Time Crystal

Choy Sheung Lam 1155143776
Ng Hing Wing 1155141874

What happen if we break time-symmetry ?

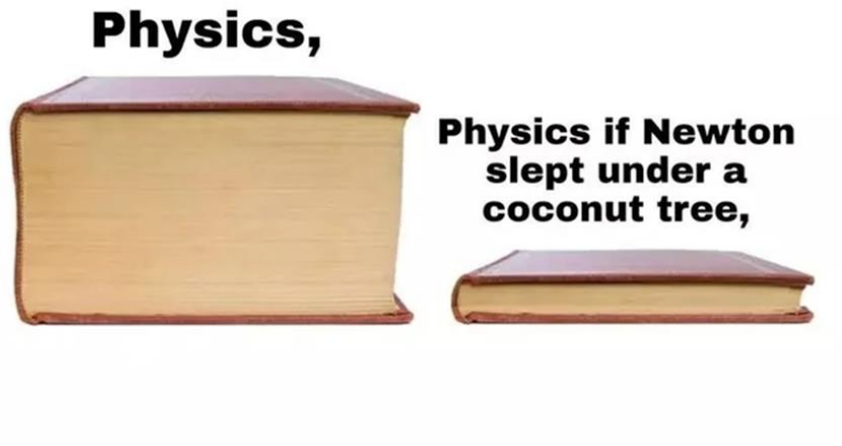
Background

Time Translational Symmetry

Same Physics done in different time creates same result

Breaking Time Translational Symmetry?

Same Physics done in different time creates diff result



Discrete Time Symmetry

Same system config. appear in time with a fixed period

Between Period total random or not related system config.

What constitutes as a time crystal?

Broken time translational symmetry

No entropy generated by oscillation (Contrast to what we thought about heat and oscillation)

Robust long-range interaction and long sustain time

Experiment

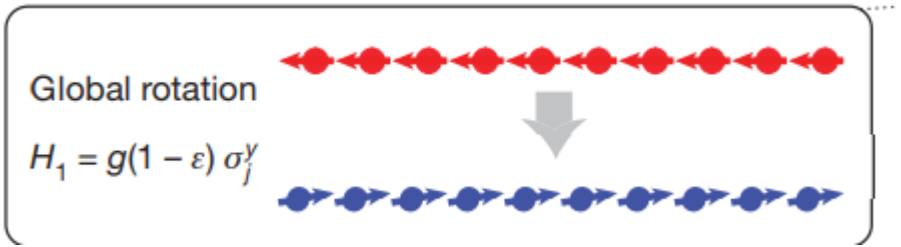
H1:EM field input

Why: Driving the system EXTERNALLY (Control the system)

How: Raman Laser Input

Problem: Noise

Solution: Dynamical decoupling sequence



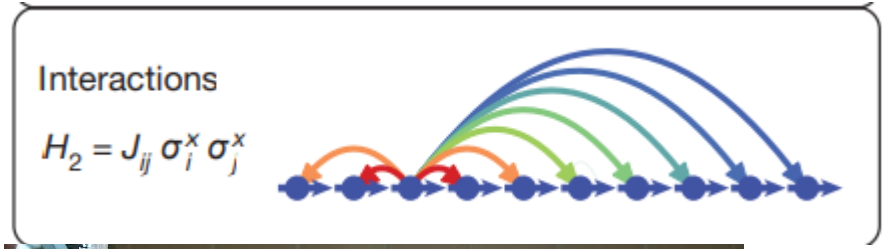
H2:Applying spin-dependent optical dipole forces

Why: Couple spin(Generate an Ising Hamiltonian), Create Long Range Interaction and Trigger Many-Body Localization

How: 3 Layers Paul traps

Effect: Forcing them to couple back together

$$J_{i,j} = \Omega^2 \omega_R \sum_{m=1}^{N} \frac{b_{i,m} b_{j,m}}{\mu^2 - \omega_m^2},$$

