

Executed Command

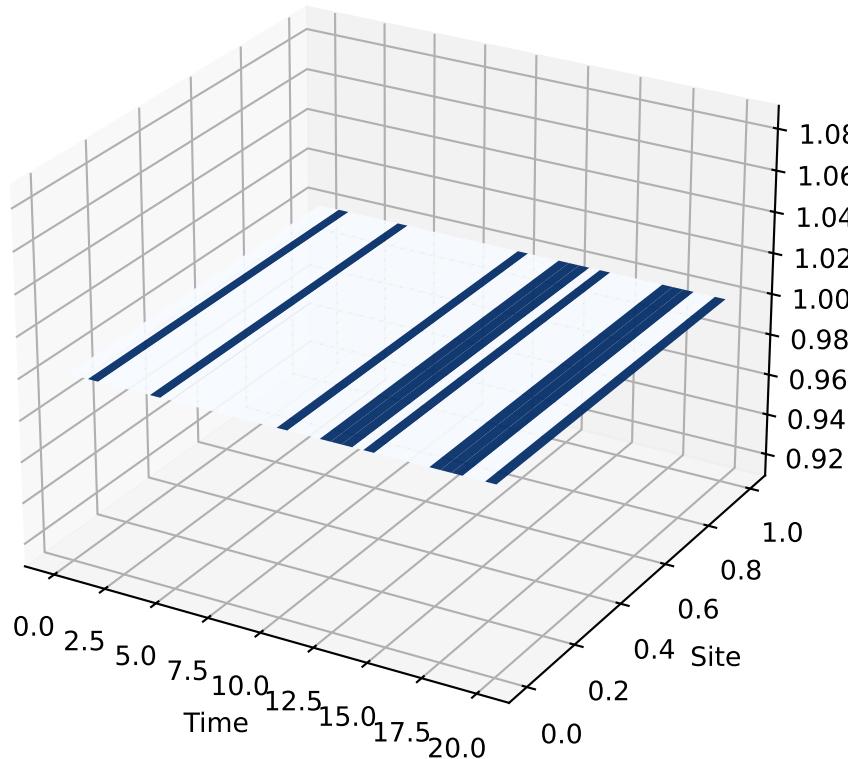
Reference: pipelines/PIPELINE\_RUN\_GUIDE.md

Script: pipelines/hardcoded\_hubbard\_pipeline.py

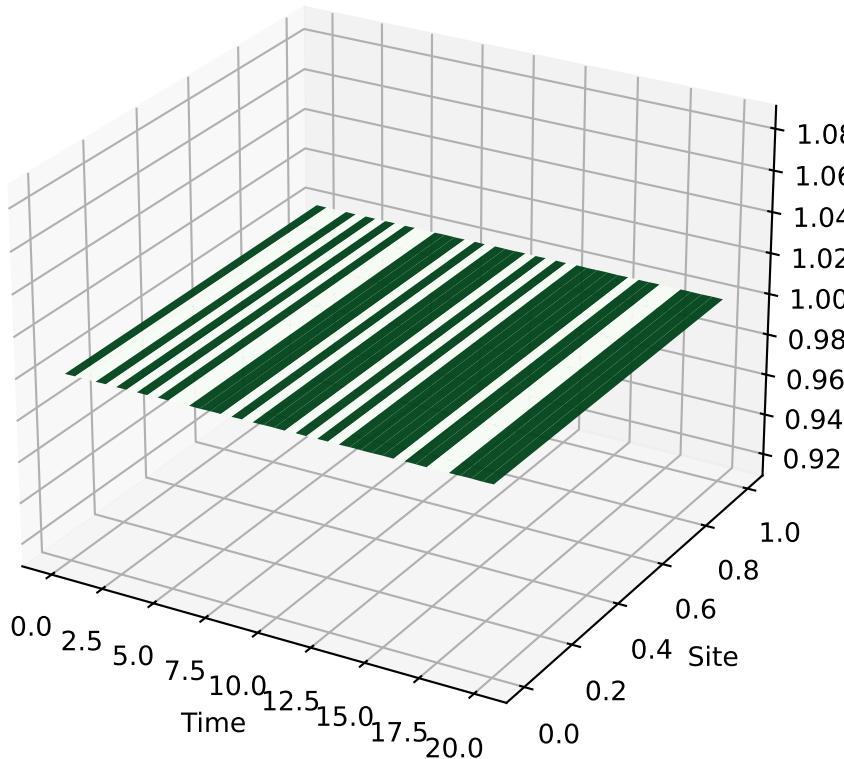
```
/opt/anaconda3/bin/python pipelines/hardcoded_hubbard_pipeline.py --L 2 --t 1.0 --u 4.0 --dv 0.0 --boundary
periodic --ordering blocked --t-final 20.0 --num-times 201 --suzuki-order 2 --trotter-steps 64 --term-order
sorted --vqe-reps 2 --vqe-restarts 1 --vqe-maxiter 120 --skip-qpe --initial-state-source vqe --fidelity-
subspace-energy-tol 1e-8 --output-json artifacts/json/H_L2_static_t1.0_U4.0_S64_heavy.json --output-pdf
artifacts/pdf/H_L2_static_t1.0_U4.0_S64_heavy.pdf
```

# L=2 3D Densities (Total n)

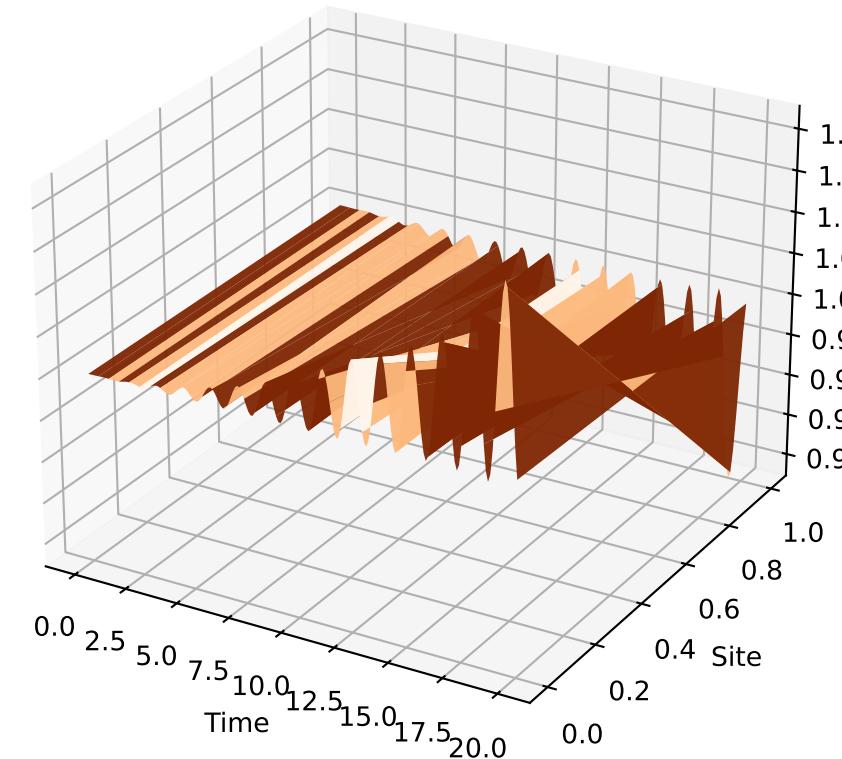
Exact GS Filtered:  $n(\text{site}, t)$



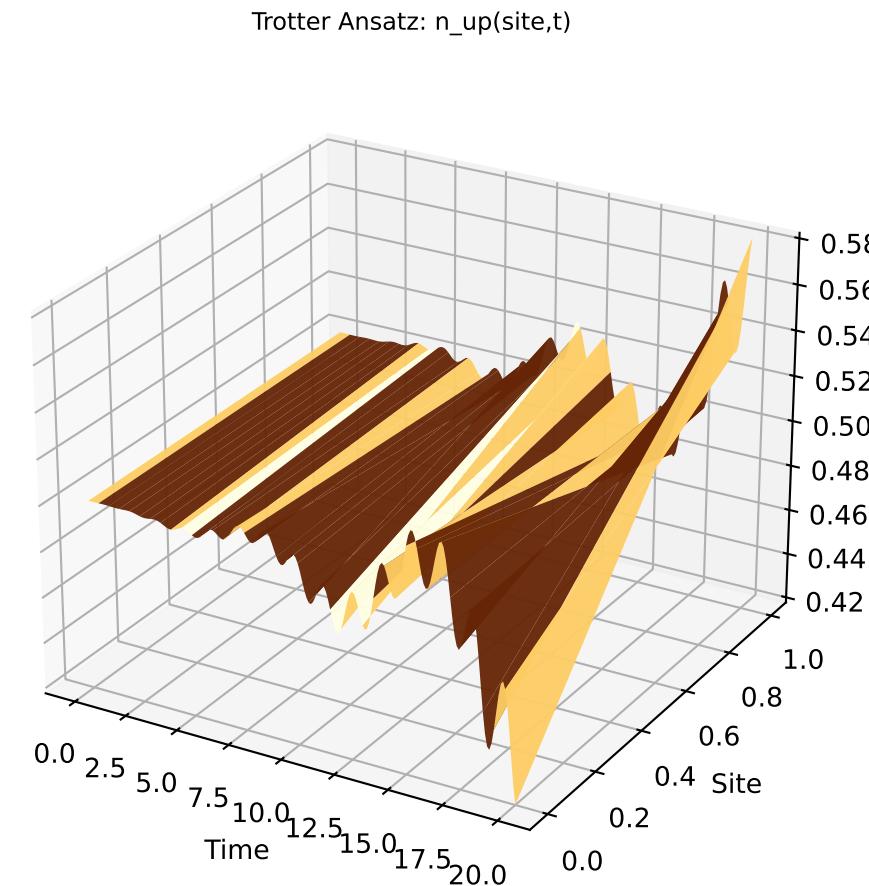
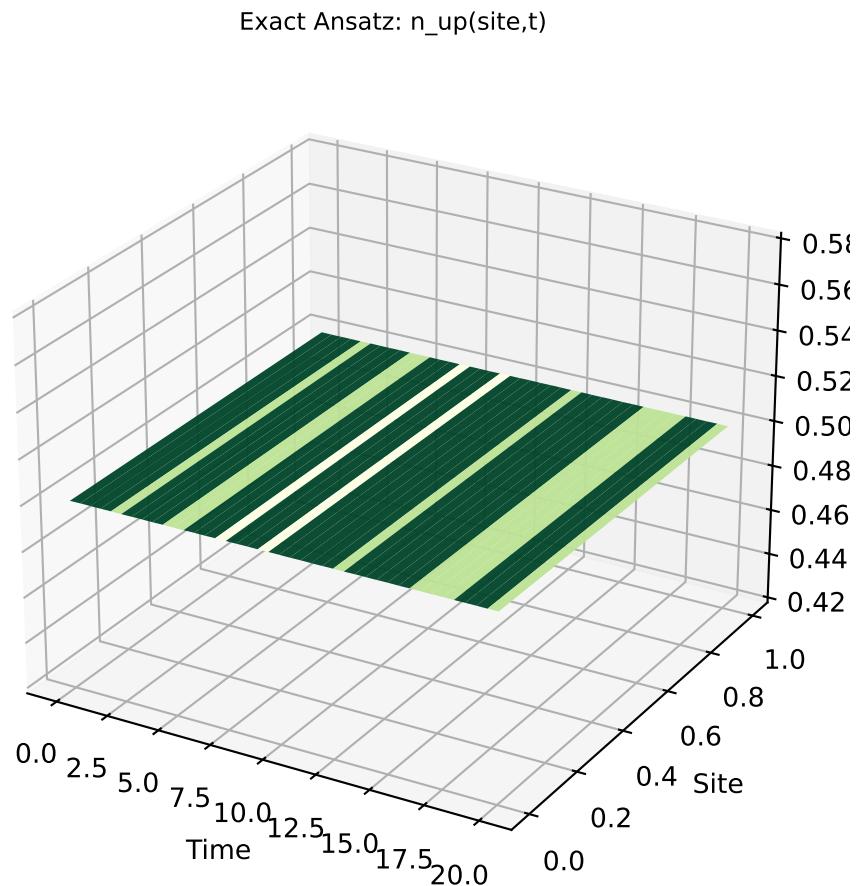
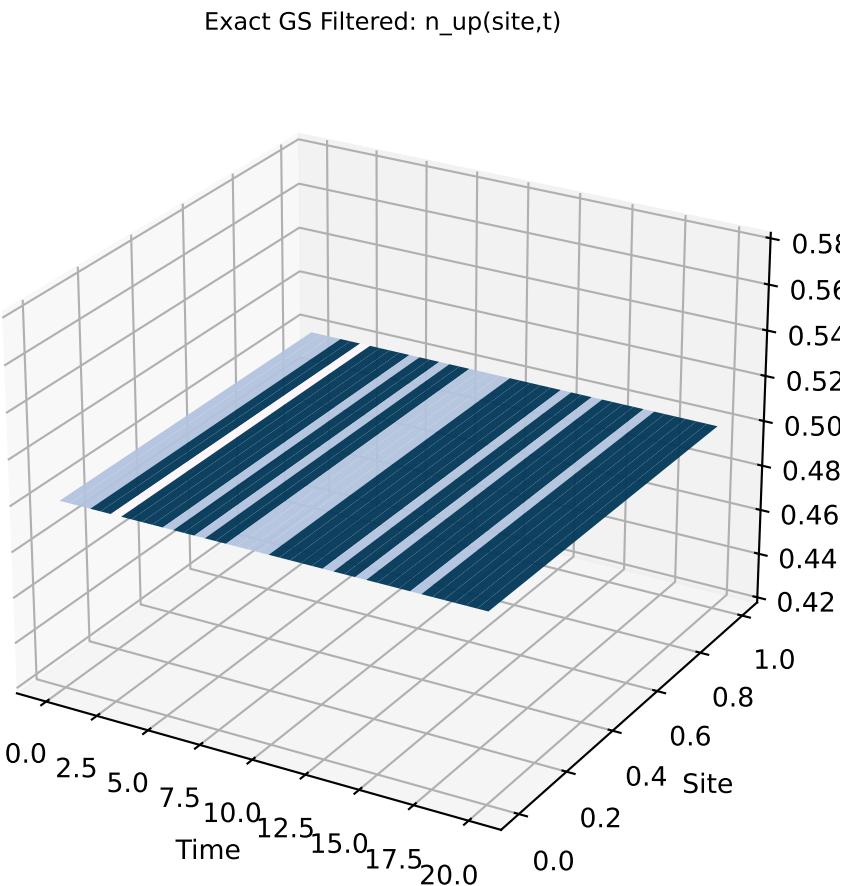
Exact Ansatz:  $n(\text{site}, t)$



