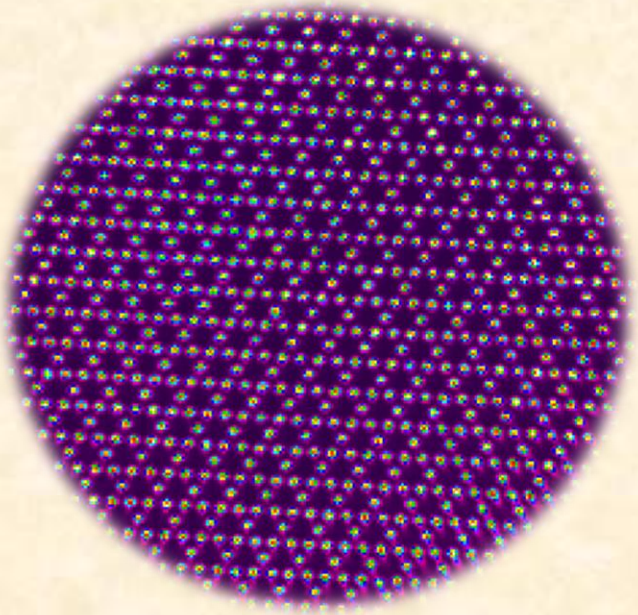
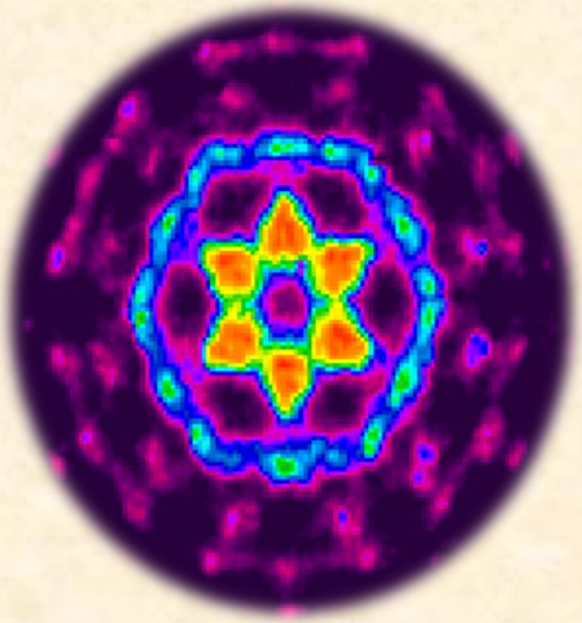
Phase Locking Large Laser Arrays

Near Field



Far Field



Nir Davidson

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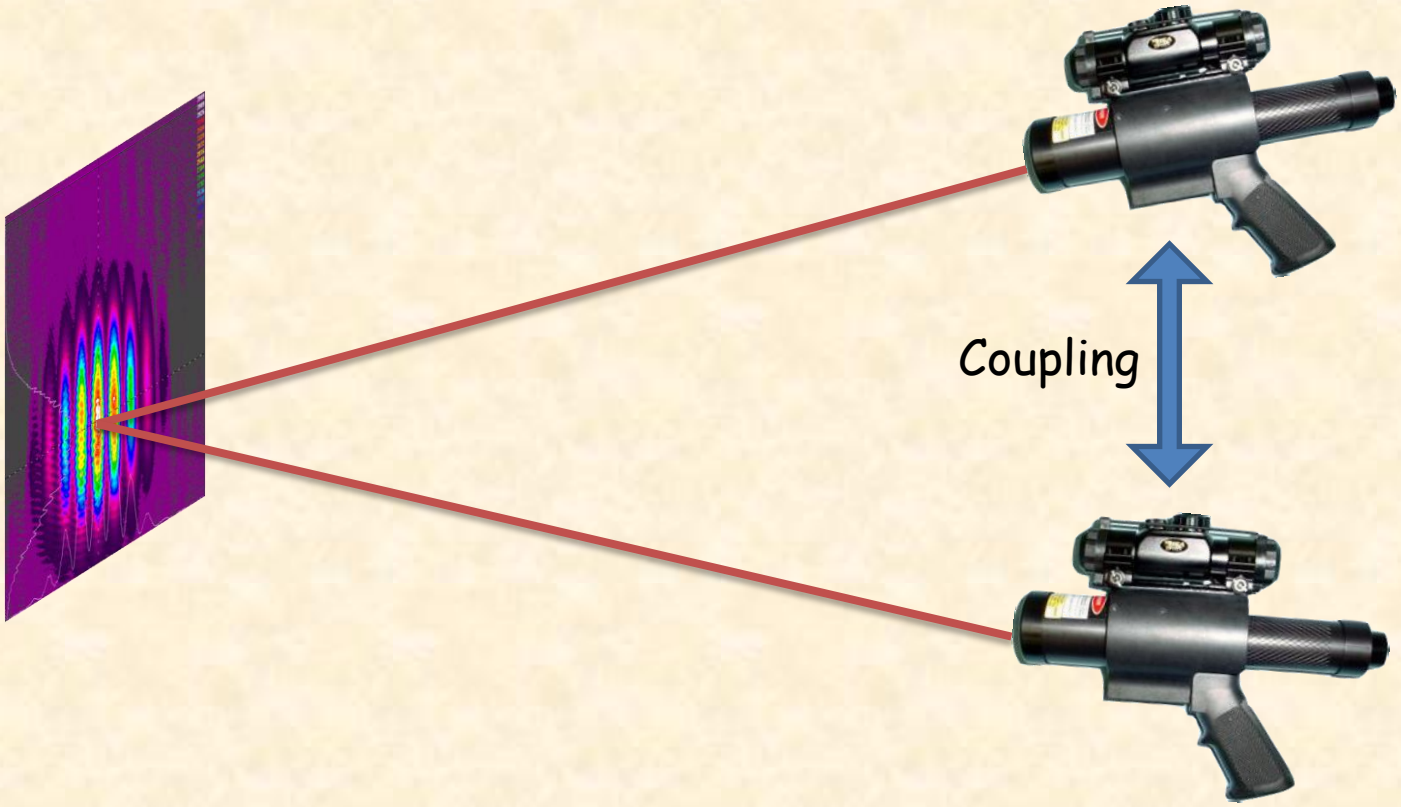
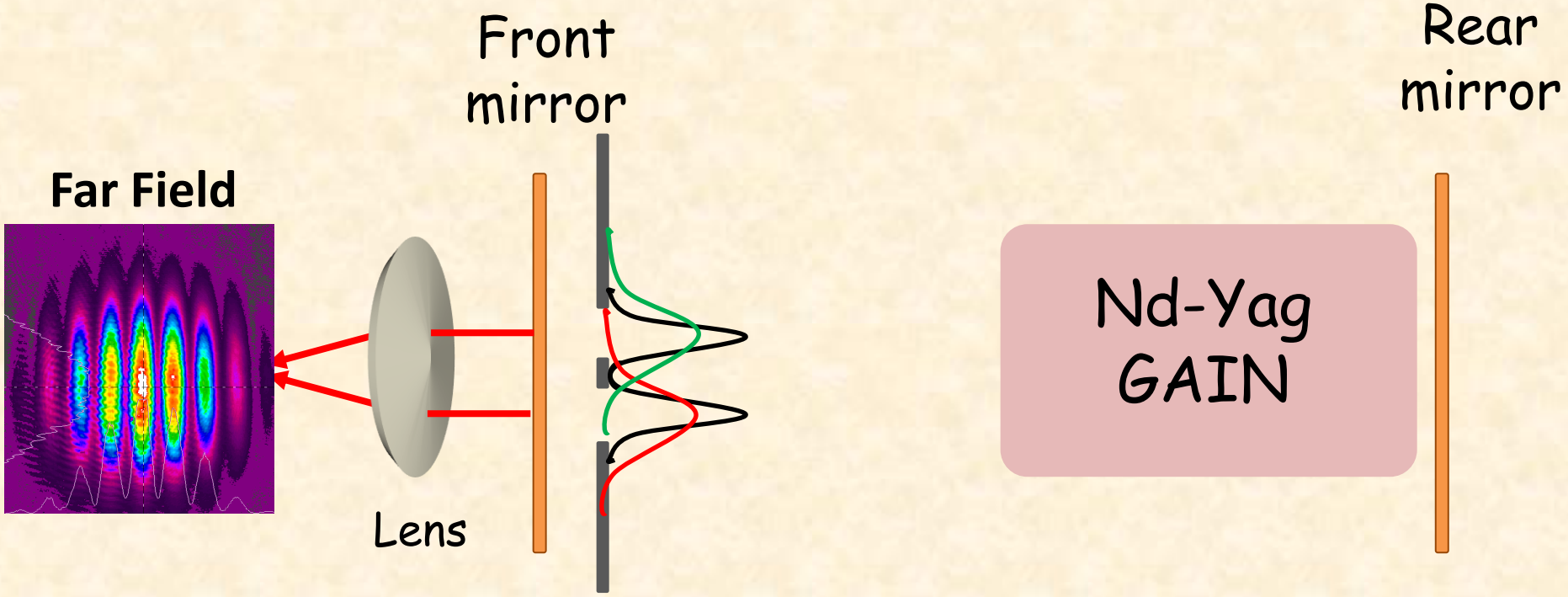
What is phase locking ?



