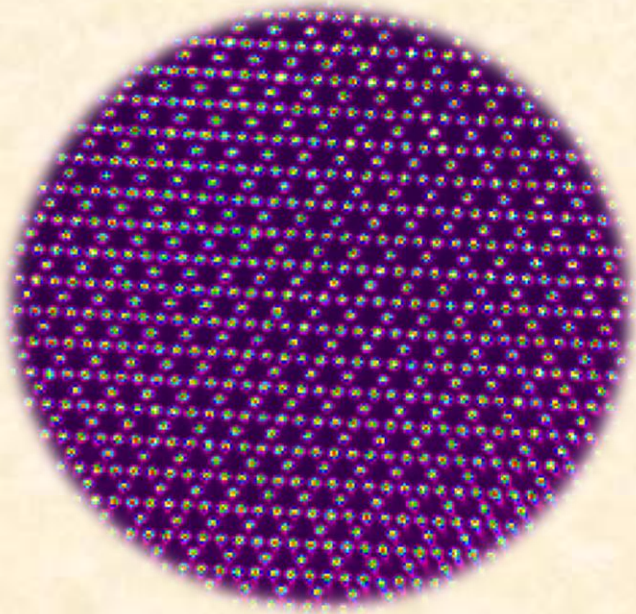
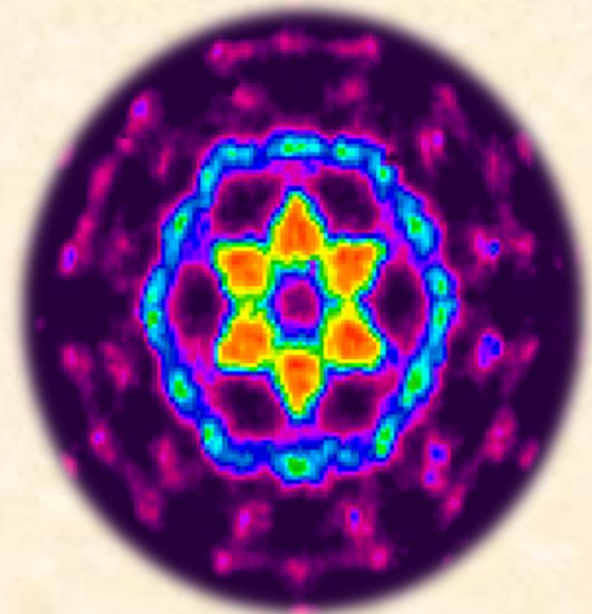


Phase Locking Large Laser Arrays

Near Field



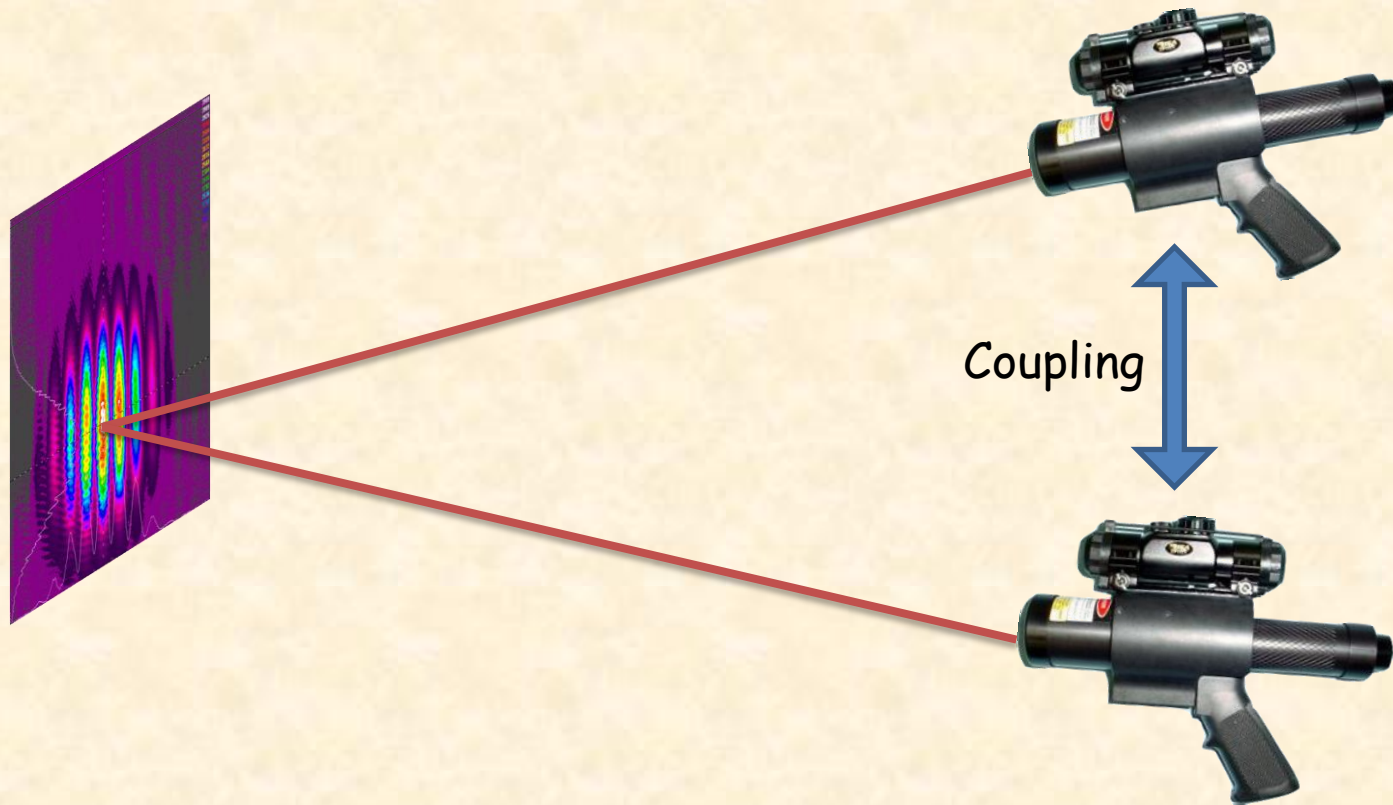
Far Field



Nir Davidson

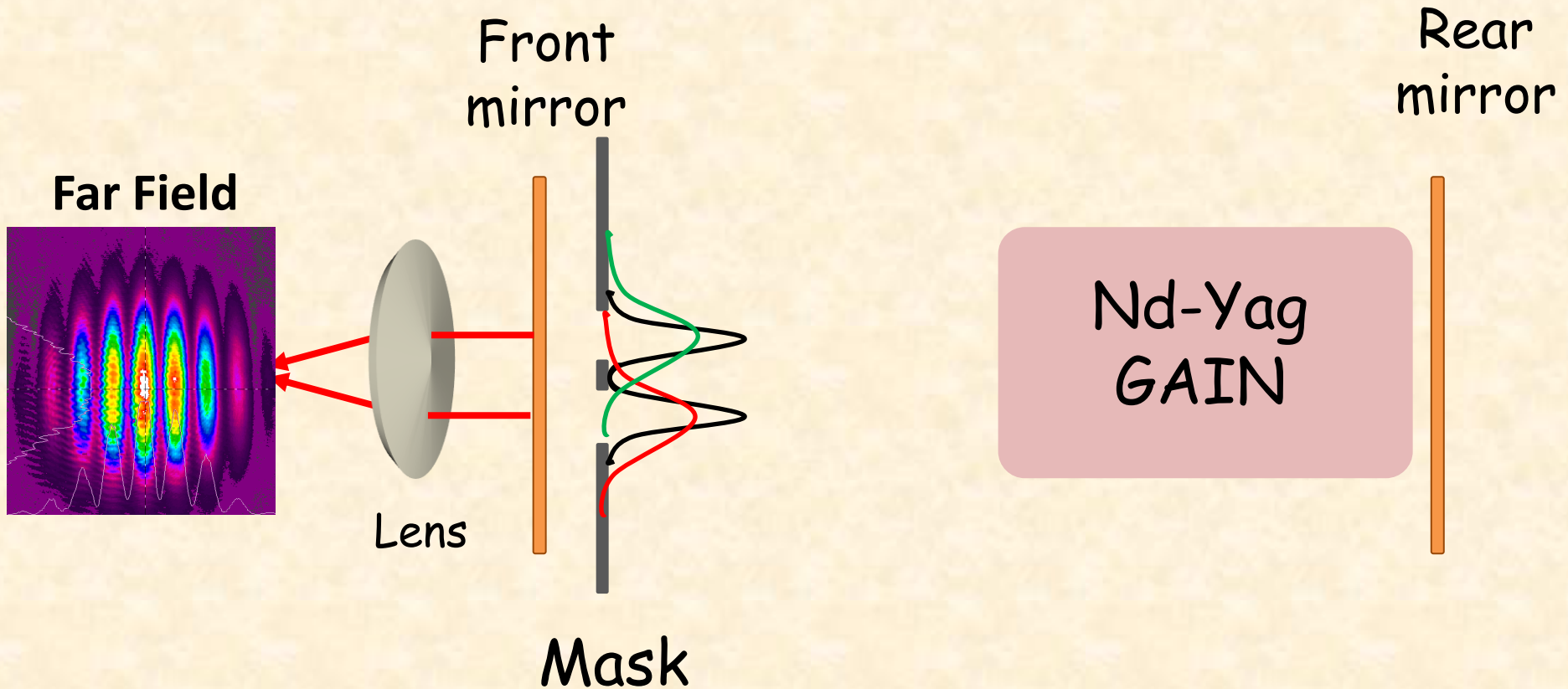
Micha Nixon, Eitan Ronen, and Asher Friesem
Weizmann Institute of Science

What is phase locking ?