Trotter Ansatz:  $n(\text{site}, t)$

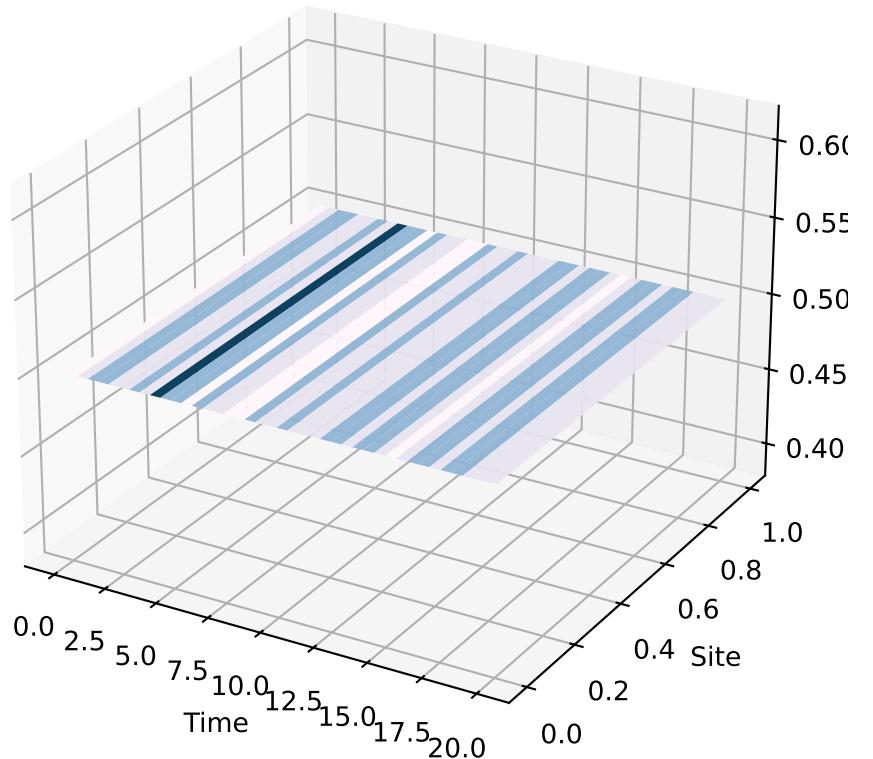


## L=2 3D Densities (Spin-Up)

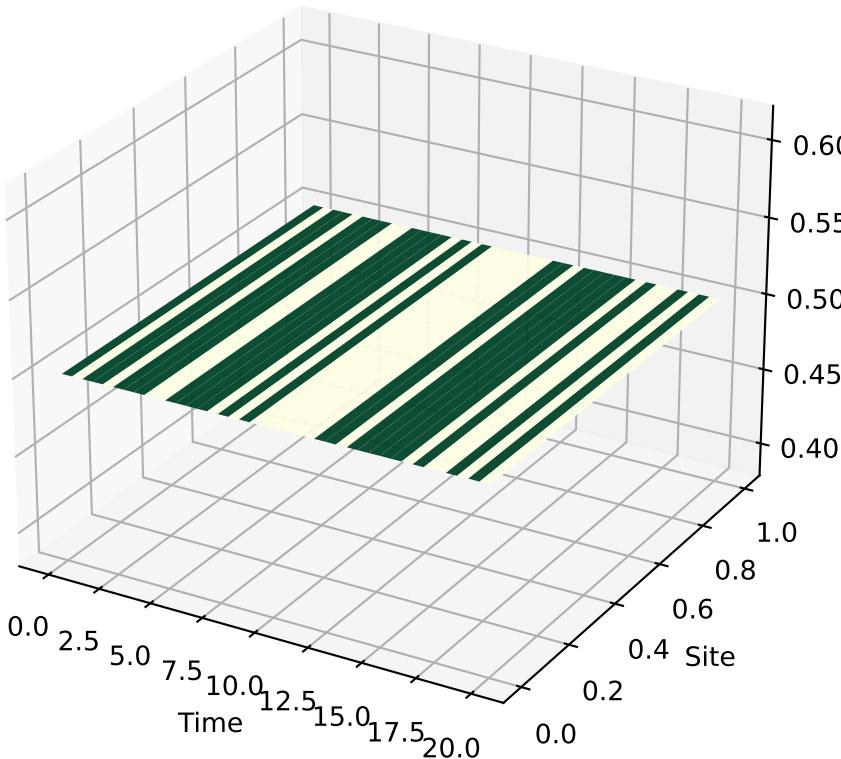


## L=2 3D Densities (Spin-Down)

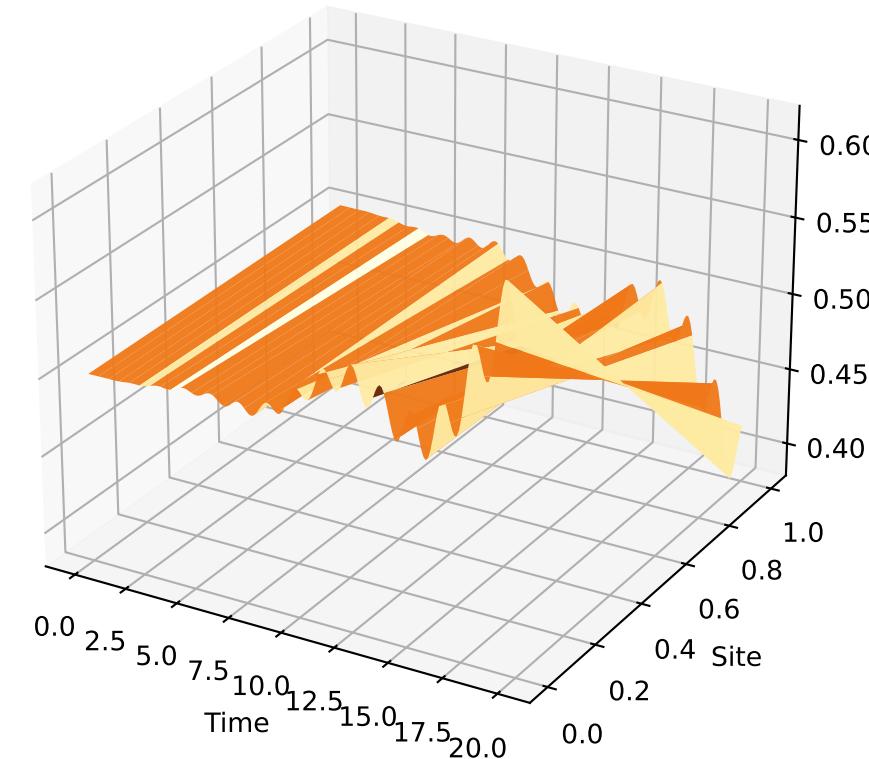
Exact GS Filtered:  $n_{dn}(site,t)$



Exact Ansatz:  $n_{dn}(site,t)$

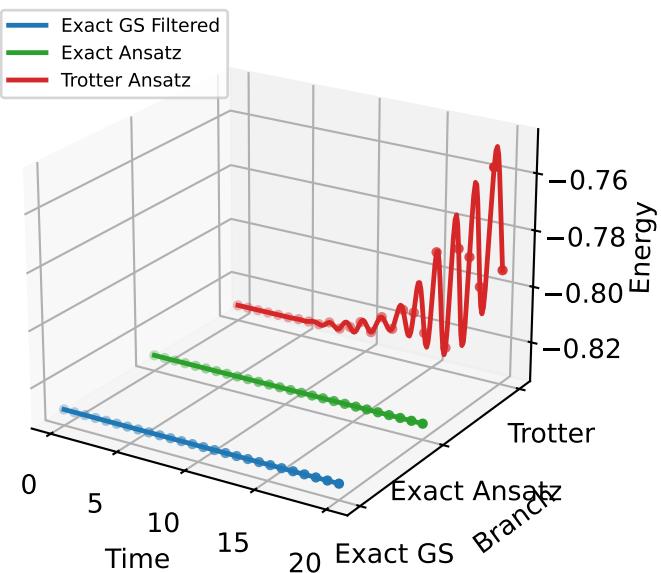


Trotter Ansatz:  $n_{dn}(site,t)$

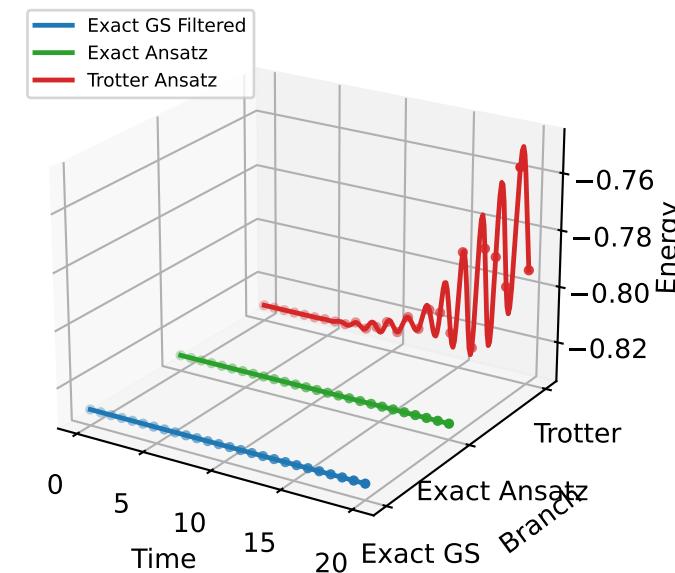


# L=2 3D Scalar Observables (Three Evolutions)

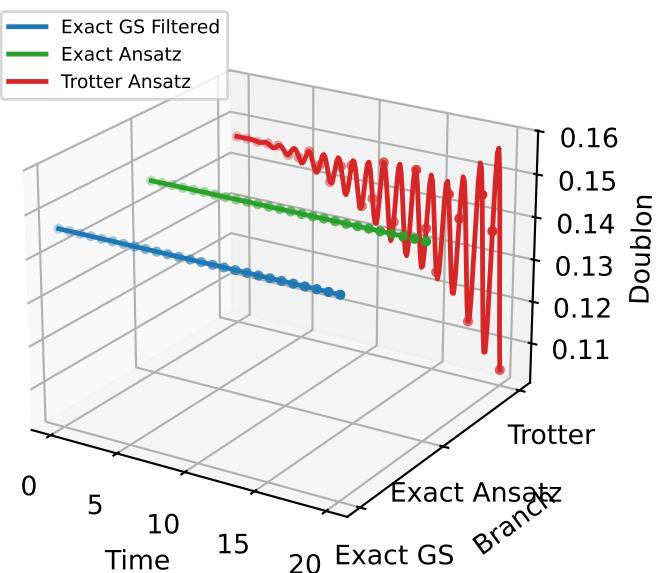
3D Lanes: Total Energy



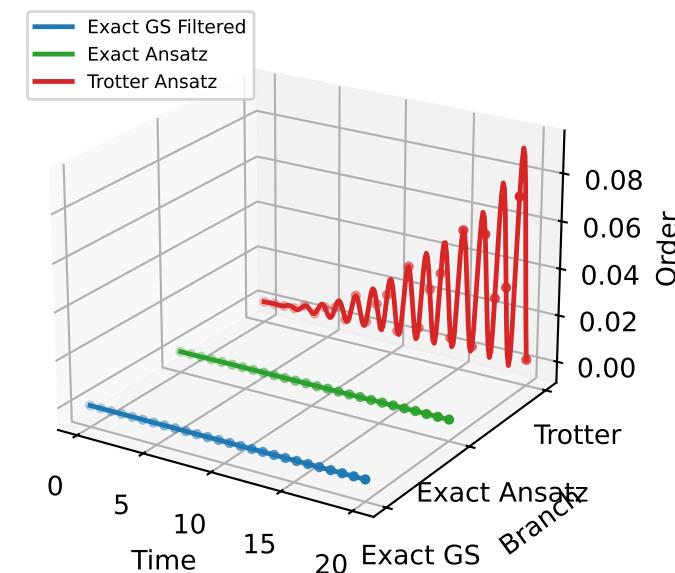
3D Lanes: Static Energy



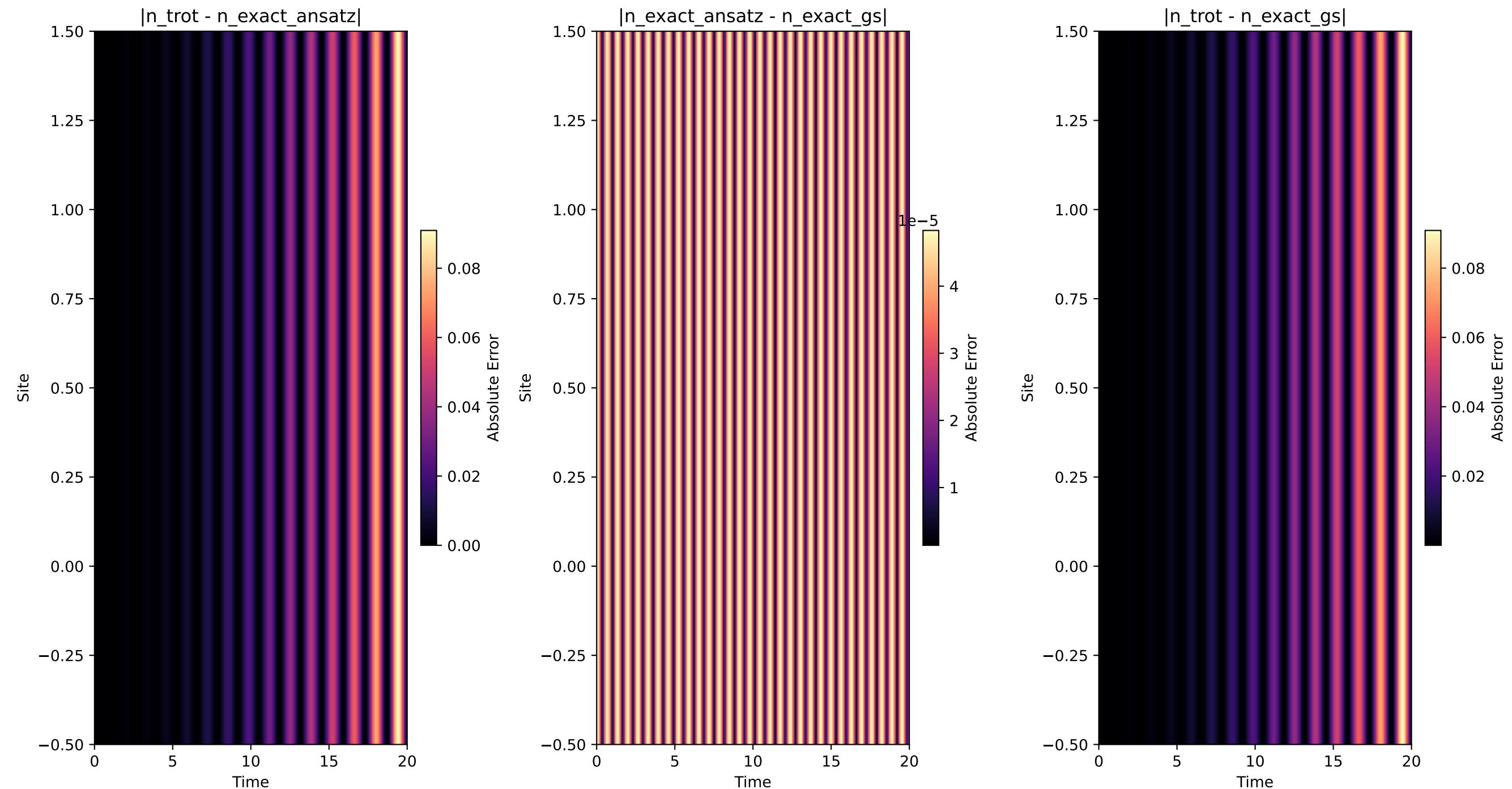
3D Lanes: Doublon



3D Lanes: Staggered Order

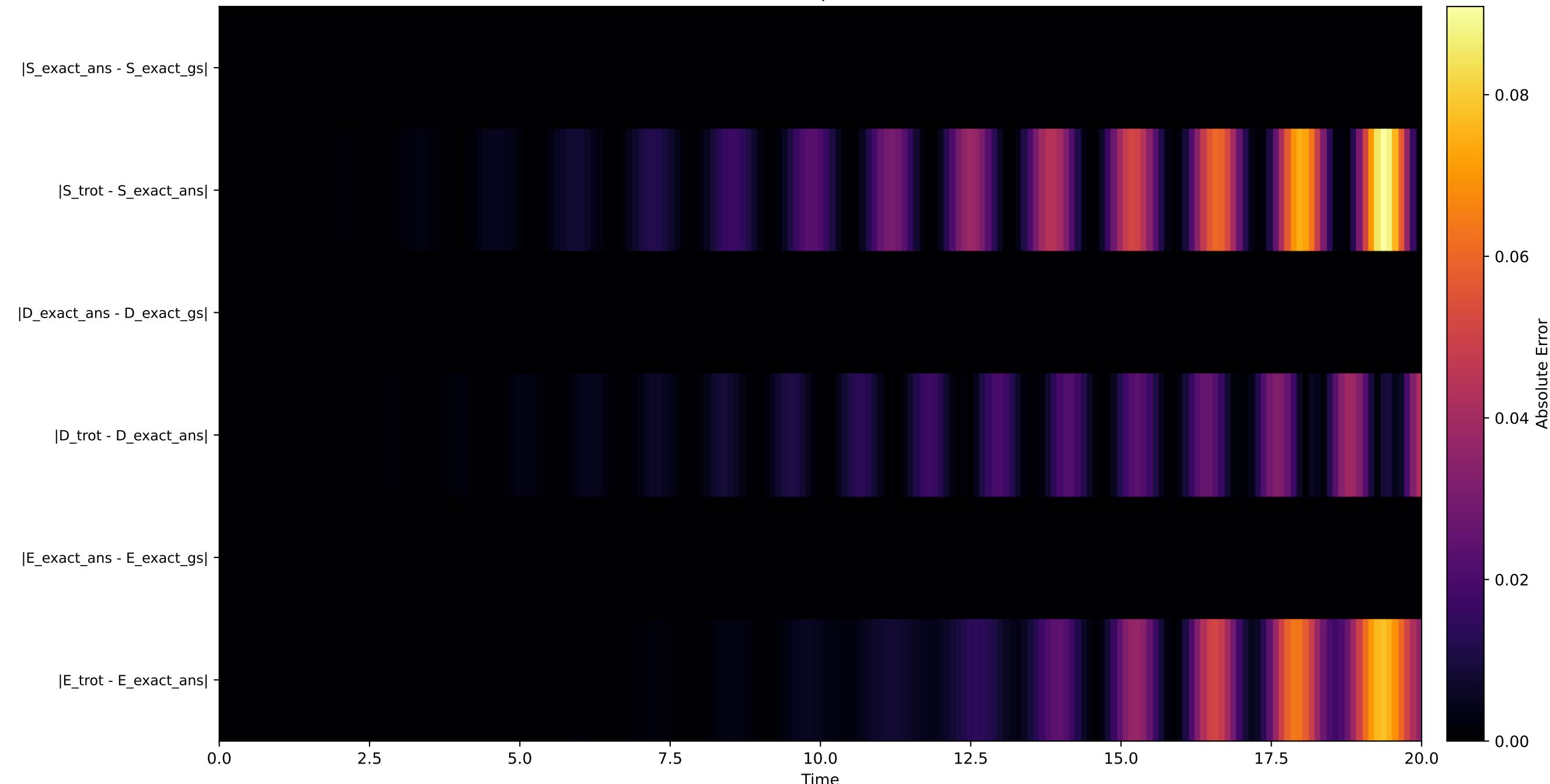


L=2 Error Heatmaps (Absolute Errors)