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

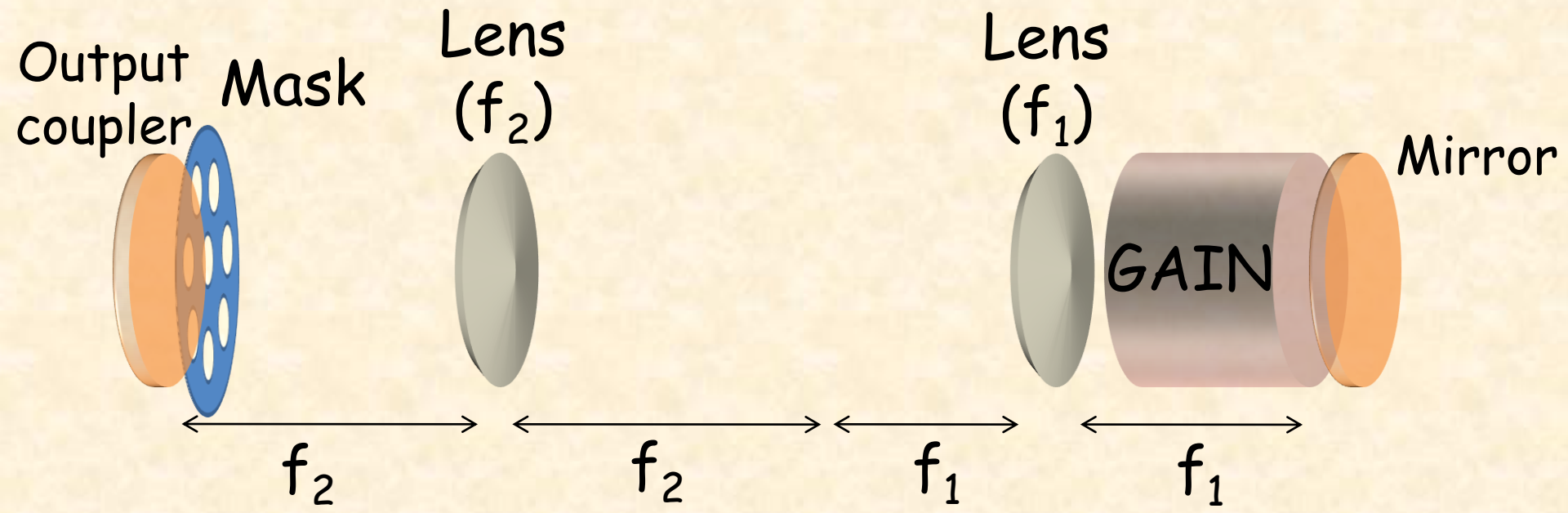
Diffractive coupling



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

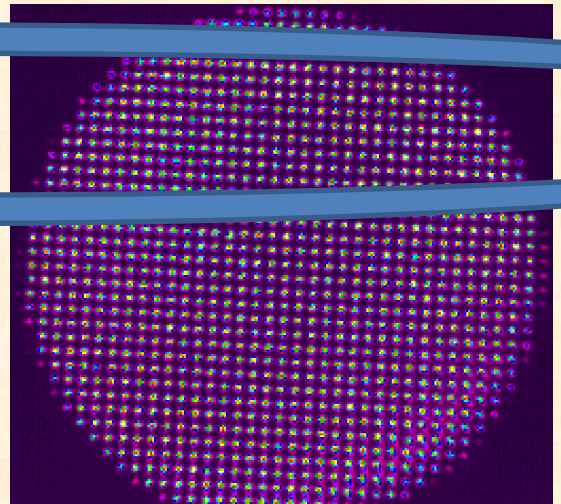
Short range interaction

Degenerate laser cavity

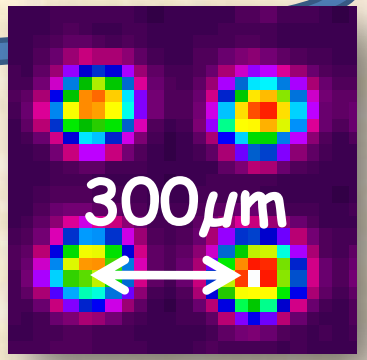


$E(x,y)$

$E(x,y)$

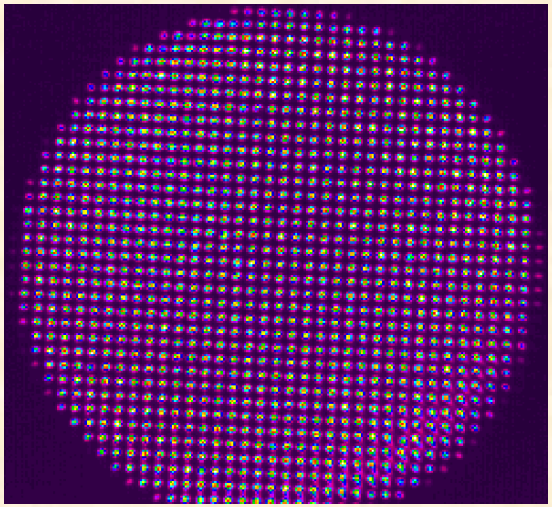


$E(-x,-y)$

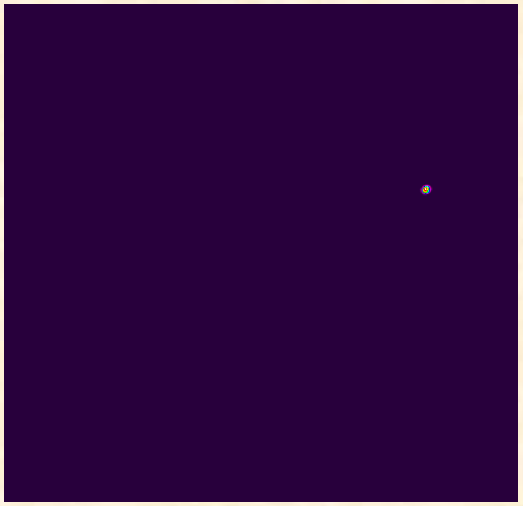


Degenerate cavity square array

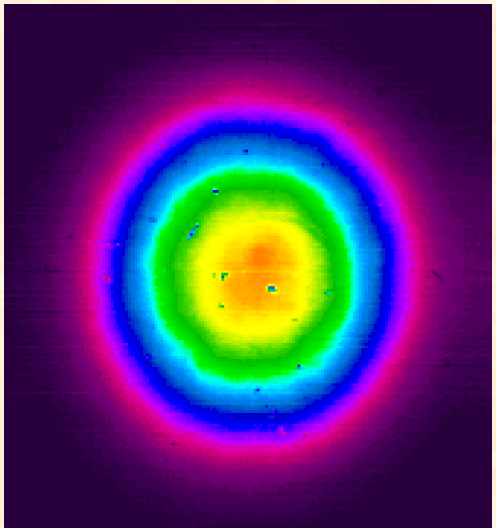
Near field



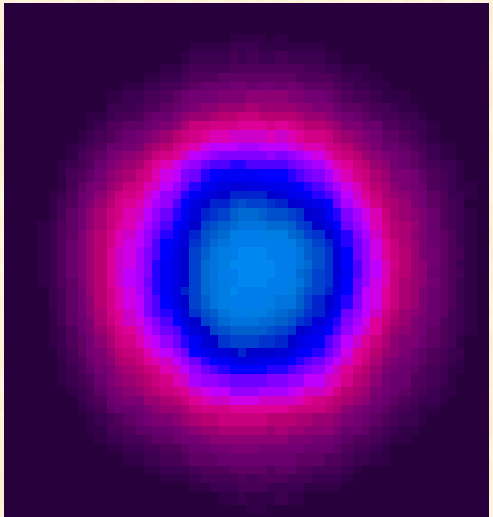
Near field



Far field



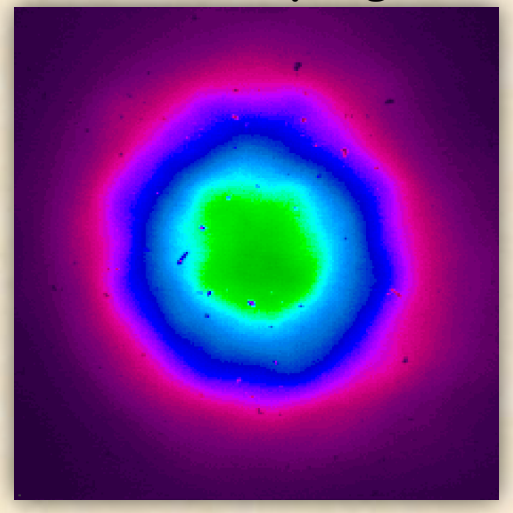
Far field



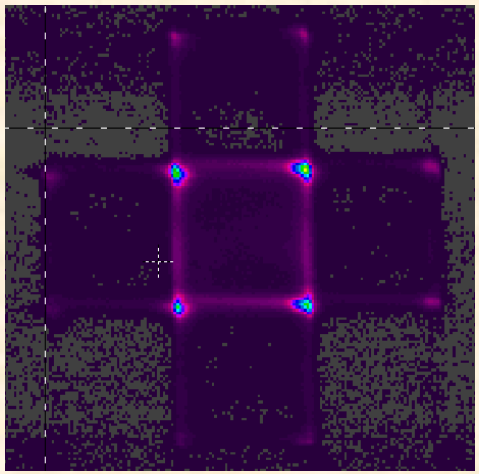
Degenerate cavity

Far Field

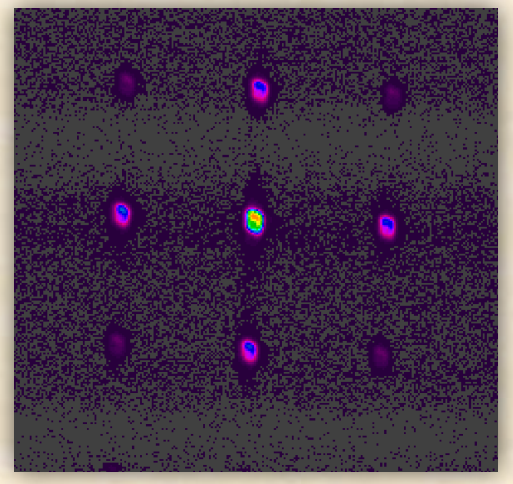
No coupling



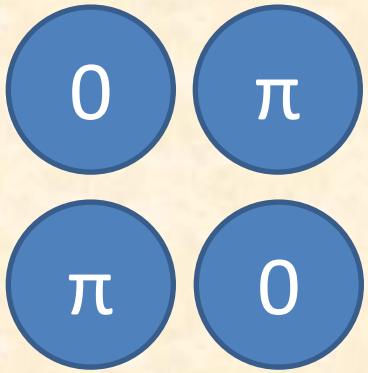
Negative coupling

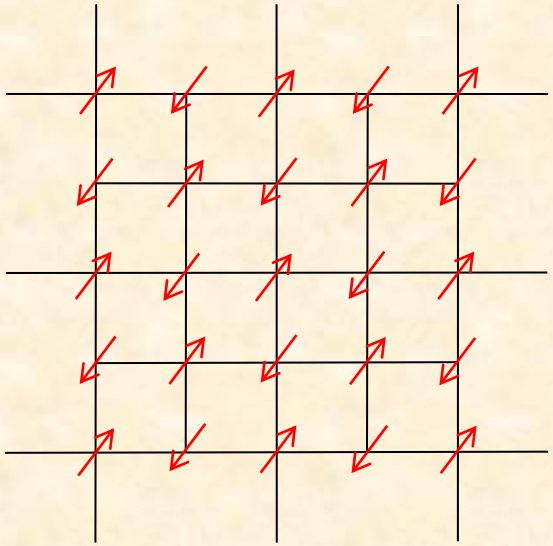


Positive coupling



Lasers ⟷ Spin



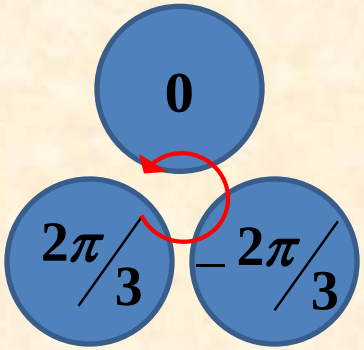


Kuramoto Model $\dot{\theta}_i = \Sigma \kappa_{ij} \sin(\theta_j - \theta_i)$

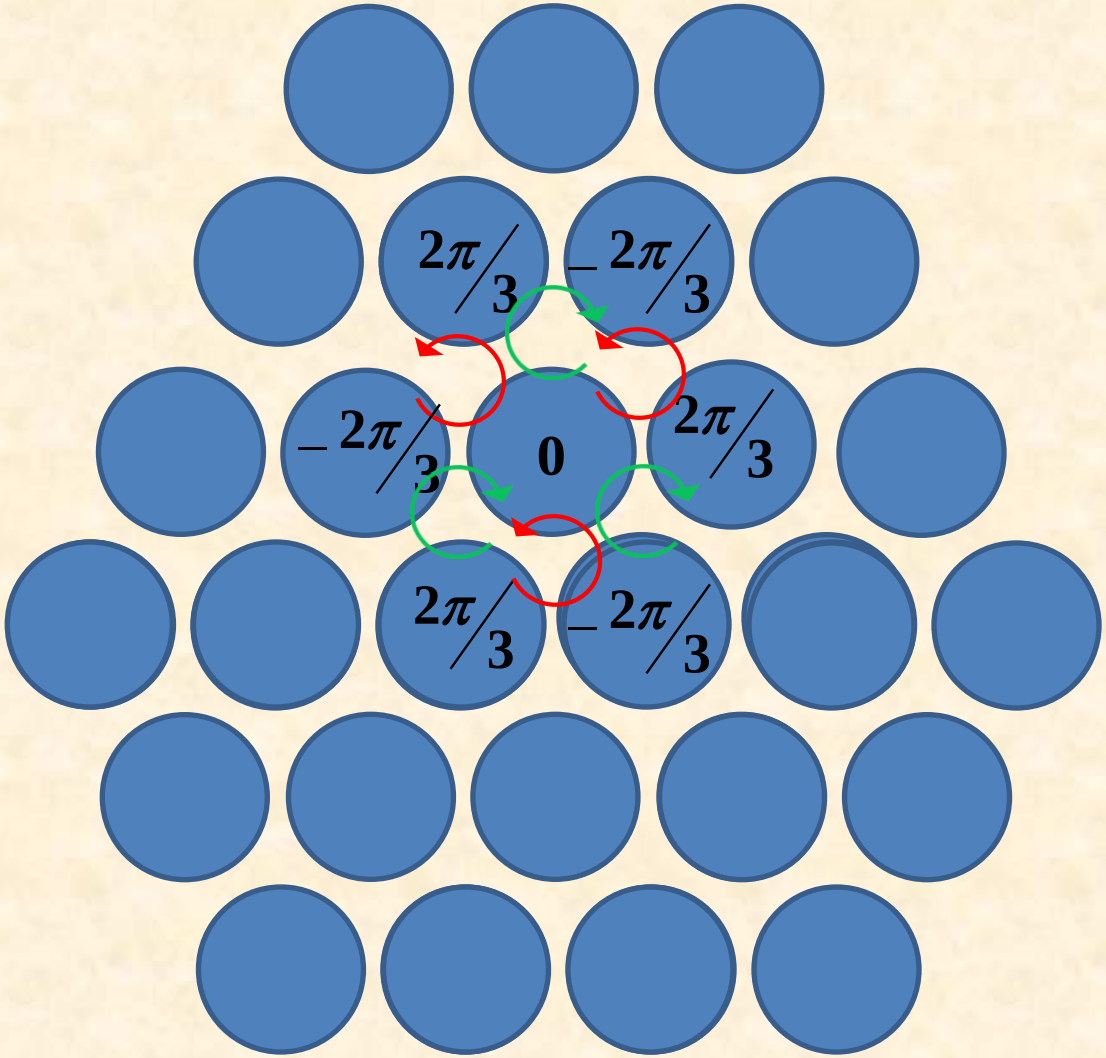
XY model with anti ferromagnetic interactions