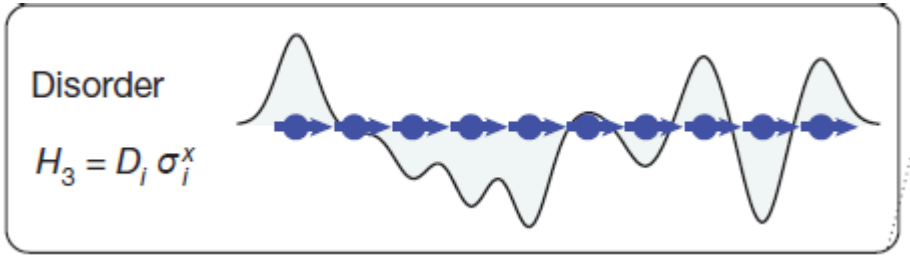


H3:Applying strong random disordered field with stark shift

Why: Trigger Many-Body Localization

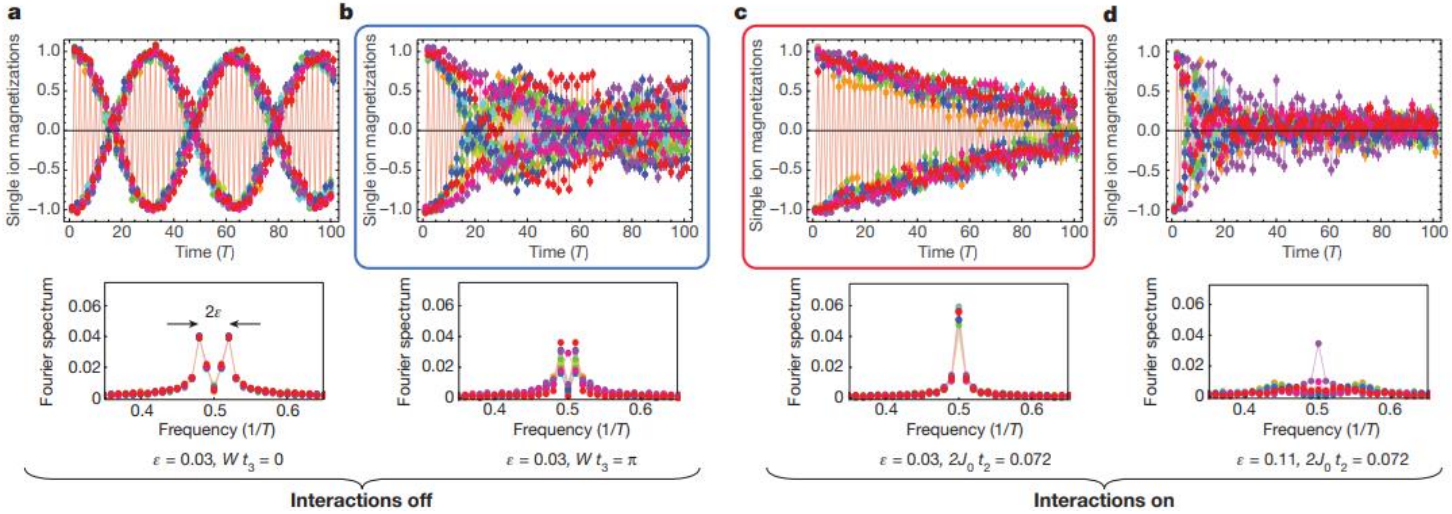
How: Applying strong random disordered field which “induces” 4th order stark shift