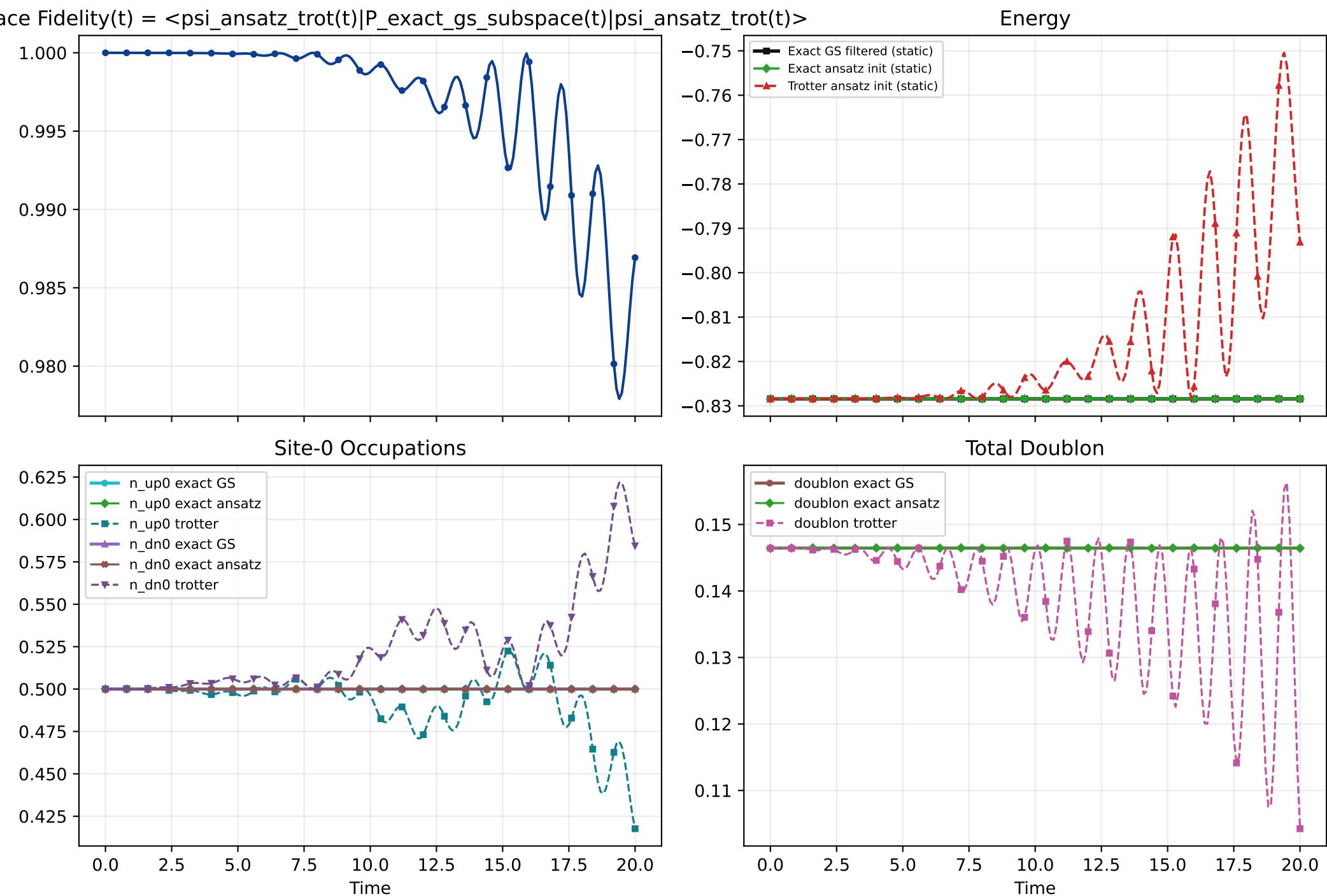


## L=2 Scalar Error Heatmap

Absolute Error Heatmap (Scalar Observables)



# Hardcoded Hubbard Pipeline: L=2

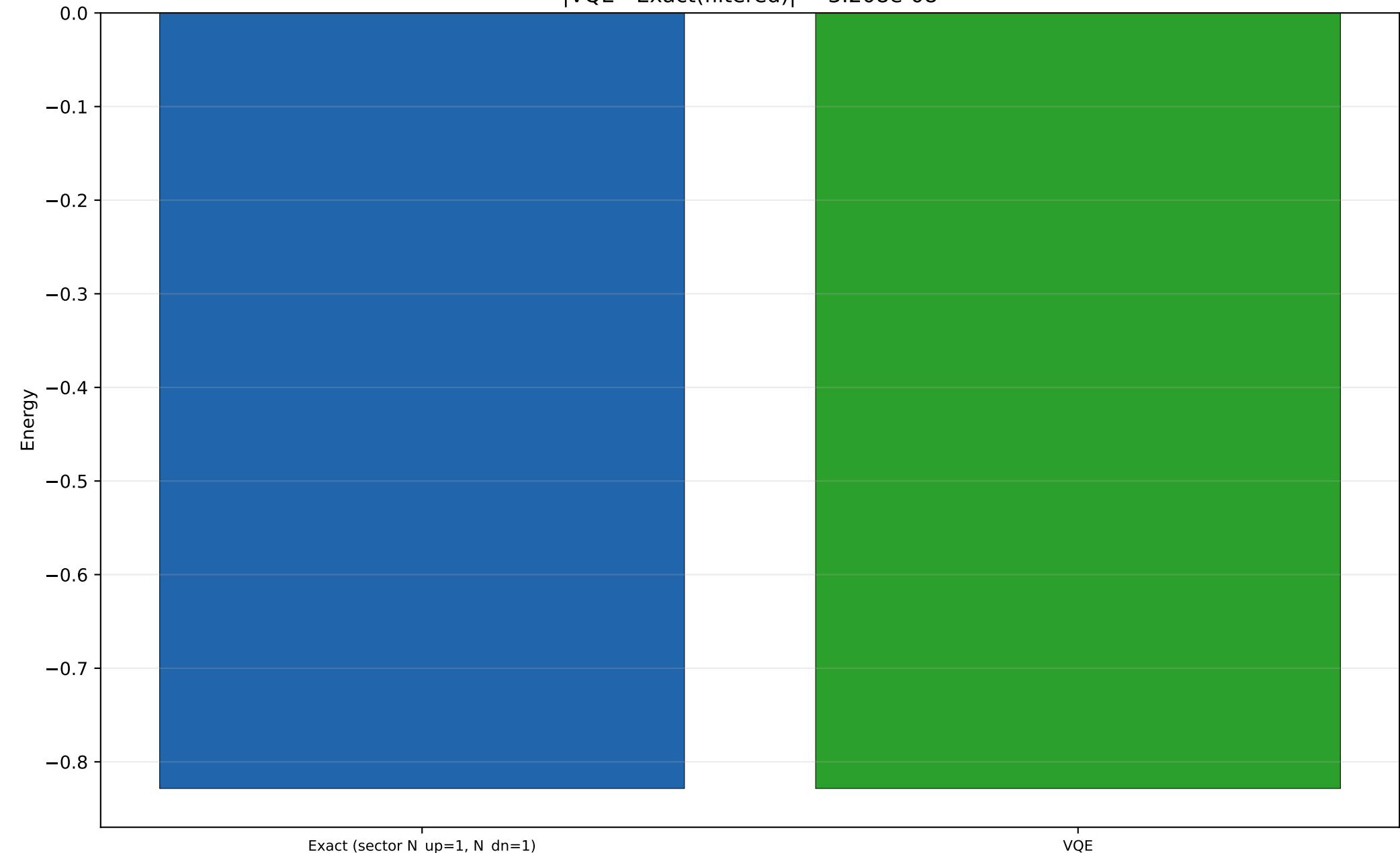


## Appendix – L=2

This section contains supporting/redundant views and metadata.  
Core non-redundant analysis appears earlier in the PDF.

VQE optimises within the half-filled sector; exact (filtered) is the true sector ground state.  
Full-Hilbert exact energy is in the JSON text summary only.

VQE Energy vs Exact (filtered sector)  
 $|VQE - \text{Exact(filtered)}| = 3.208e-08$



Hardcoded Hubbard pipeline summary

```
settings: {"L": 2, "t": 1.0, "u": 4.0, "dv": 0.0, "boundary": "periodic", "ordering": "blocked", "t_final": 20.0, "num_times": 100}
exact_trajectory_label: Exact_Hardcode
exact_trajectory_method: python_matrix_eigendecomposition
fidelity_definition: fidelity(t) =  $\langle \psi_{\text{ansatz}}(\text{trot}(t)) | P_{\text{exact\_gs}}(\text{subspace}(t)) | \psi_{\text{ansatz}}(\text{trot}(t)) \rangle$ , where  $P_{\text{exact\_gs}}(\text{subspace}(t))$  is the projector onto the exact ground state subspace
subspace_fidelity_at_t0: 0.9999999932870716
energy_t0_exact_gs: -0.8284271247461902
energy_t0_exact_ansatz: -0.8284270926619848
energy_t0_trotter: -0.828427092661985
ground_state_exact_energy (full Hilbert): -1.000000000000000
ground_state_exact_energy_filtered: -0.8284271247461901
filtered_sector: {'n_up': 1, 'n_dn': 1}
vqe_energy: -0.8284270926619854
qpe_energy_estimate: None
initial_state_source: vqe
hamiltonian_terms: 11
reference_sanity: {'checked': False, 'reason': 'no matching bundled reference for these settings'}
```

#### Executed Command

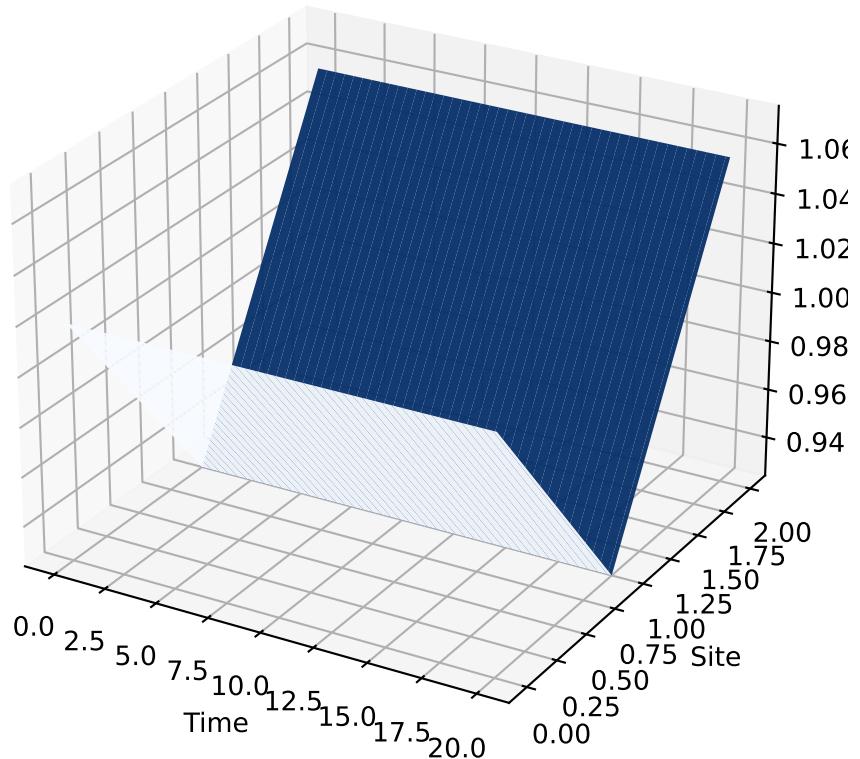
Reference: pipelines/PIPELINE\_RUN\_GUIDE.md

Script: pipelines/hardcoded\_hubbard\_pipeline.py

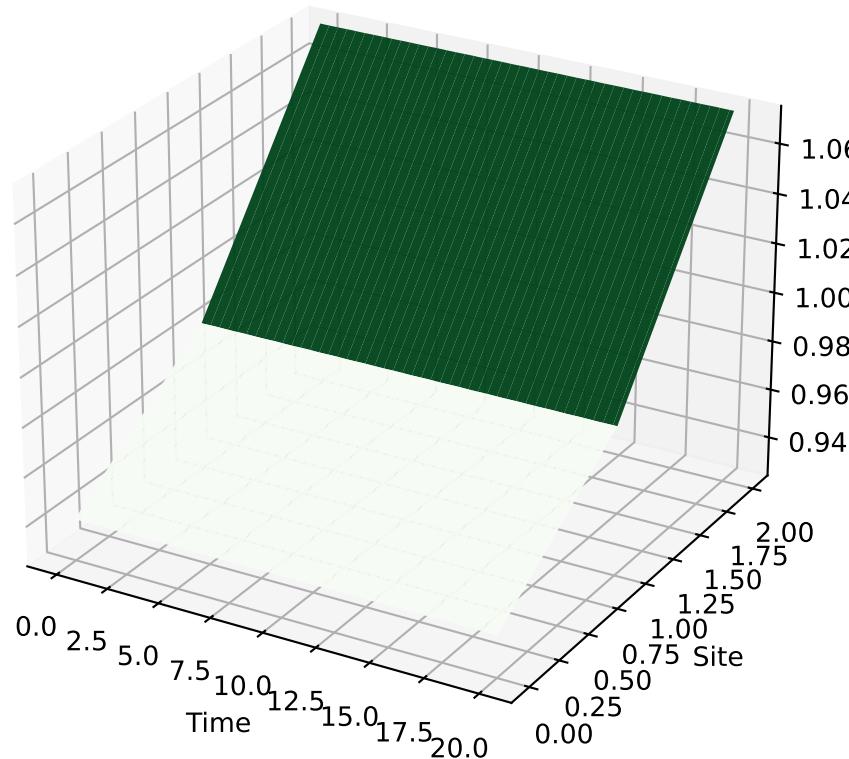
```
/opt/anaconda3/bin/python pipelines/hardcoded_hubbard_pipeline.py --L 3 --t 1.0 --u 4.0 --dv 0.0 --boundary
periodic --ordering blocked --t-final 20.0 --num-times 401 --suzuki-order 2 --trotter-steps 128 --term-order
sorted --vqe-reps 2 --vqe-restarts 3 --vqe-maxiter 600 --skip-qpe --initial-state-source vqe --fidelity-
subspace-energy-tol 1e-8 --output-json artifacts/json/H_L3_static_t1.0_U4.0_S128_heavy.json --output-pdf
artifacts/pdf/H_L3_static_t1.0_U4.0_S128_heavy.pdf
```