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

Triangle Array

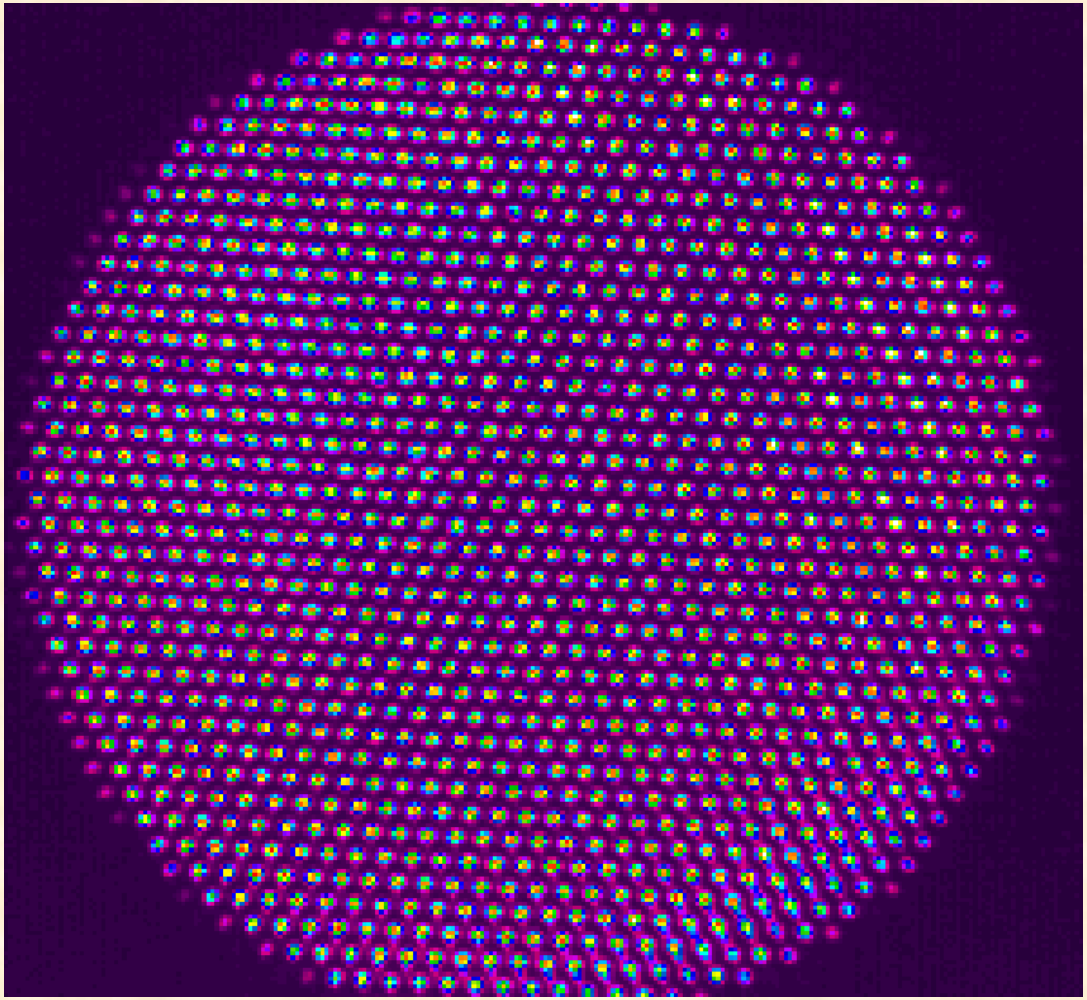


Triangle Array

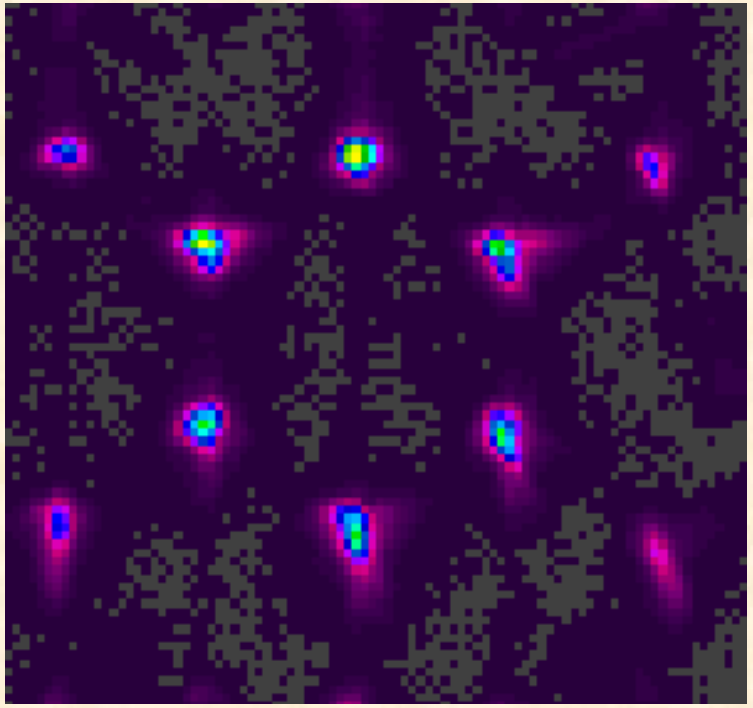


Triangular array

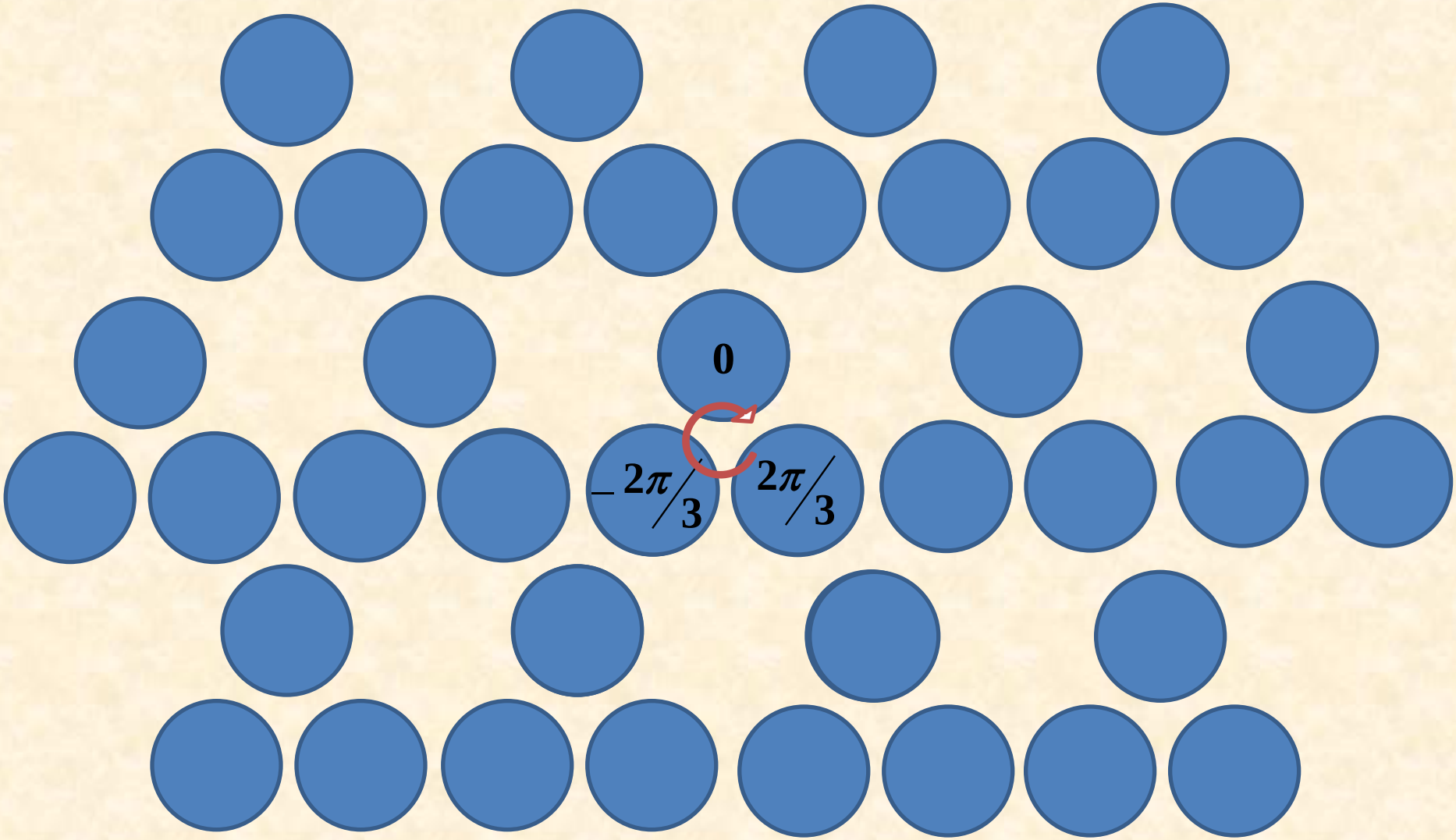
Near Field



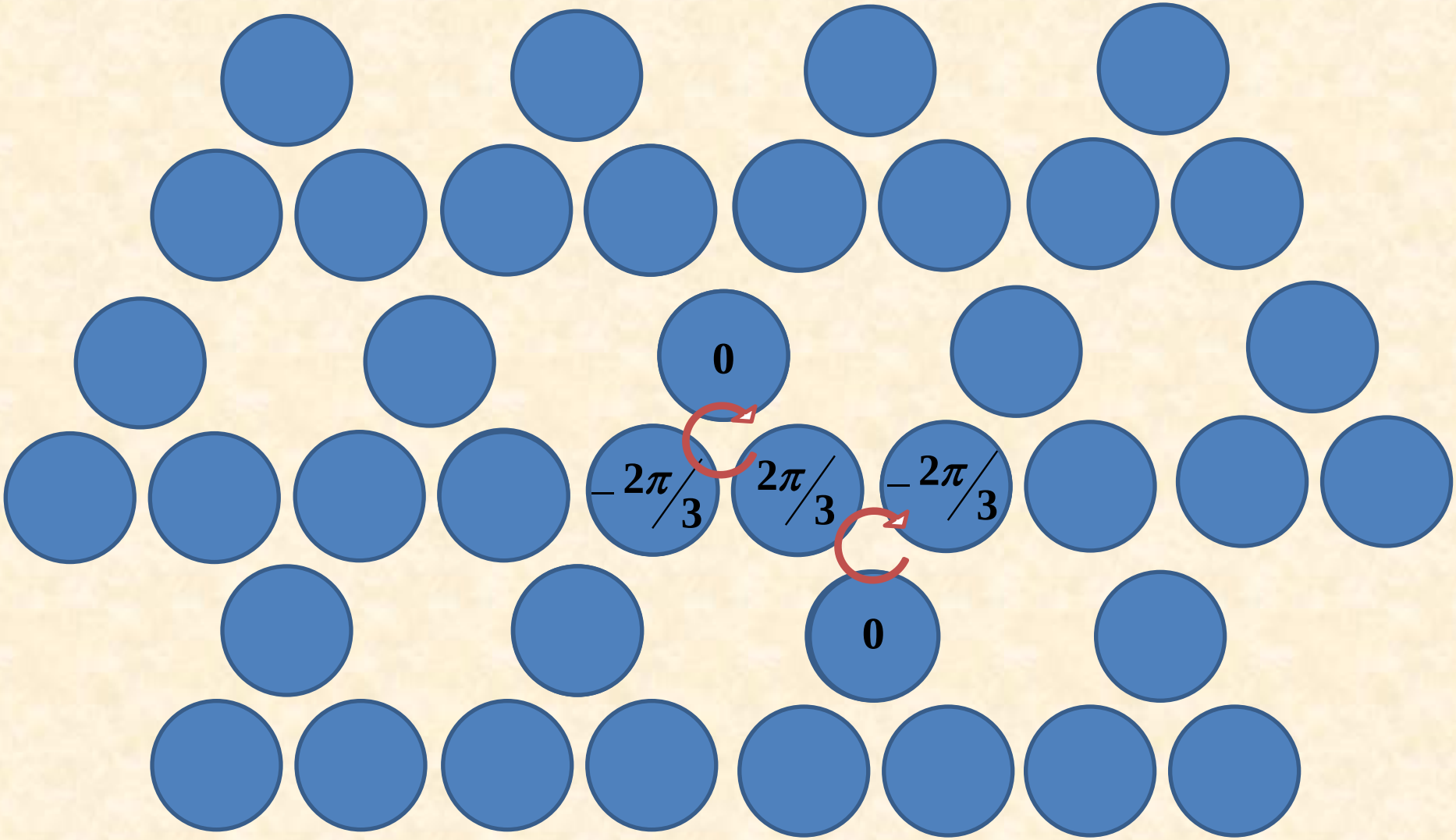
Far Field



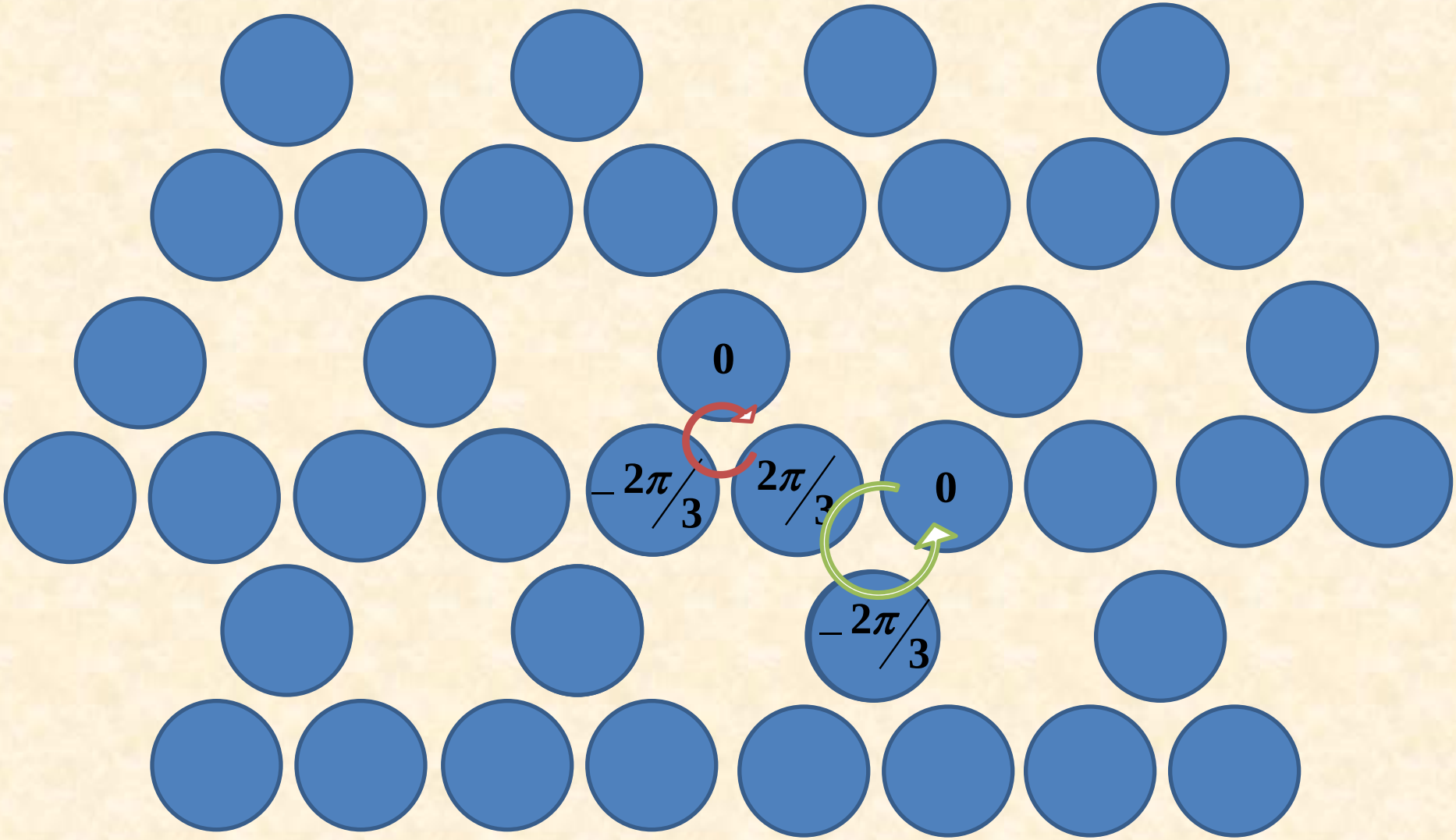
Kagome Array



Kagome Array

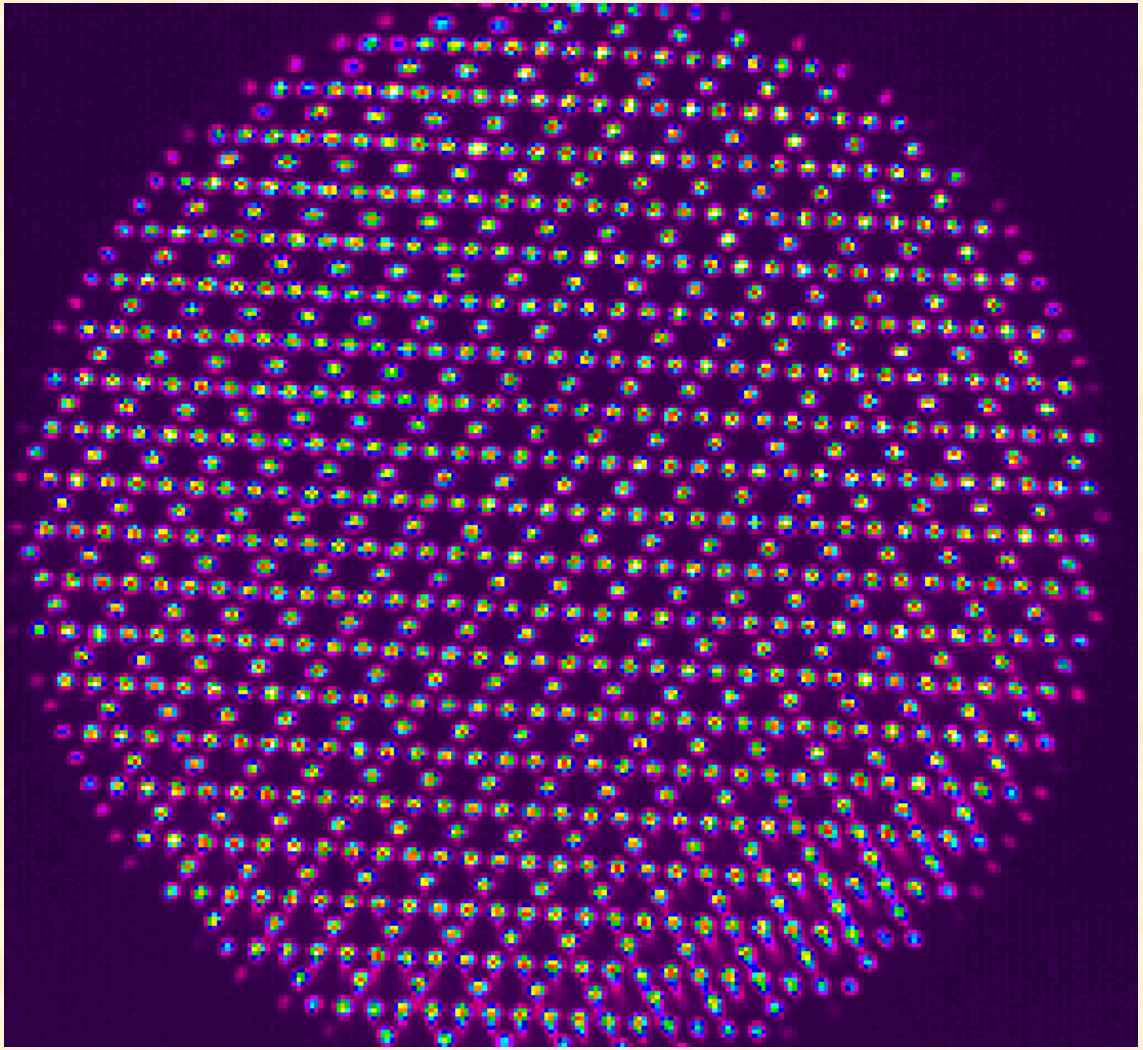