$$\Delta\varphi(t) = \varphi_2(t) - \varphi_1(t) = \textit{const}$$

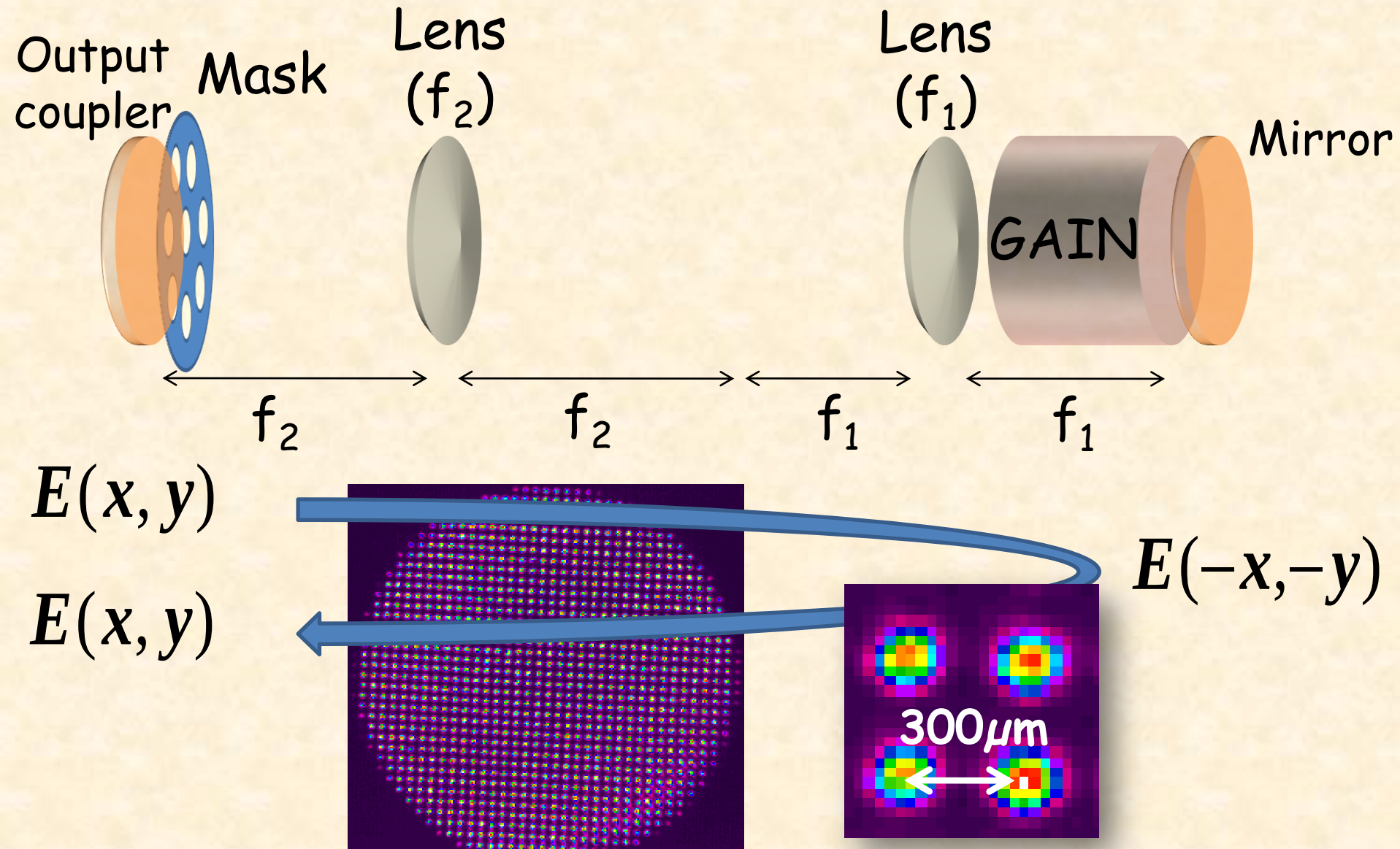
Diffractive coupling



$$\kappa_{ij} = \langle E_i | E_j \rangle \cong e^{-\alpha(i-j)^2}$$

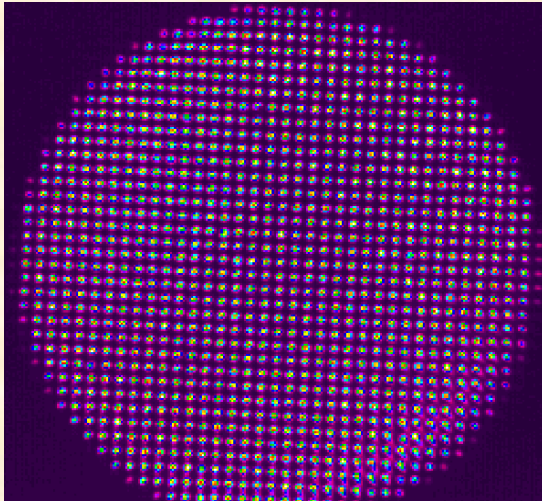
Short range interaction

Degenerate laser cavity

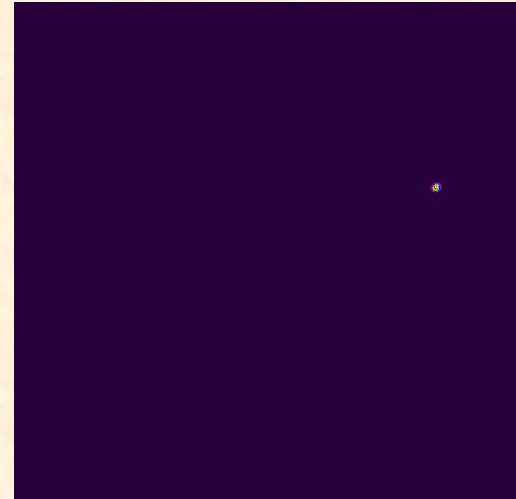


Degenerate cavity square array

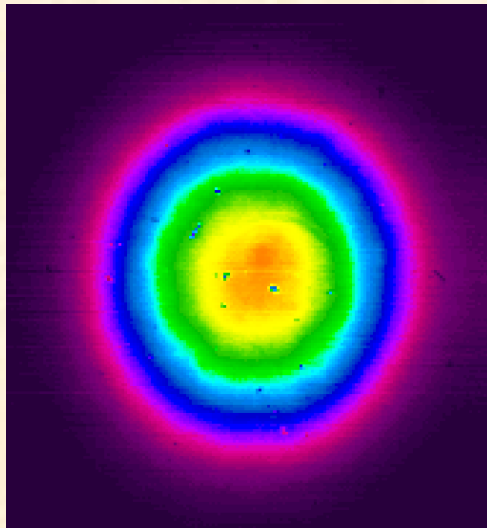
Near field



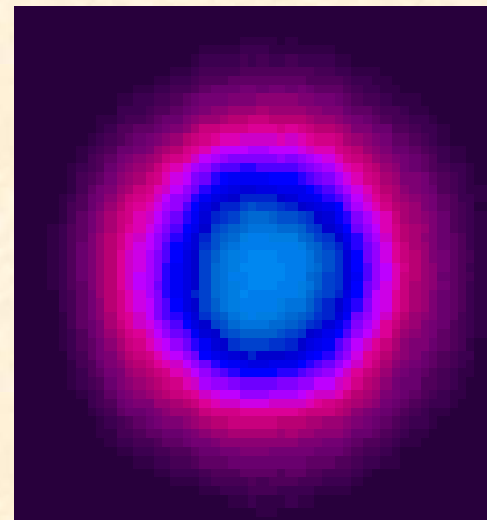
Near field



Far field



Far field

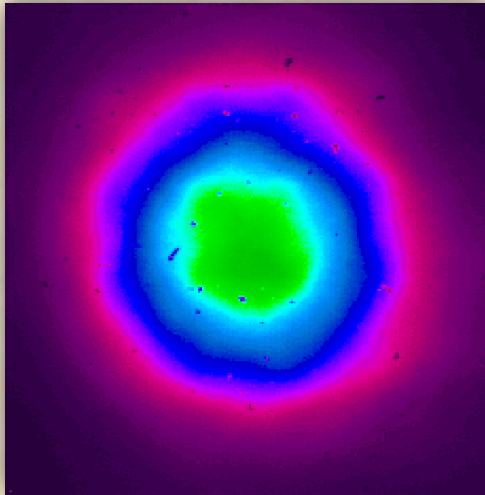


Degenerate cavity

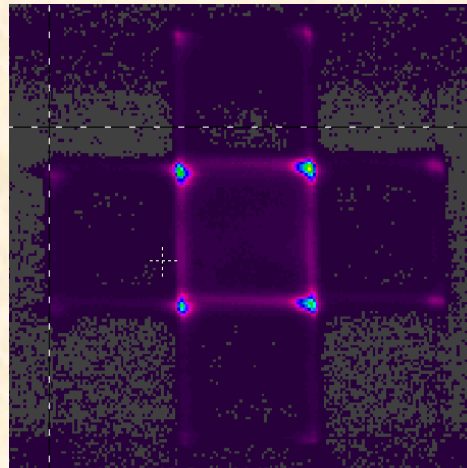


Far
Field

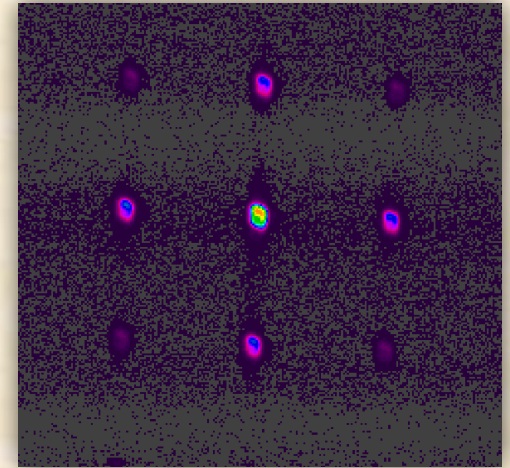
No coupling



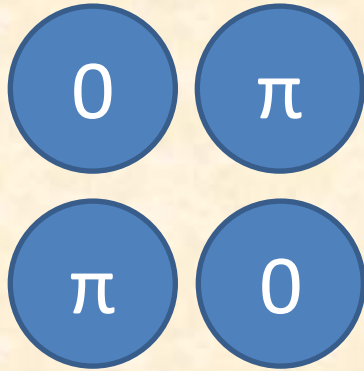
Negative coupling



Positive coupling

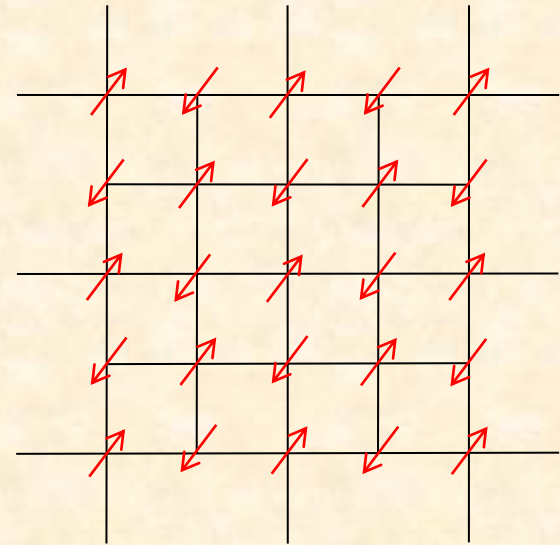


Lasers $\longleftrightarrow$ Spin



Kuramoto Model

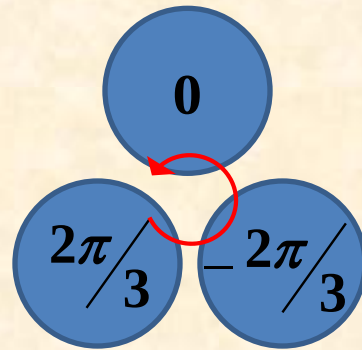
XY model with **anti**
ferromagnetic interactions



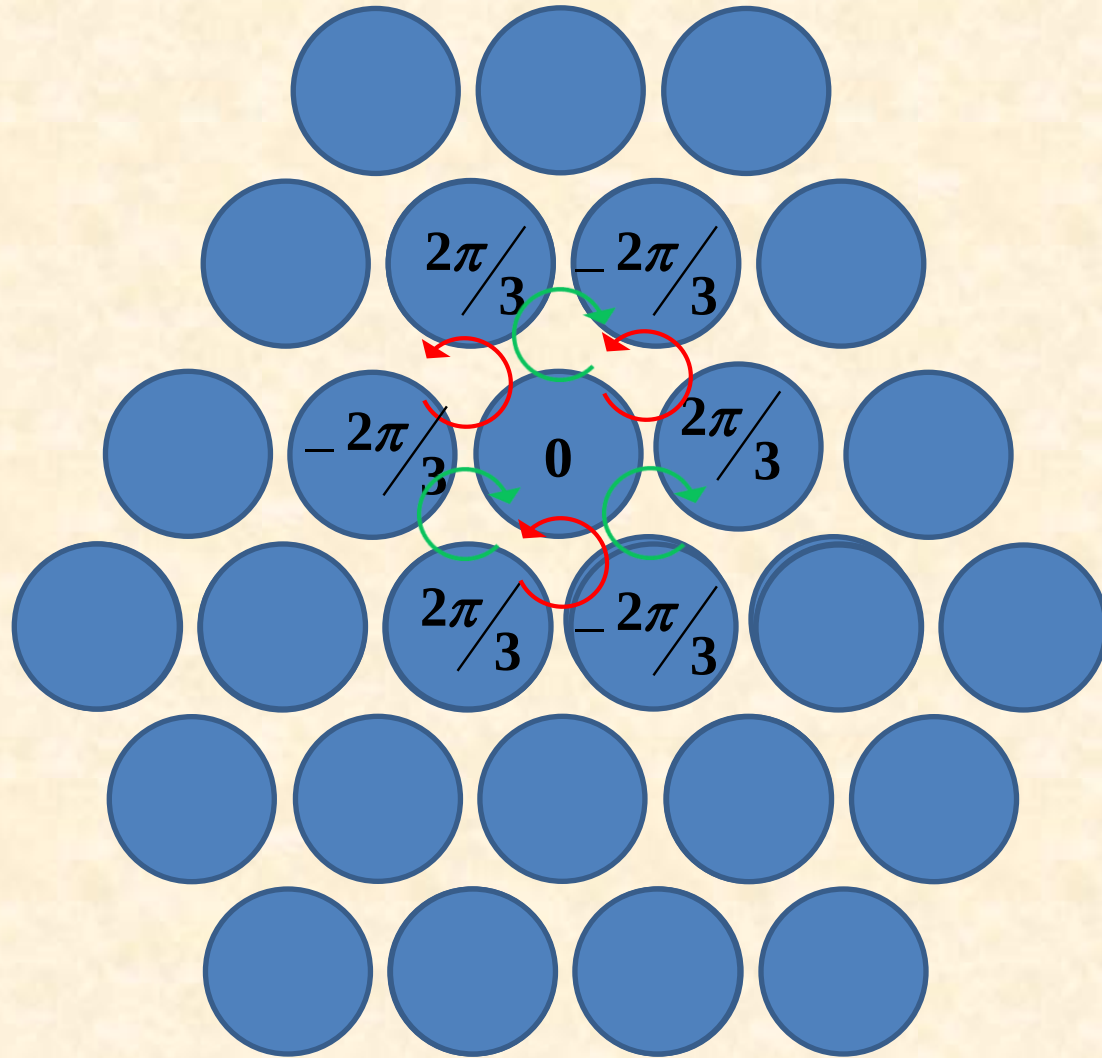
$$\dot{\theta}_i = \sum \kappa_{ij} \sin(\theta_j - \theta_i)$$