Effect: Trigger Many-Body Localization



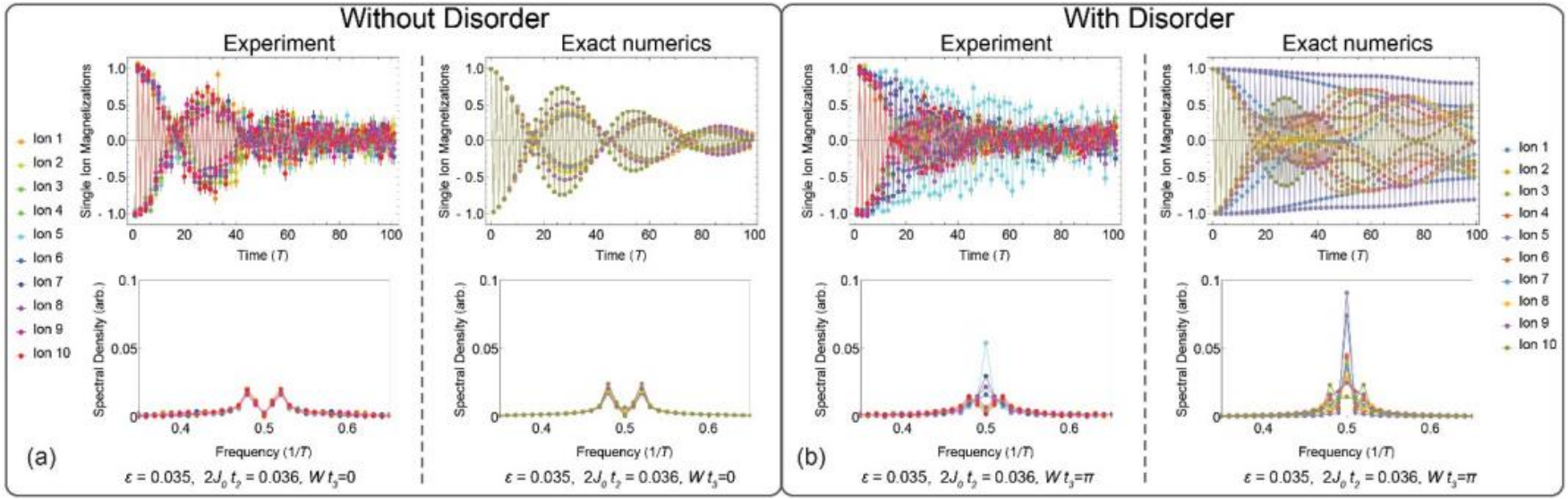
Interaction on/off

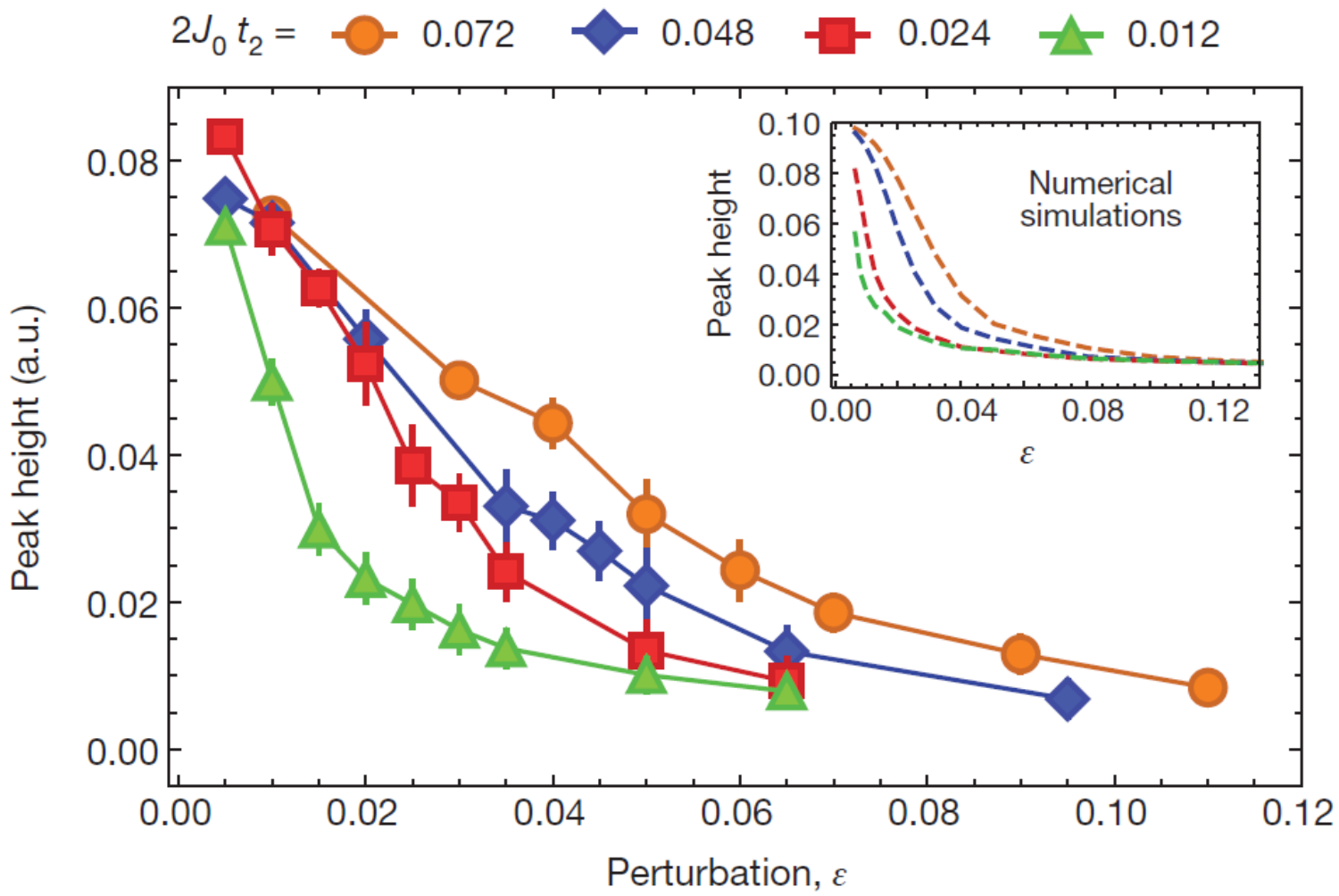
Single peak with interaction



With perturbation

More stable with perturbation




$2J_0\,t_2$ =
0.072
0.048
0.024
0.012
Peak height (a.u.)
0.00
0.02
0.04
0.06
0.08
0.00
0.02
0.04
0.06
0.08
