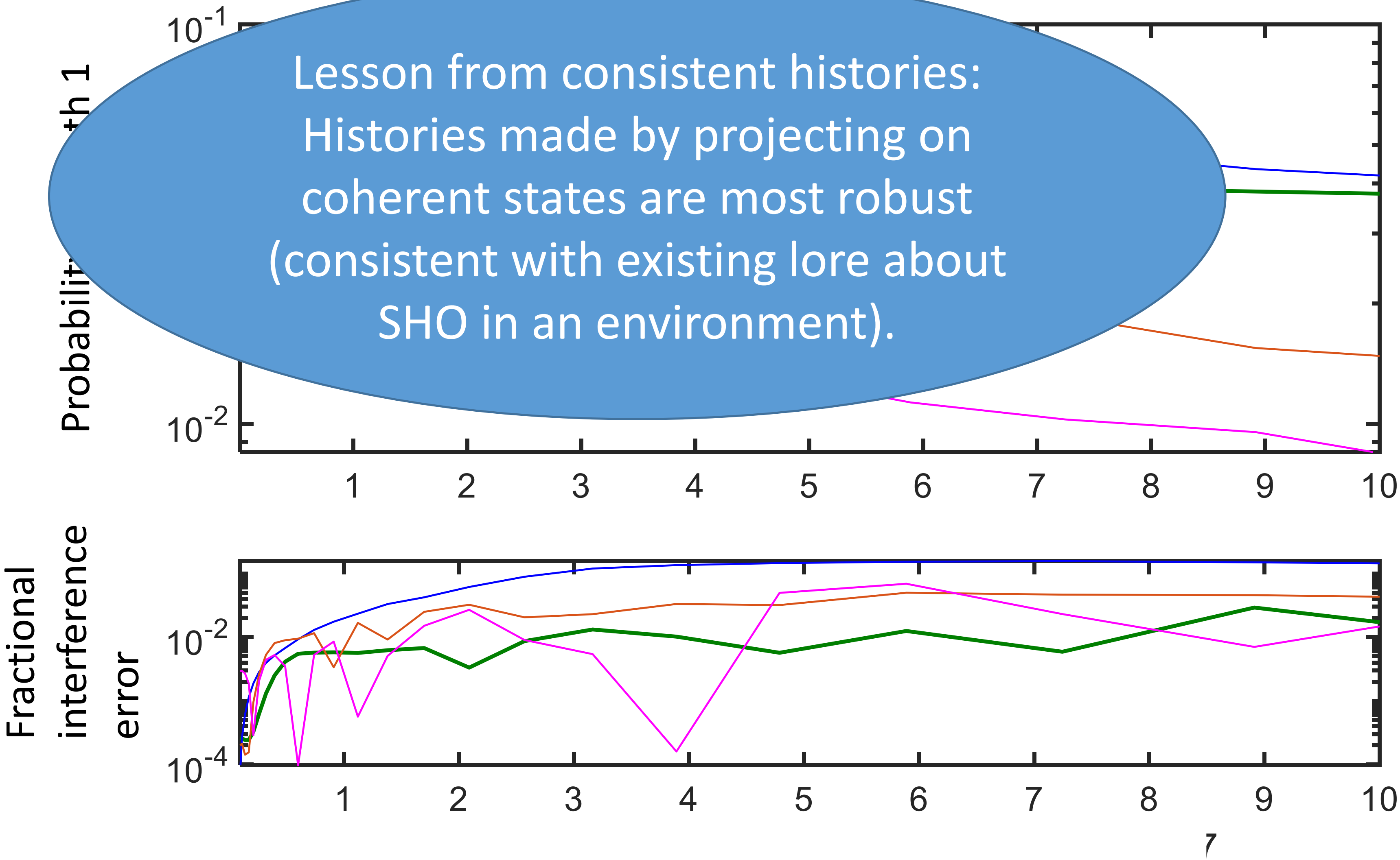
Lesson from consistent histories: Histories made by projecting on coherent states are most robust (consistent with existing lore about SHO in an environment).