### L=3 3D Densities (Total n)

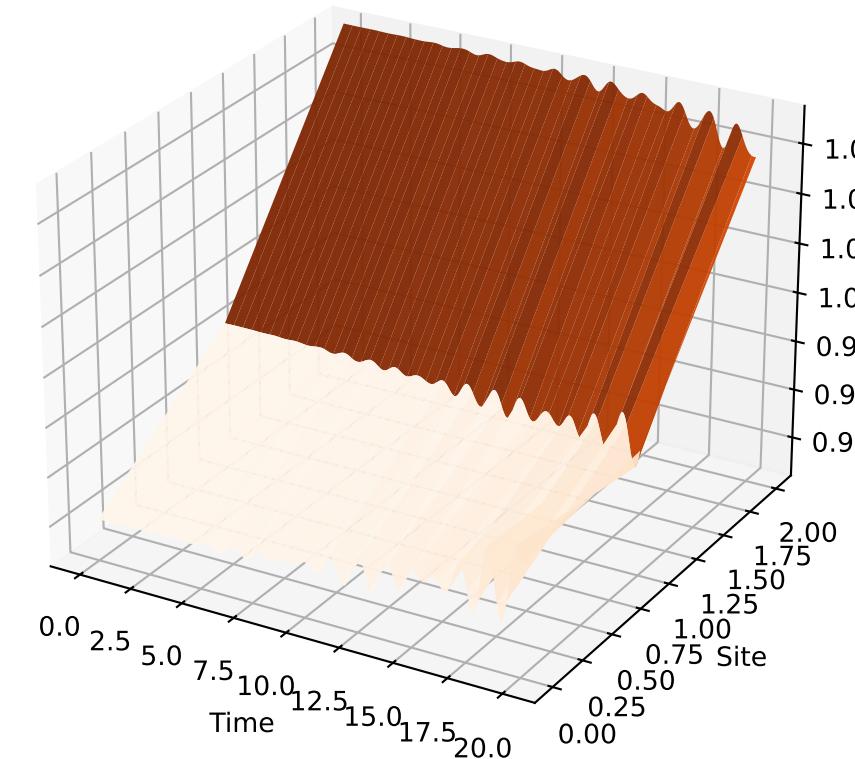
Exact GS Filtered:  $n(\text{site}, t)$



Exact Ansatz:  $n(\text{site}, t)$

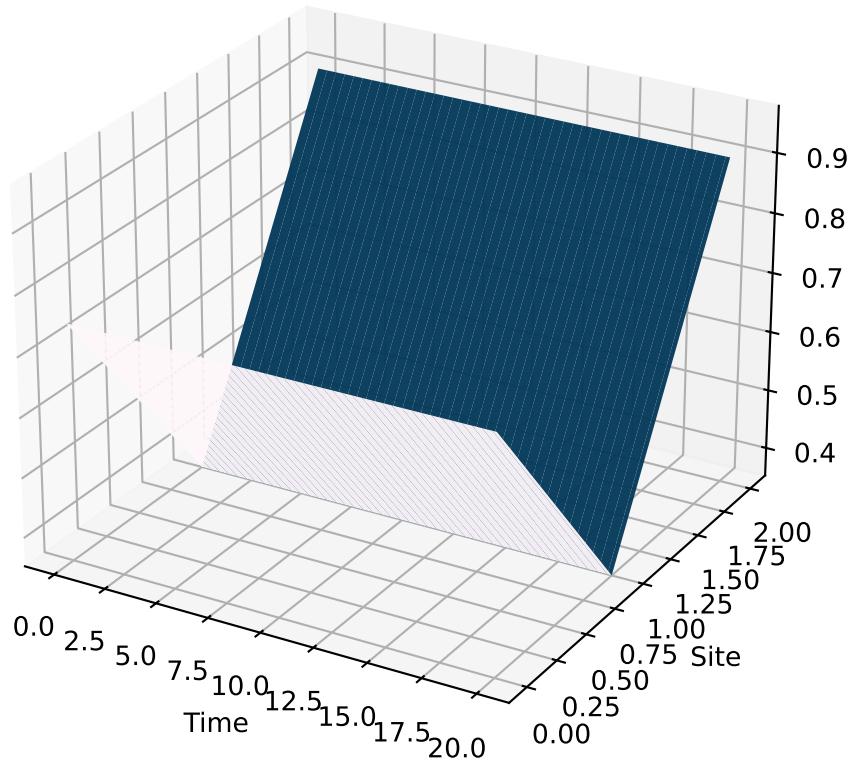


Trotter Ansatz:  $n(\text{site}, t)$

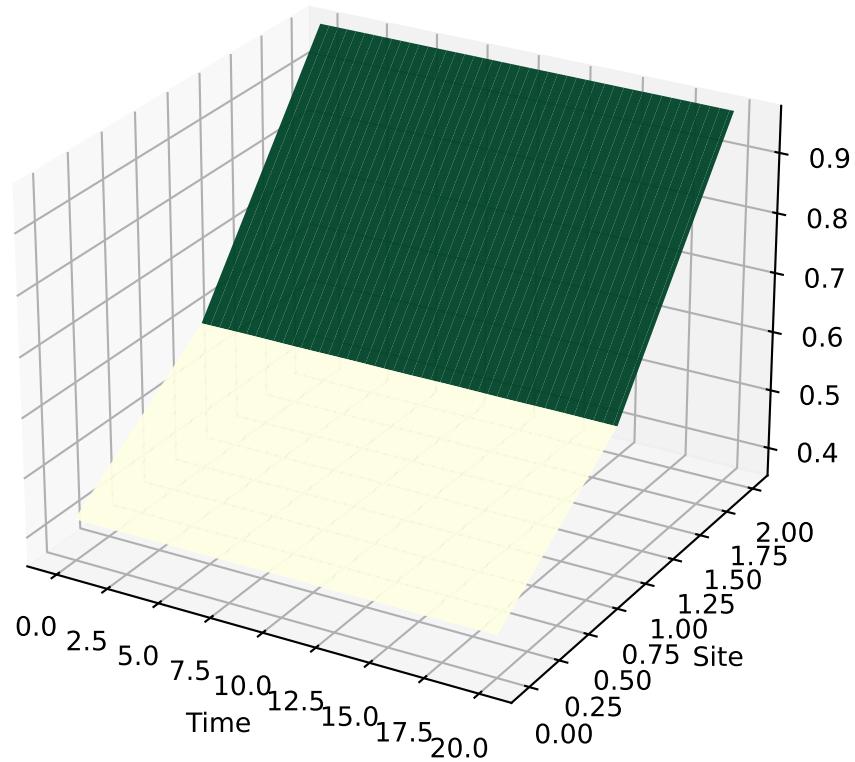


### L=3 3D Densities (Spin-Up)

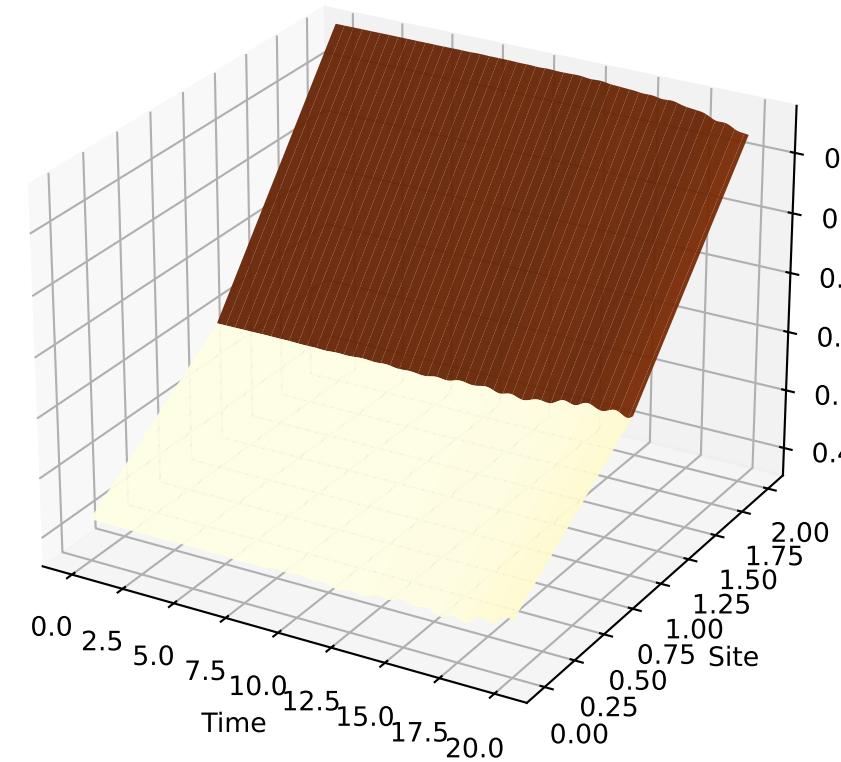
Exact GS Filtered:  $n_{\text{up}}(\text{site}, t)$



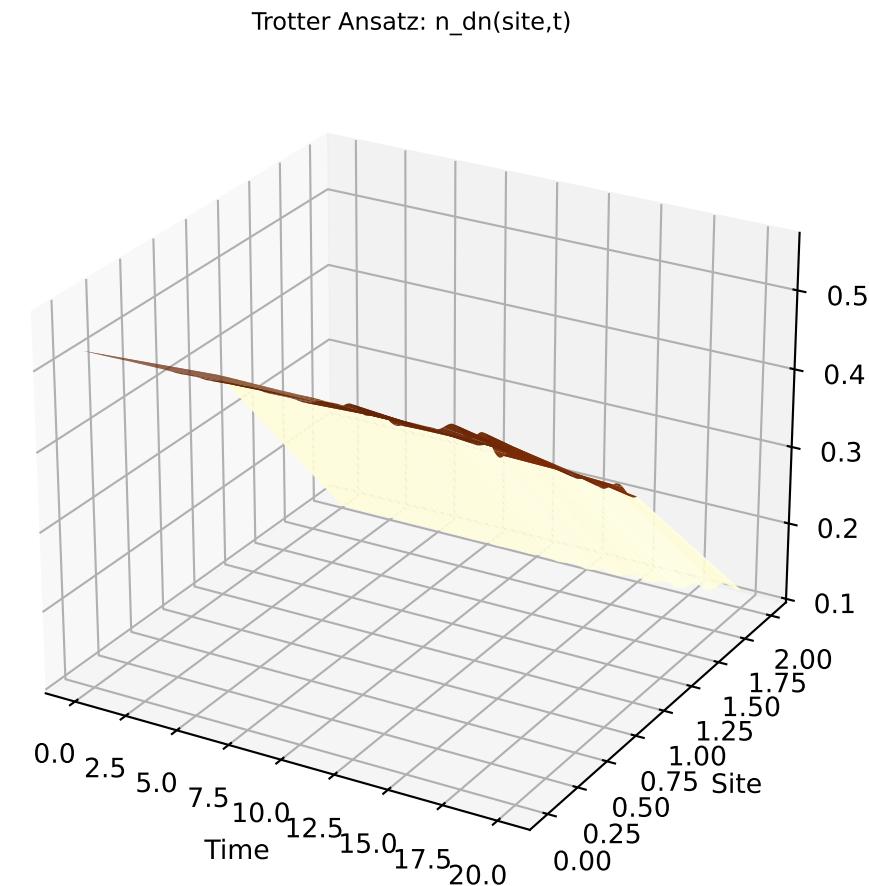
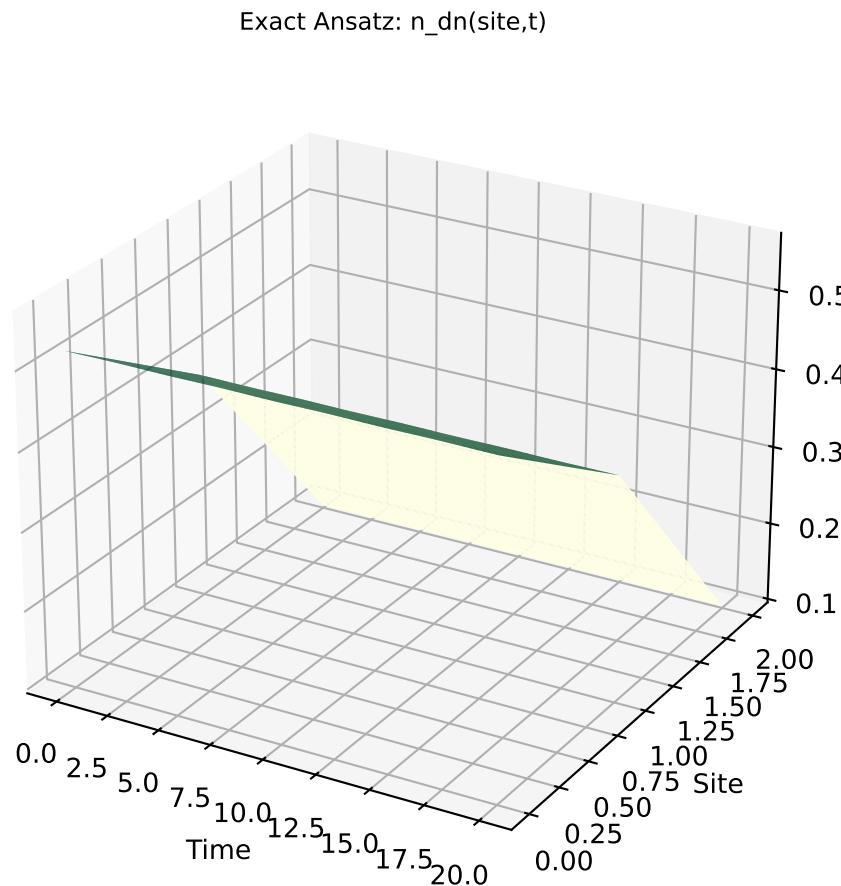
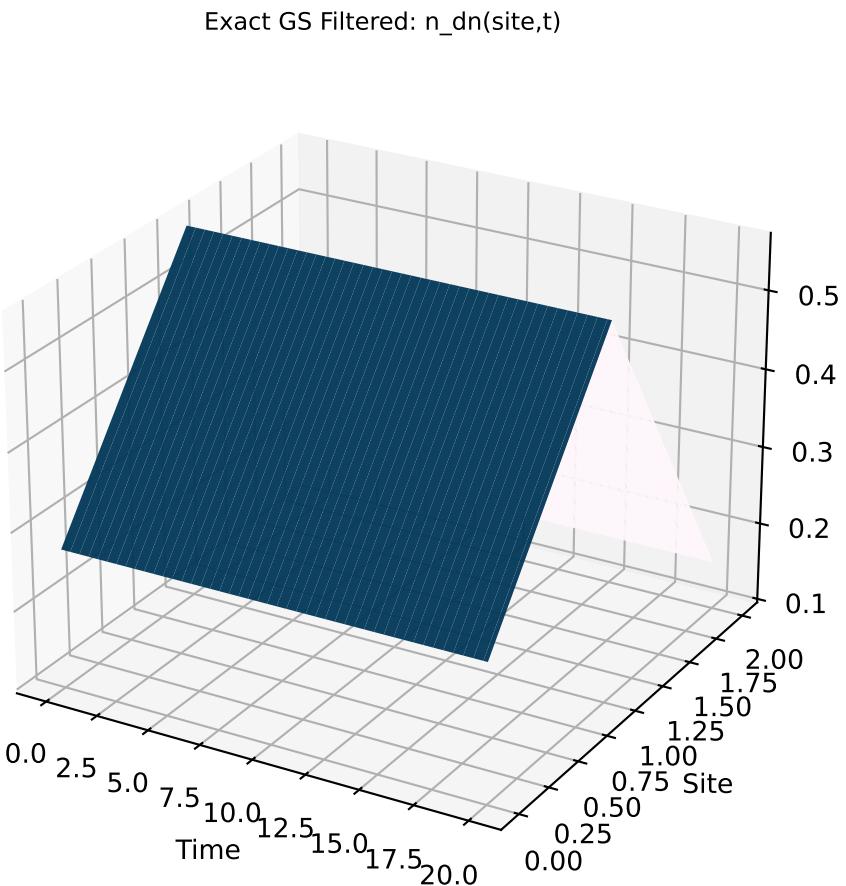
Exact Ansatz:  $n_{\text{up}}(\text{site}, t)$