0.10
0.12
Perturbation, ε
Peak height
0.00
0.02
0.04
0.06
0.08
0.10
0.00
0.04
0.08
0.12
ε
Numerical
simulations

Why Many-Body Localization matters?

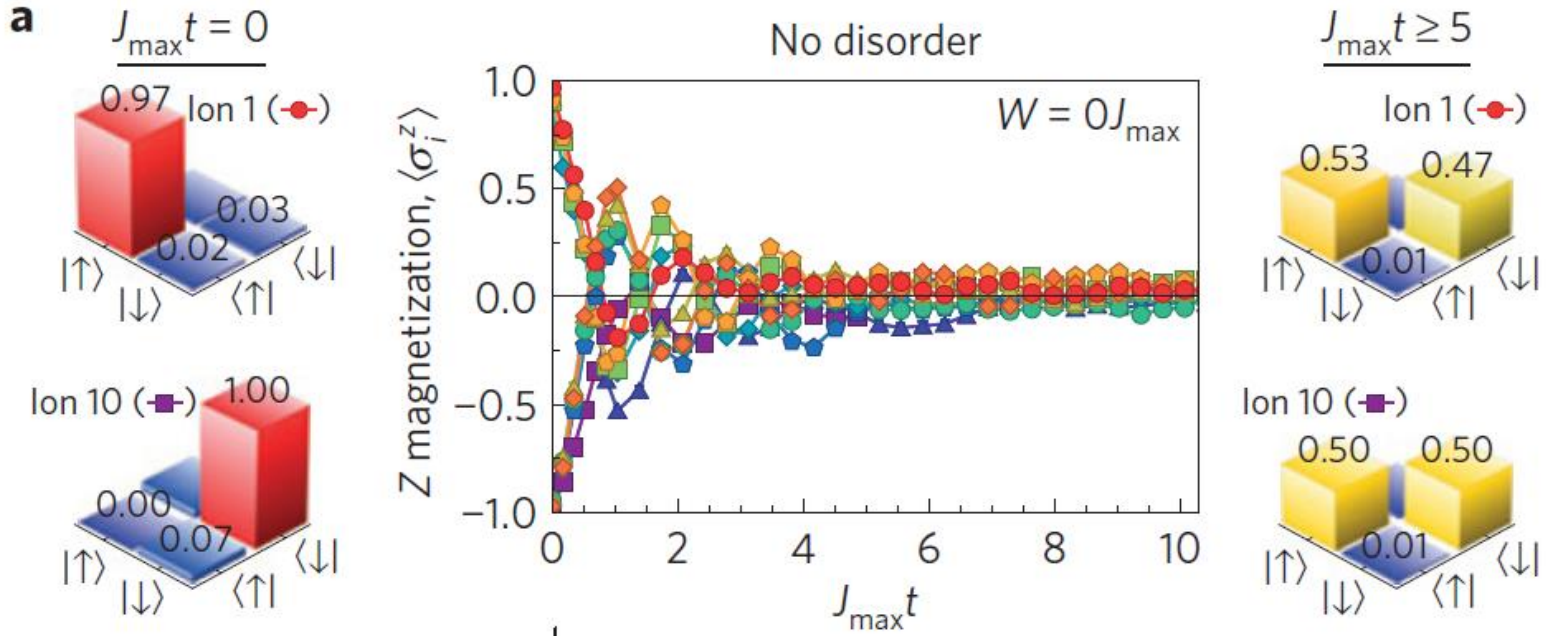
- We want to create a robust system, something can stand up to the effect of entropy
- It is pointless to see H2/H3 separately, Let see it as one.