Kagome Array

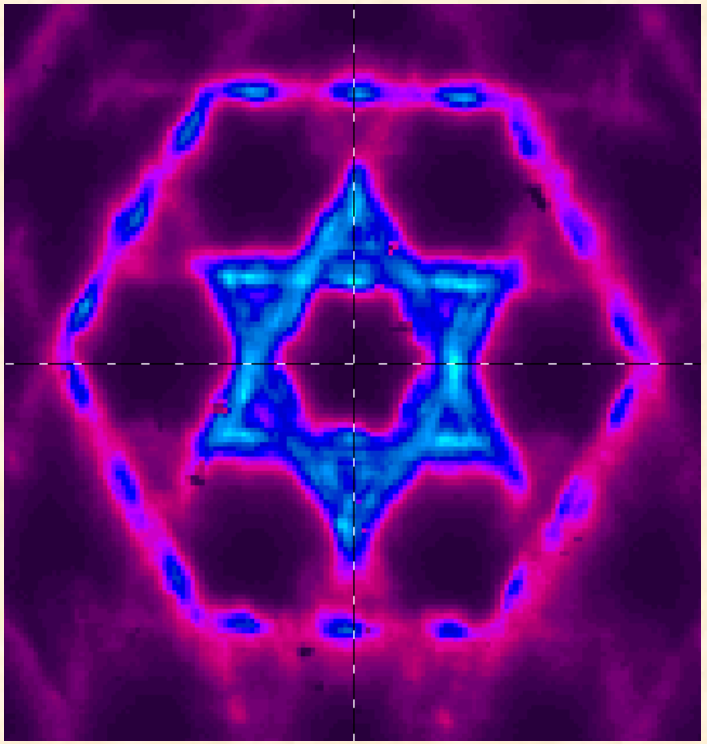


Kagome array

Near Field

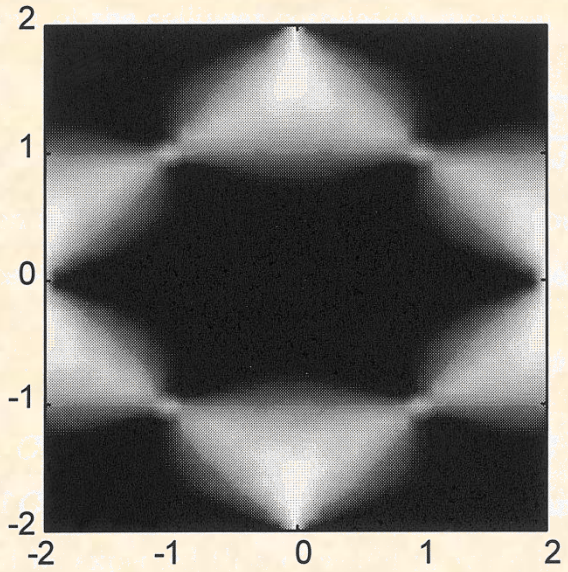


Far Field

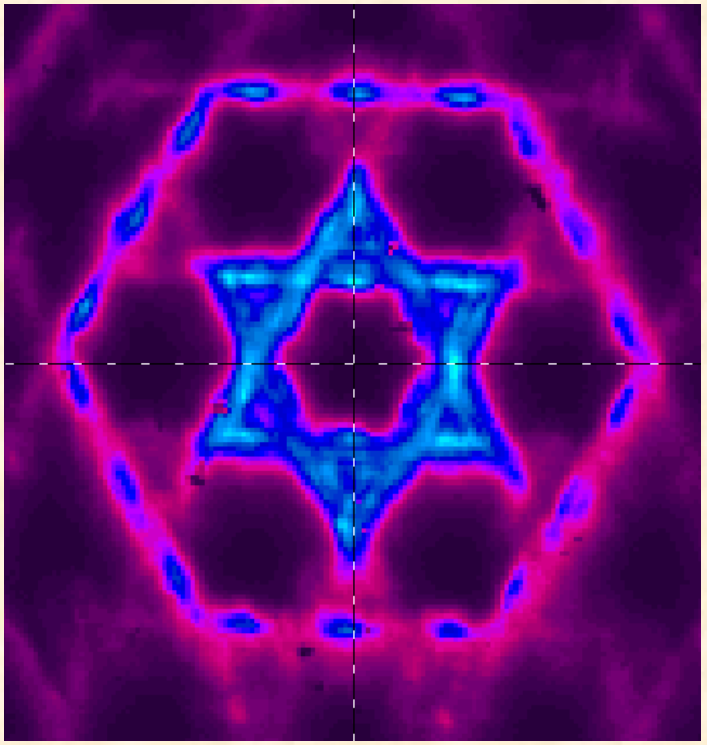


Kagome array

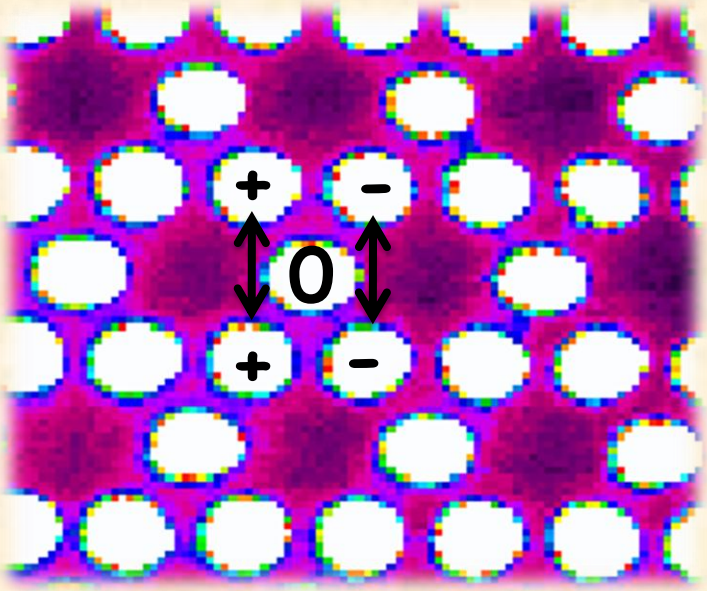
Moessner and Chalker *"Low-temperature properties of classical geometrically frustrated antiferromagnets"*, *Phys. Rev.* B **58** 12049 (1998)