$$H = J \sum_{i \neq j}^n \vec{\sigma}_i \cdot \vec{\sigma}_j$$

Triangle Array

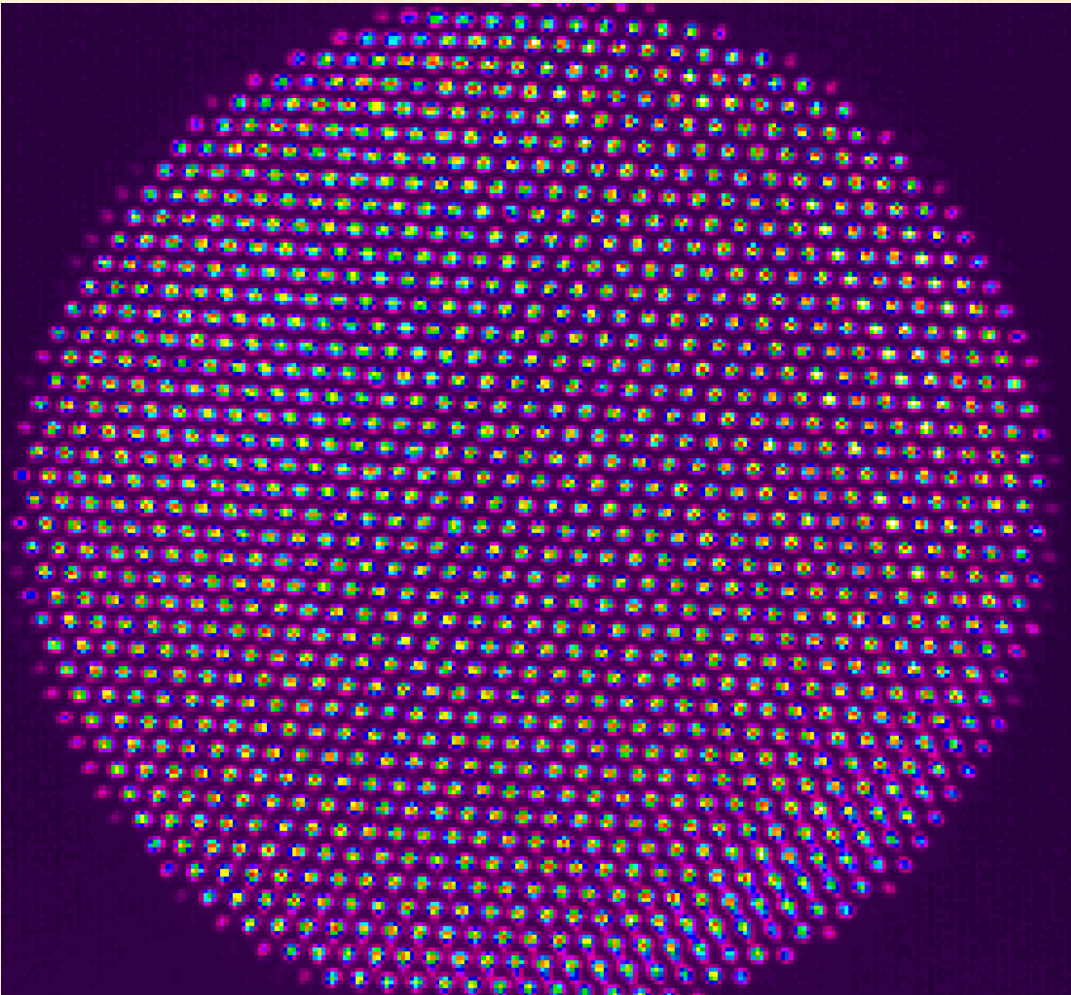


Triangle Array

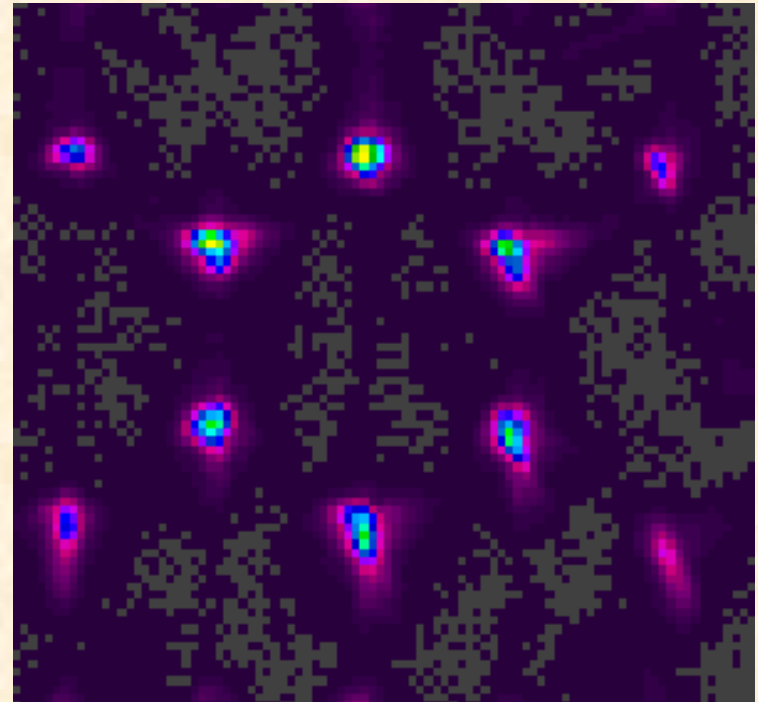


Triangular array

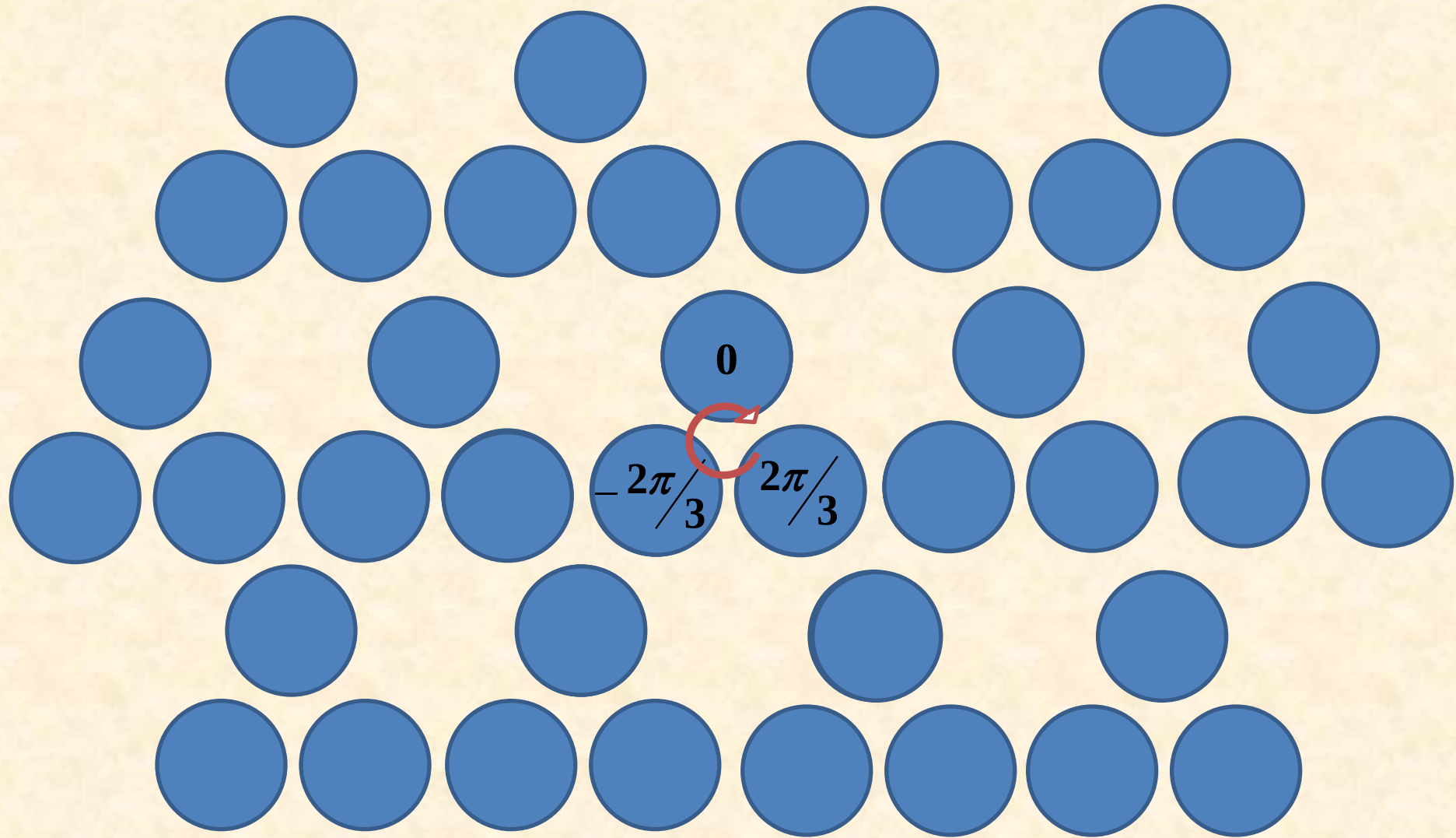
Near Field



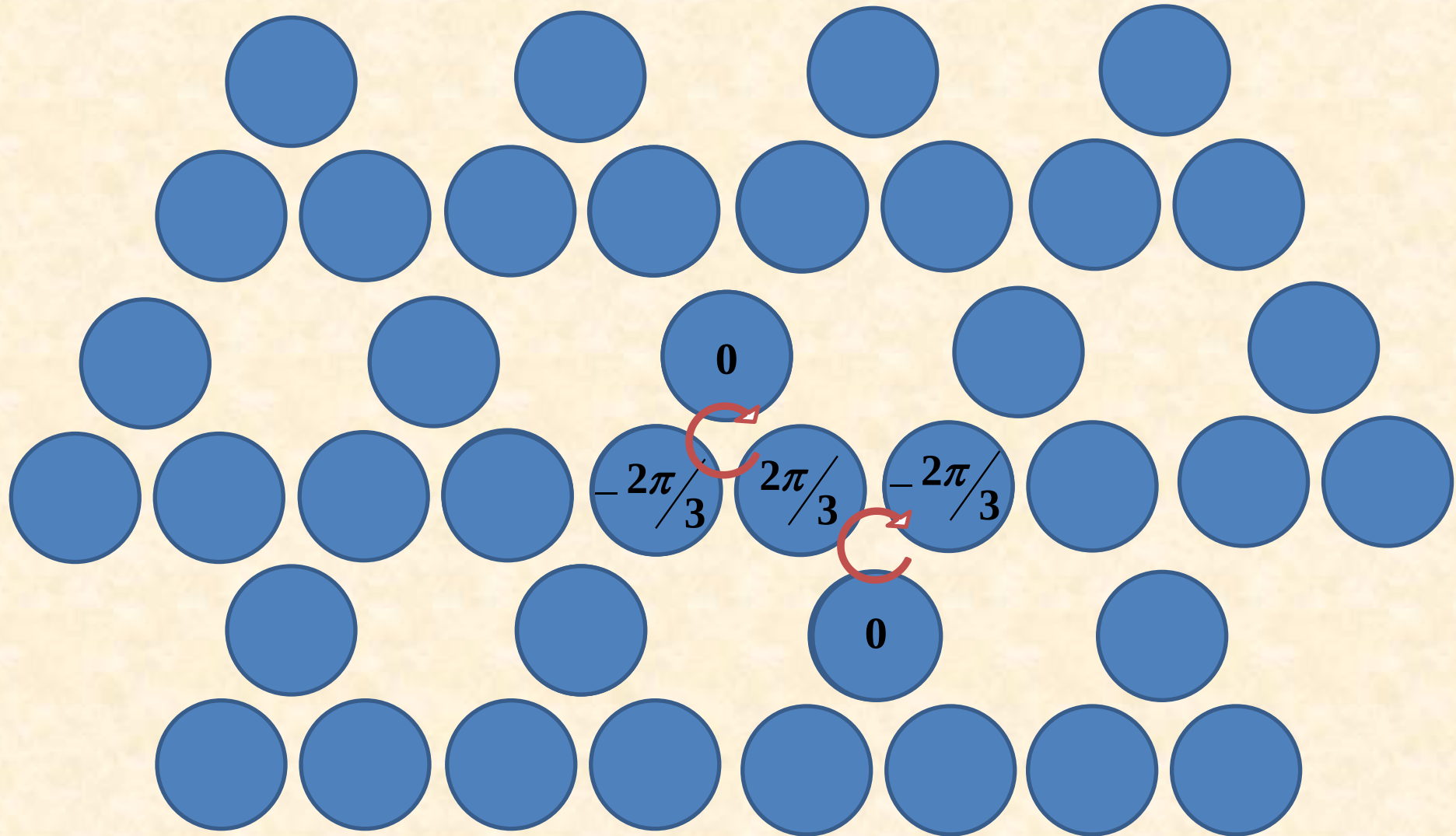
Far Field



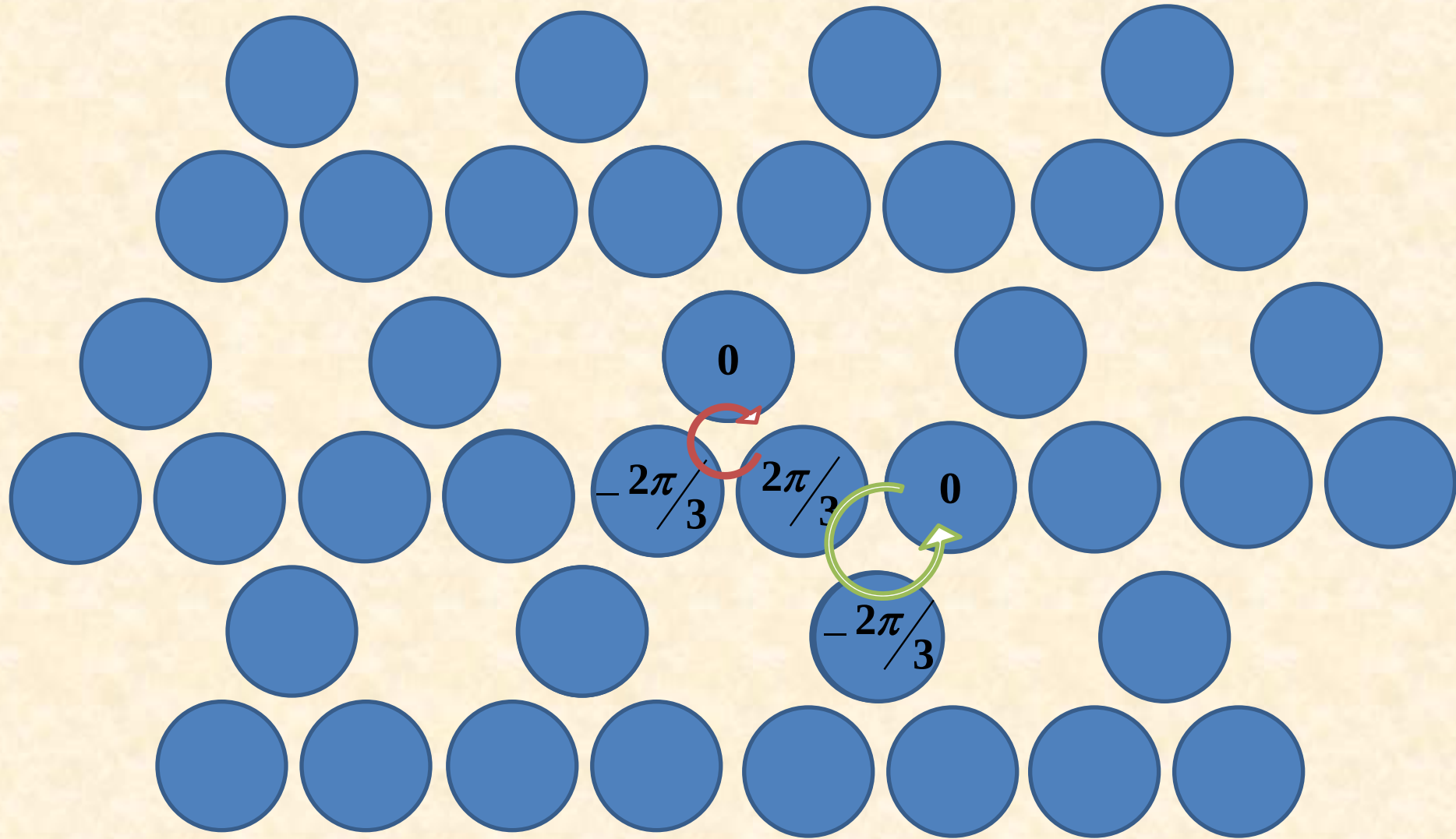
Kagome Array



Kagome Array

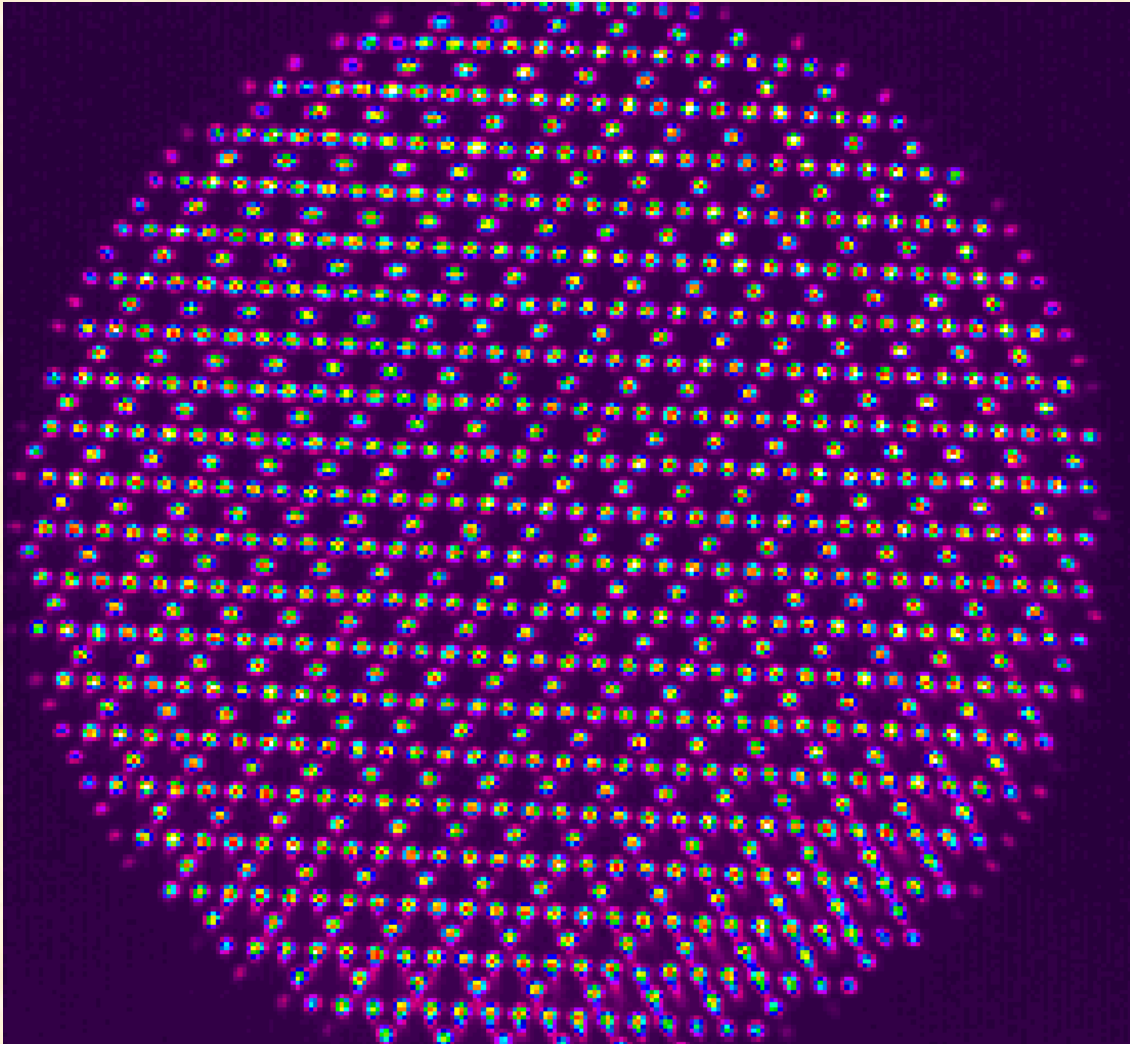


Kagome Array

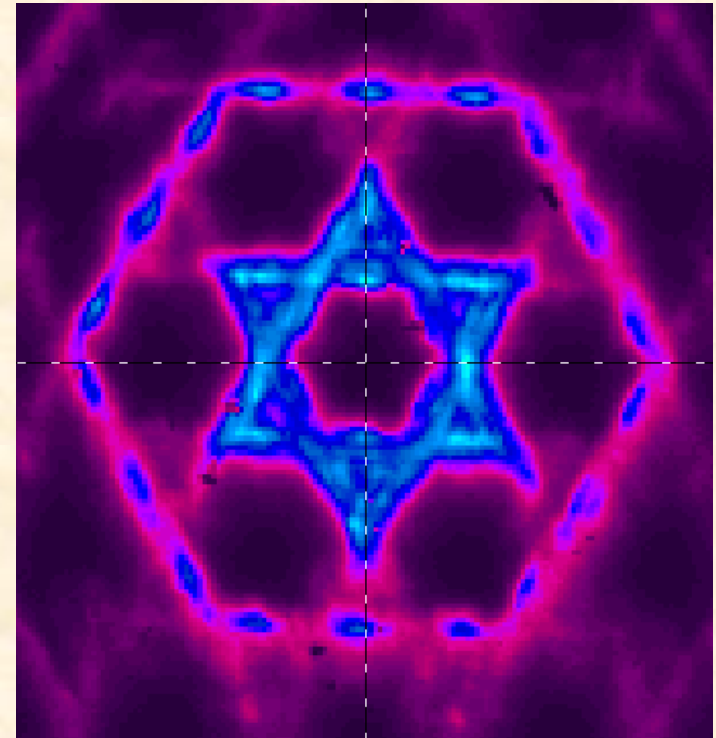


Kagome array

Near Field

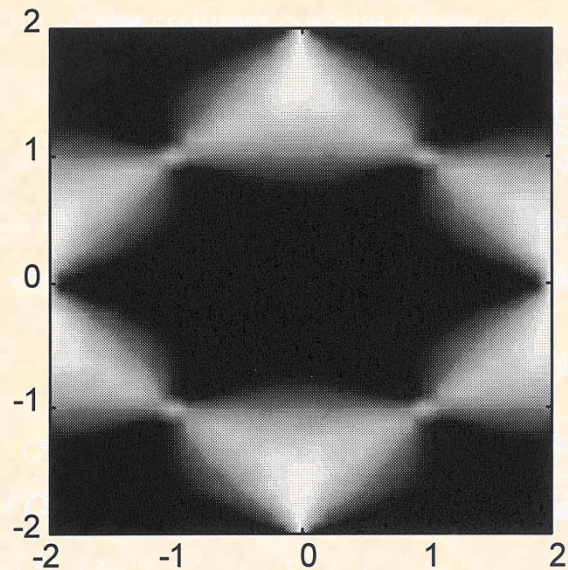


Far Field

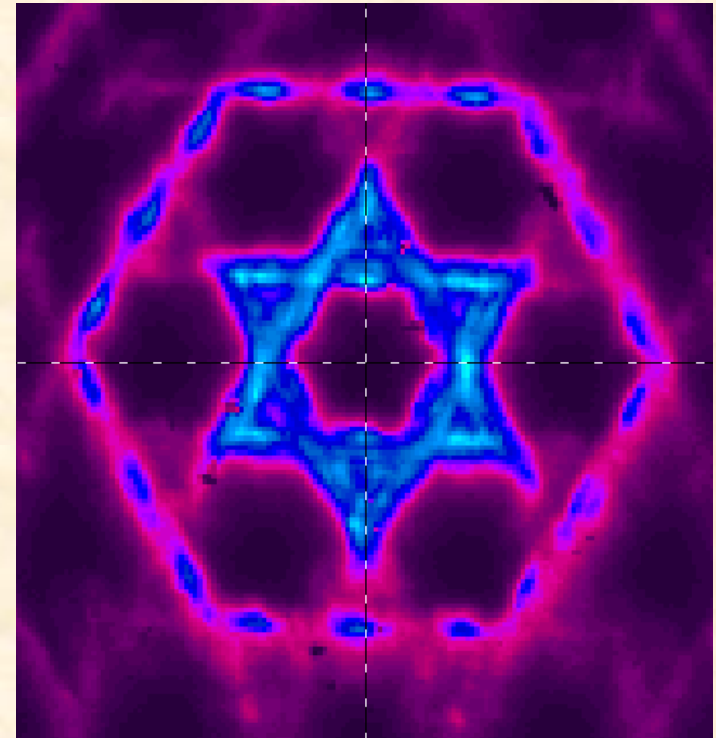