$$H_{\text{Ising}} = \sum_{i<j} J_{i,j}\sigma_i^x\sigma_j^x + \frac{B}{2}\sum_i \sigma_i^z + \sum_i \frac{D_i}{2}\sigma_i^z$$

- Also, as you can argue the result of MBL is not directly related to the stability of the system, therefore I am going to use a system without H1

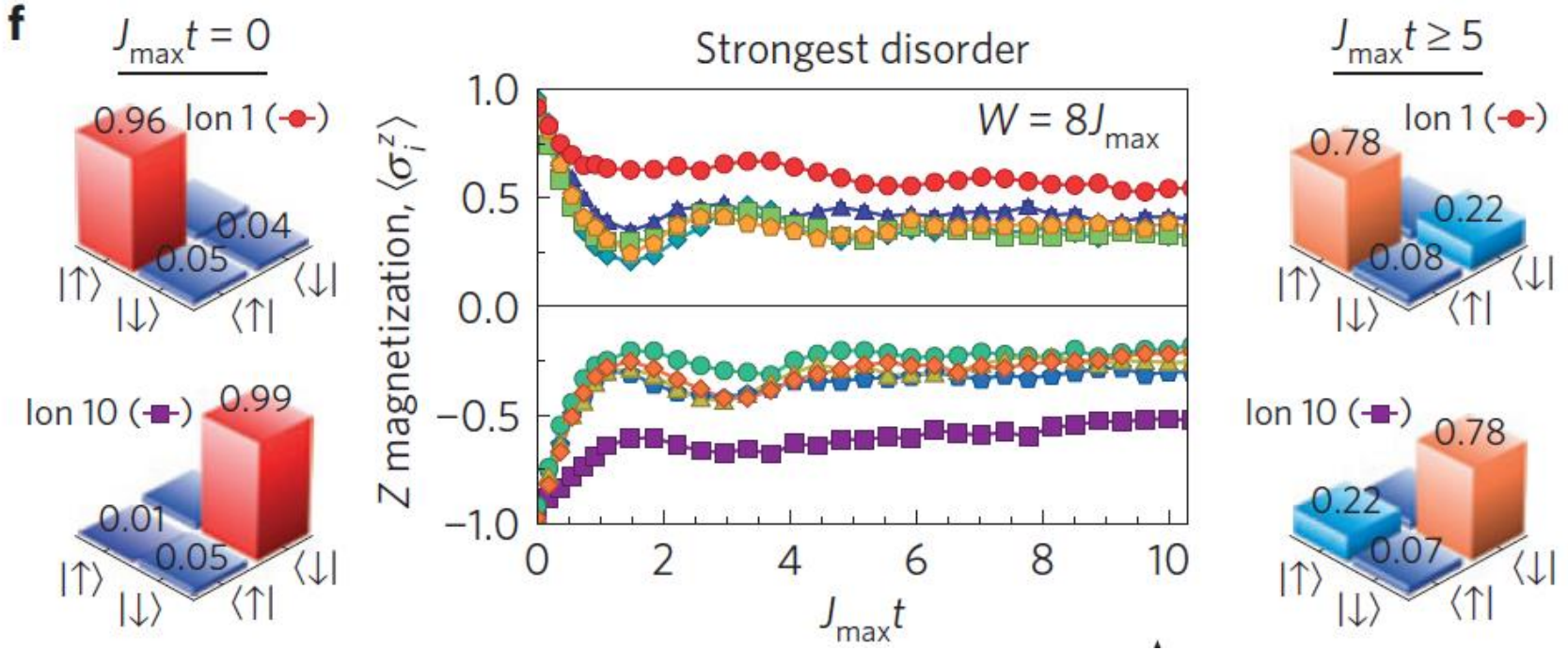
No Disorder

No Disorder⇒ Information stored by spins basically destroyed



With Disorder

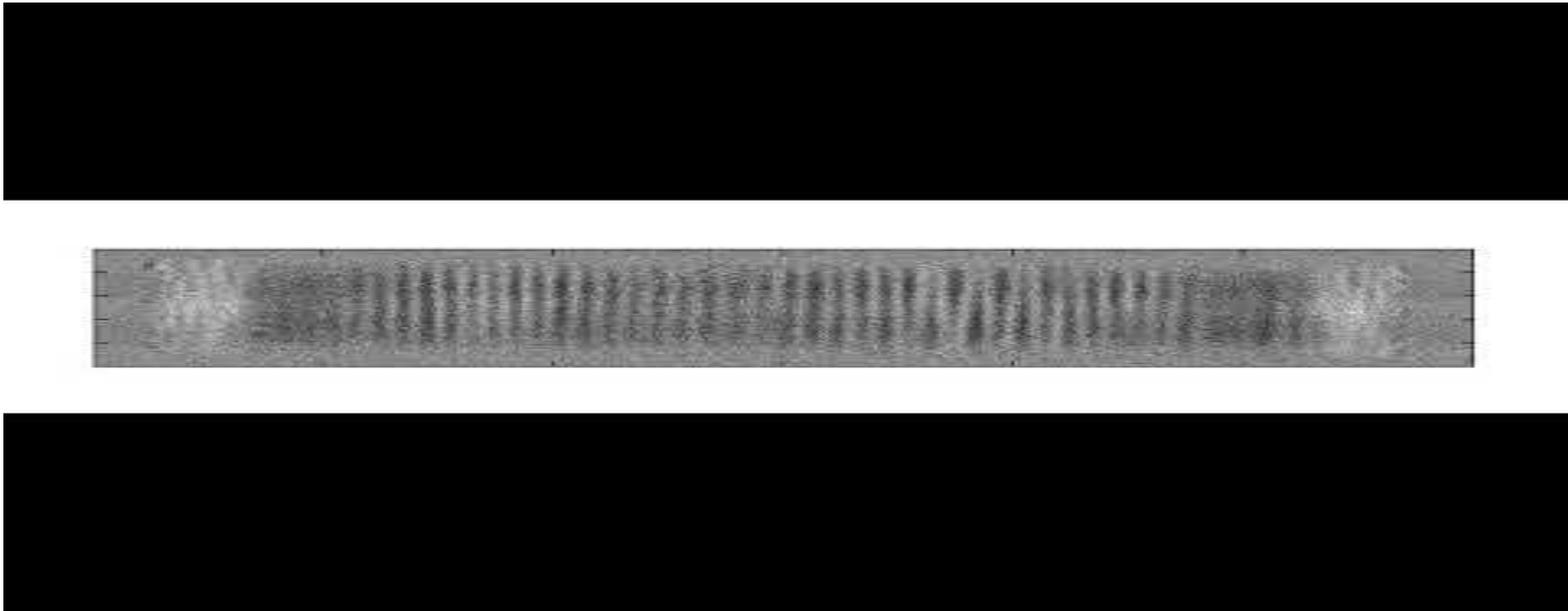
•With Disorder⇒ Information stored by spins still recognizable