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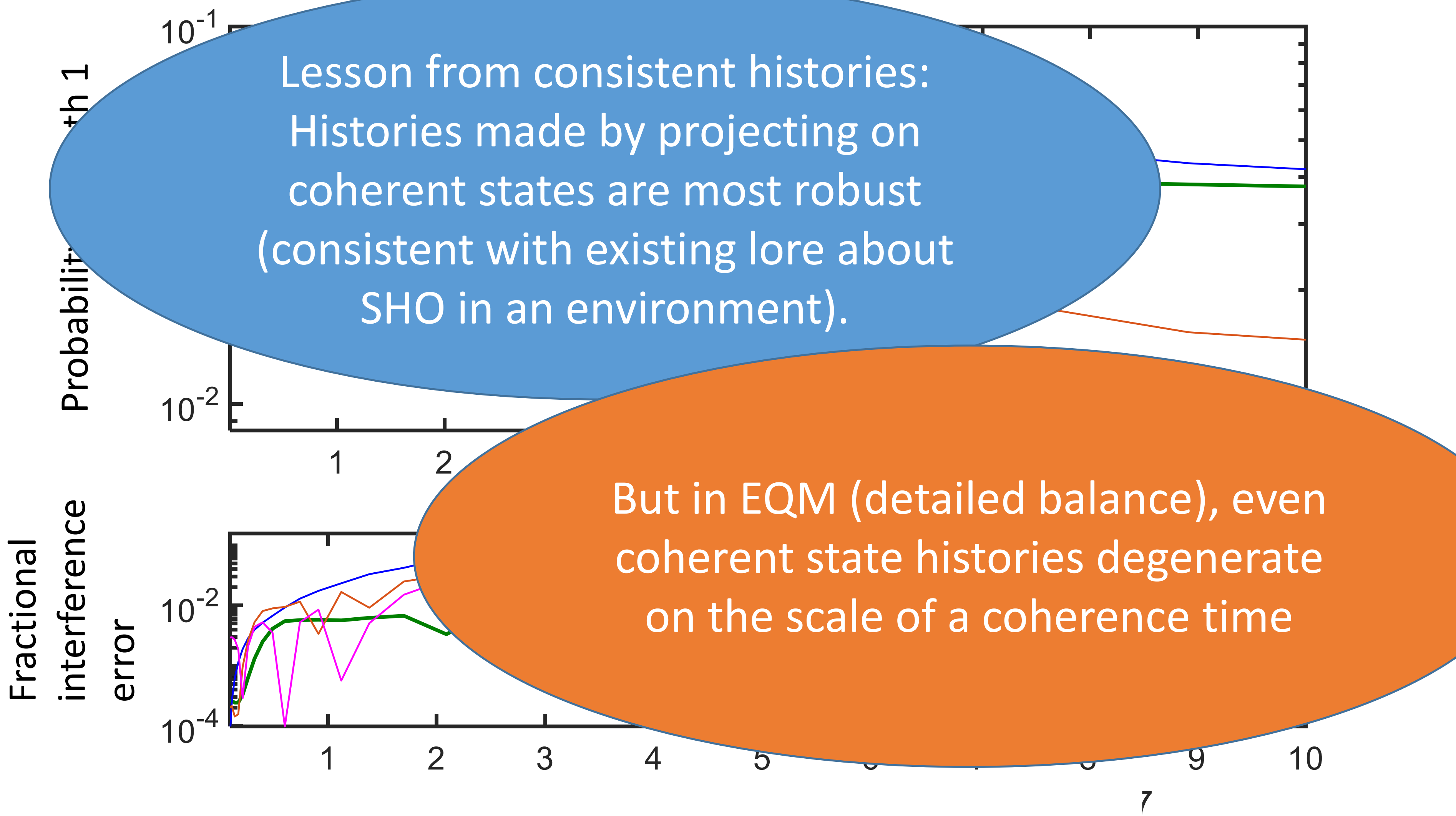