Kagome array

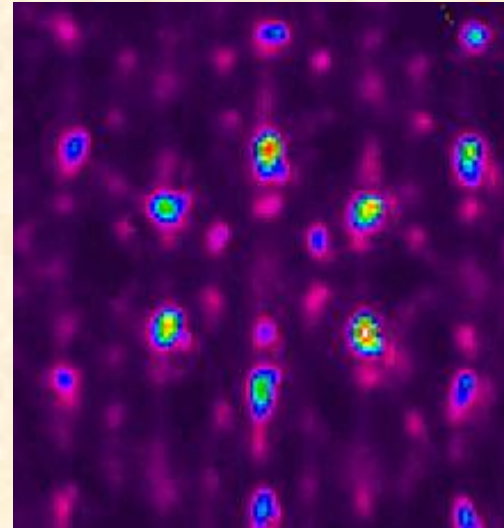
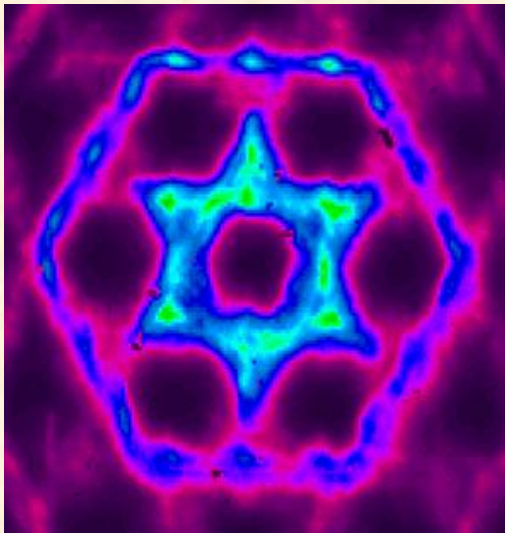
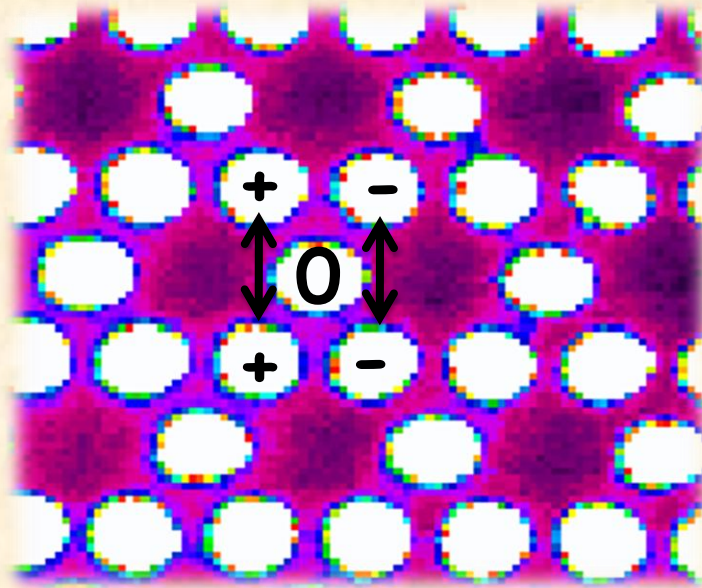
Moessner and Chalker “Low-temperature properties of classical geometrically frustrated antiferromagnets”,
Phys. Rev. B **58** 12049 (1998)



Far Field

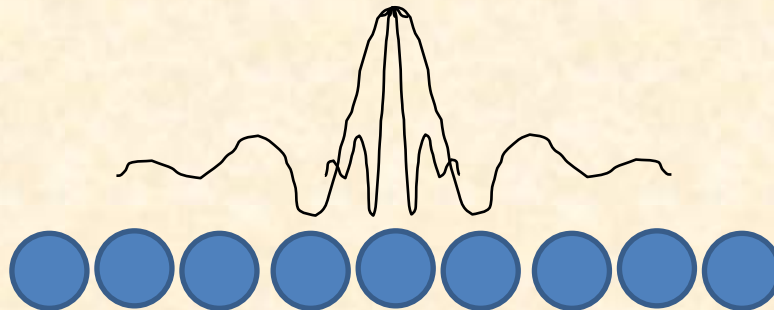
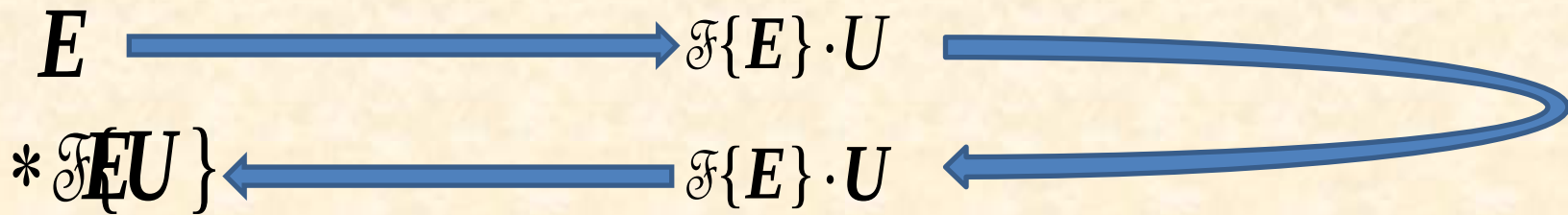
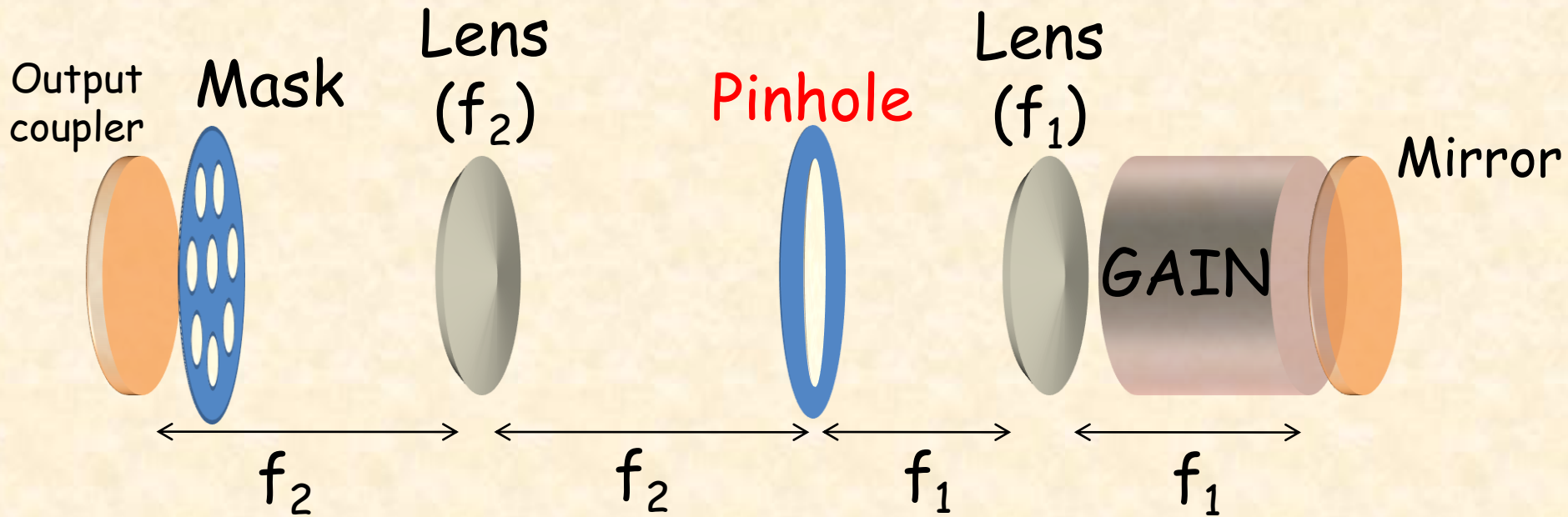


Next Nearest Neighbor Coupling

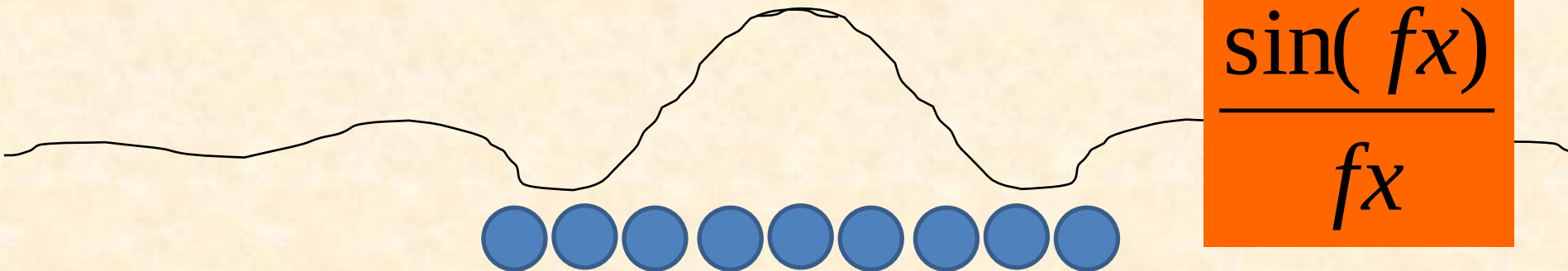
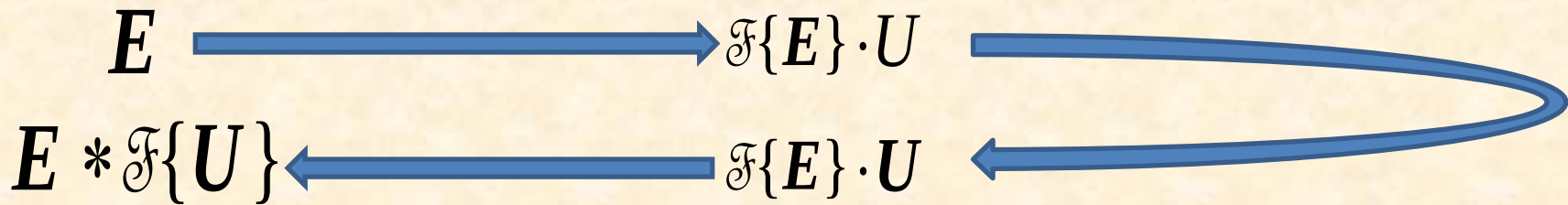
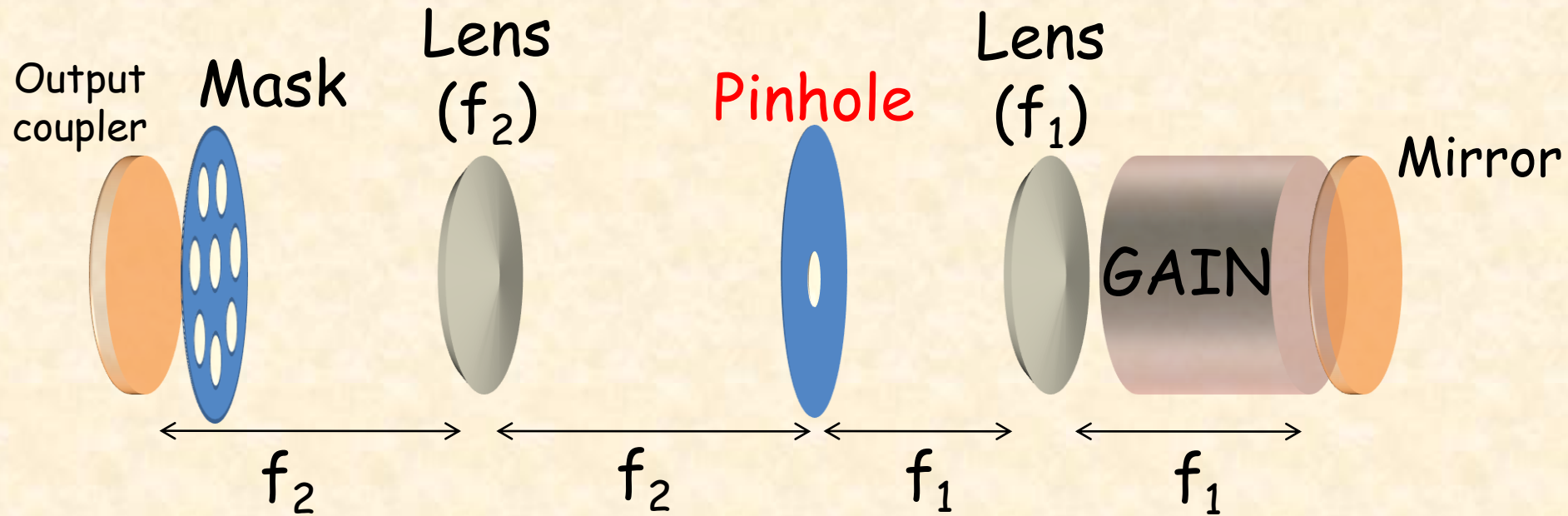