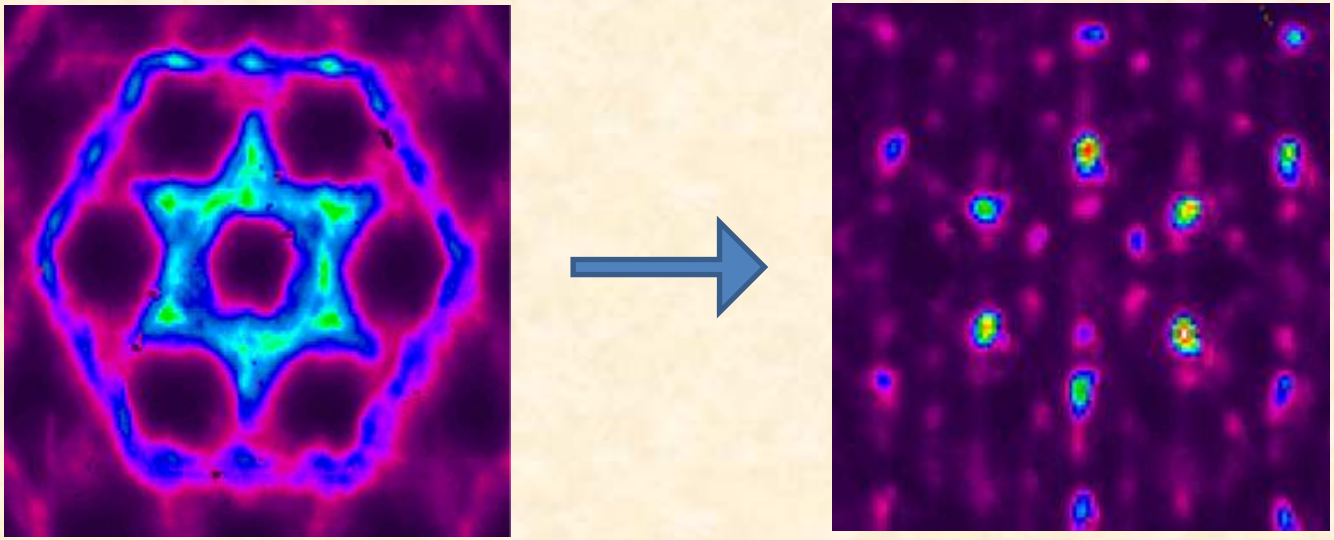


Far Field



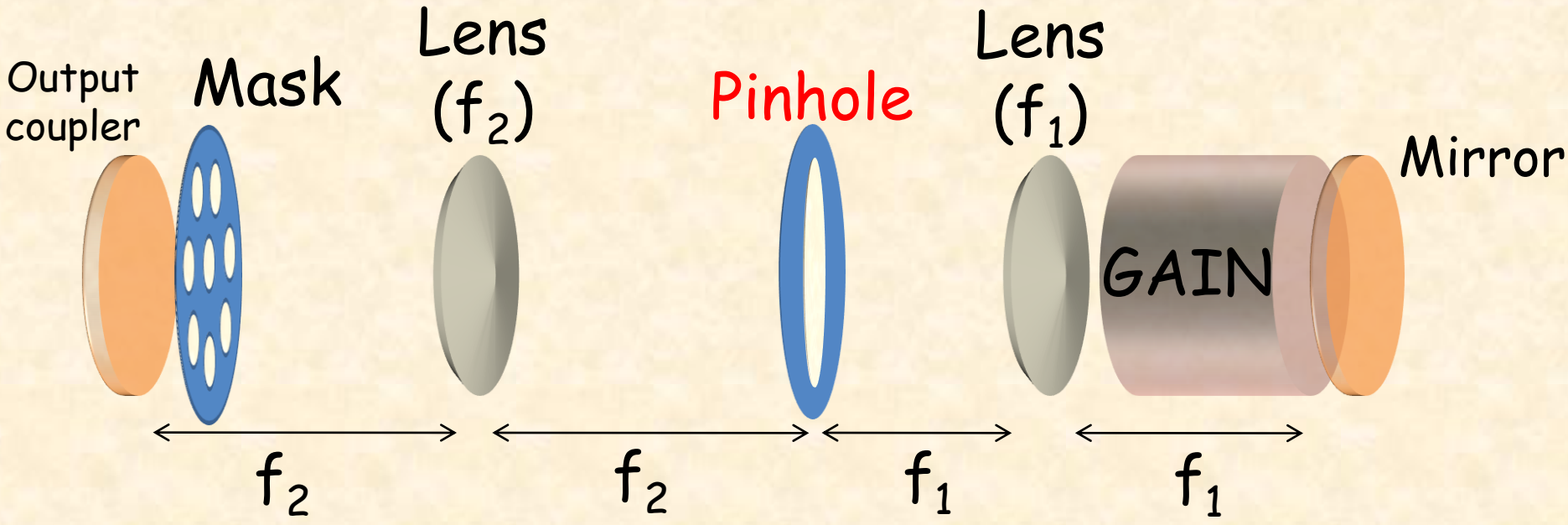
Next Nearest Neighbor Coupling





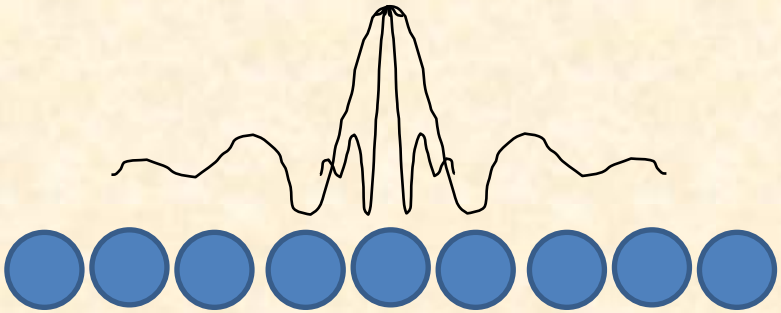
Long range coupling

Long range coupling

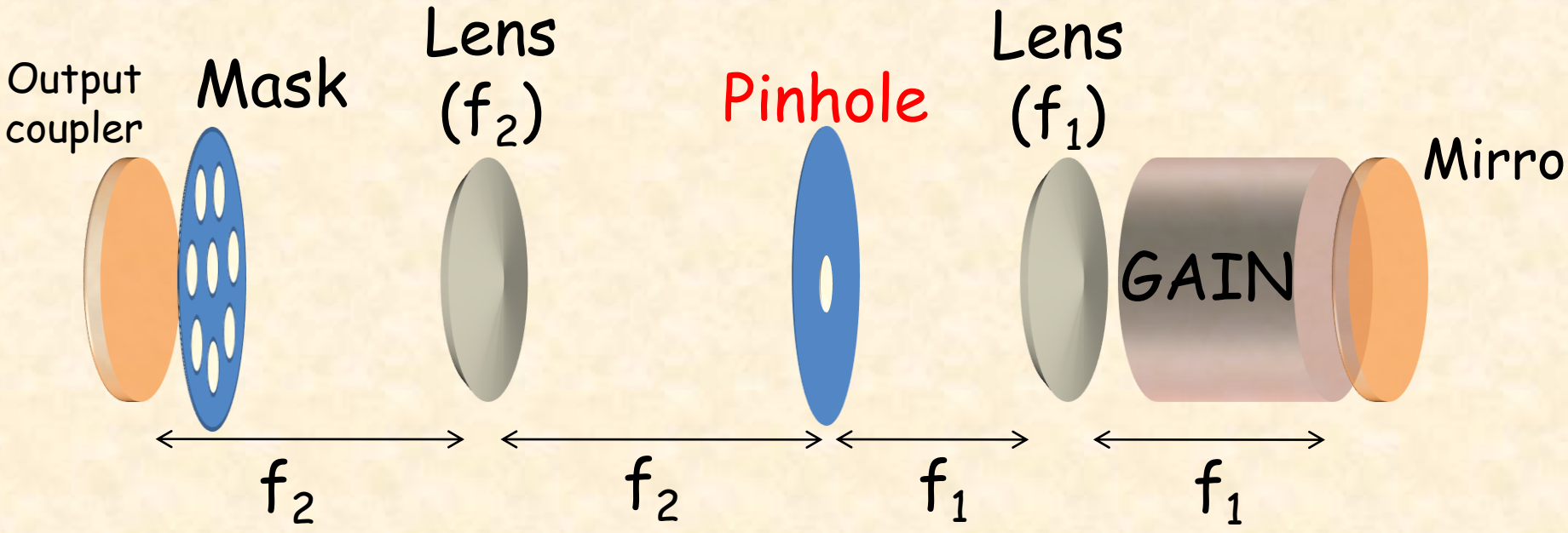


E → $\mathcal{F}\{E\}\cdot U$

$*\mathcal{F}\{EU\}$ ← $\mathcal{F}\{E\}\cdot U$

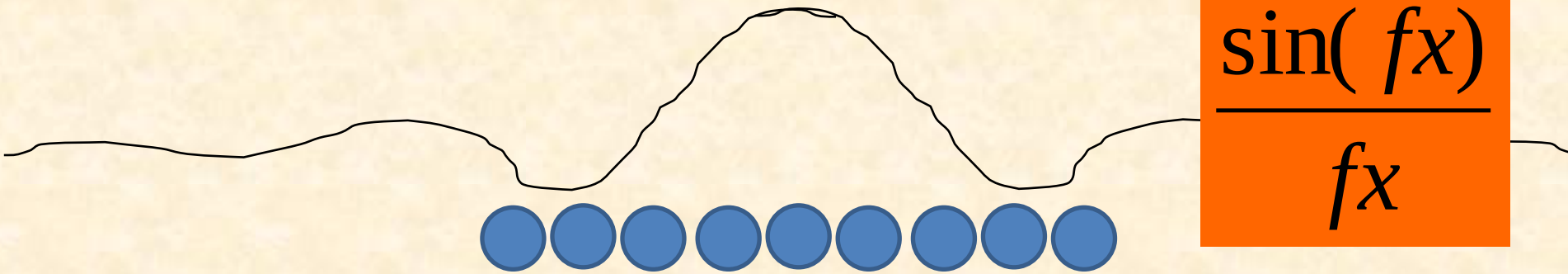


Long range coupling



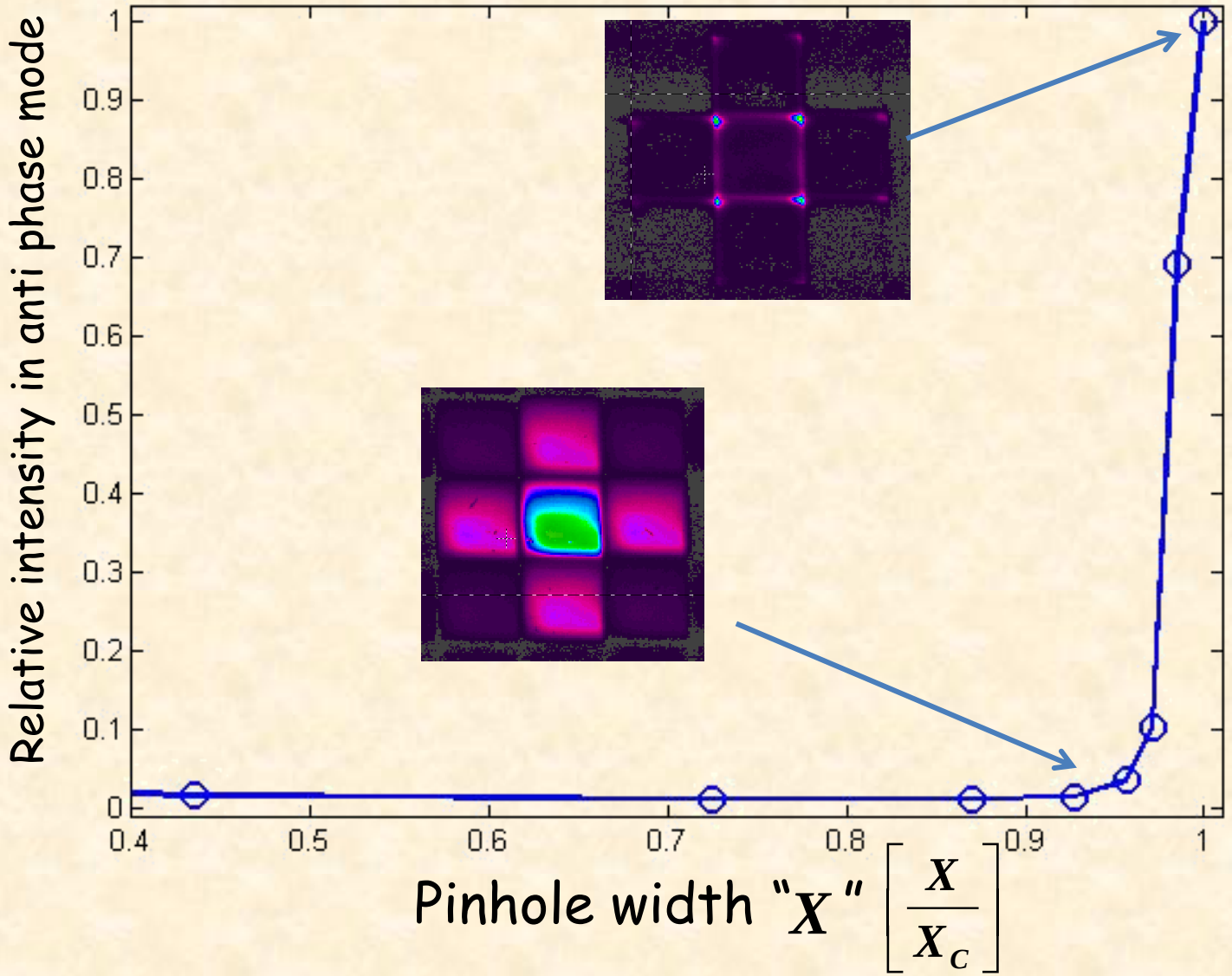
E → $\mathcal{F}\{E\}\cdot U$

$E * \mathcal{F}\{U\}$ ← $\mathcal{F}\{E\}\cdot U$

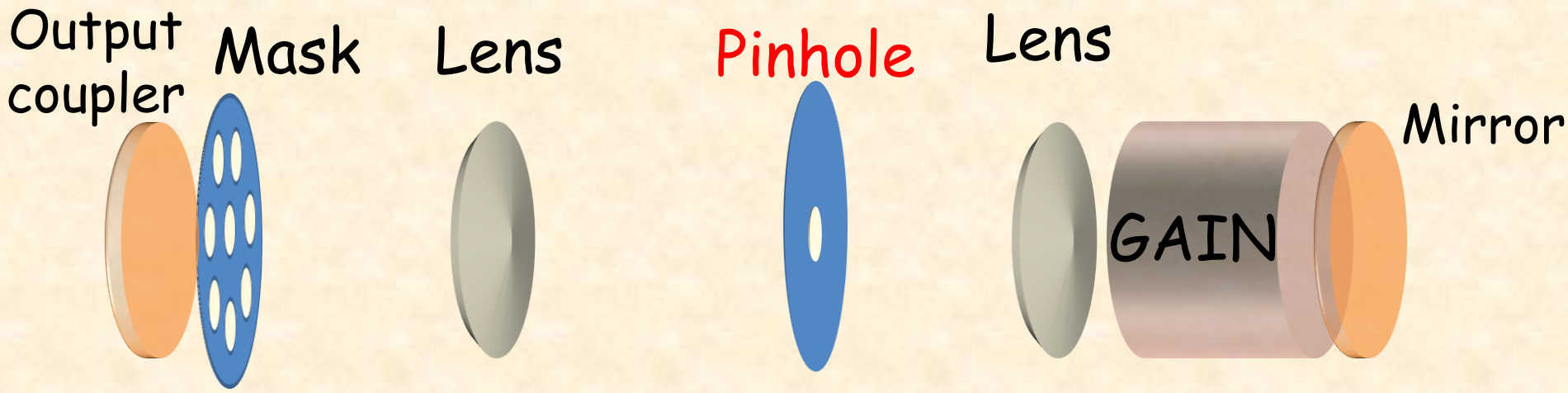


$$\frac{\sin(fx)}{fx}$$

Sharp "phase" transitions



Intermediate summary



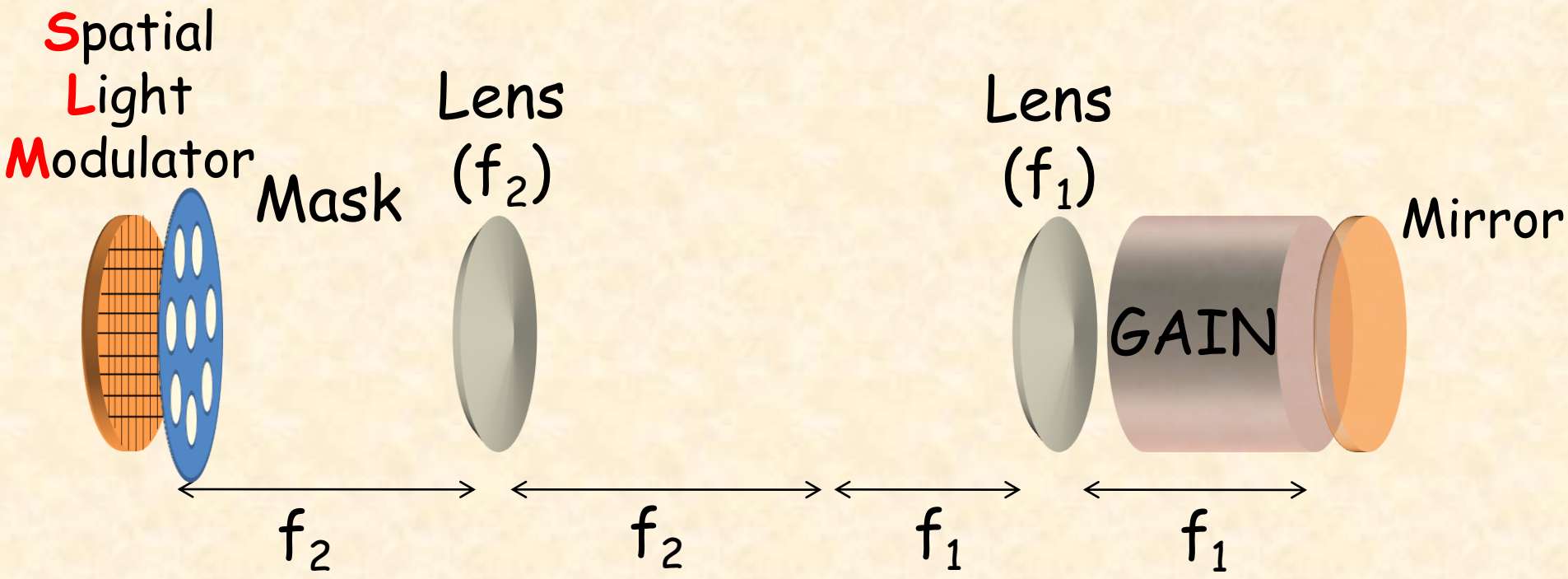
$$\kappa_{ij} = \left\langle E_i^{fin} \middle| E_j^{ini} \right\rangle \cong \frac{1}{(i-j)^2}$$