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But in EQM (detailed balance), even coherent state histories degenerate on the scale of a coherence time

Lessons from eqm studies in the adapted CL model:

- ➔ Plenty of messiness in eqm ("wallowing or interfering Everett worlds")
- ➔ Still, some intriguing sign of "classicality" show up in the power spectra of density matrix eigenstates.
- ➔ Consistent Histories formalism shows some classical behavior (which degrades after a couple of SHO periods)
- ➔ Further discussion of implications at end of talk.

Outline

1. Motivations
2. Introduction to einselection and the toy model
3. Einselection in equilibrium (technical explorations and overall assessment)
4. Eigenstate Einselection Hypothesis (if there is time)
5. Conclusions

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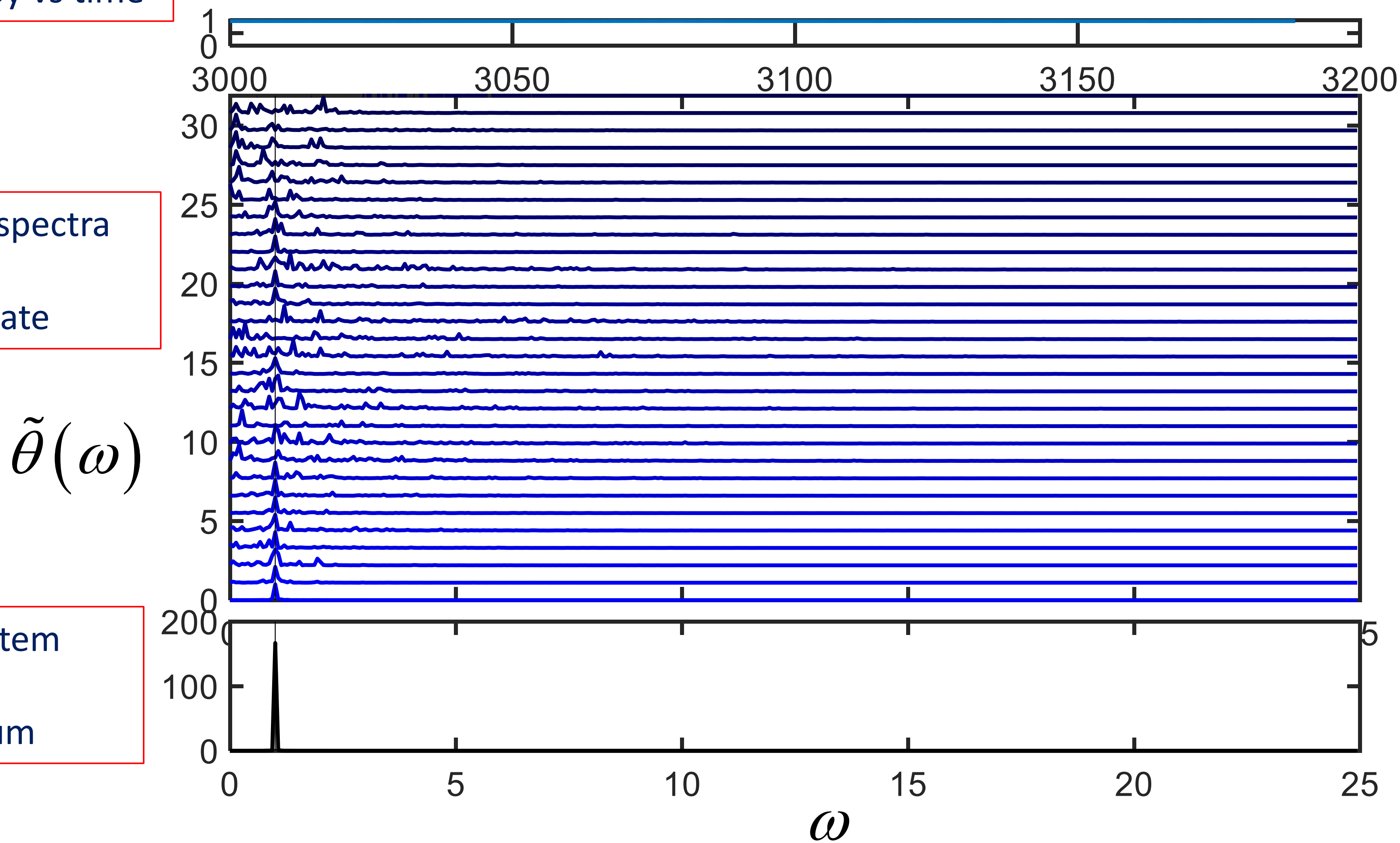
Similar power spectra to those shown above