Trotter Ansatz:  $n_{\text{up}}(\text{site}, t)$

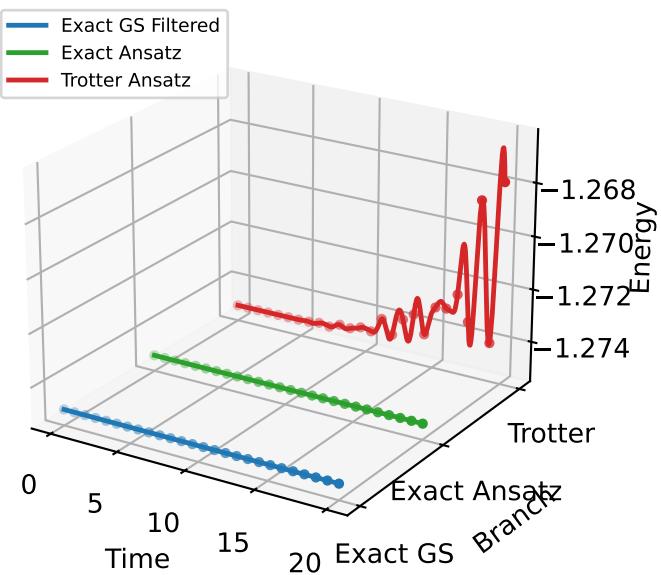


### L=3 3D Densities (Spin-Down)

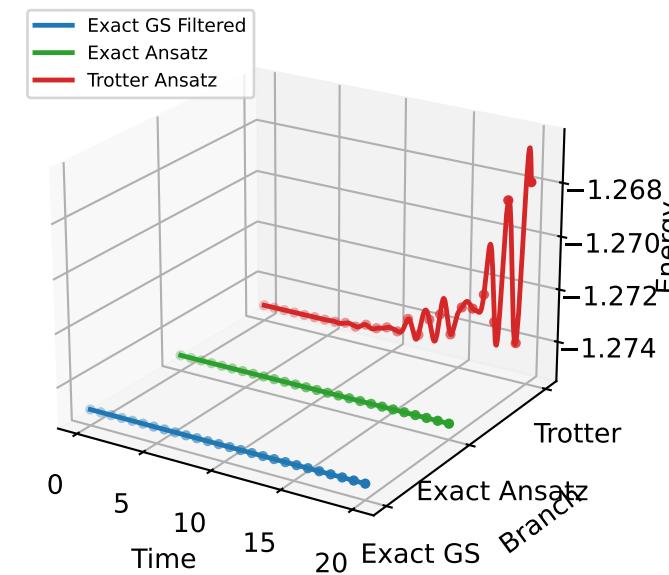


# L=3 3D Scalar Observables (Three Evolutions)

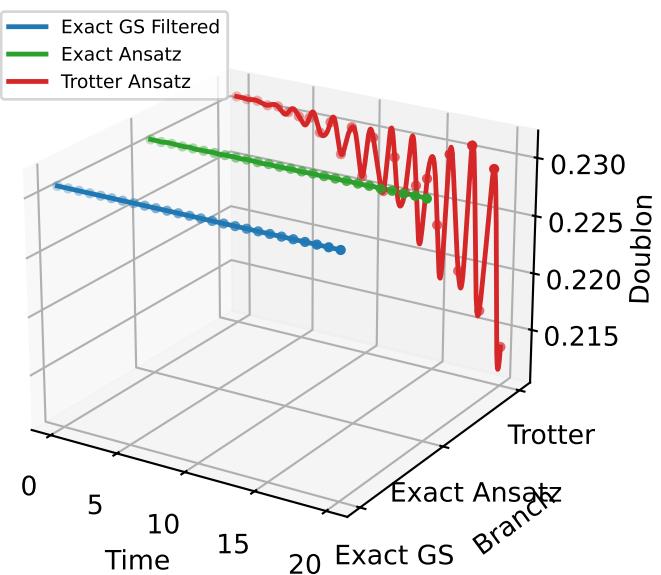
3D Lanes: Total Energy



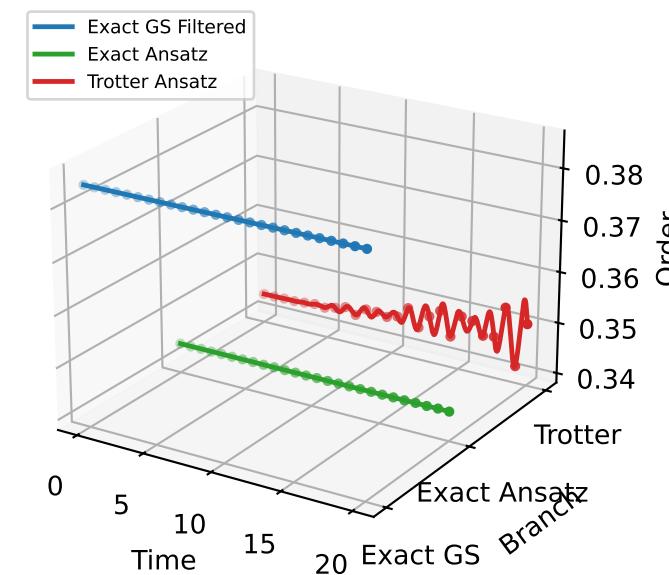
3D Lanes: Static Energy



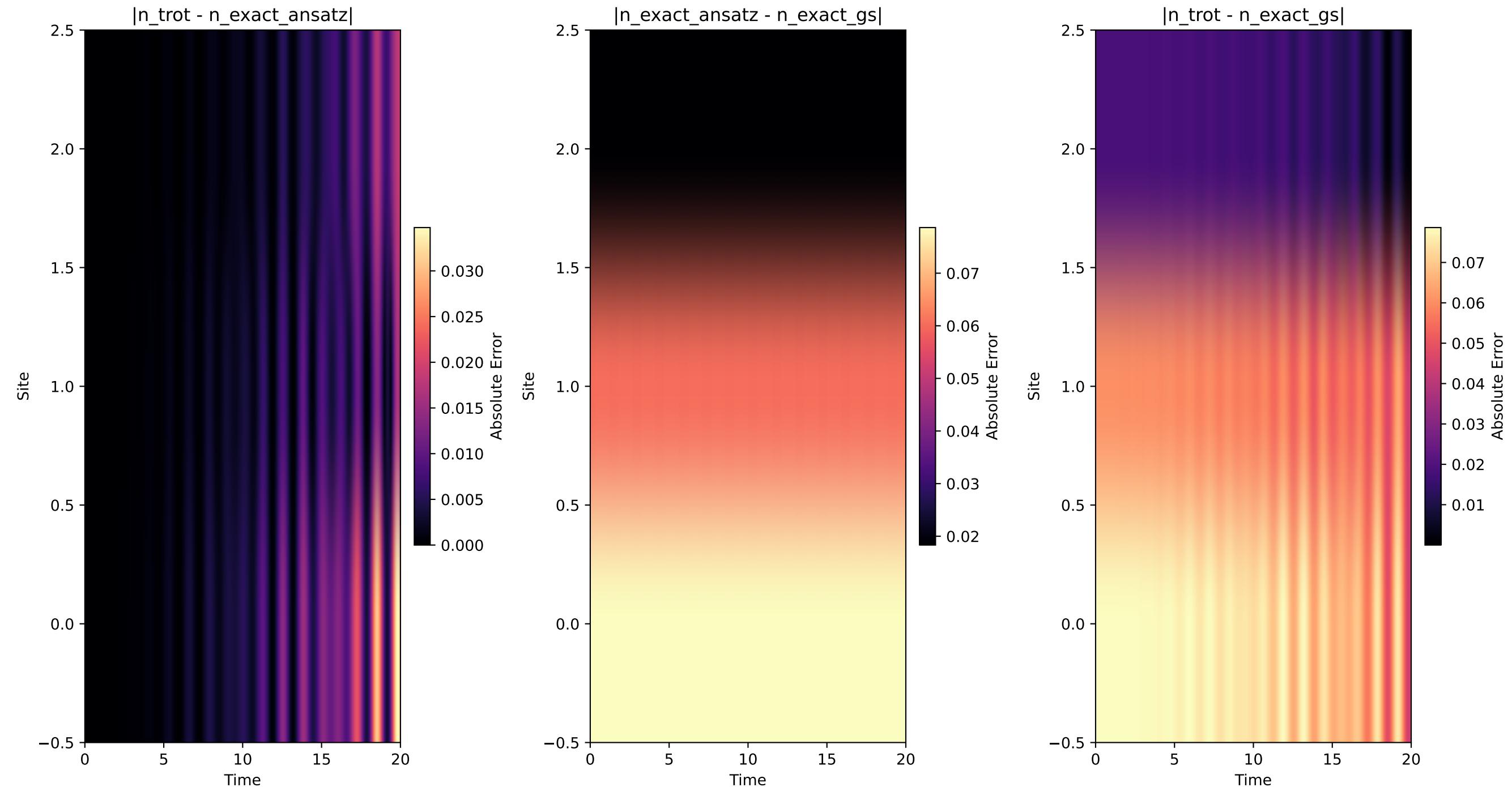
3D Lanes: Doublon



3D Lanes: Staggered Order

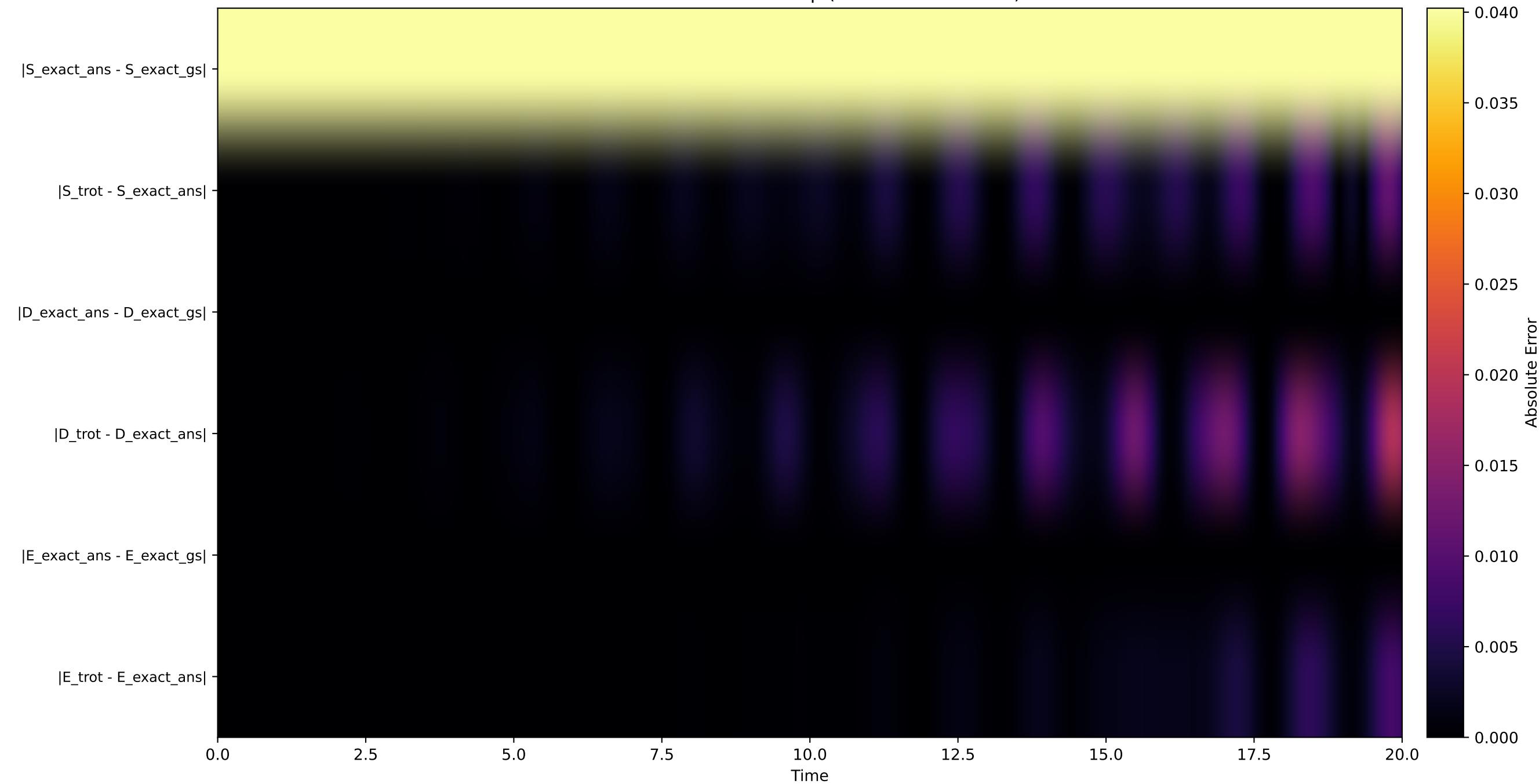


L=3 Error Heatmaps (Absolute Errors)

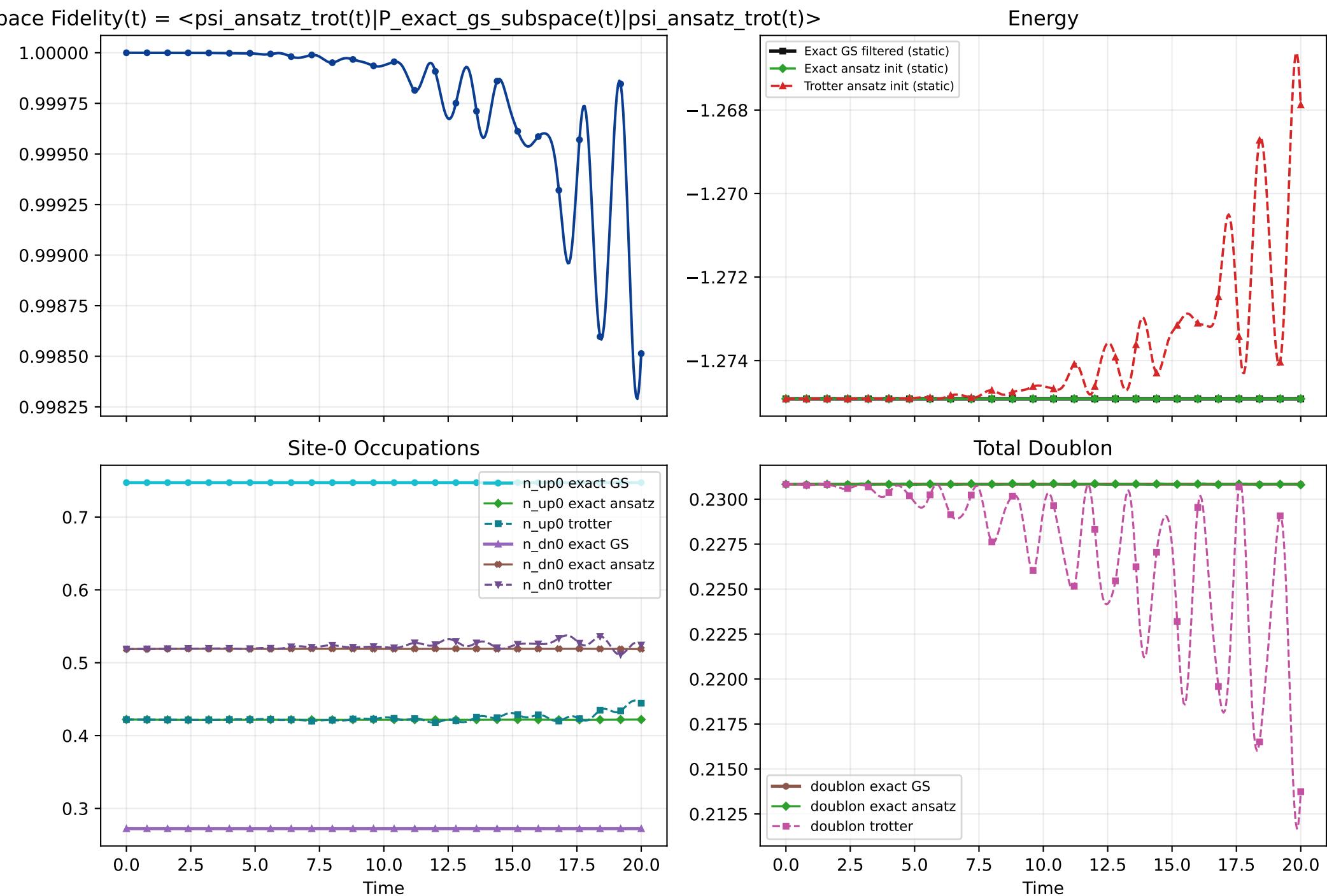


# L=3 Scalar Error Heatmap

Absolute Error Heatmap (Scalar Observables)



# Hardcoded Hubbard Pipeline: L=3

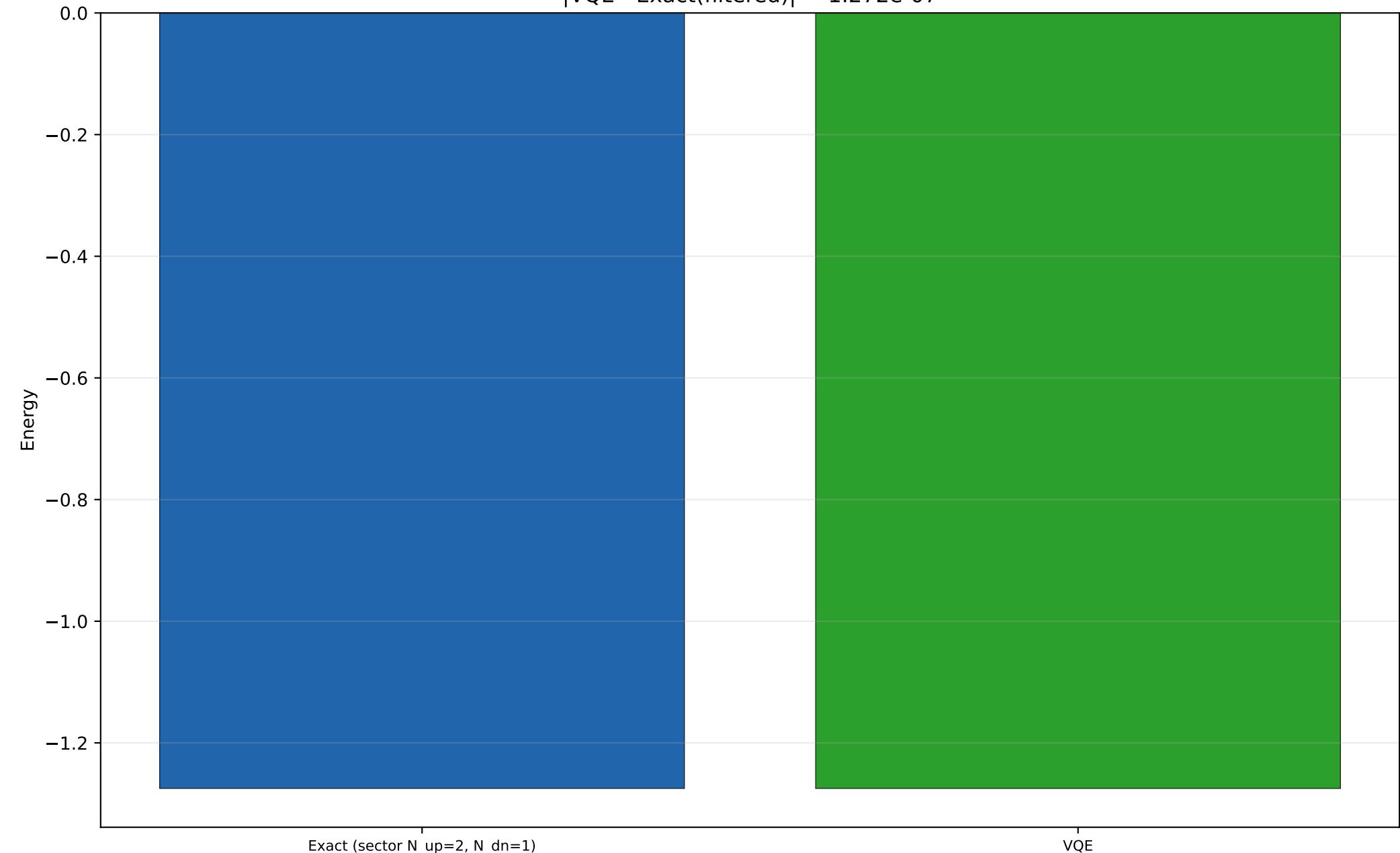


## Appendix – L=3

This section contains supporting/redundant views and metadata.  
Core non-redundant analysis appears earlier in the PDF.

VQE optimises within the half-filled sector; exact (filtered) is the true sector ground state.  
Full-Hilbert exact energy is in the JSON text summary only.

VQE Energy vs Exact (filtered sector)  
 $|VQE - Exact(filtered)| = 1.272e-07$



Hardcoded Hubbard pipeline summary

```
settings: {"L": 3, "t": 1.0, "u": 4.0, "dv": 0.0, "boundary": "periodic", "ordering": "blocked", "t_final": 20.0, "num_times": 1000}
exact_trajectory_label: Exact_Hardcode
exact_trajectory_method: python_matrix_eigendecomposition
fidelity_definition: fidelity(t) = <psi_ansatz_trot(t)|P_exact_gs_subspace(t)|psi_ansatz_trot(t)>, where P_exact_gs_subspace(t) = P_gs @ U(t)
subspace_fidelity_at_t0: 0.9999999180073835
energy_t0_exact_gs: -1.2749172176353754
energy_t0_exact_ansatz: -1.2749170904348224
energy_t0_trotter: -1.2749170904348222
ground_state_exact_energy (full Hilbert): -3.123105625618
ground_state_exact_energy_filtered: -1.2749172176353751
filtered_sector: {'n_up': 2, 'n_dn': 1}
vqe_energy: -1.27491709043483
qpe_energy_estimate: None
initial_state_source: vqe
hamiltonian_terms: 22
reference_sanity: {'checked': False, 'reason': 'no matching bundled reference for these settings'}
```

#### Executed Command

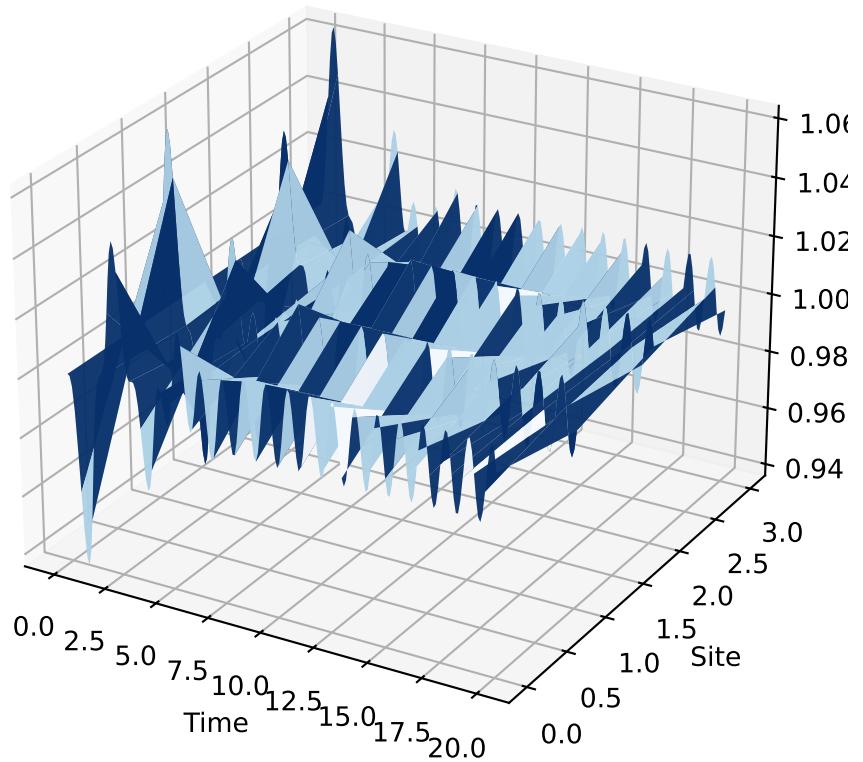
Reference: pipelines/PIPELINE\_RUN\_GUIDE.md