Long
range coupling

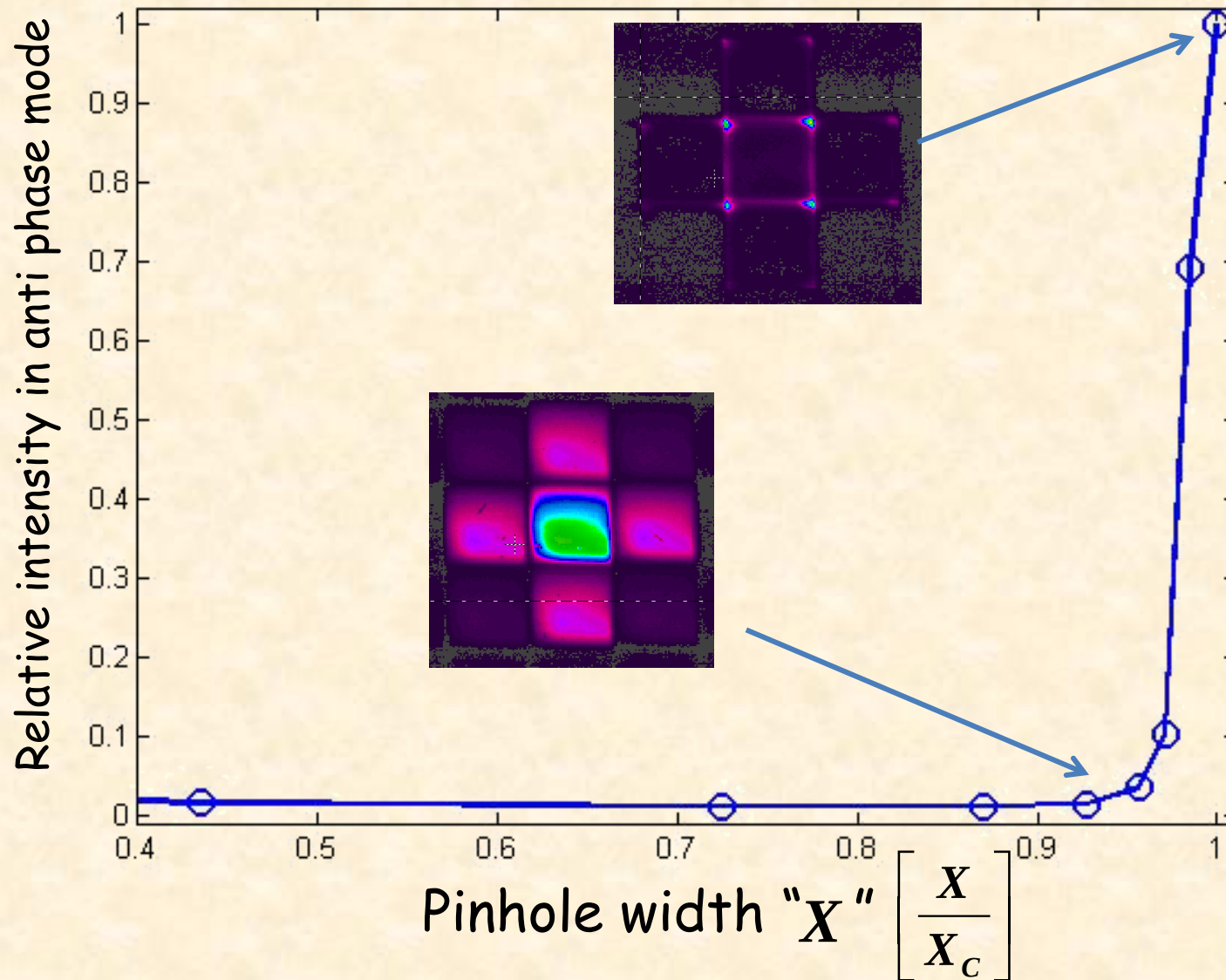
Long range coupling



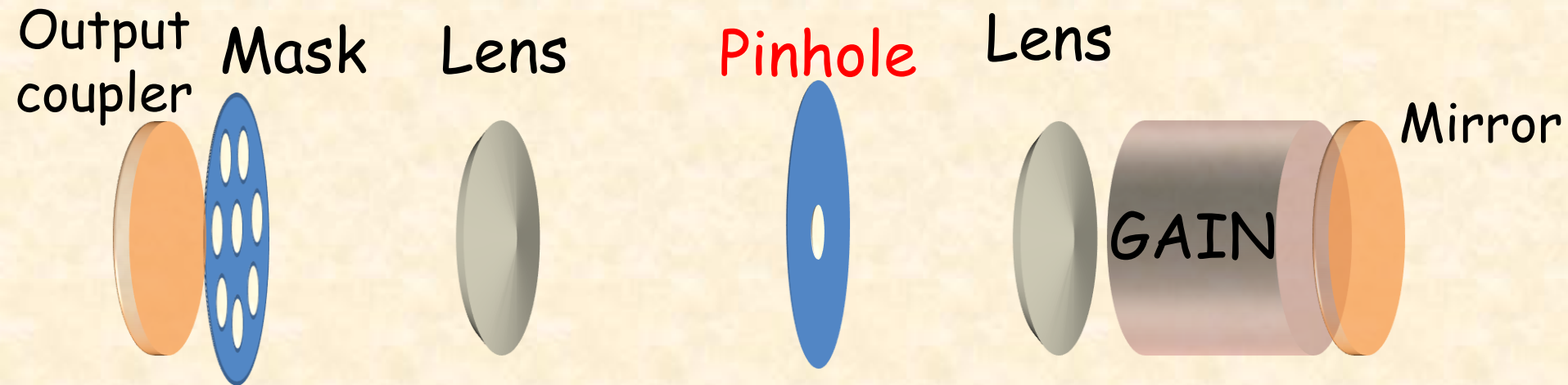
Long range coupling



Sharp "phase" transitions



Intermediate summary



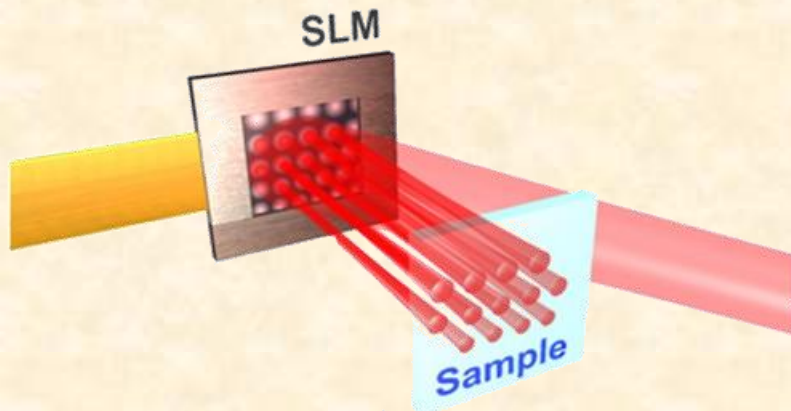
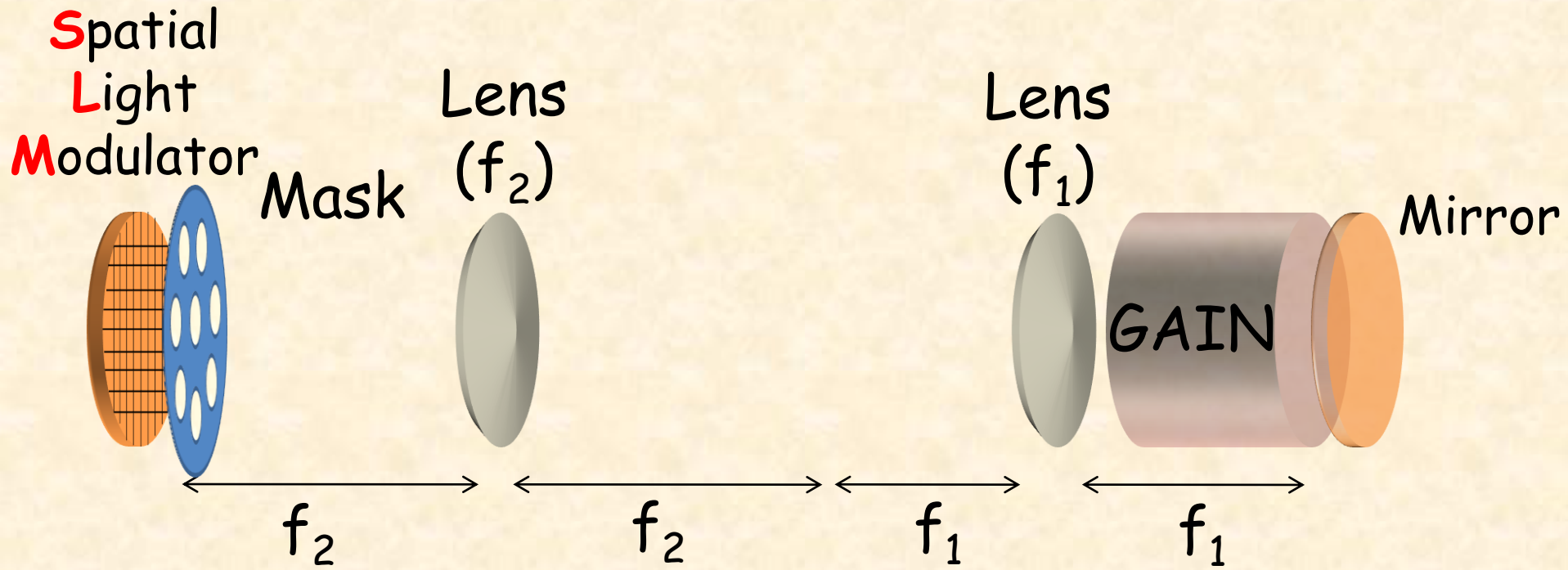
$$\kappa_{ij} = \langle \mathbf{E}_i^{fin} | \mathbf{E}_j^{ini} \rangle \cong \frac{1}{(\mathbf{i} - \mathbf{j})^2}$$

Long range interaction

$$\kappa_{ij} = \langle \mathbf{E}_i^{fin} | \mathbf{E}_j^{ini} \rangle \cong e^{-\alpha(\mathbf{i} - \mathbf{j})^2}$$

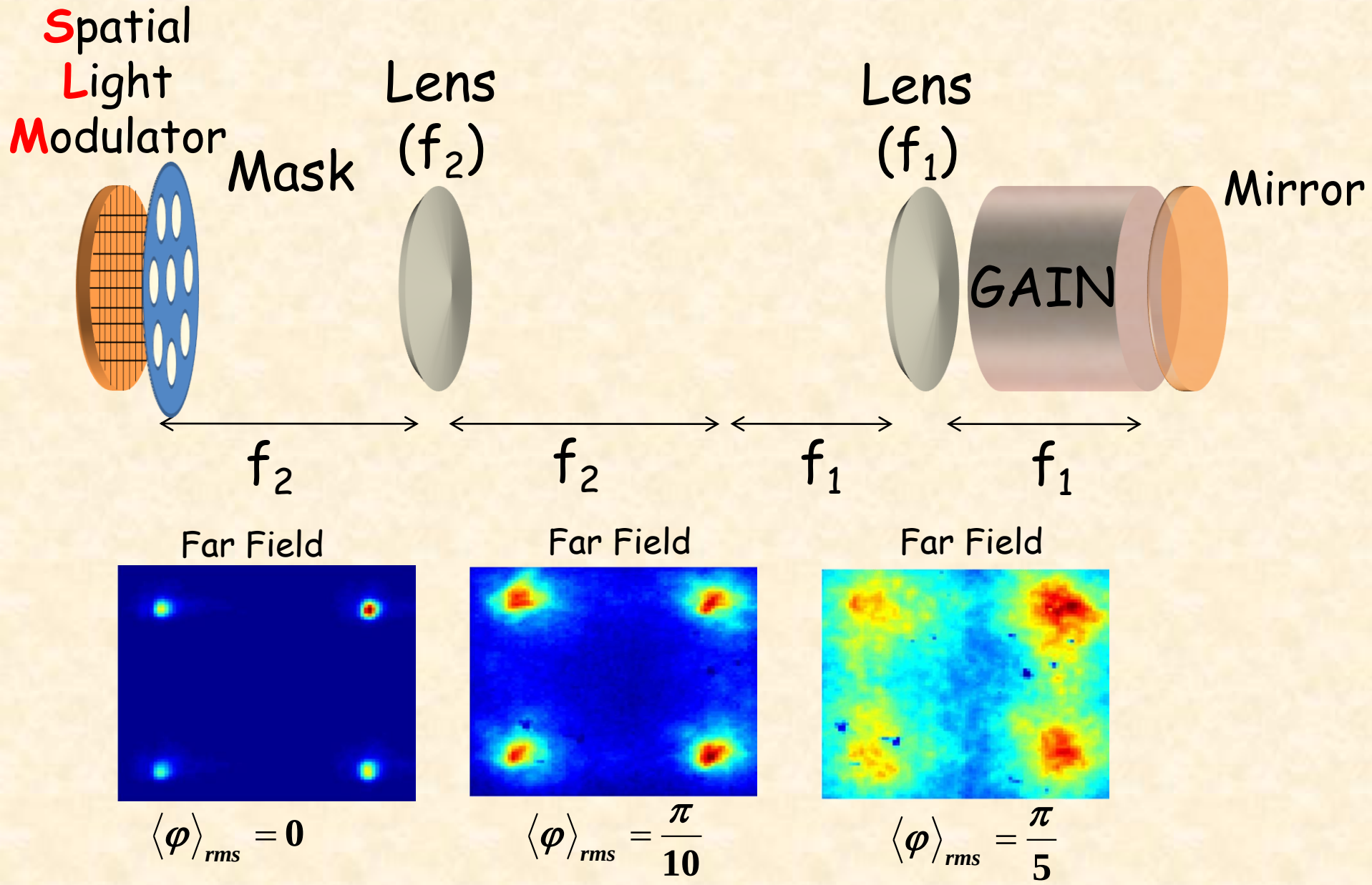
Short range interaction

Adding disorder



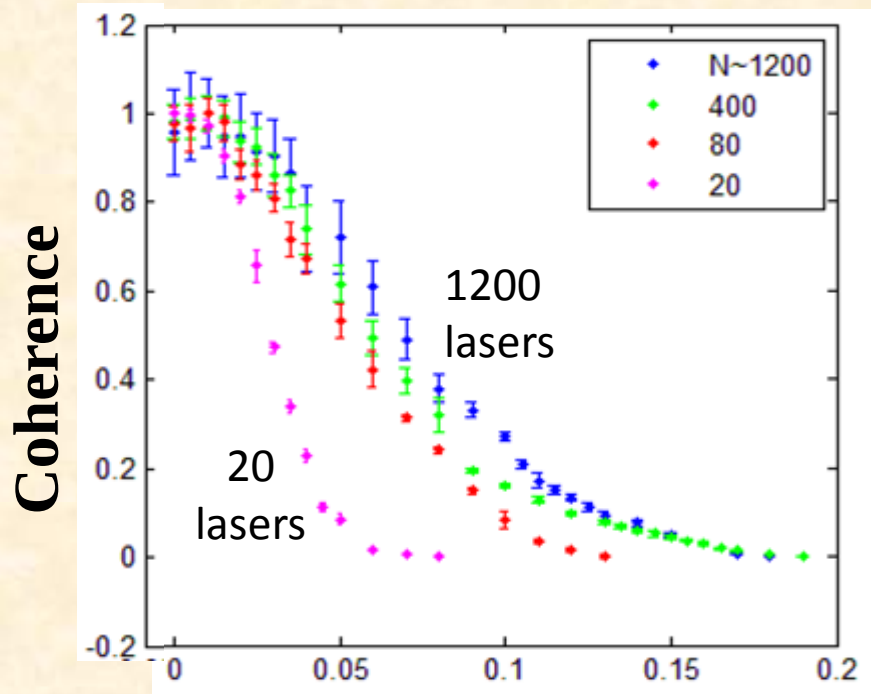
$$\dot{\theta}_i = \Omega_i + \sum \kappa_{ij} \sin(\theta_j - \theta_i)$$

Adding disorder



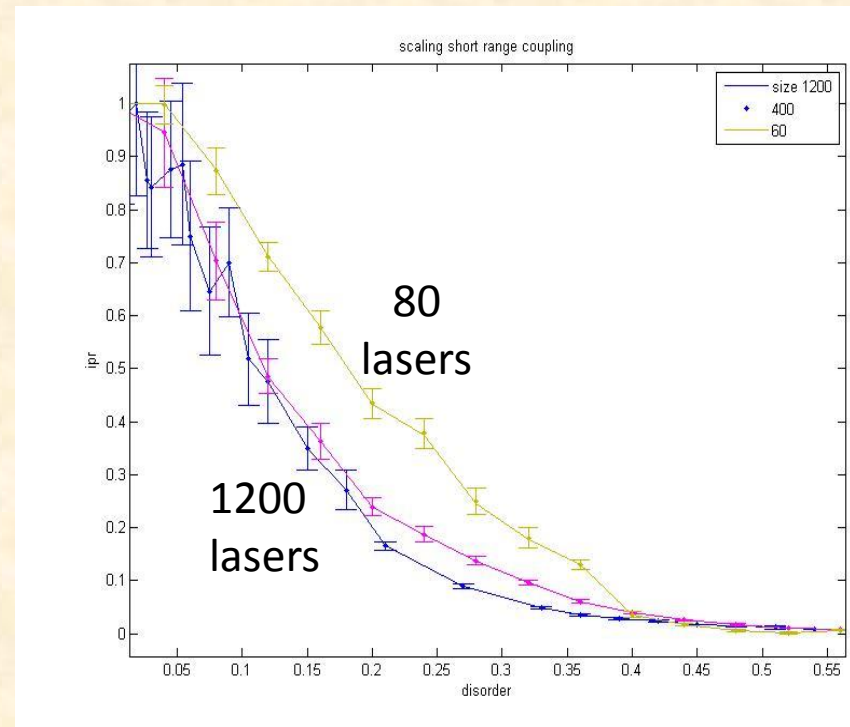
Long Vs. short range coupling scaling system size