Entropy vs time

Power spectra by eigenstate

Full system power spectrum



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Same as previous slide, but calculated for a state that has the phases of the coefficients of the expansion in energy eigenstates (of the whole system) randomized

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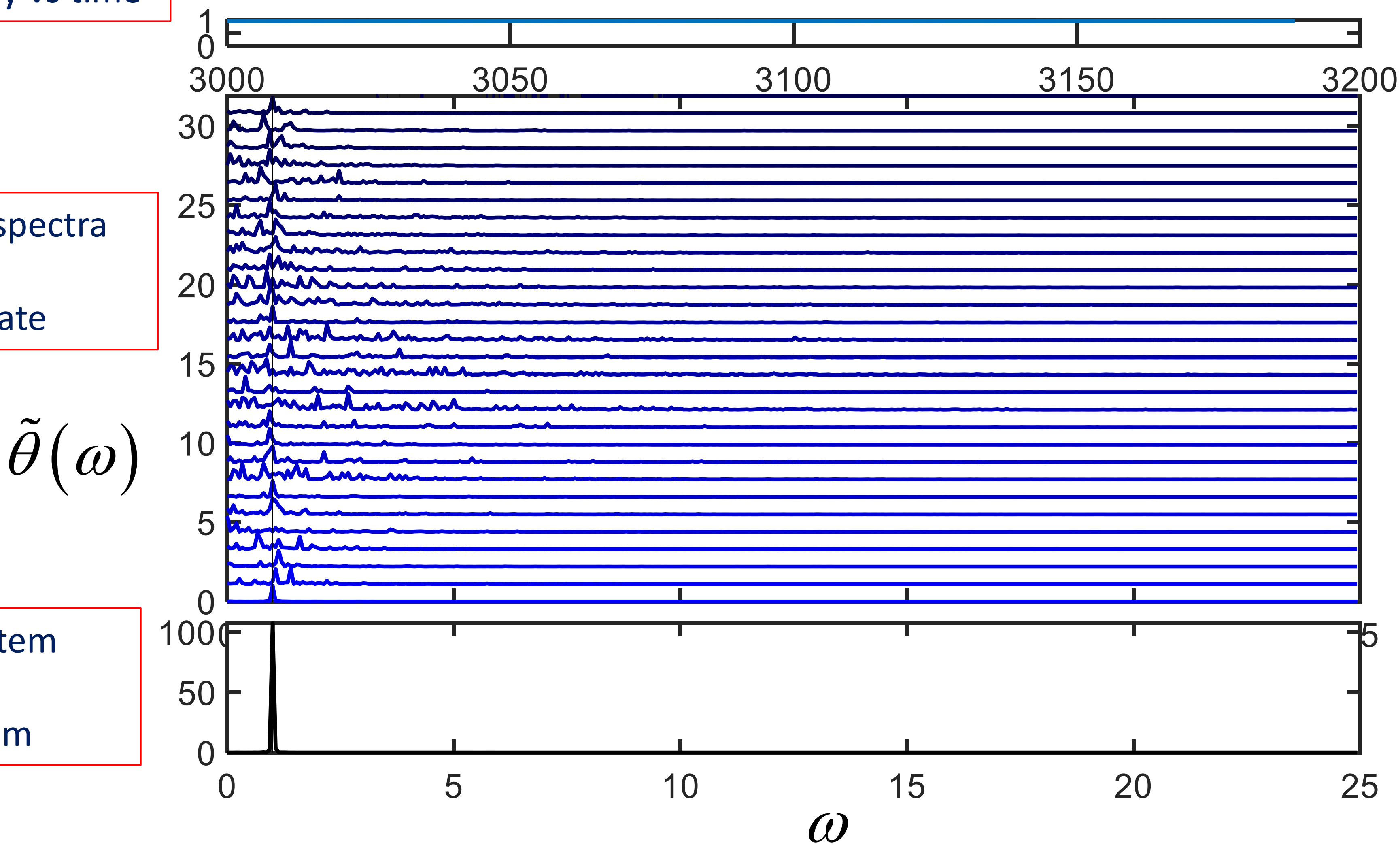