Script: pipelines/hardcoded\_hubbard\_pipeline.py

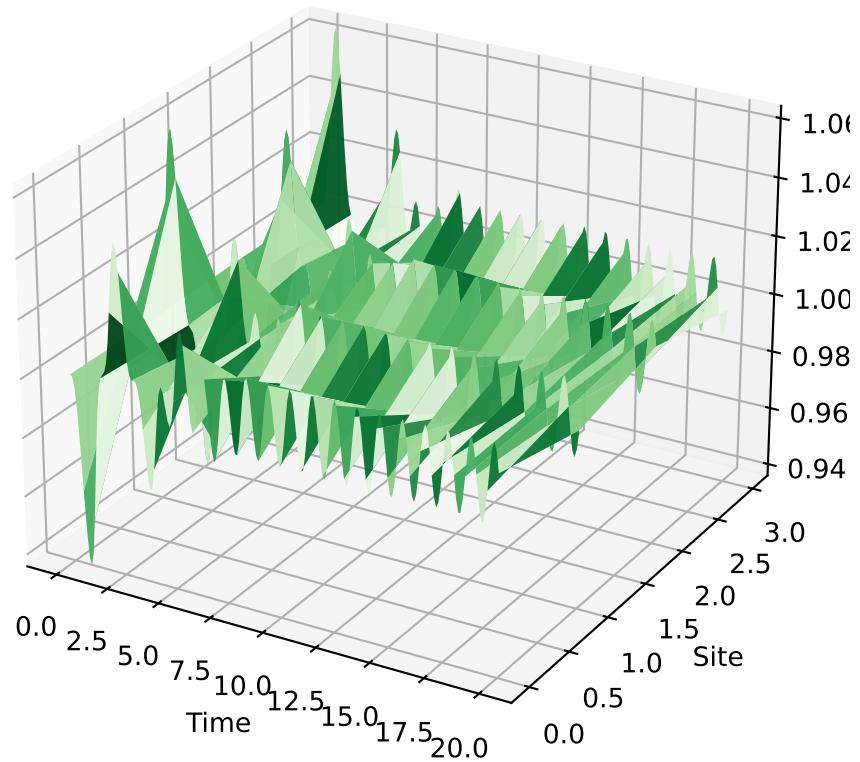
```
/opt/anaconda3/bin/python pipelines/hardcoded_hubbard_pipeline.py --L 4 --t 1.0 --u 4.0 --dv 0.0 --boundary
periodic --ordering blocked --enable-drive --drive-A 0.5 --drive-omega 2.0 --drive-tbar 3.0 --drive-phi 0.0
--drive-pattern staggered --drive-time-sampling midpoint --drive-t0 0.0 --fidelity-subspace-energy-tol 1e-8
--vqe-reps 4 --vqe-restarts 4 --vqe-maxiter 4000 --vqe-method COBYLA --vqe-seed 7 --t-final 20.0 --num-times
201 --trotter-steps 256 --exact-steps-multiplier 3 --suzuki-order 2 --term-order sorted --skip-qpe --initial-
state-source vqe --output-json artifacts/json/H_L4_vt_t1.0_U4.0_S256_dyn.json --output-pdf
artifacts/pdf/H_L4_vt_t1.0_U4.0_S256_dyn.pdf
```

# L=4 3D Densities (Total n)

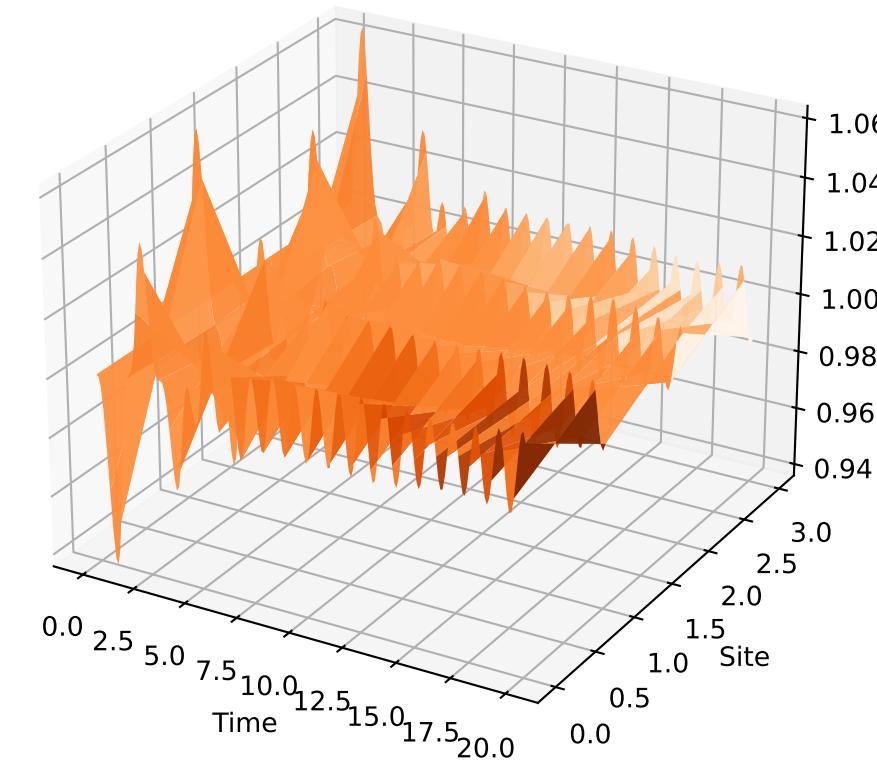
Exact GS Filtered:  $n(\text{site}, t)$



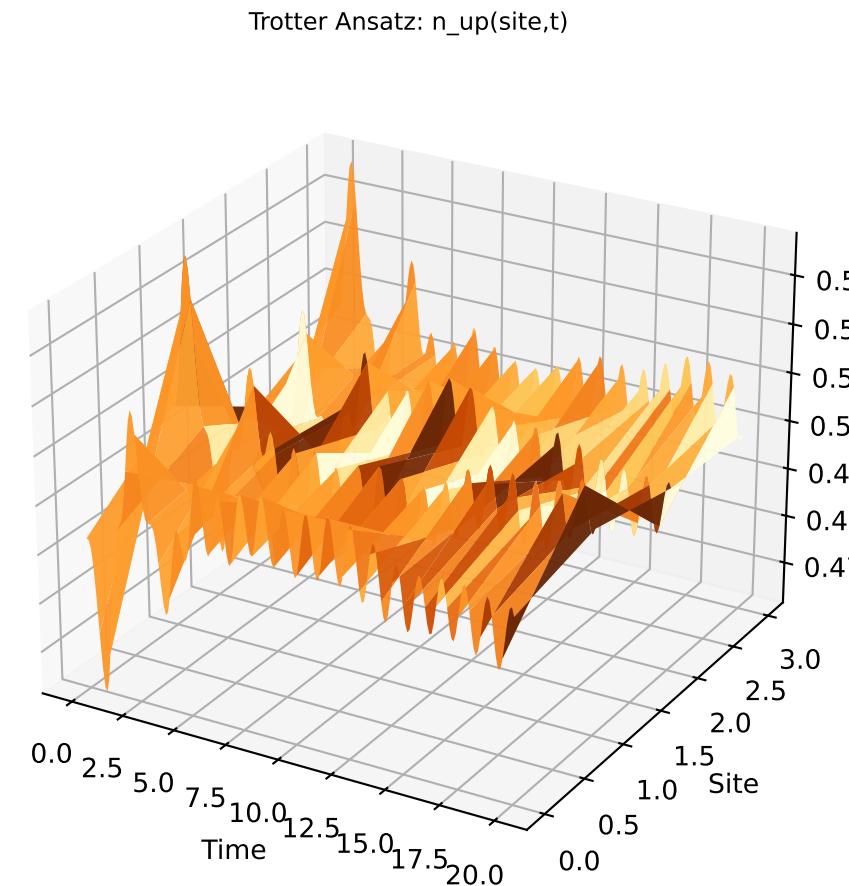
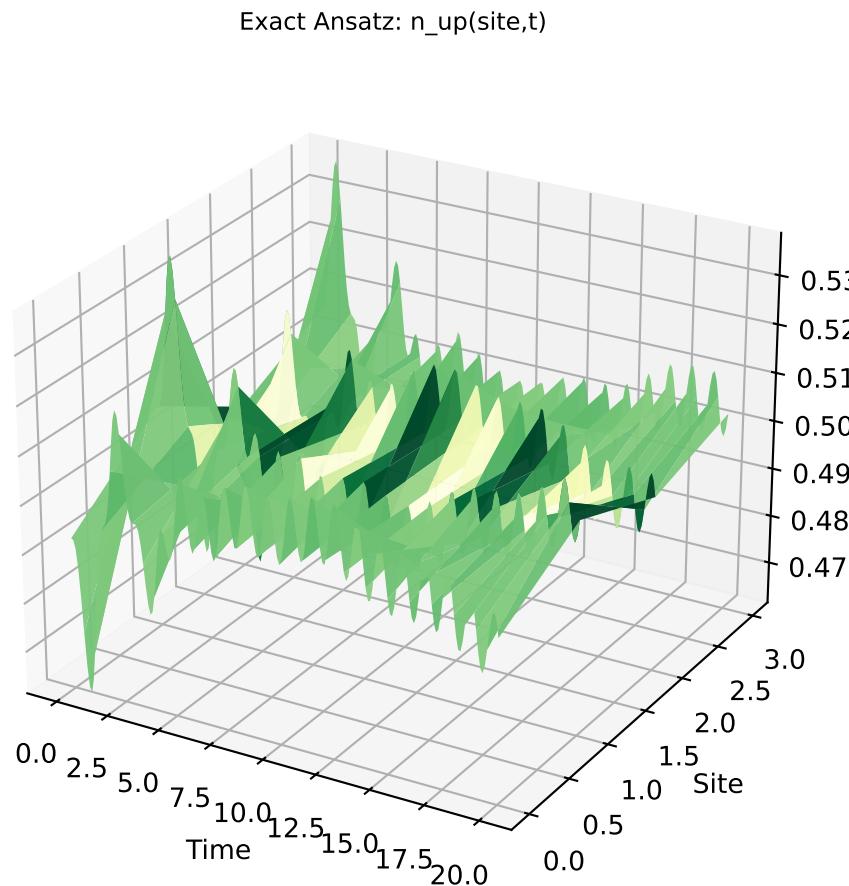
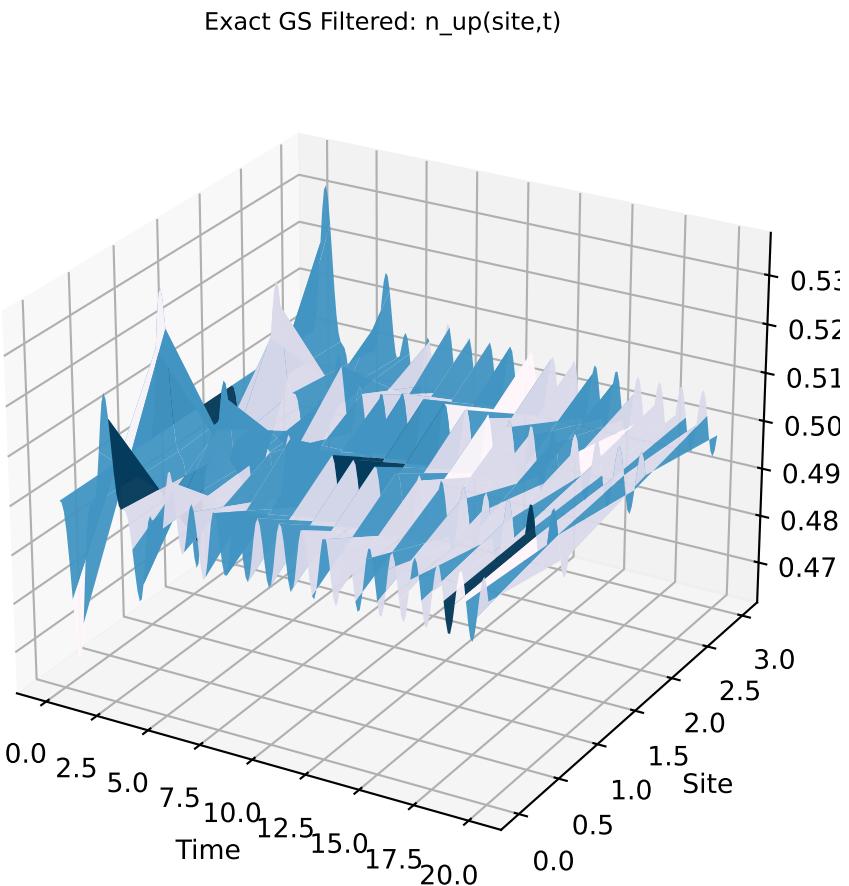
Exact Ansatz:  $n(\text{site}, t)$