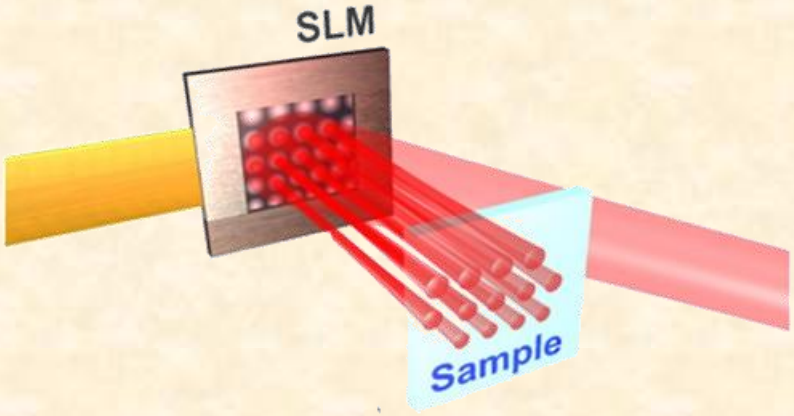
Long range interaction

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

Short range interaction

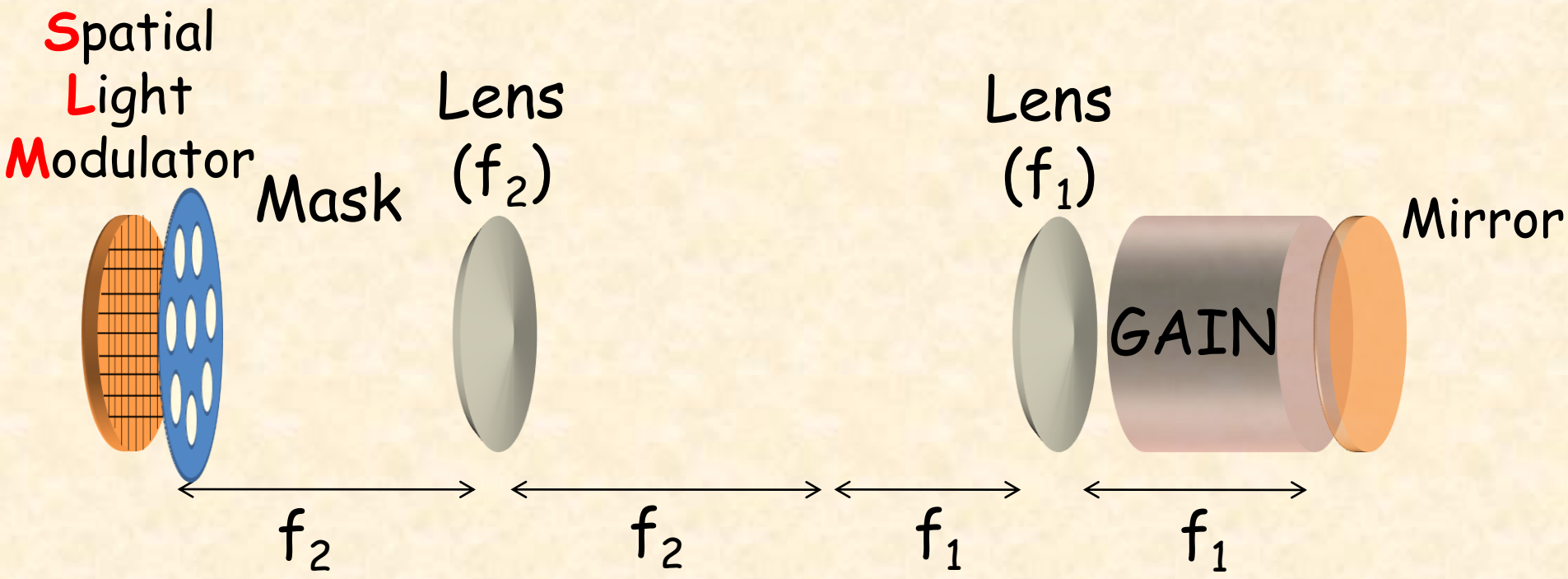
Adding disorder



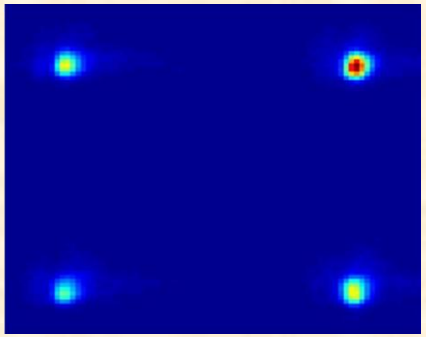


$$\dot{\theta}_i = \Omega_i + \Sigma \kappa_{ij} \sin(\theta_j - \theta_i)$$

Adding disorder

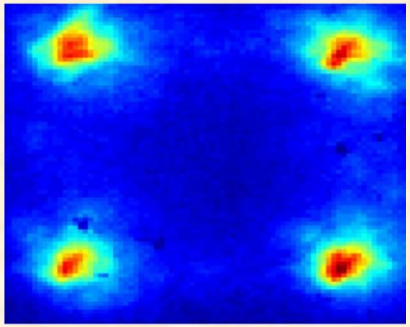


Far Field



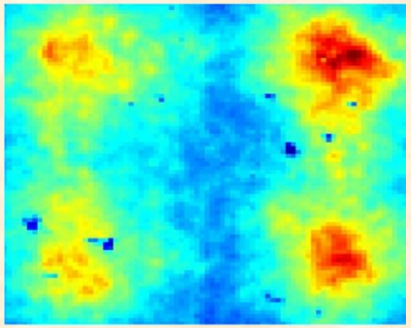
$\langle \varphi \rangle_{rms} = 0$

Far Field



$\langle \varphi \rangle_{rms} = \frac{\pi}{10}$

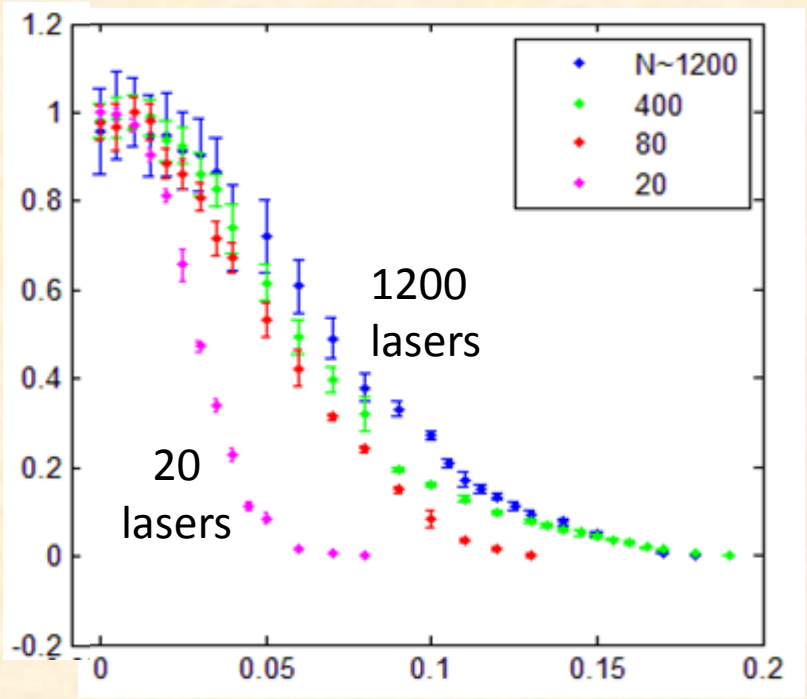
Far Field



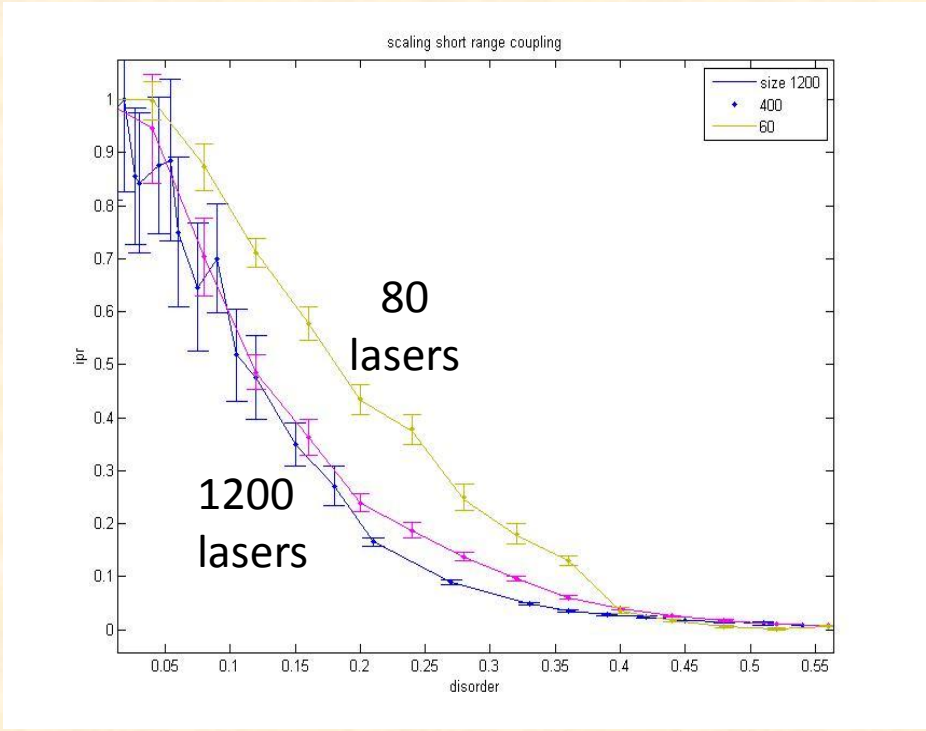
$\langle \varphi \rangle_{rms} = \frac{\pi}{5}$