Long



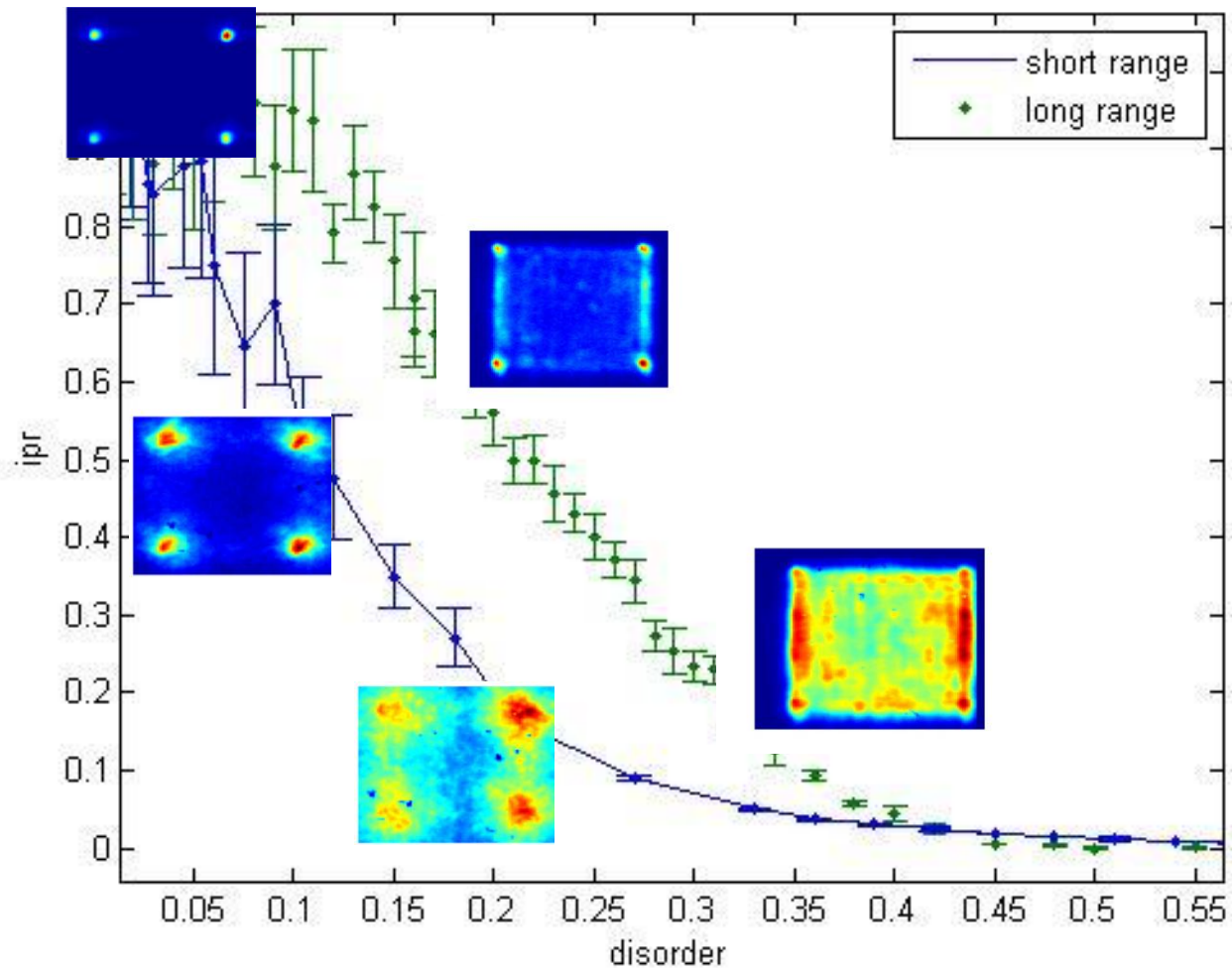
Width of disorder

Short



Width of disorder

Long vs. short range coupling



Lasing through a Diffuser

Output
coupler

Lens

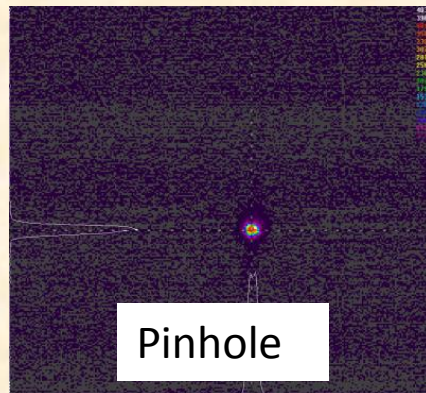
Pinhole

Lens

Mirror

GAIN

C
C
D



Lasing through a Diffuser

Output coupler



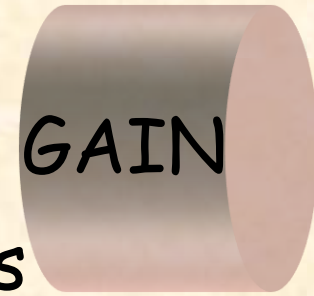
Lens



Pinhole



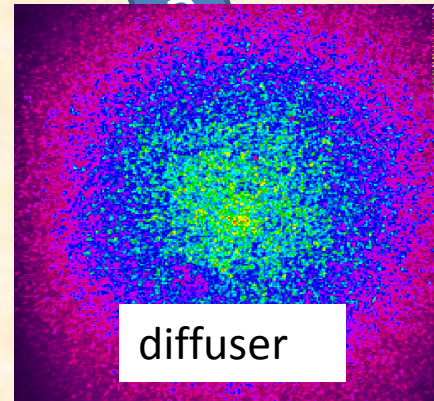
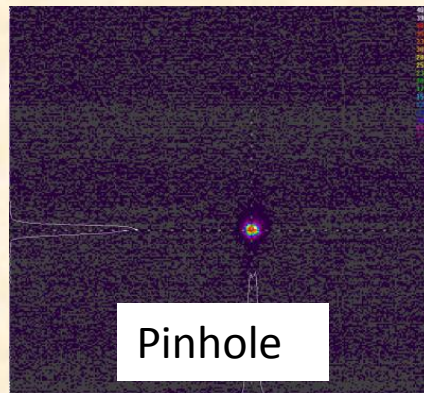
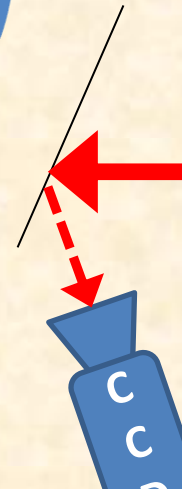
Lens



Mirror



Diffuser



Lasing through a Diffuser

Output coupler

Lens

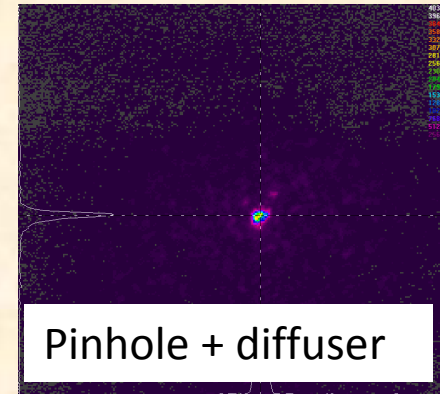
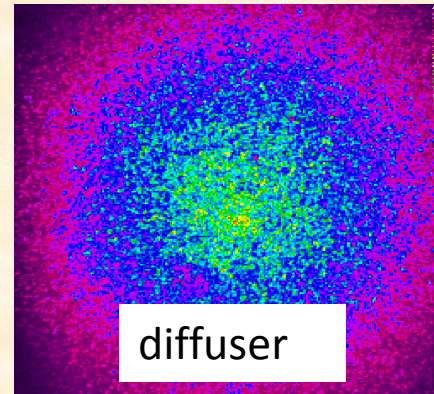
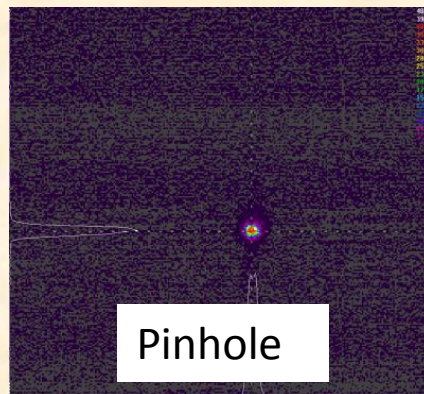
Pinhole

Lens

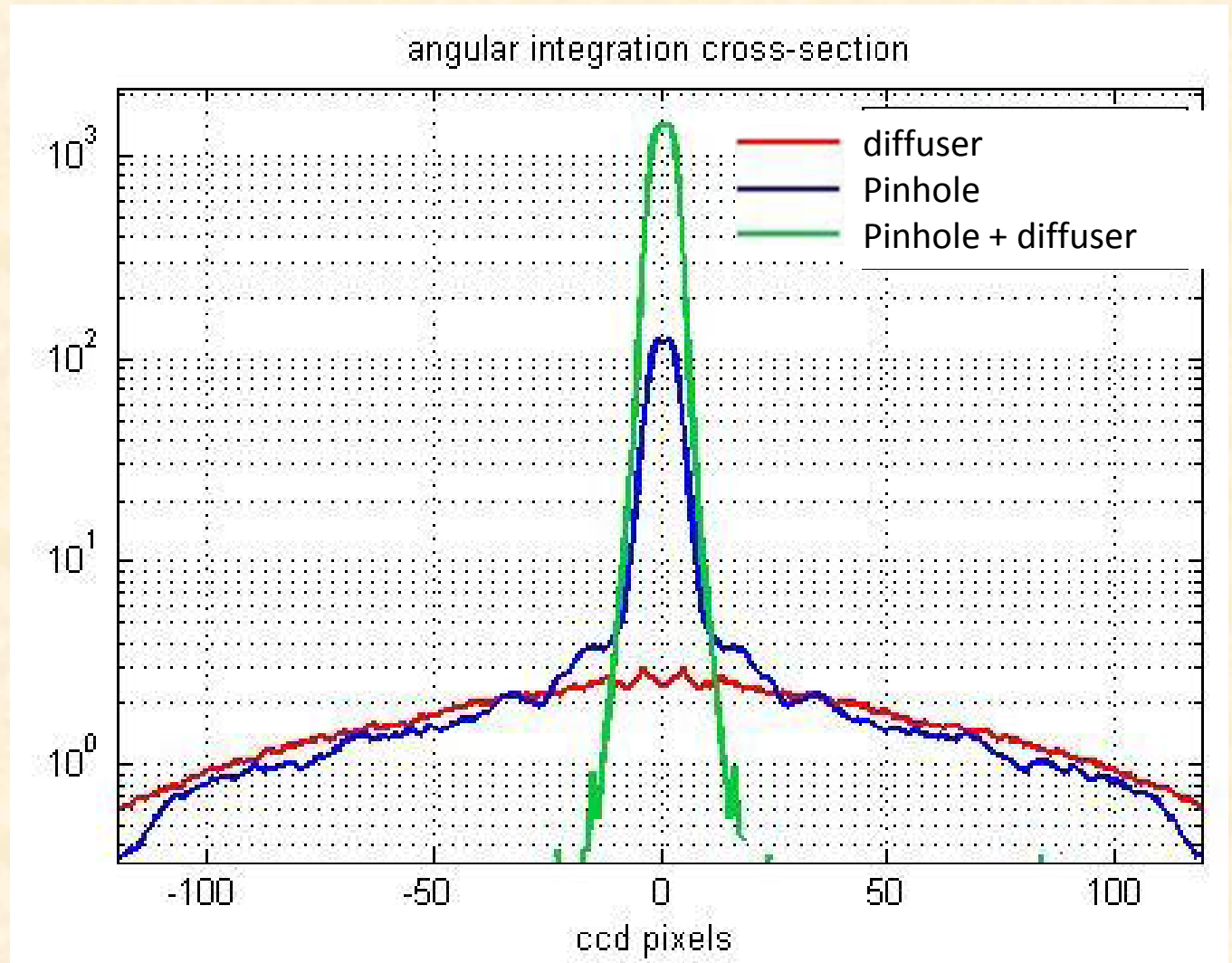
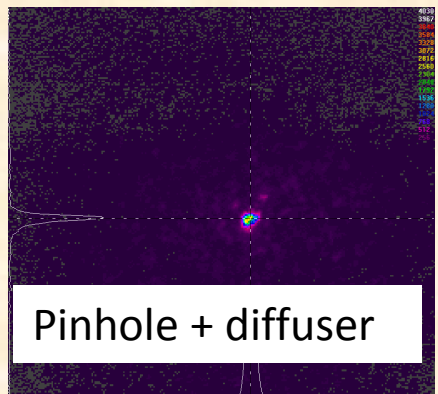
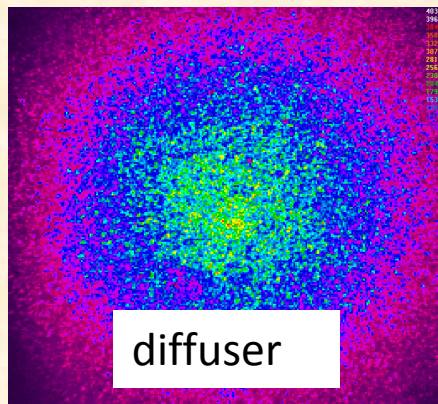
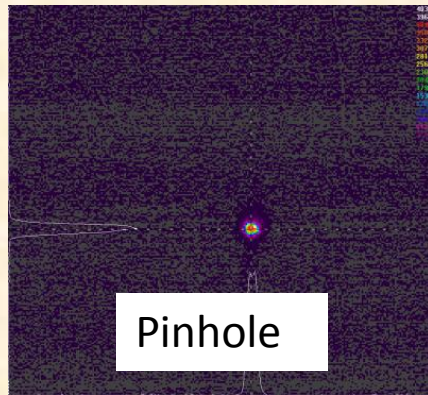
Mirror