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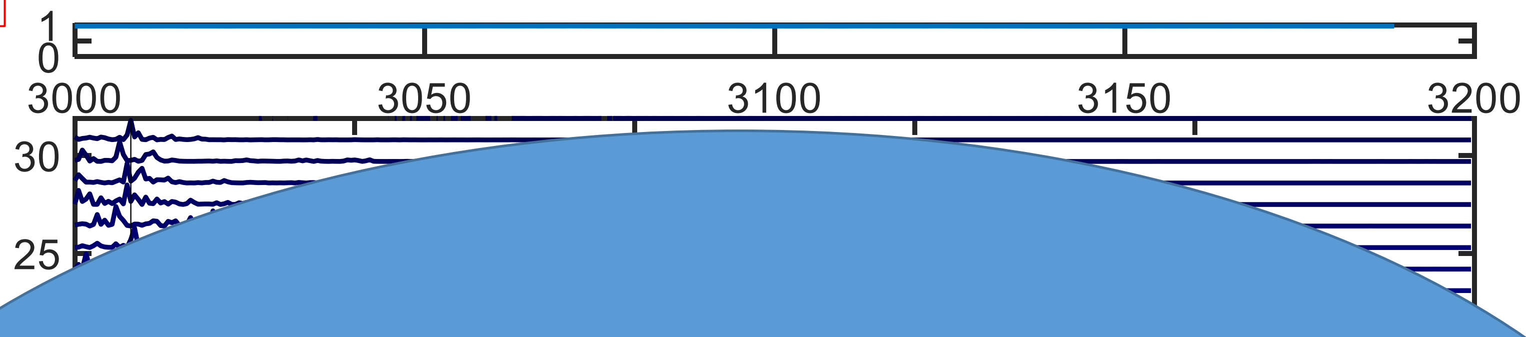

Power spectra by eigenstate

Full sy

power spectrum

- Interesting behavior of power spectra a reflection of intrinsic properties of (certain) energy eigenstates of the entire system
- Compare with “Eigenstate Thermalization Hypothesis” (ETH)
- “Eigenstate Einselection Hypothesis” (EEH)

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- The adapted CL (ACL) model reproduced results about decoherence and einselection known from the standard CL model
- The ACL allows the exploration of these phenomena under conditions not accessible to the CL model (specifically eqm.)
- We have found einselection phenomena are highly degraded in eqm., but **not** completely destroyed.
- A suggestion: Classical phenomena may persist in equilibrium on a time scale short compared to a decoherence time… interesting for cosmology.

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Interesting connection with cosmological motivations

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Compare with "de Sitter Equilibrium" scenario where decoherence time is the age of the Universe

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