Long Vs. short range coupling
scaling system size

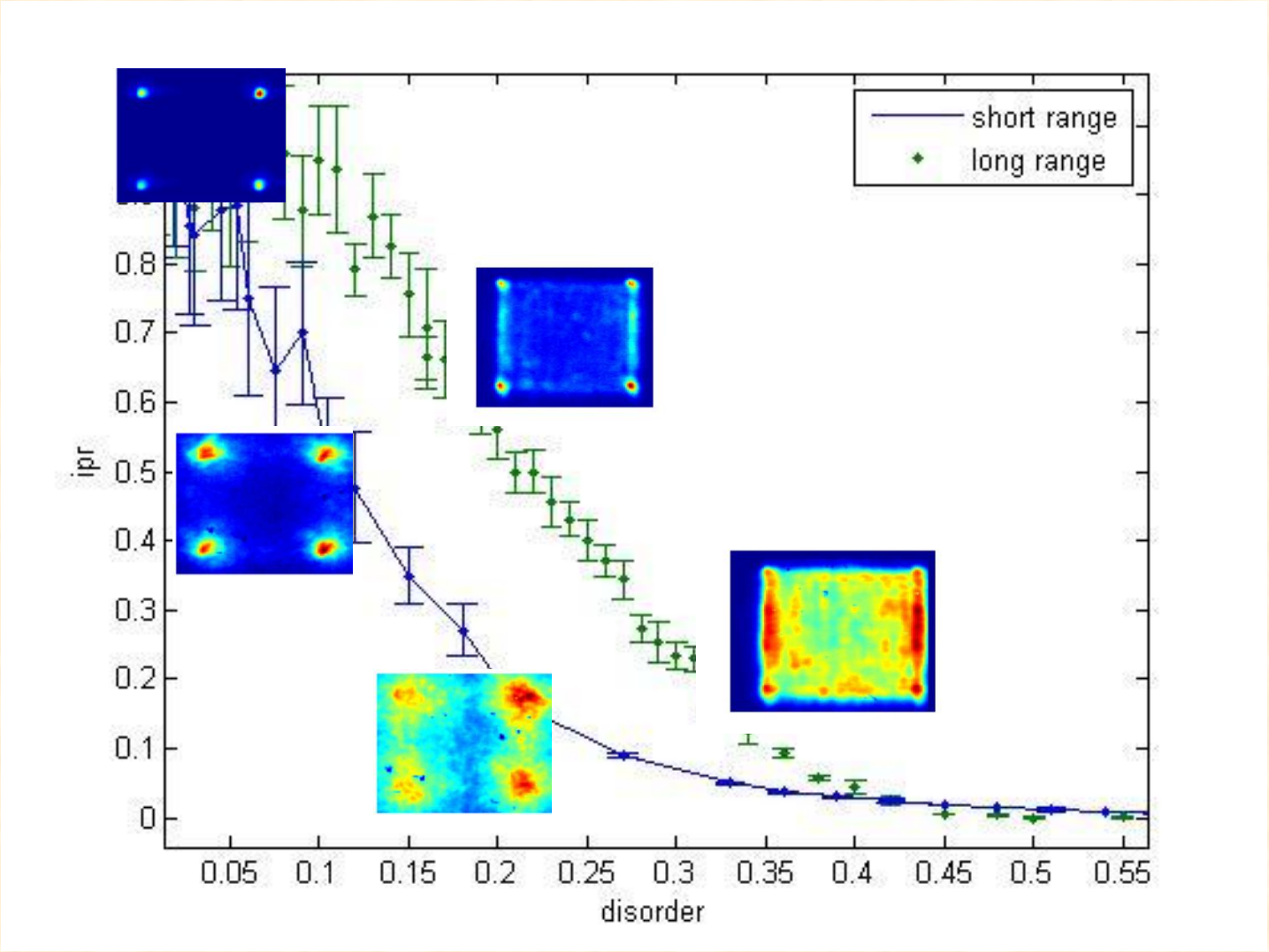
Long



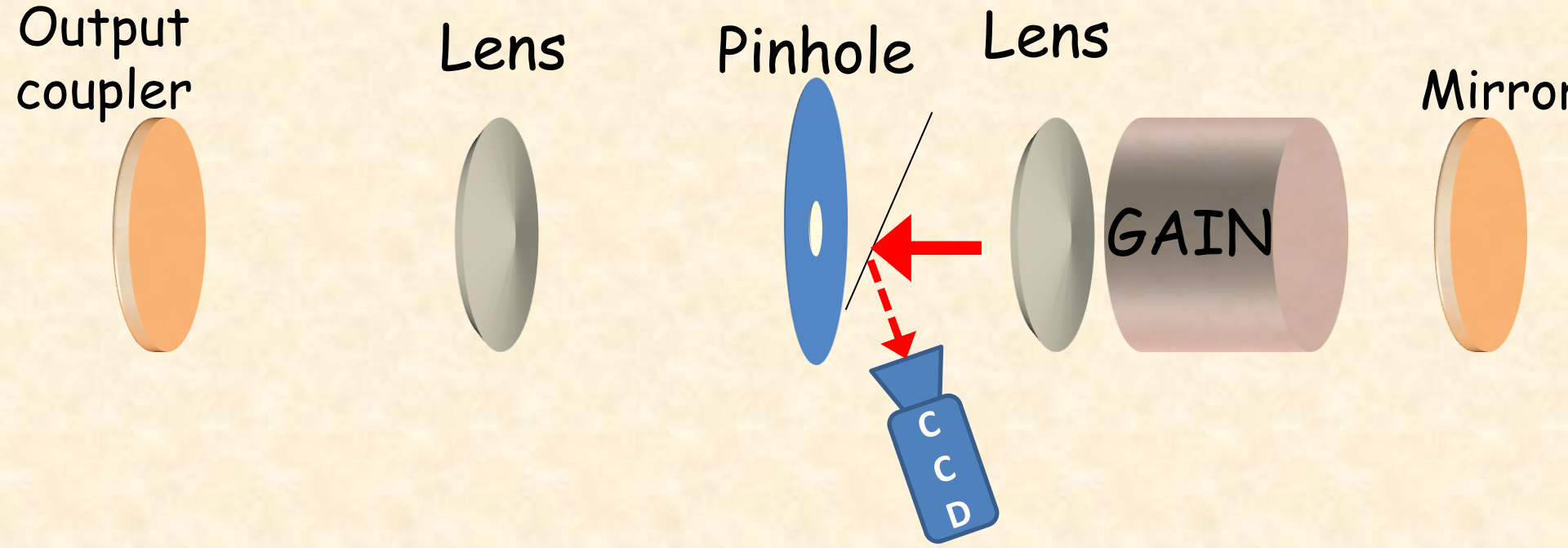
Short

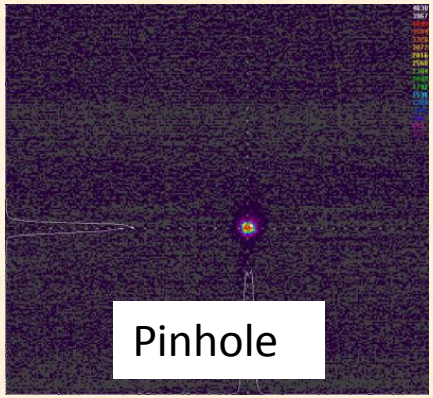


Long vs. short range coupling

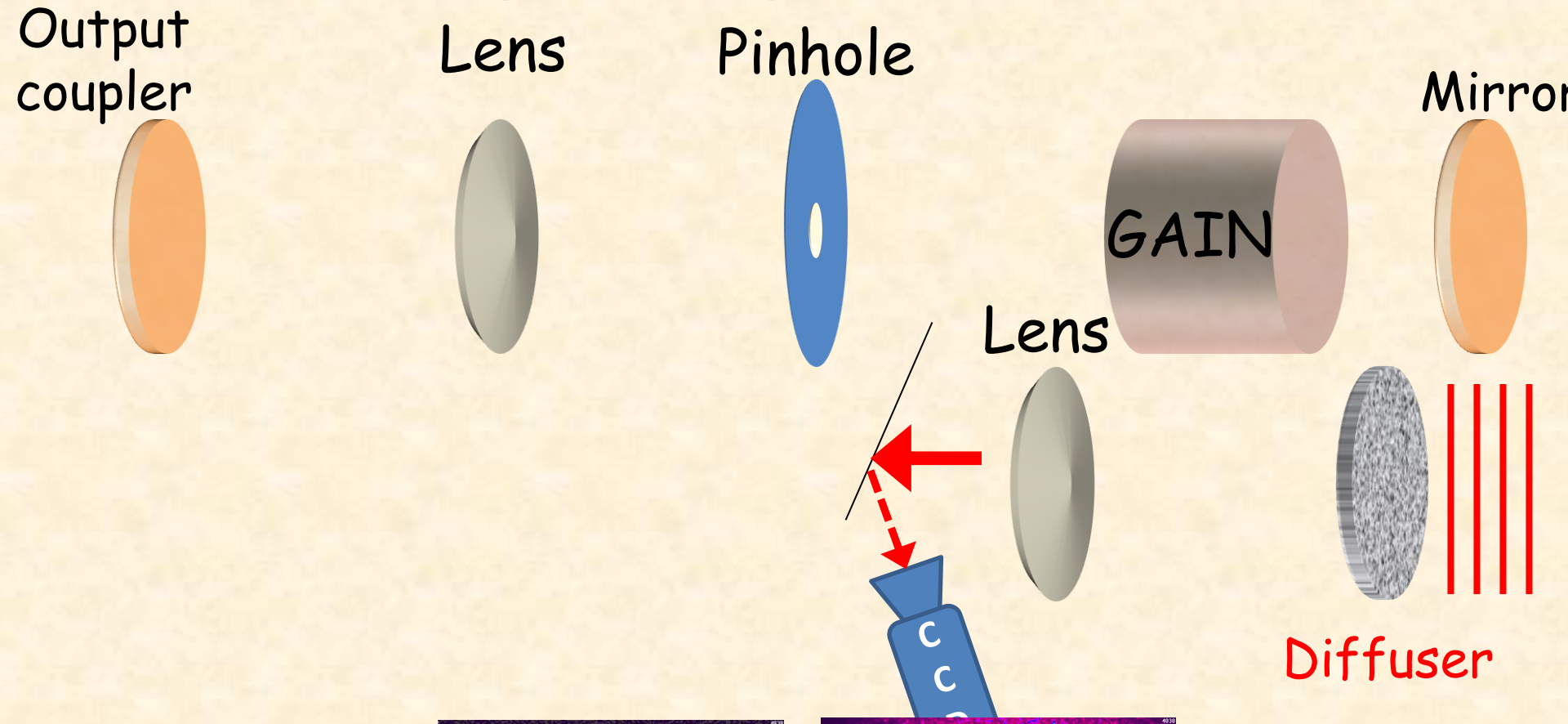


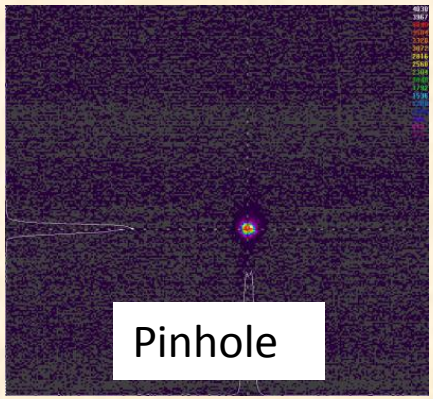
Lasing through a Diffuser

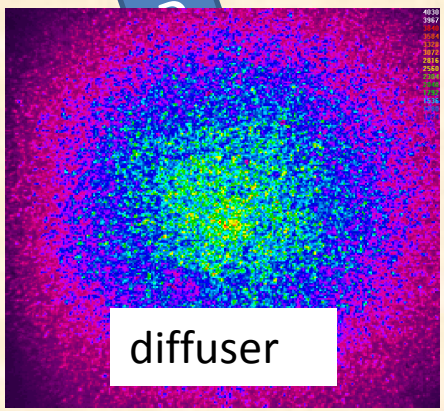




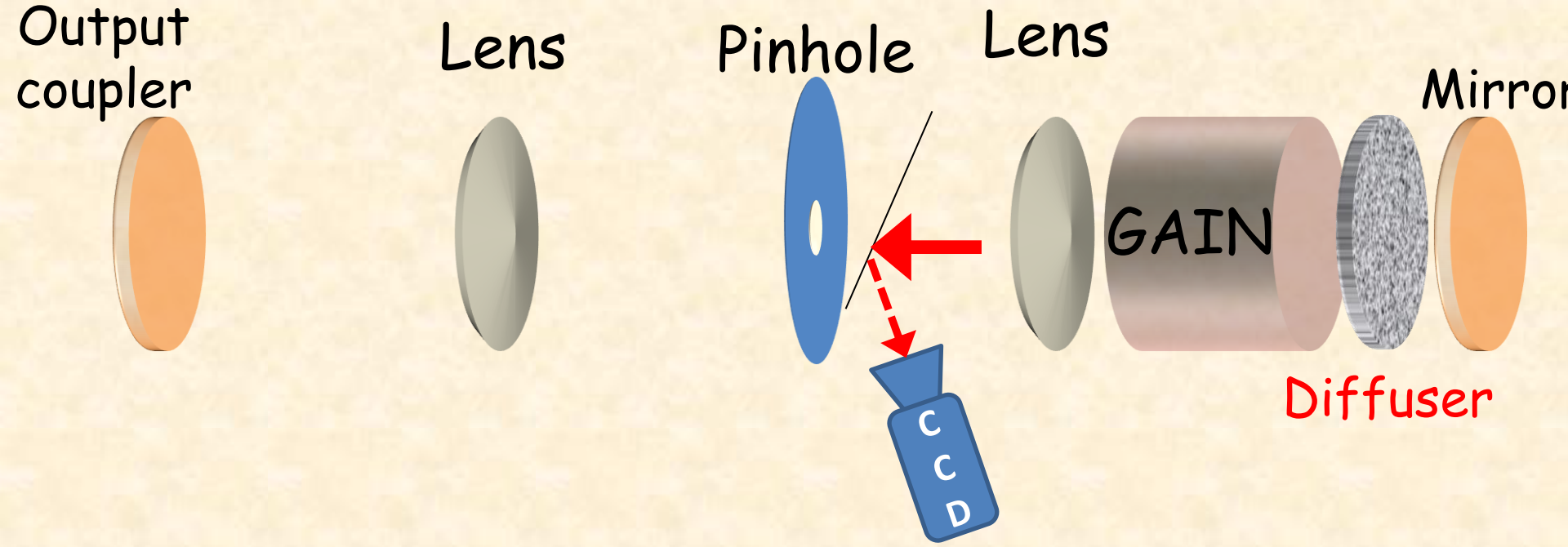
Lasing through a Diffuser

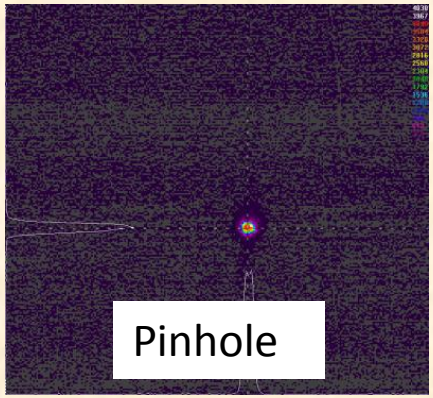


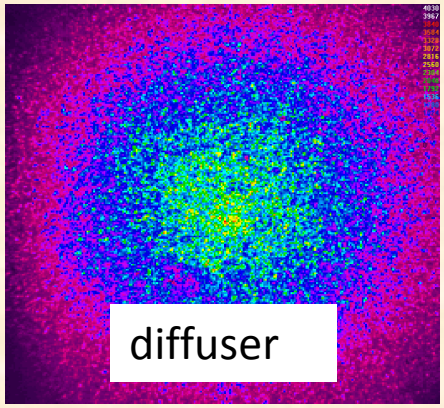


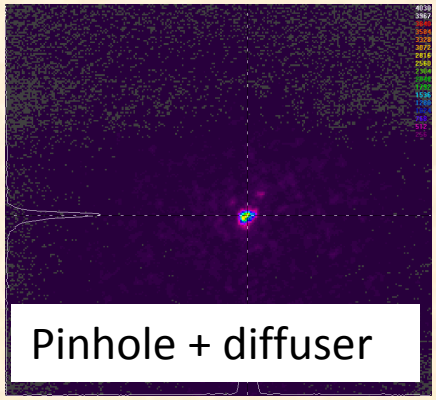


Lasing through a Diffuser

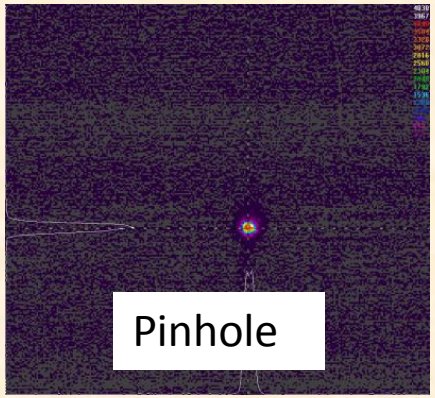