Results

Spin-dependent fluorescence captured on a camera

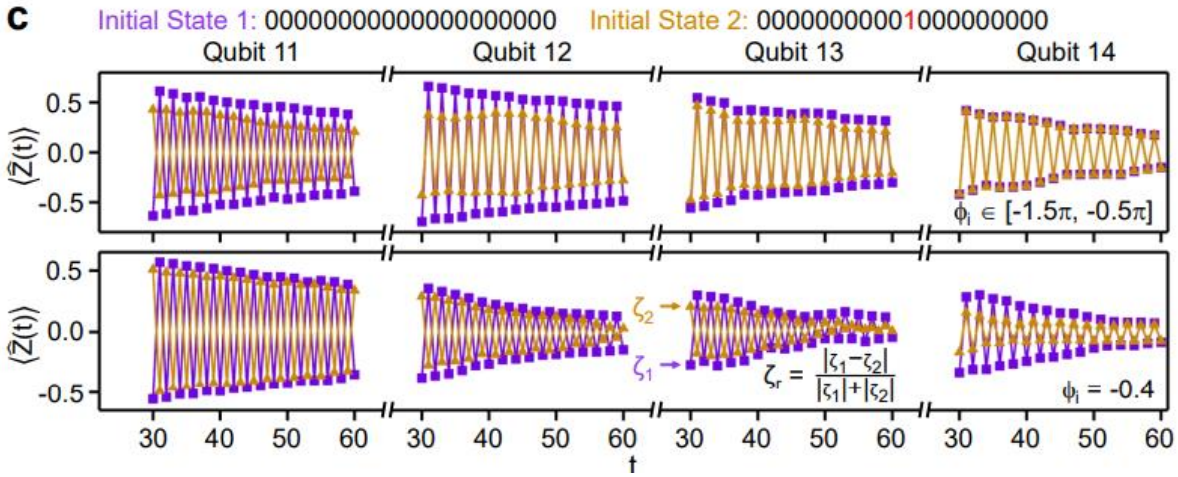
World's first video recording of a space-time crystal



Conclusion

Possible applications in Quantum Computation

Time crystal qubit



Reference

Biercuk, M. J., Uys, H., VanDevender, A. P., Shiga, N., Itano, W. M., & Bollinger, J. J. (2009, April 23). *Optimized dynamical decoupling in a model Quantum Memory*. Nature News. Retrieved October 17, 2022, from https://www.nature.com/articles/nature07951

Mi, X., Ippoliti, M., Quintana, C., Greene, A., Chen, Z., Gross, J., Arute, F., Arya, K., Atalaya, J., Babbush, R., Bardin, J. C., Basso, J., Bengtsson, A., Bilmes, A., Bourassa, A., Brill, L., Broughton, M., Buckley, B. B., Buell, D. A., … Roushan, P. (2021, November 30). *Time-crystalline eigenstate order on a quantum processor*. Nature News. Retrieved October 17, 2022, from https://www.nature.com/articles/s41586-021-04257-w?fr=operanews

Smith, J., Lee, A., Richerme, P., Neyenhuis, B., Hess, P. W., Hauke, P., Heyl, M., Huse, D. A., & Monroe, C. (2016, June 6). *Many-body localization in a quantum simulator with programmable random disorder*. Nature News. Retrieved October 17, 2022, from https://www.nature.com/articles/nphys3783

Zhang, J., Hess, P. W., Kyprianidis, A., Becker, P., Lee, A., Smith, J., Pagano, G., Potirniche, I.-D., Potter, A. C., Vishwanath, A., Yao, N. Y., & Monroe, C. (2017, March 9). *Observation of a discrete time crystal*. Nature News. Retrieved October 17, 2022, from https://www.nature.com/articles/nature21413