GAIN

Diffuser

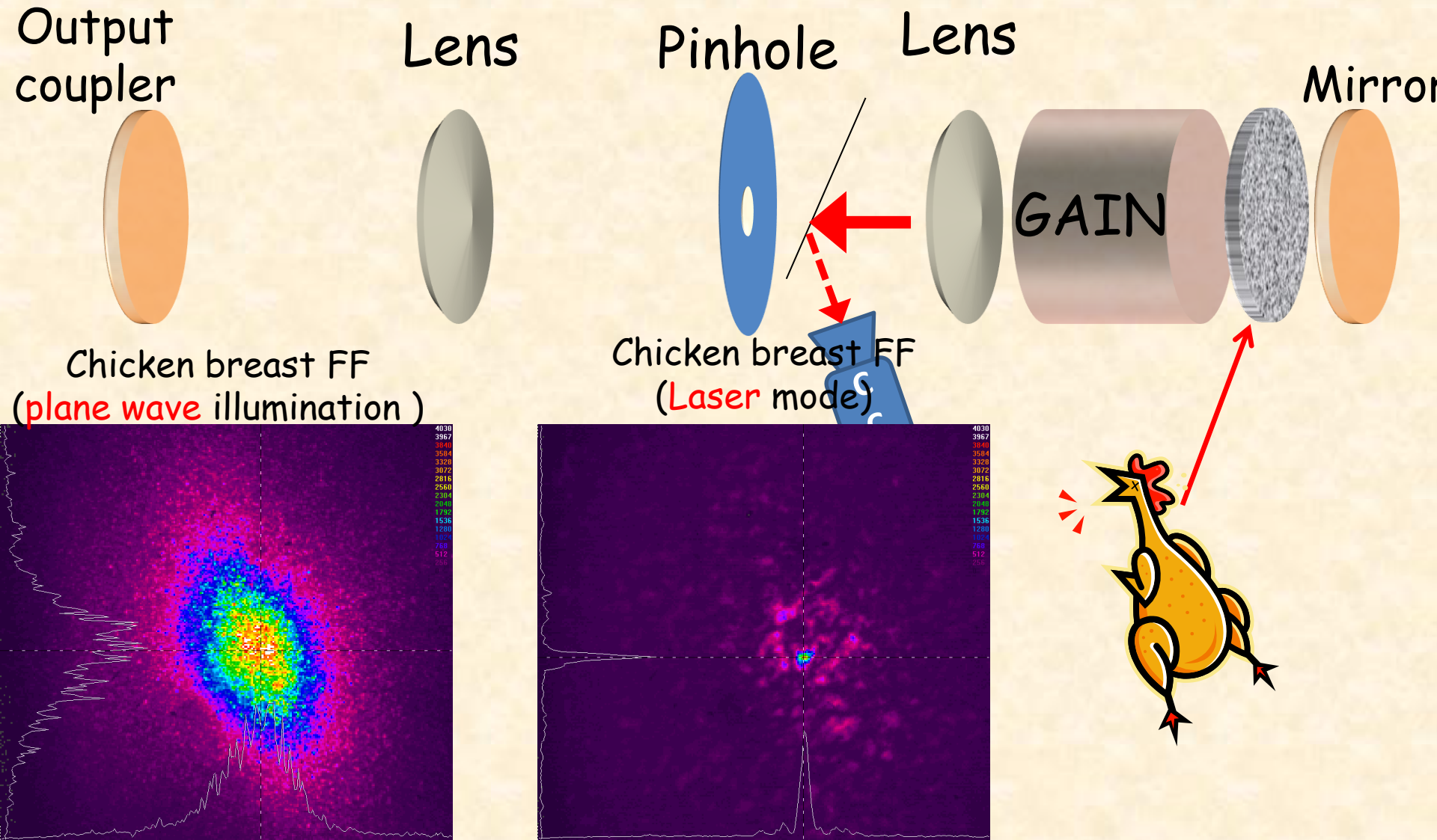


Lasing through a Diffuser



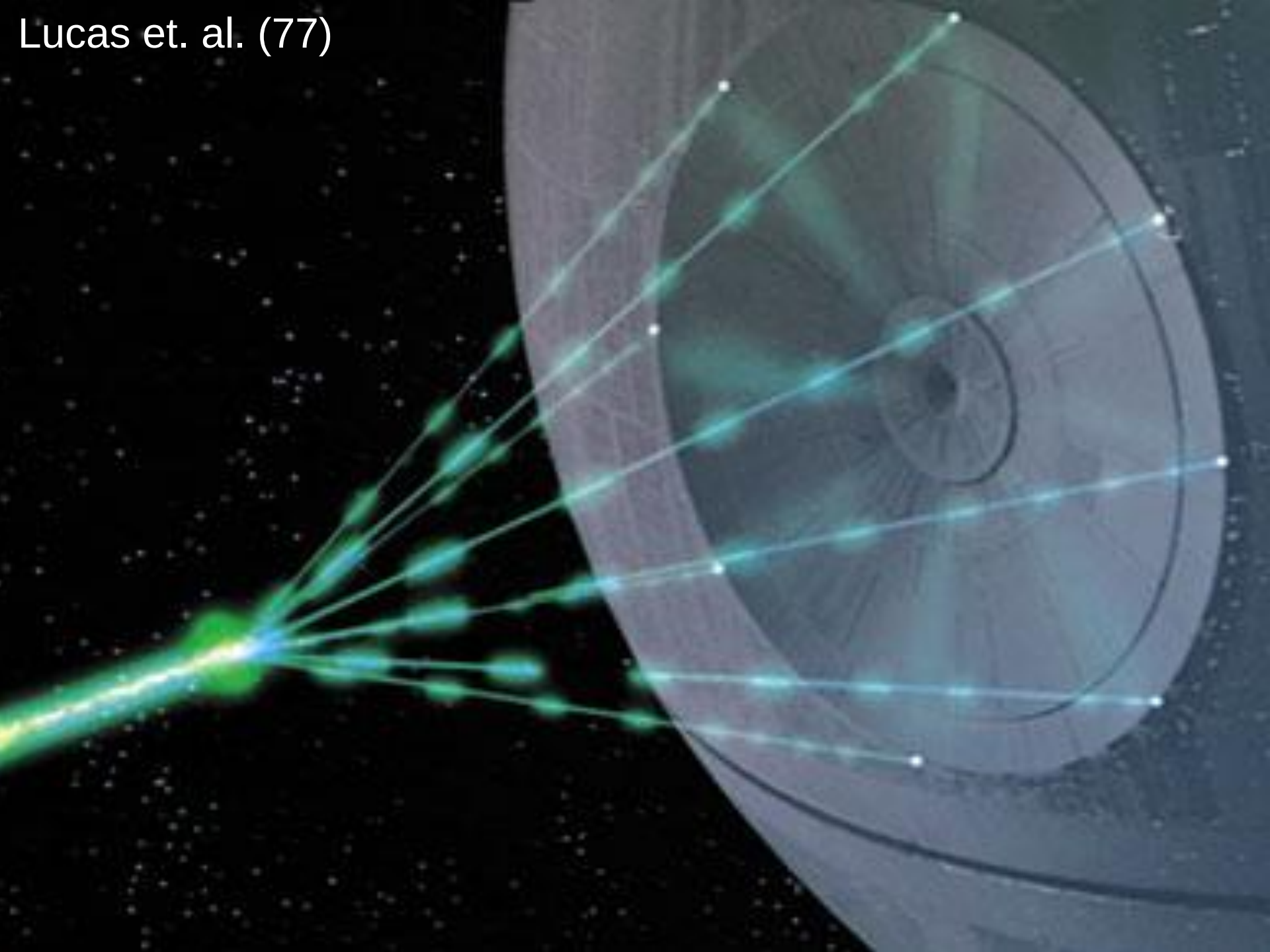
x80 increase of central peak

Lasing through a **chicken** (breast)



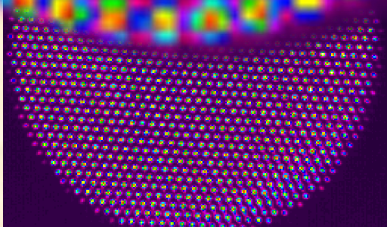
What else?

- Effects of external fields, temperature, noise.
- Adding time delayed coupling (with I. Kanter).
Nixon et al, PRL 106, 223901 (2011), PRL, in press (2012)
- Lasers with random lengths: EVS of random matrices.
- Chaos synchronization.
- Dynamics.

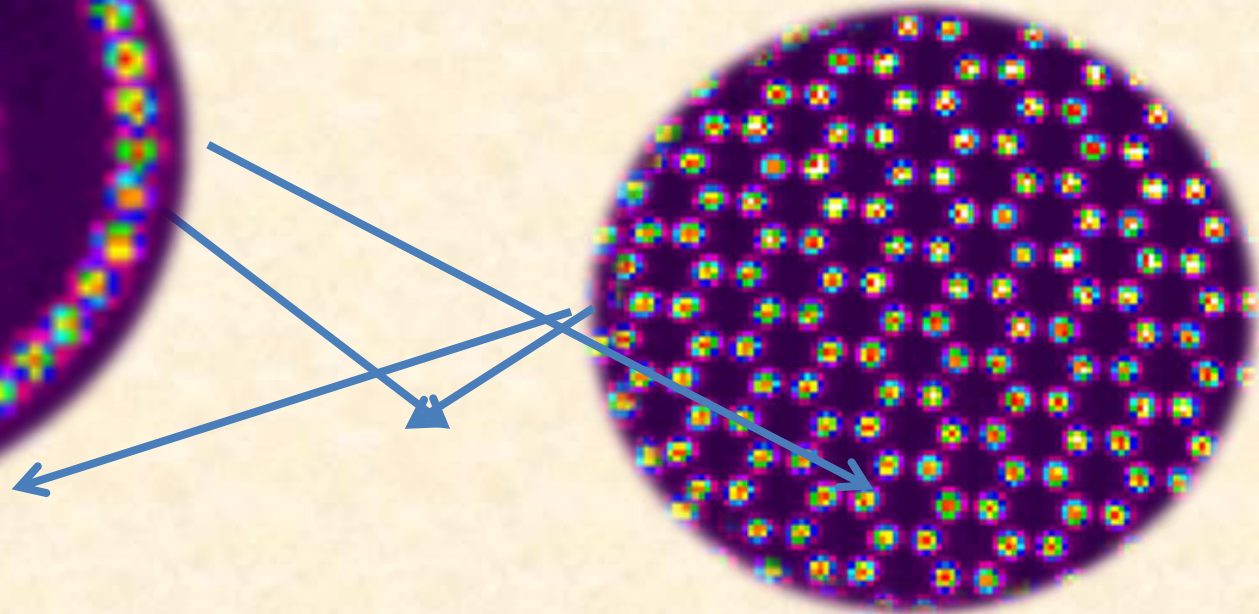
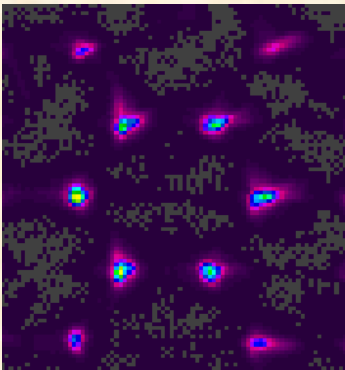


Very large arrays

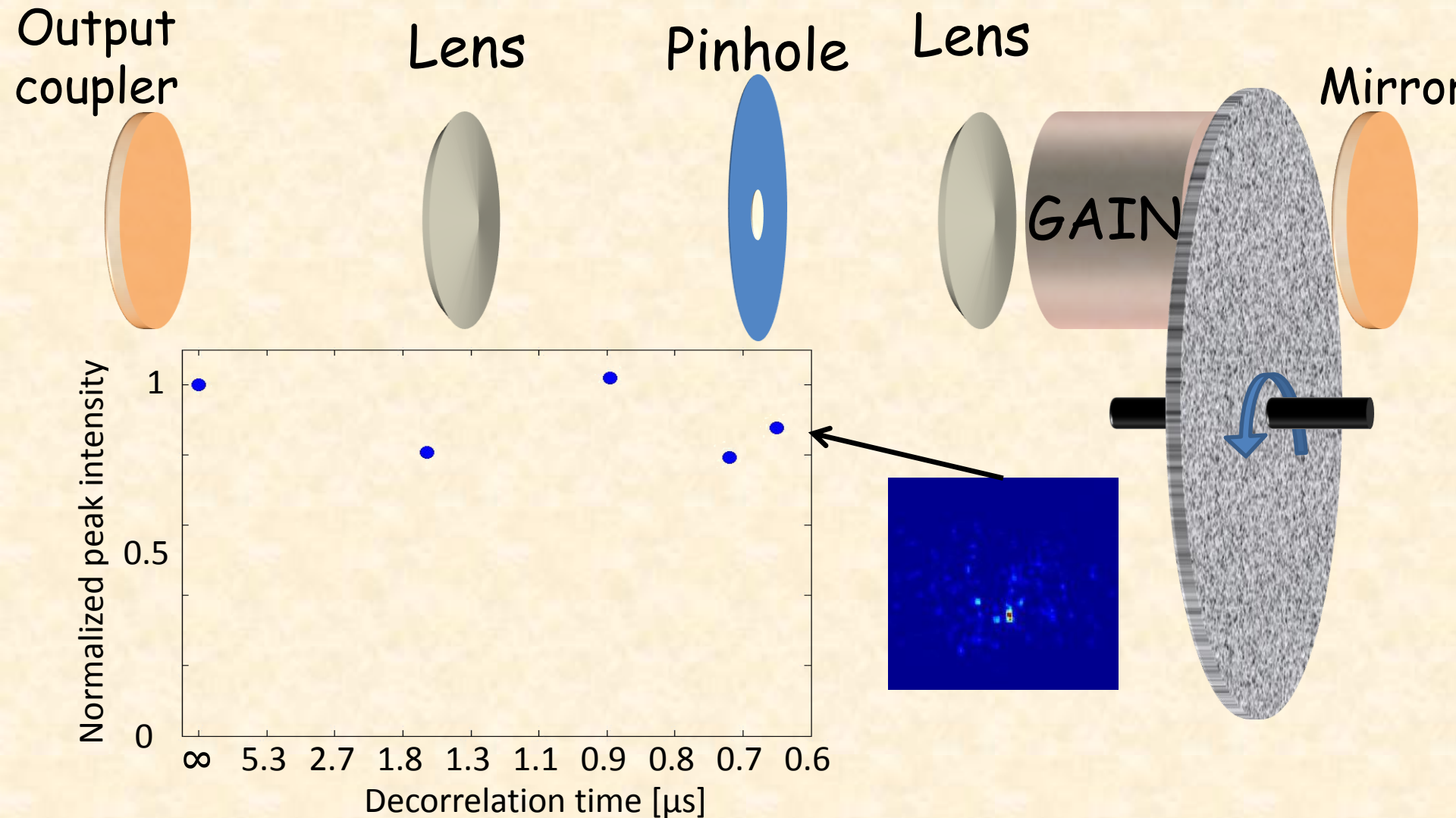
Near
Fields



Far
Fields

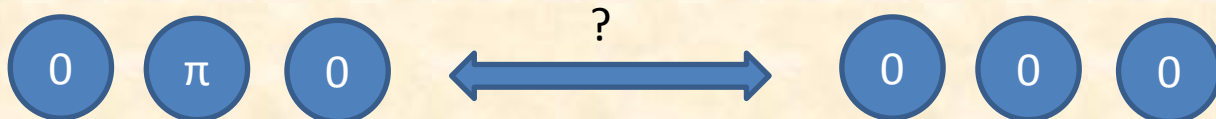
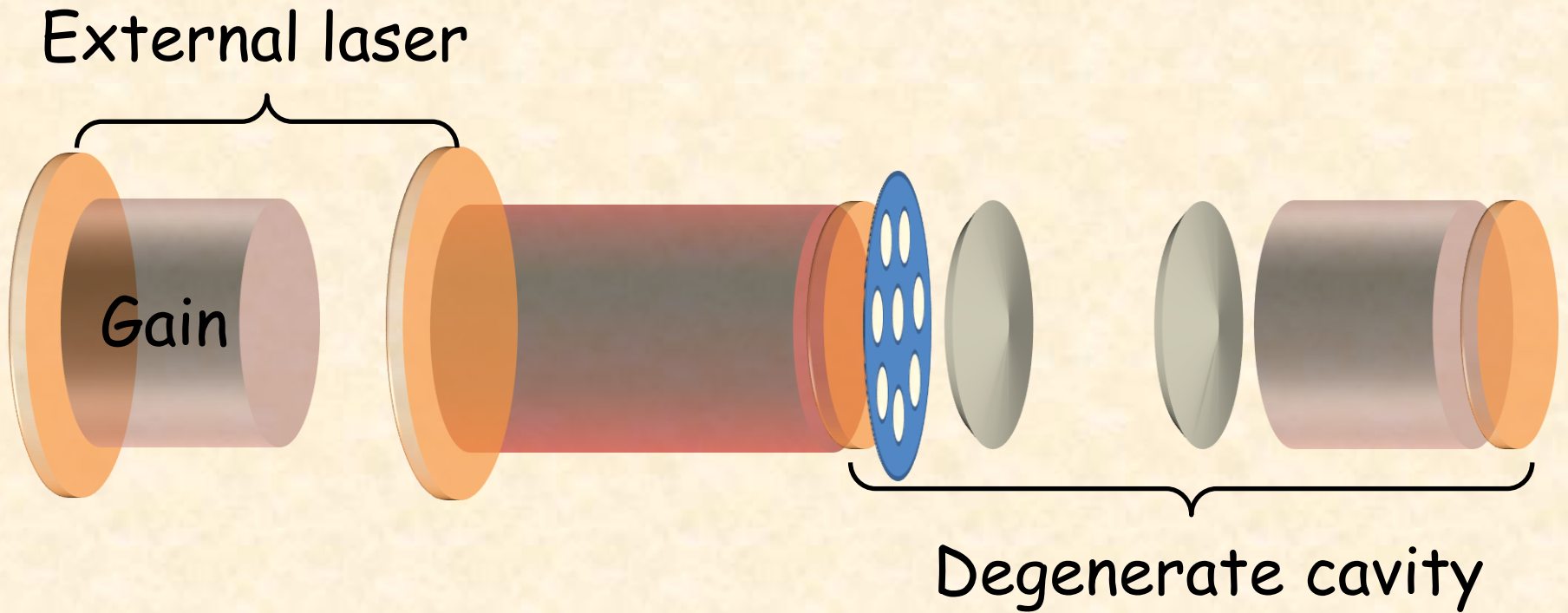


Lasing through a **Rapidly** changing diffuser



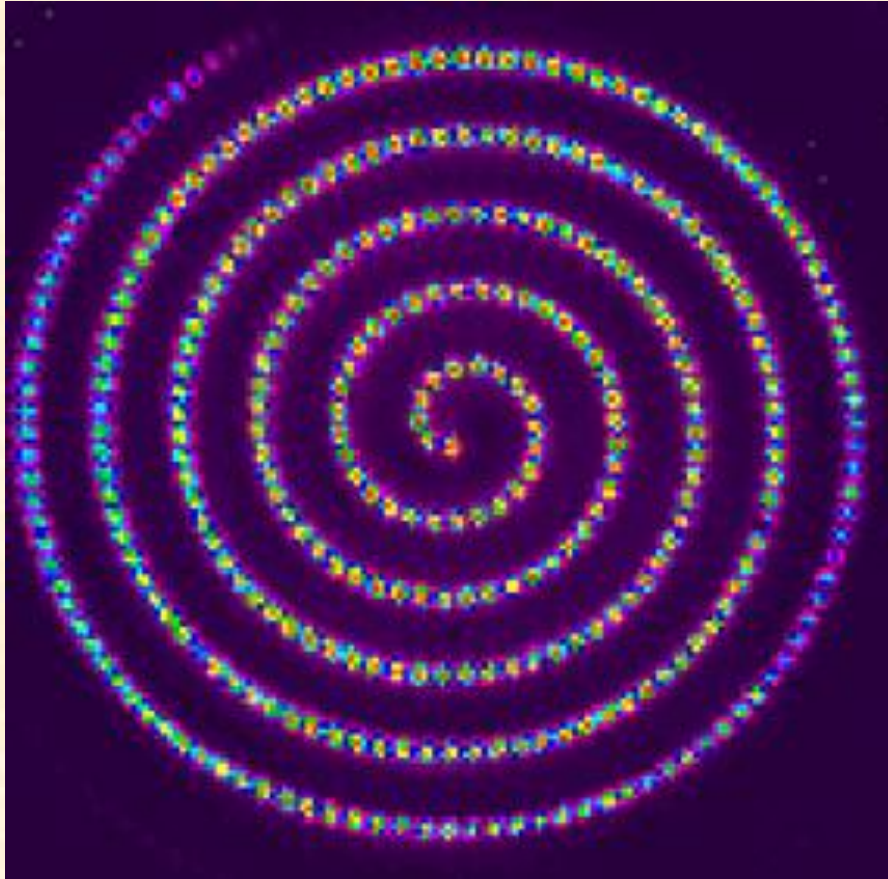


External "field"