Trotter Ansatz:  $n(\text{site}, t)$

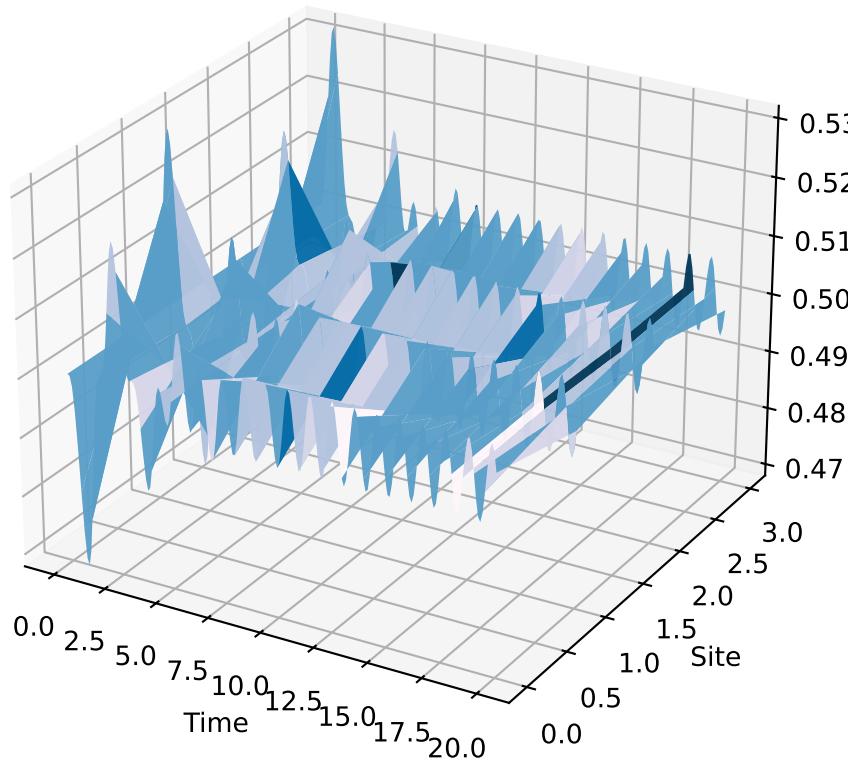


# L=4 3D Densities (Spin-Up)

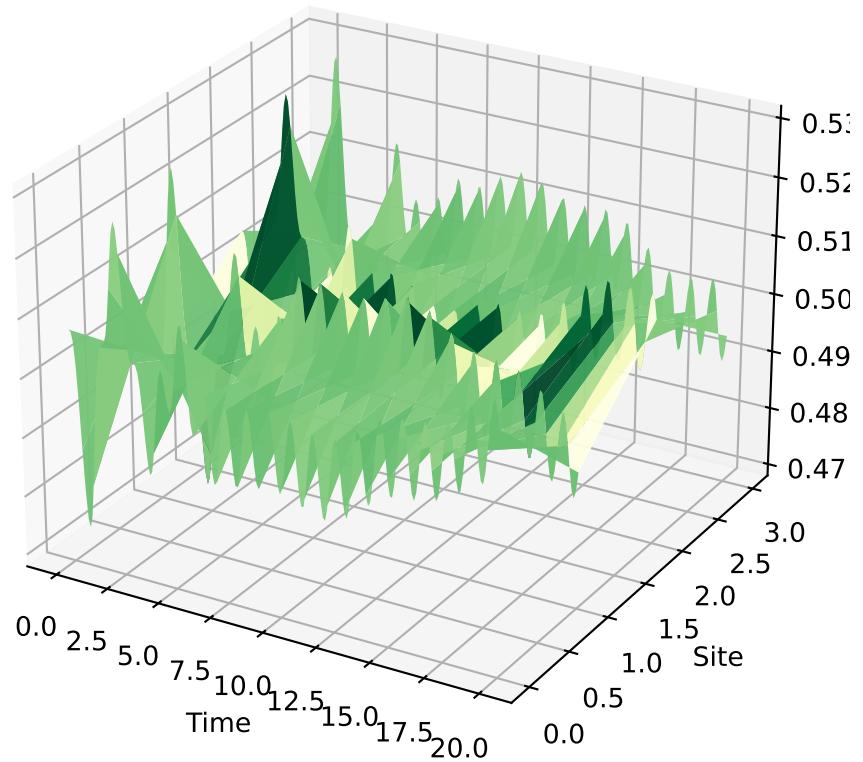


# L=4 3D Densities (Spin-Down)

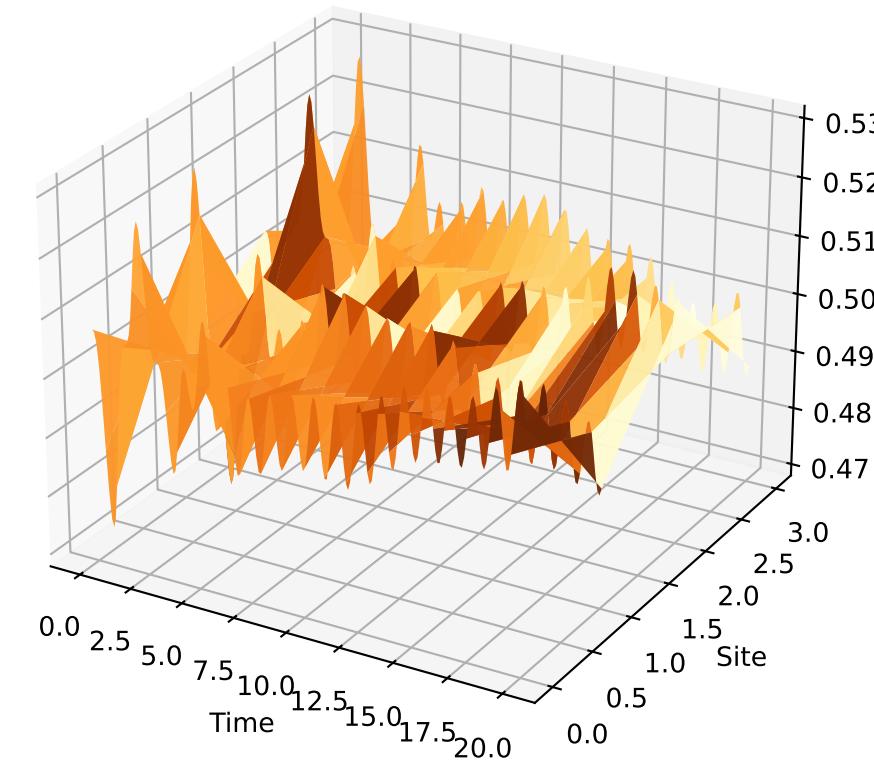
Exact GS Filtered:  $n_{dn}(site,t)$



Exact Ansatz:  $n_{dn}(site,t)$

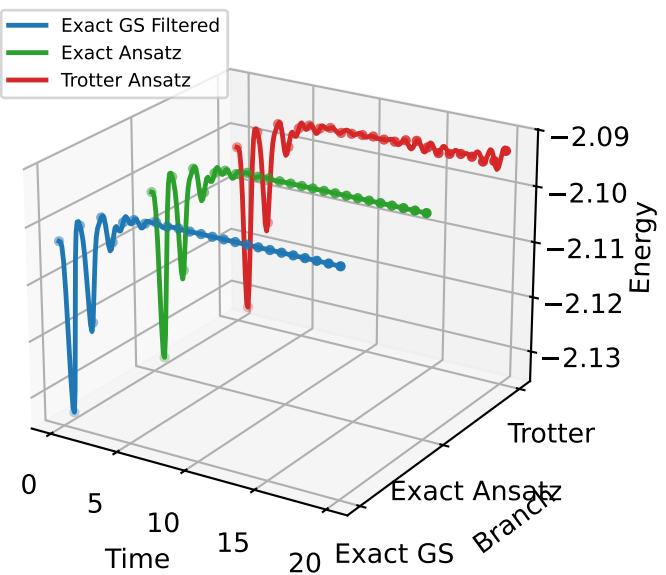


Trotter Ansatz:  $n_{dn}(site,t)$

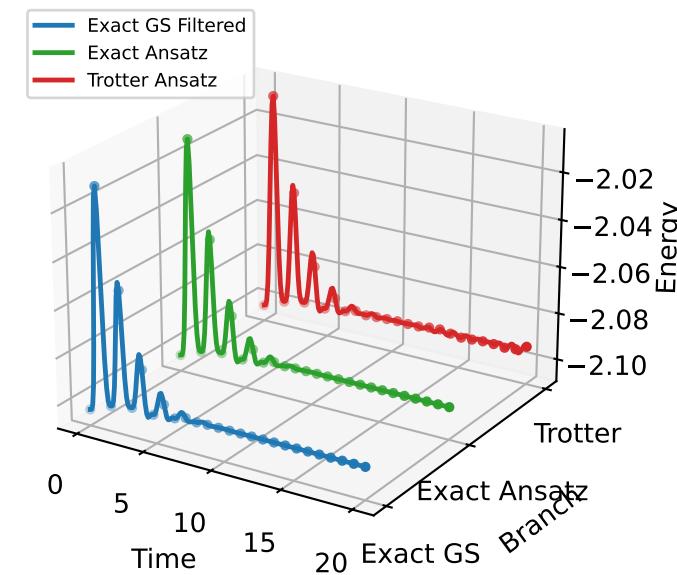


# L=4 3D Scalar Observables (Three Evolutions)

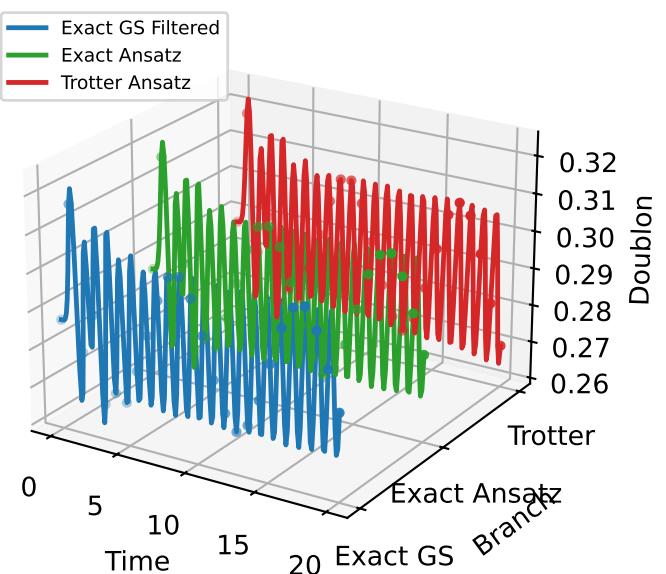
3D Lanes: Total Energy



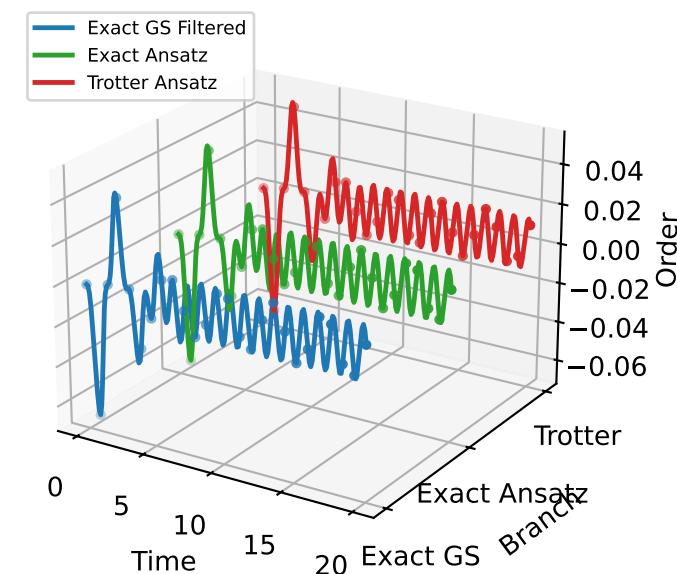
3D Lanes: Static Energy



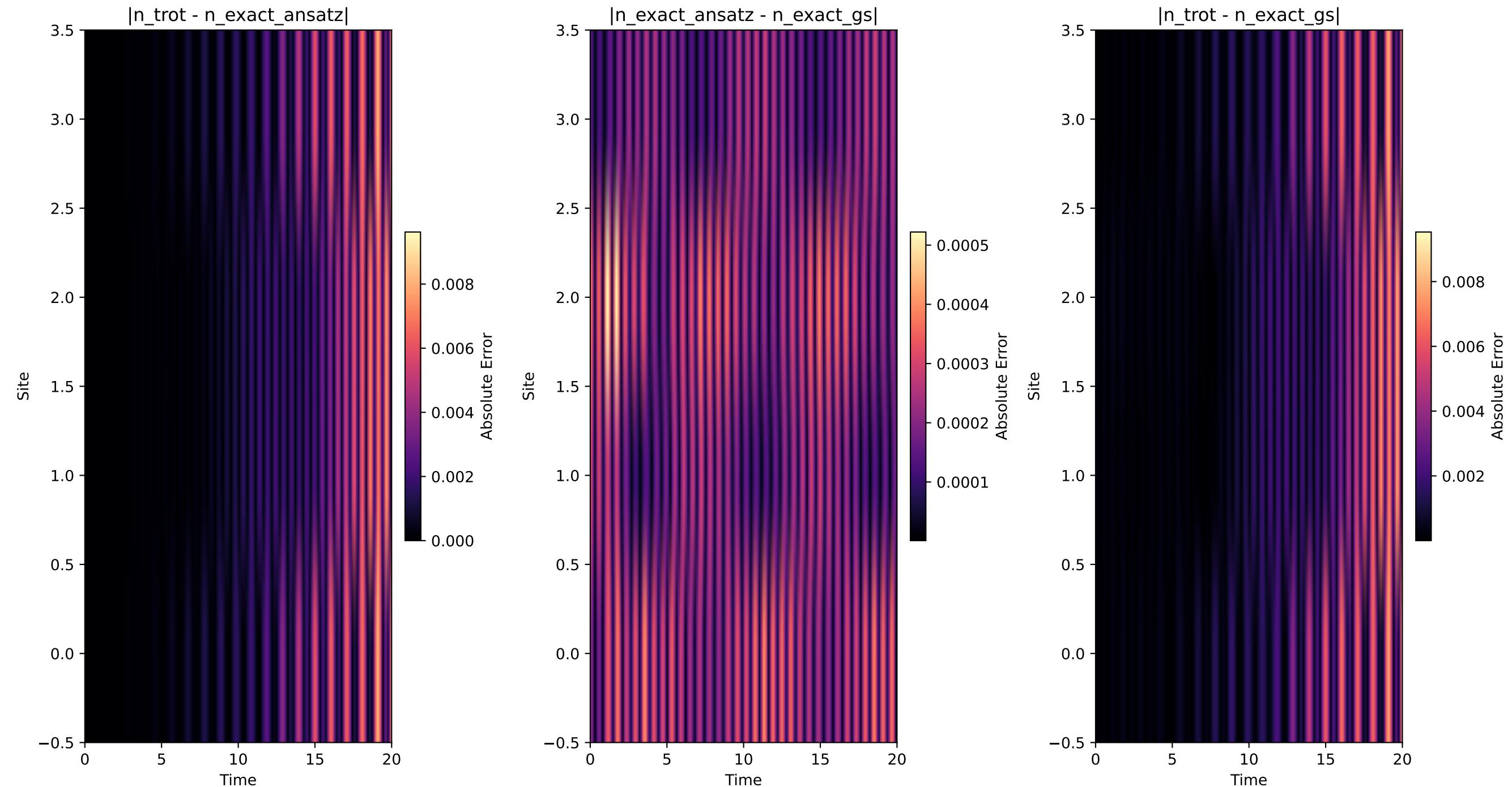
3D Lanes: Doublon



3D Lanes: Staggered Order

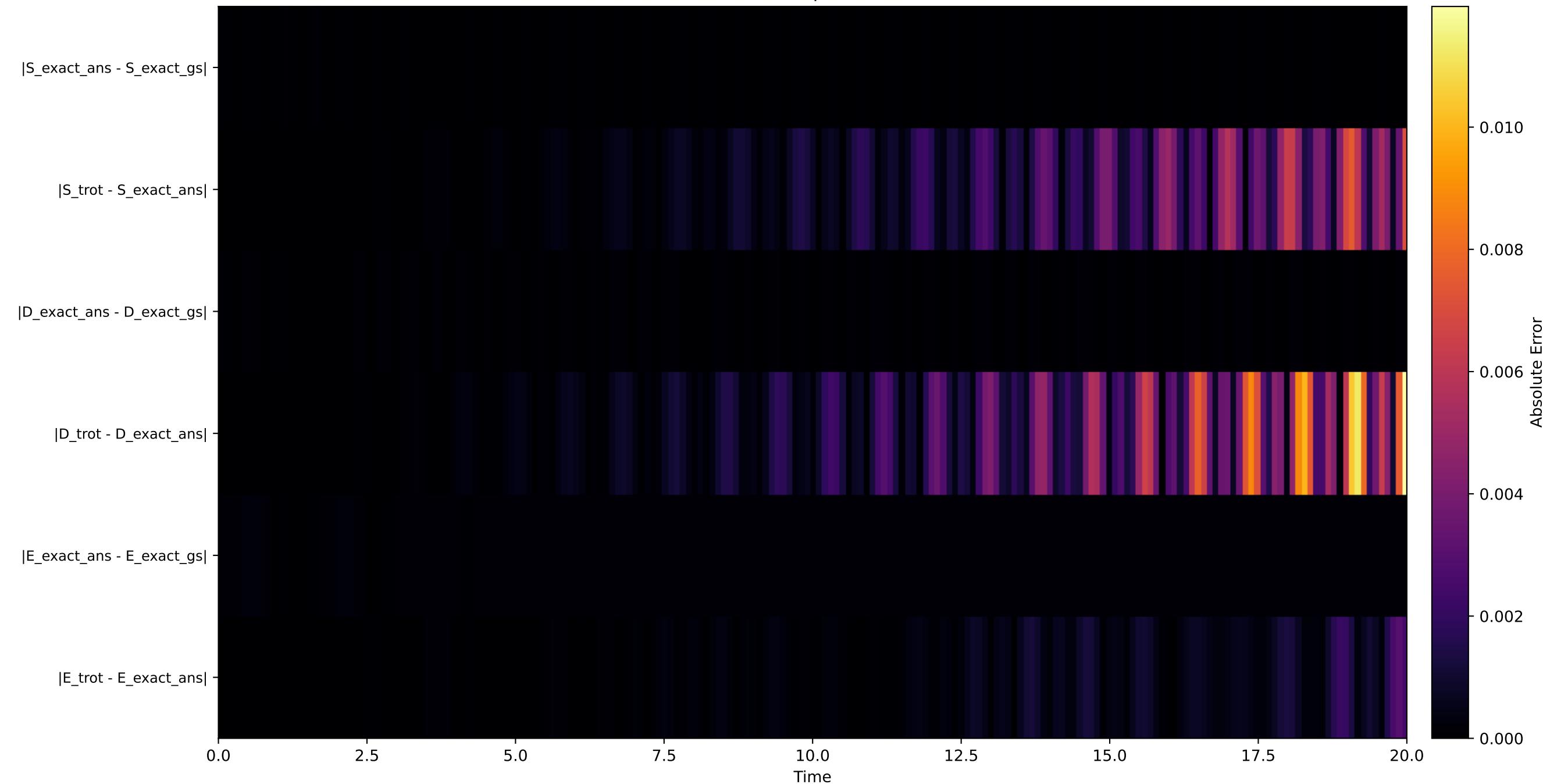


L=4 Error Heatmaps (Absolute Errors)



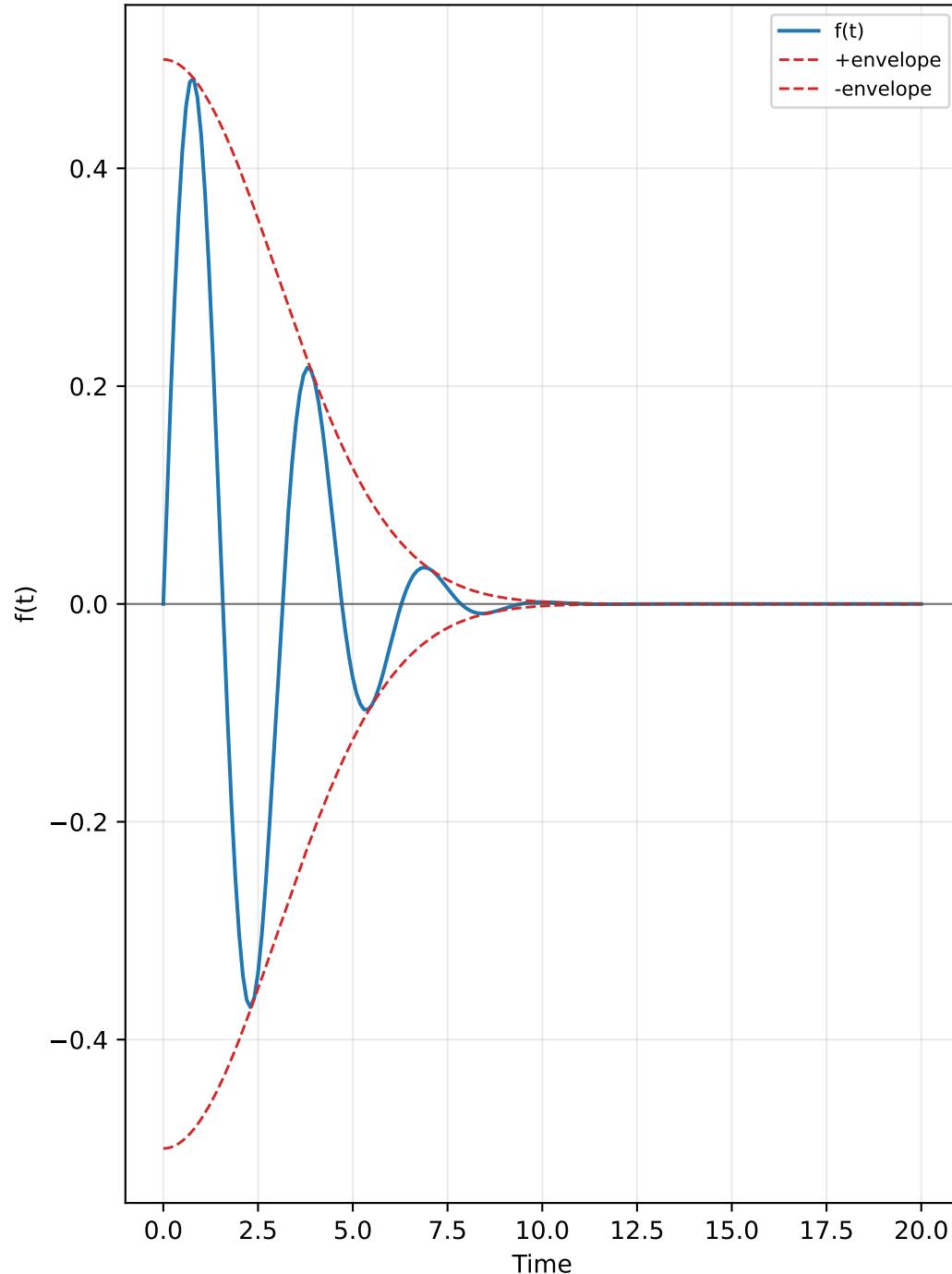
# L=4 Scalar Error Heatmap

Absolute Error Heatmap (Scalar Observables)