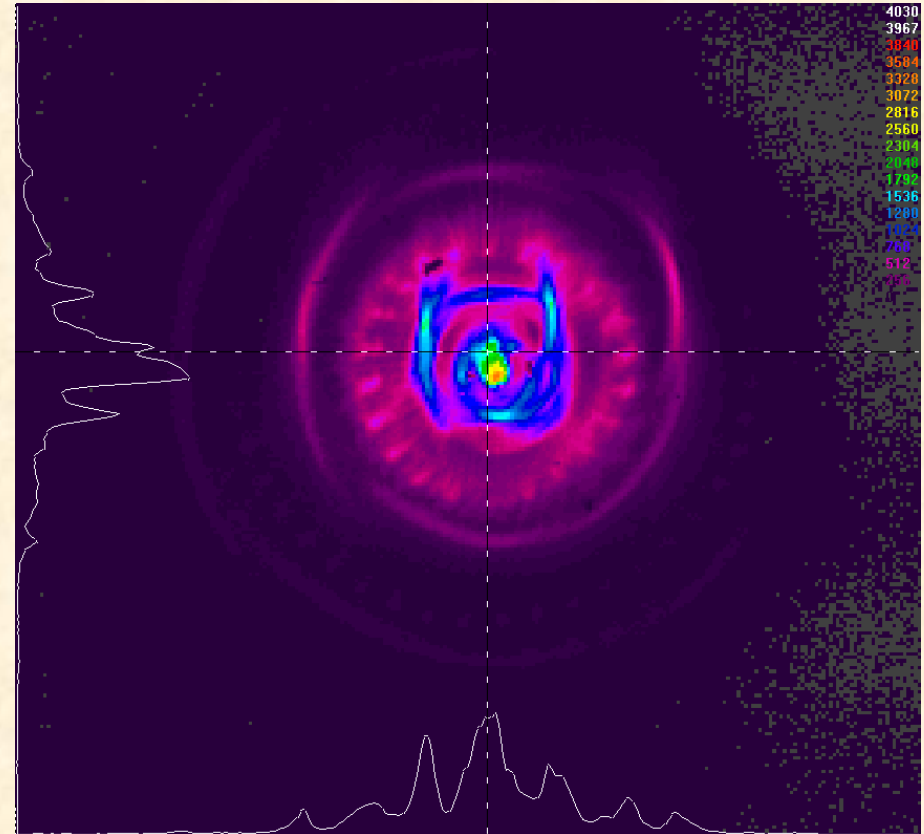


External Field for 1D

Near field spiral

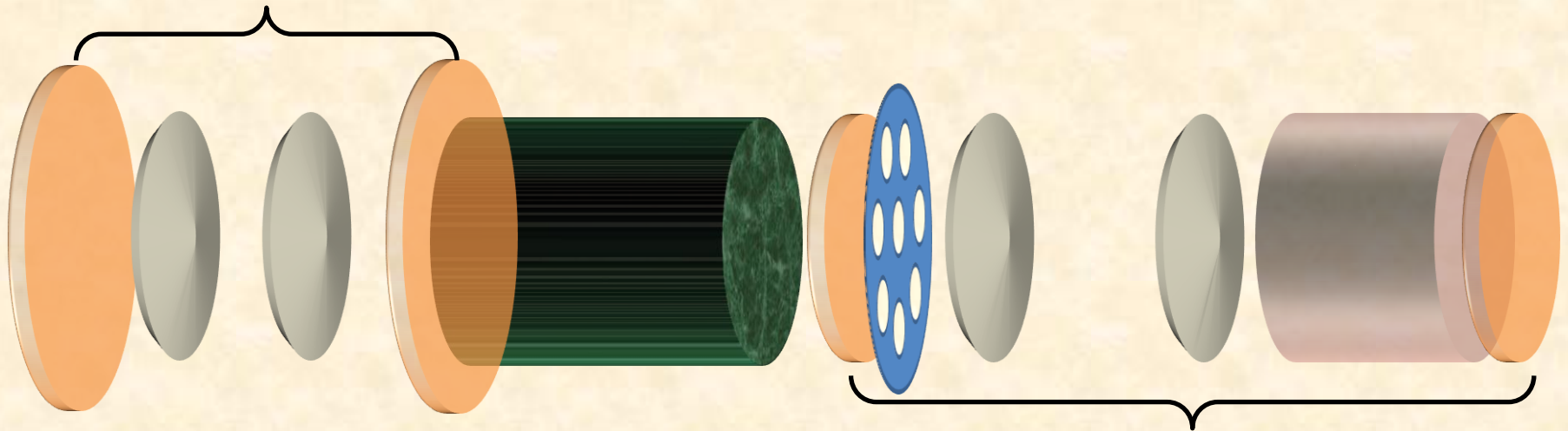


Far field

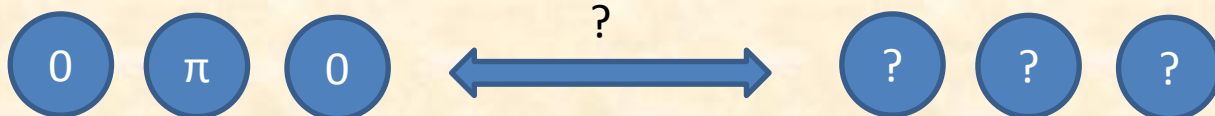


External disordered field

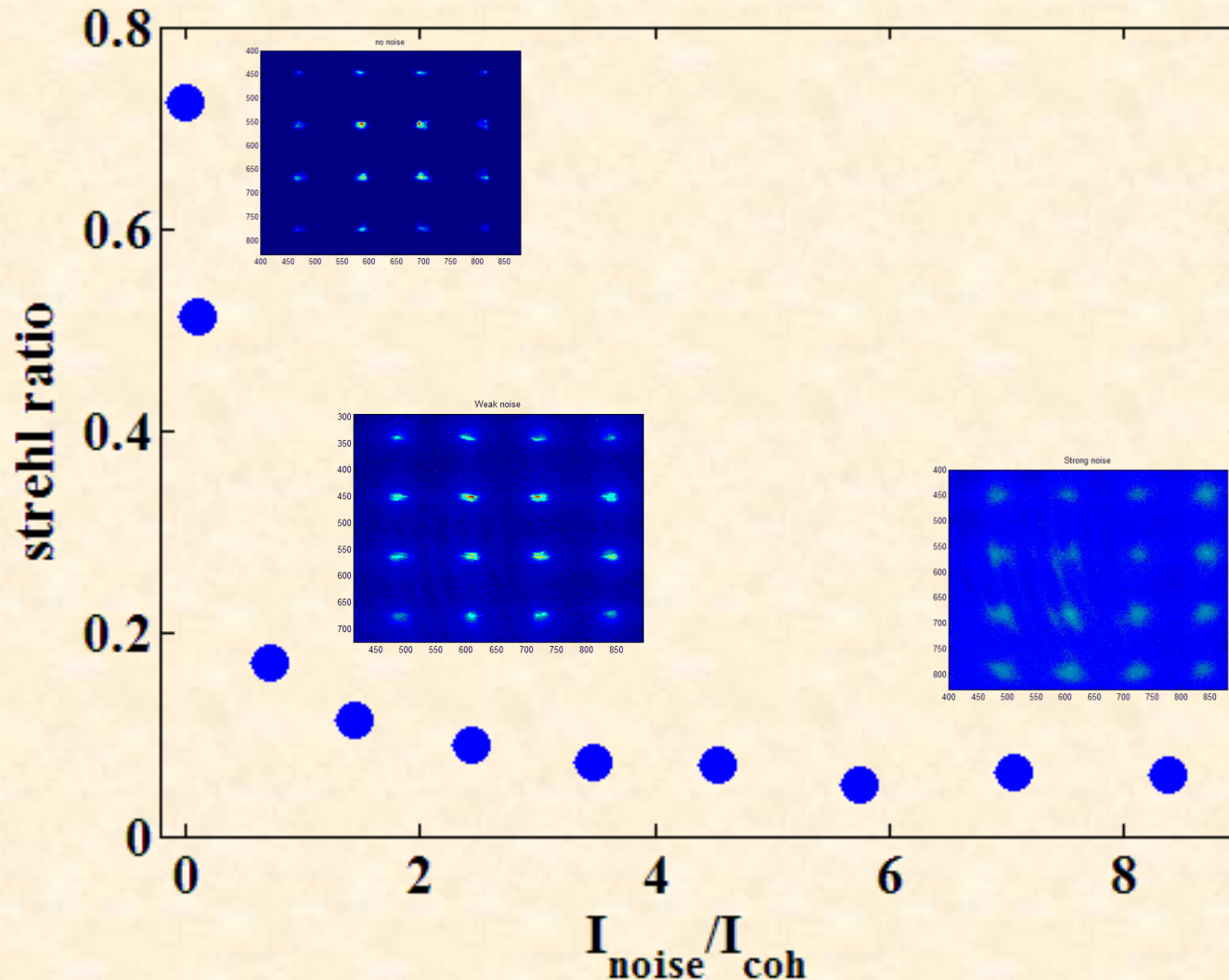
External degenerate laser cavity



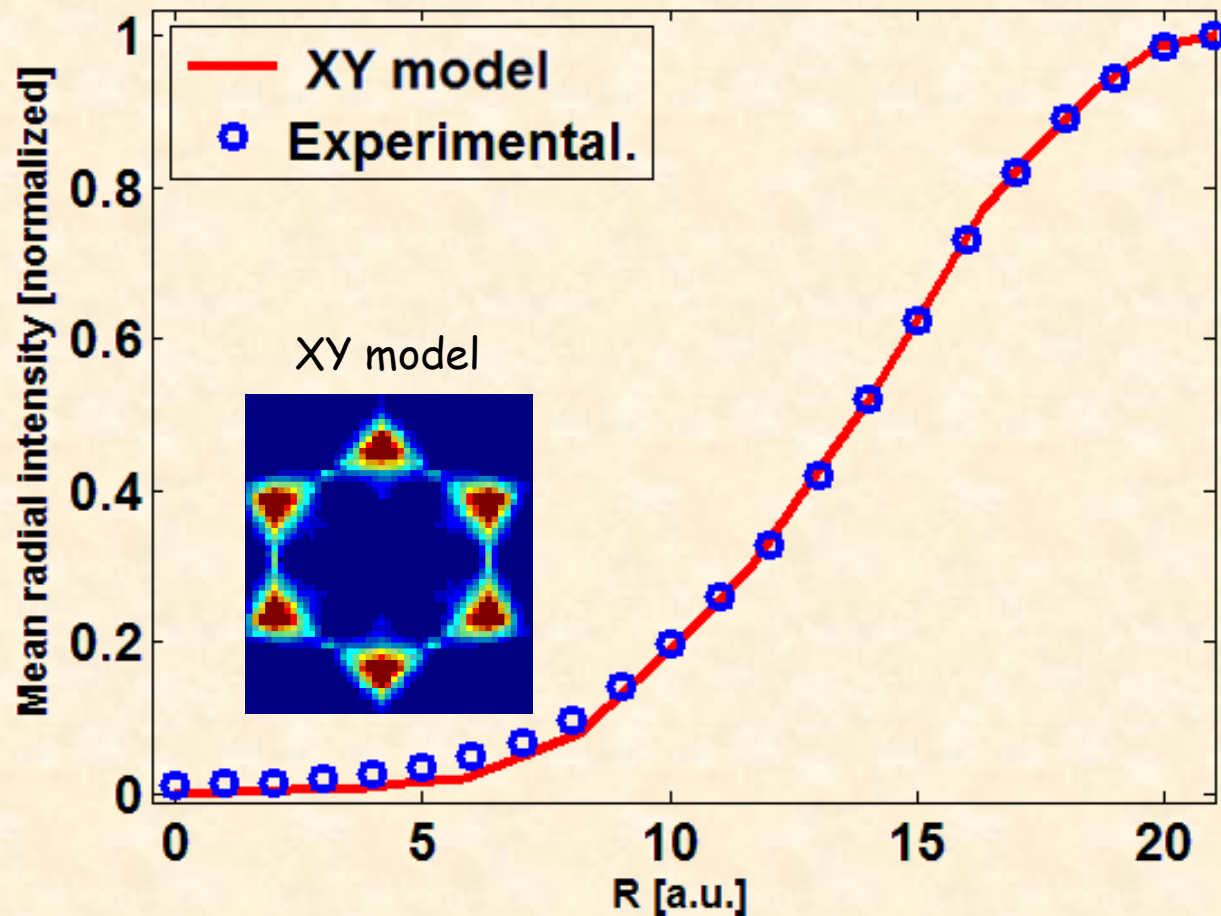
Degenerate cavity



Effects of finite "temperature" in square array

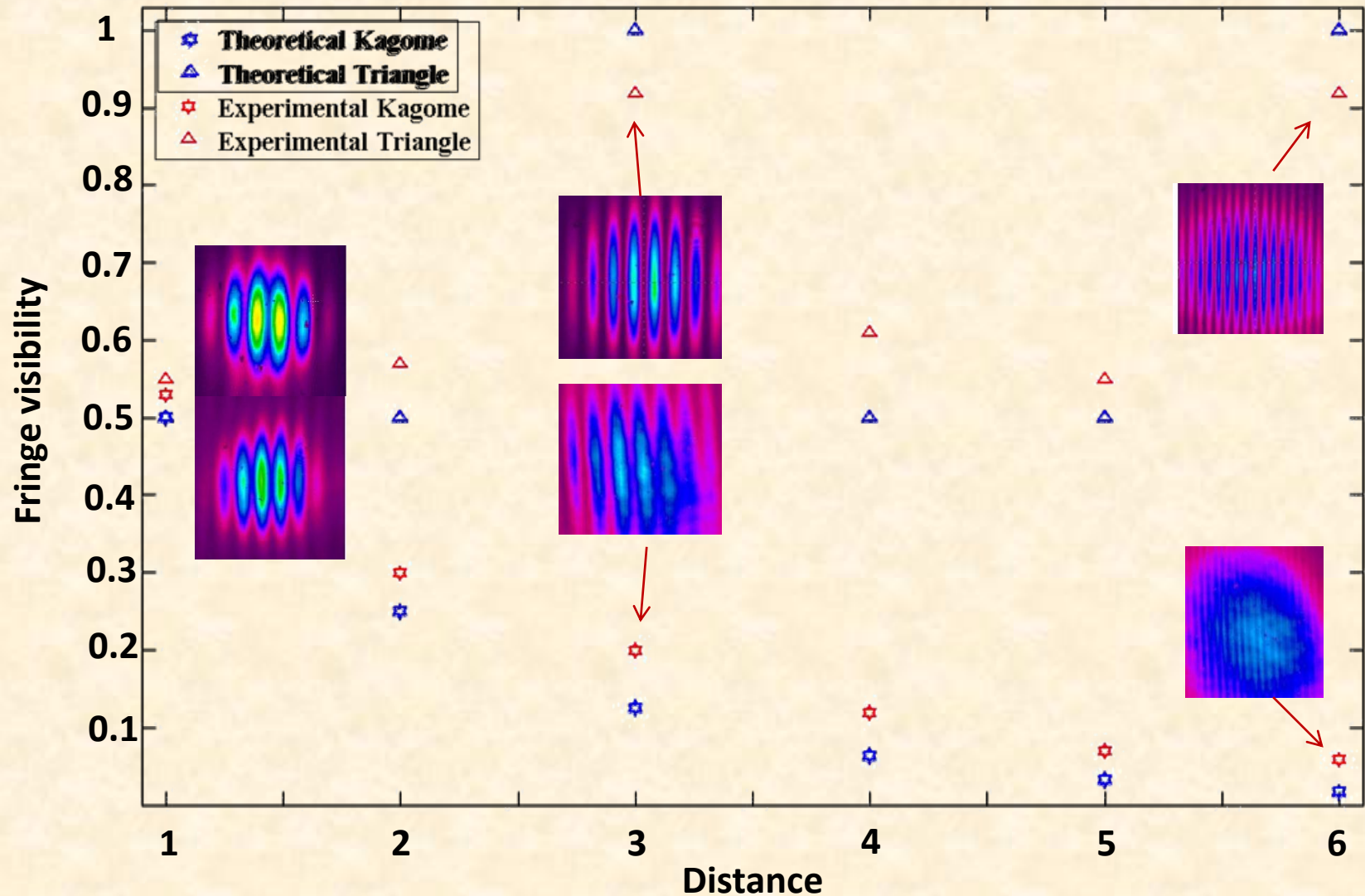


Is it a true "ground state"?



Simulations: Finds ground states using a Monte Carlo simulation that minimizes the spins energy.

Short range phase ordering



Next Nearest Neighbor Coupling