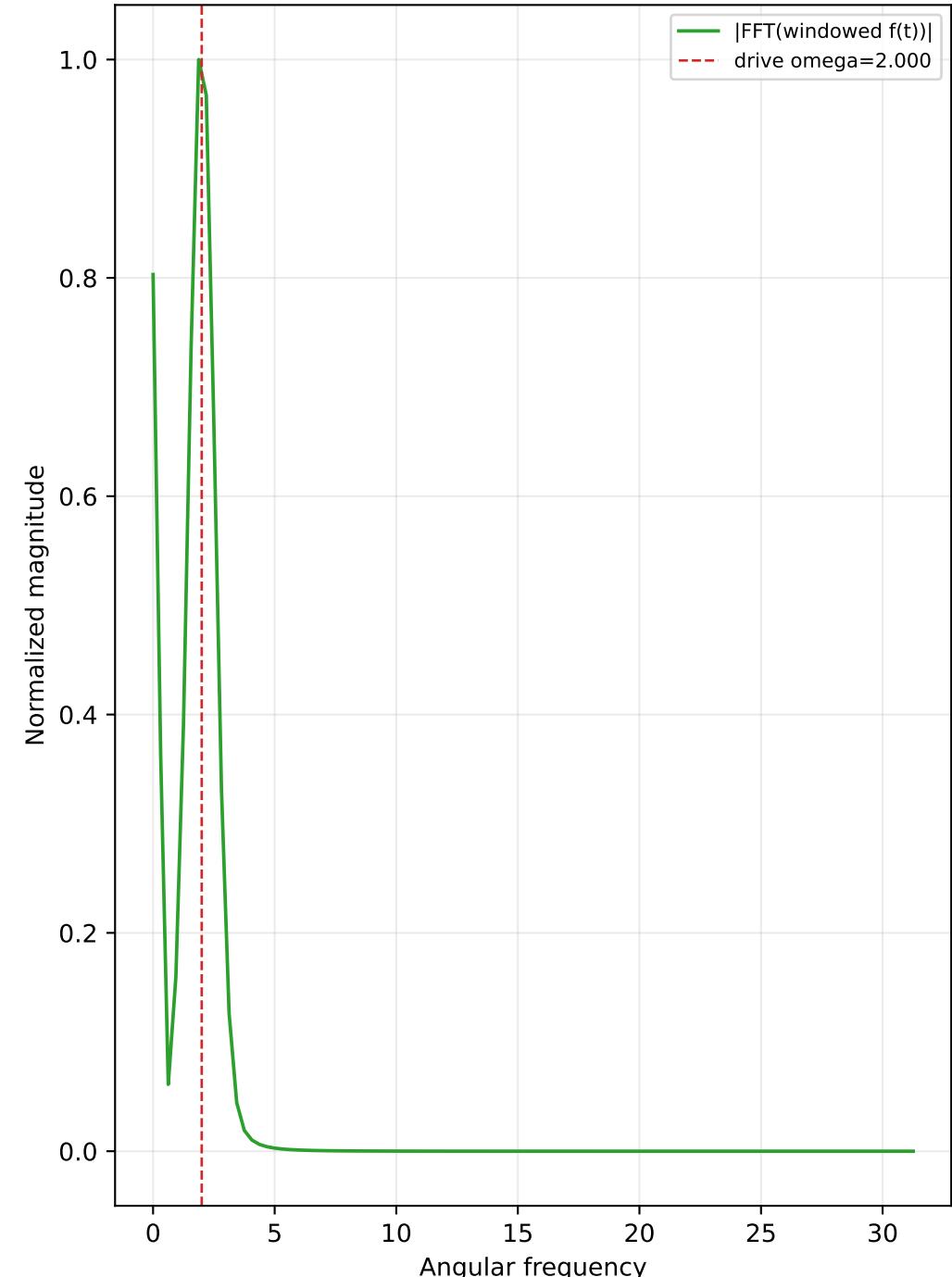


Drive Diagnostics: A=0.5, omega=2.0, tbar=3.0, phi=0.0, t0=0.0

Drive Waveform and Gaussian Envelope

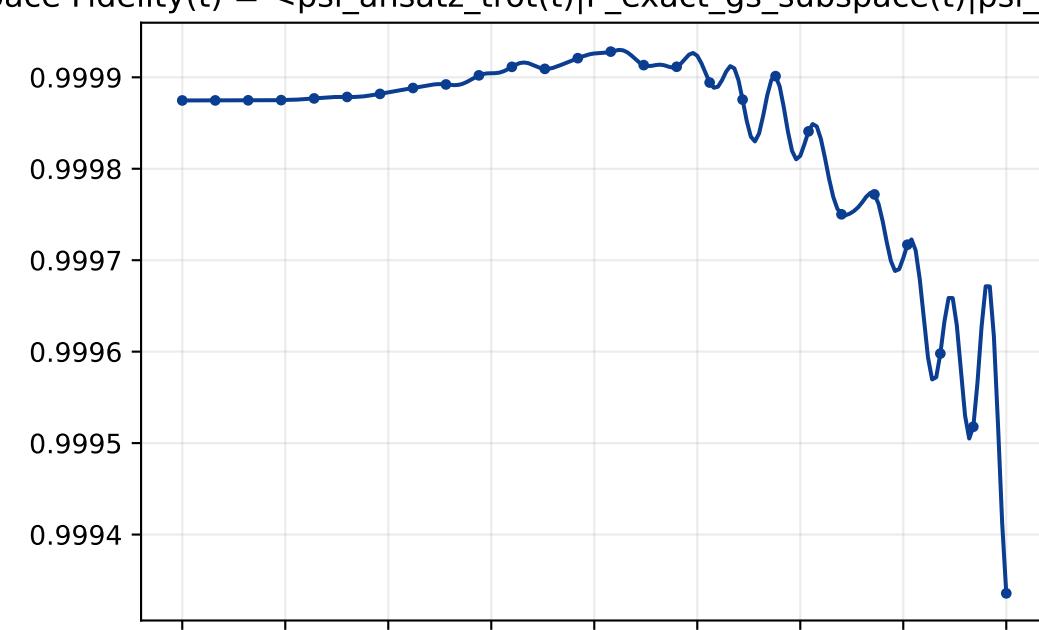


Drive Spectrum (Normalized Magnitude)

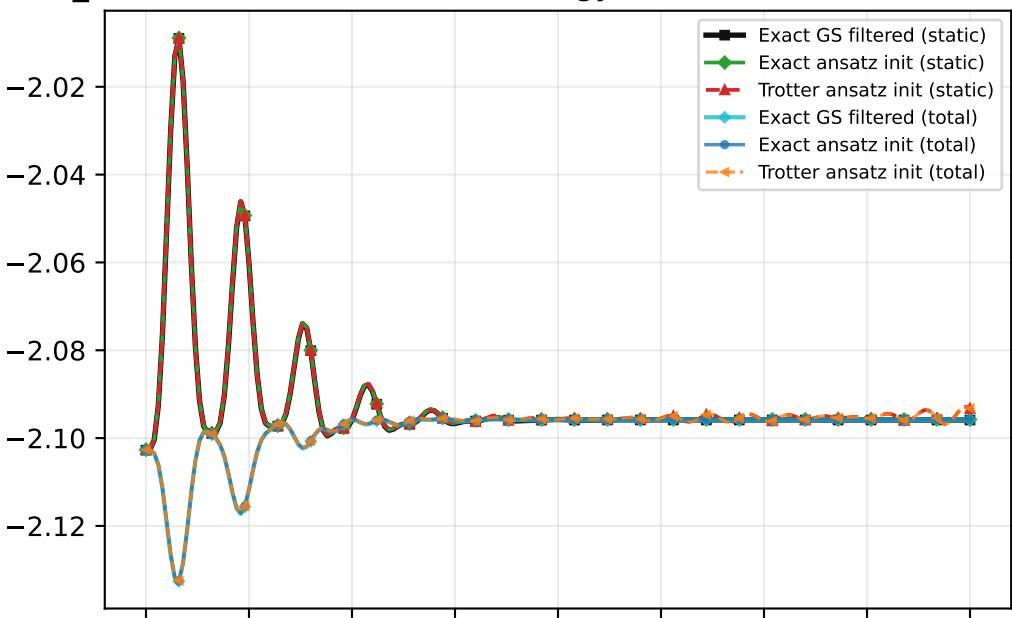


# Hardcoded Hubbard Pipeline: L=4

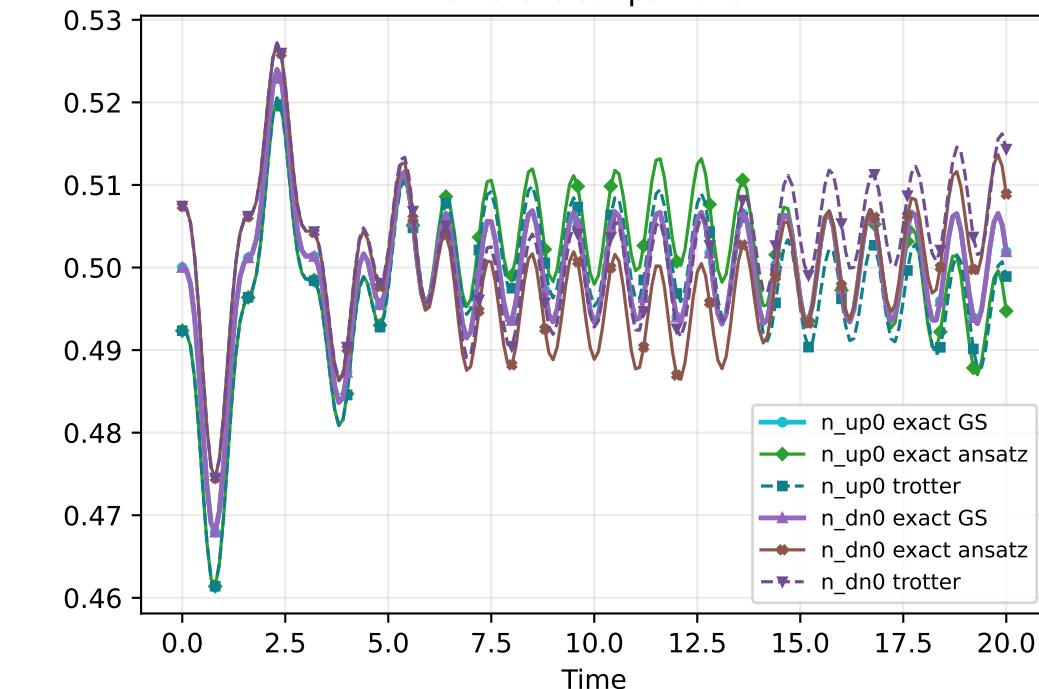
Space Fidelity( $t$ ) =  $\langle \psi_{\text{ansatz\_trot}}(t) | P_{\text{exact\_gs\_subspace}}(t) | \psi_{\text{ansatz\_trot}}(t) \rangle$



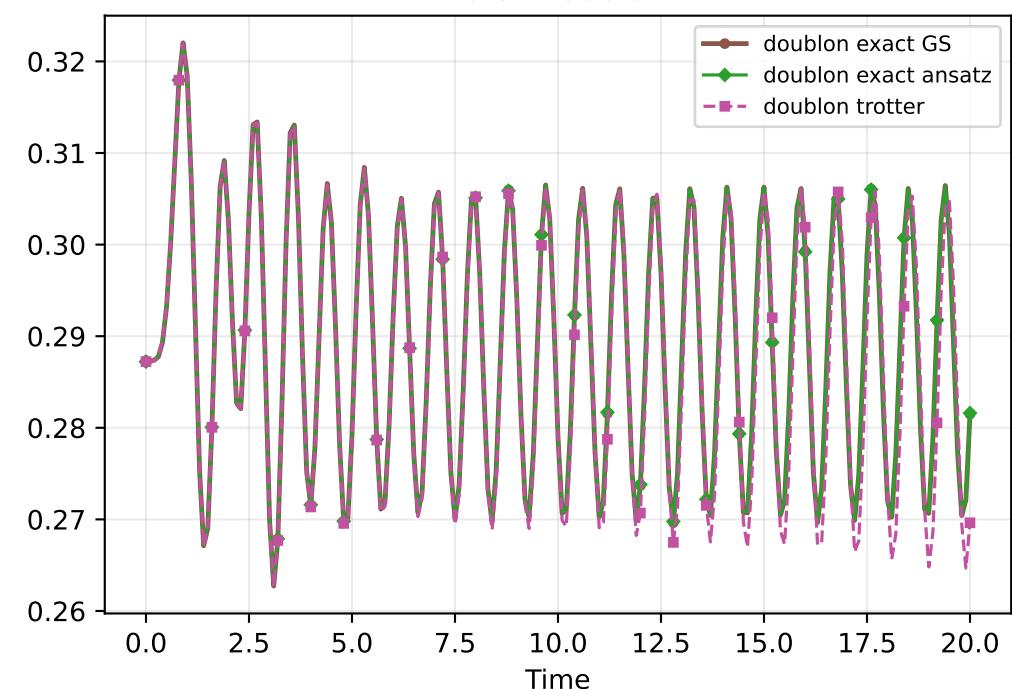
Energy



Site-0 Occupations



Total Doublon

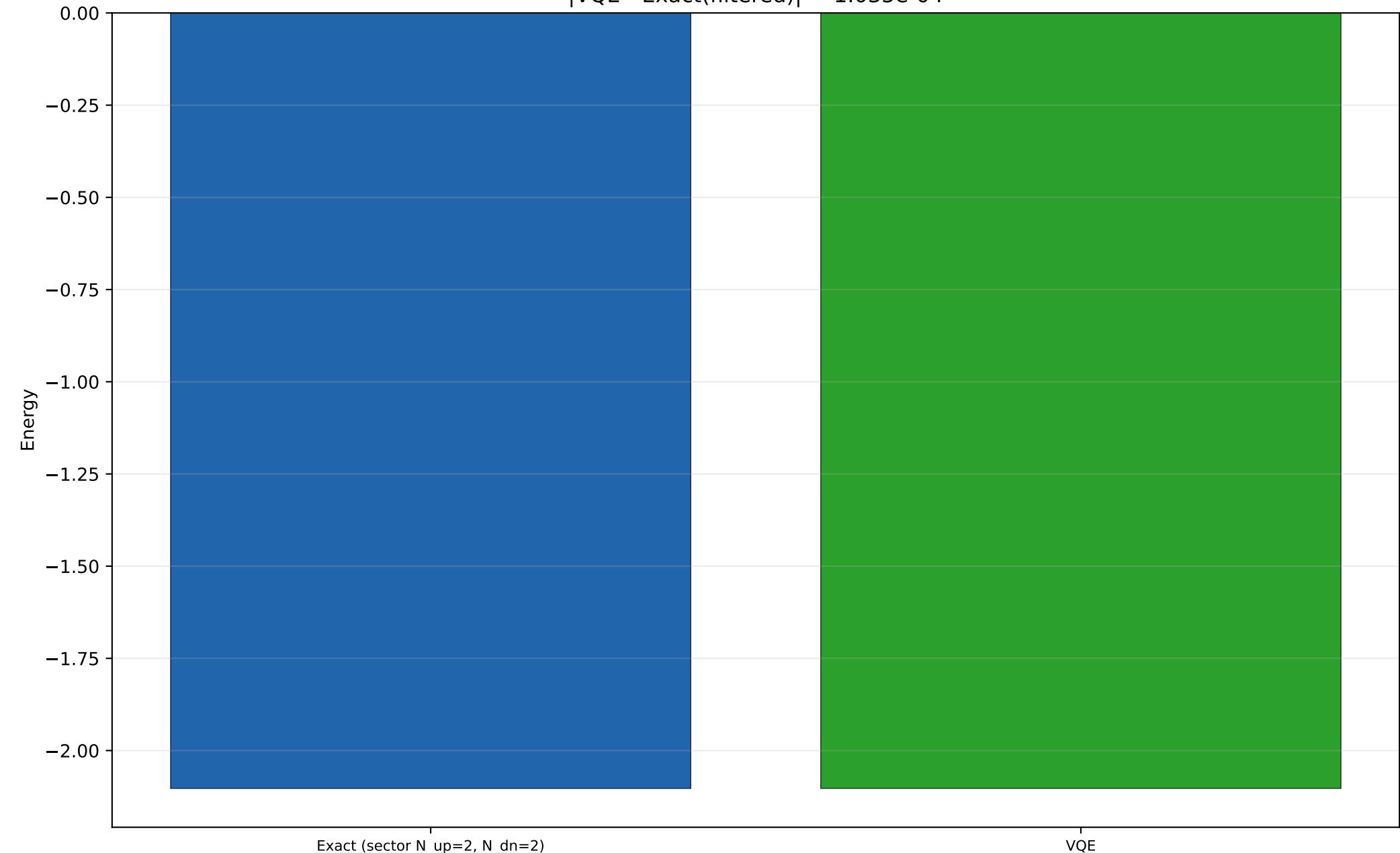


## Appendix – L=4

This section contains supporting/redundant views and metadata.  
Core non-redundant analysis appears earlier in the PDF.

VQE optimises within the half-filled sector; exact (filtered) is the true sector ground state.  
Full-Hilbert exact energy is in the JSON text summary only.

VQE Energy vs Exact (filtered sector)  
 $|VQE - \text{Exact(filtered)}| = 1.035e-04$



Hardcoded Hubbard pipeline summary

```
settings: {"L": 4, "t": 1.0, "u": 4.0, "dv": 0.0, "boundary": "periodic", "ordering": "blocked", "t_final": 20.0, "num_times": exact_trajectory_label: Exact_Hardcode
exact_trajectory_method: python_matrix_eigendecomposition
fidelity_definition: fidelity(t) = <psi_ansatz_trot(t)|P_exact_gs_subspace(t)|psi_ansatz_trot(t)>, where P_exact_gs_subspace(t)
subspace_fidelity_at_t0: 0.9998746882400258
energy_t0_exact_gs: -2.102748483462075
energy_t0_exact_ansatz: -2.1026450003175245
energy_t0_trotter: -2.1026450003175245
ground_state_exact_energy (full Hilbert): -3.418550718874
ground_state_exact_energy_filtered: -2.1027484834620753
filtered_sector: {'n_up': 2, 'n_dn': 2}
vqe_energy: -2.1026450003175046
qpe_energy_estimate: None
initial_state_source: vqe
hamiltonian_terms: 29
reference_sanity: {'checked': False, 'reason': 'no matching bundled reference for these settings'}
```