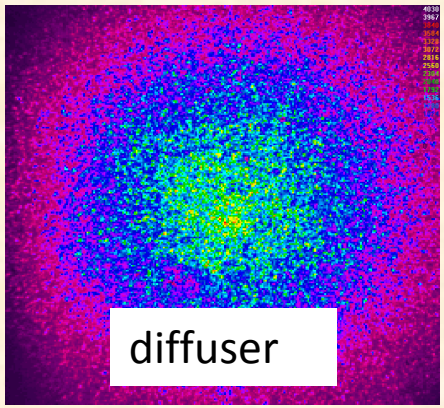


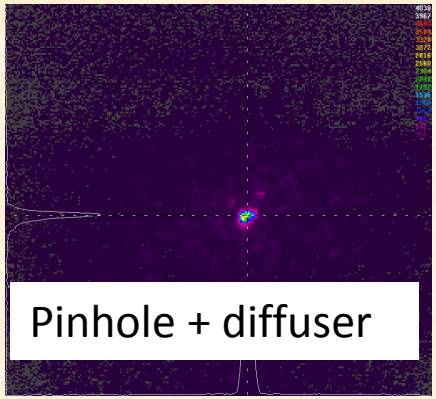


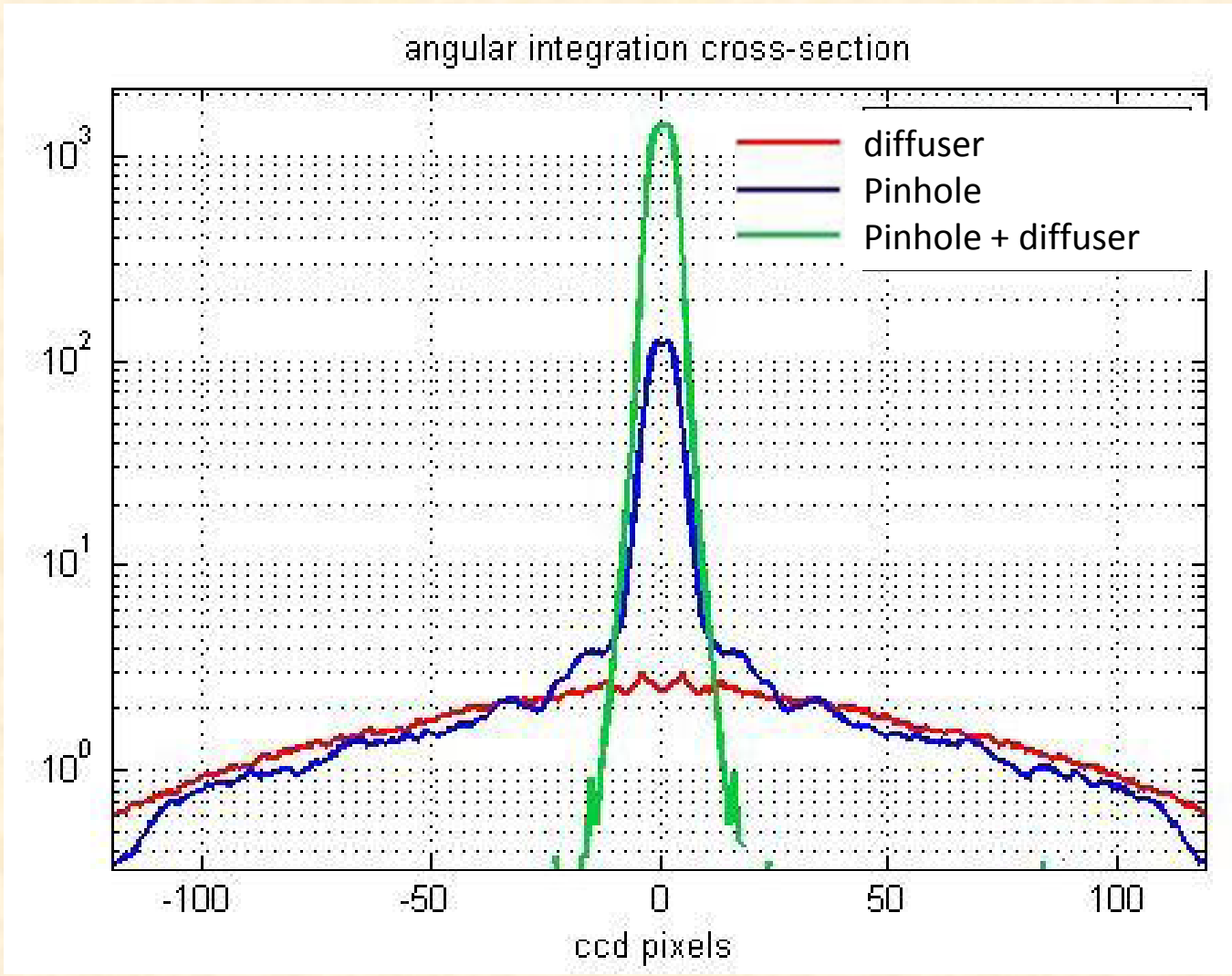


Lasing through a Diffuser



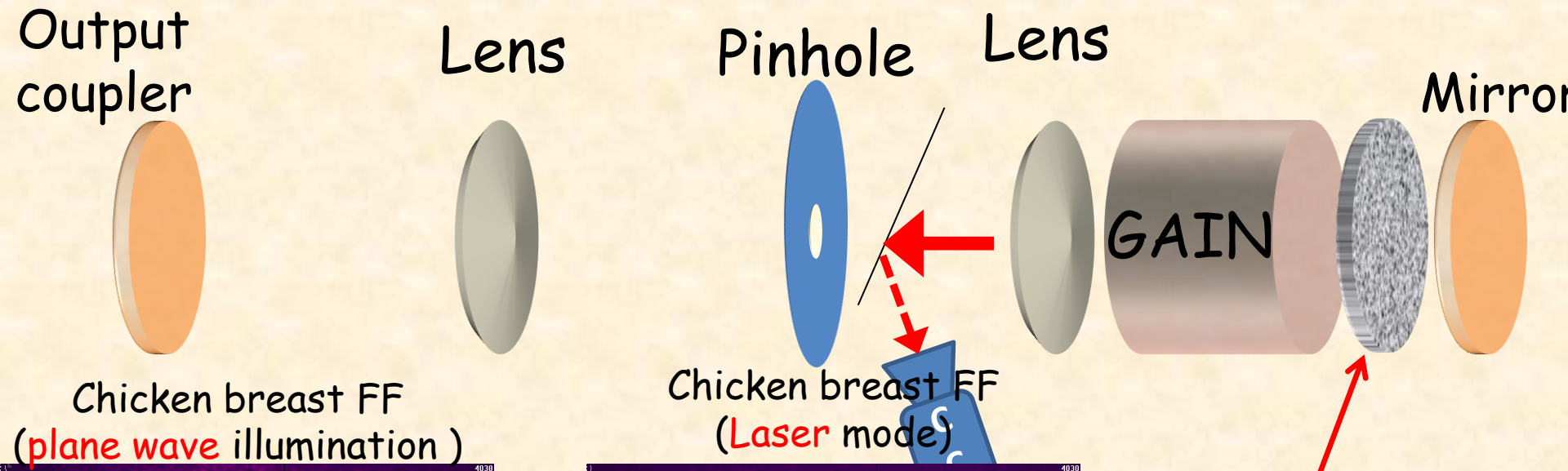




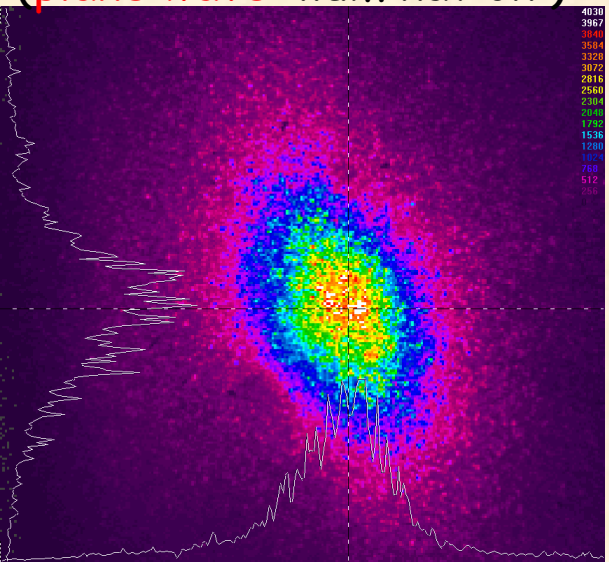


x80 increase of central peak

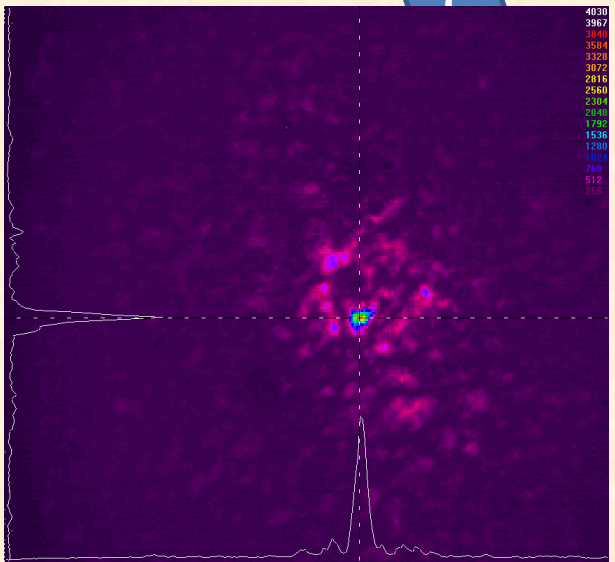
Lasing through a chicken (breast)



Chicken breast FF
(plane wave illumination)



Chicken breast FF
(Laser mode)

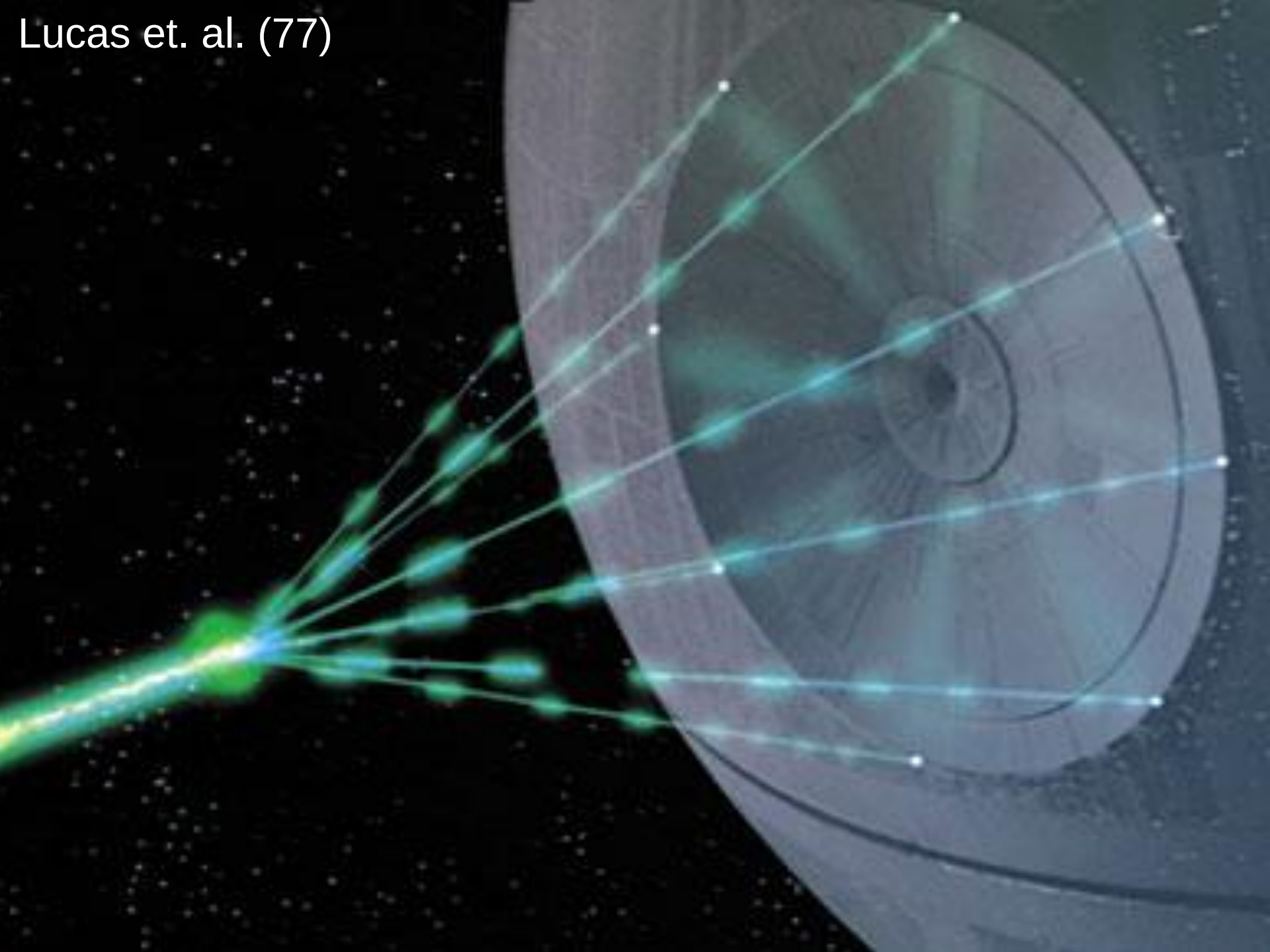


What else?

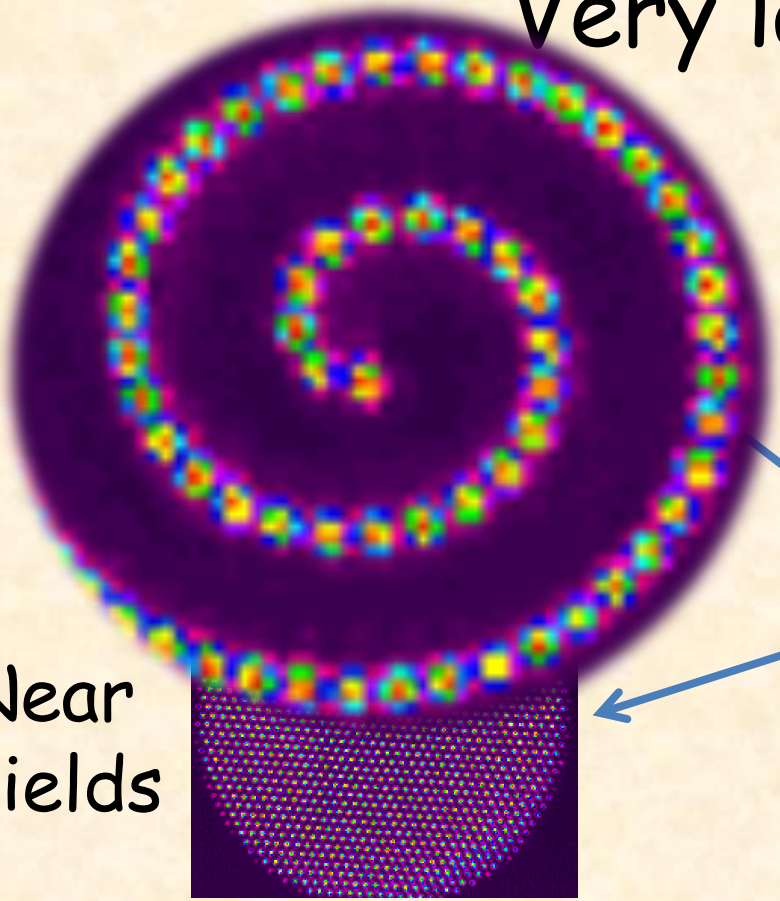
- Effects of external fields, temperature, noise.
- Adding time delayed coupling (with I. Kanter).

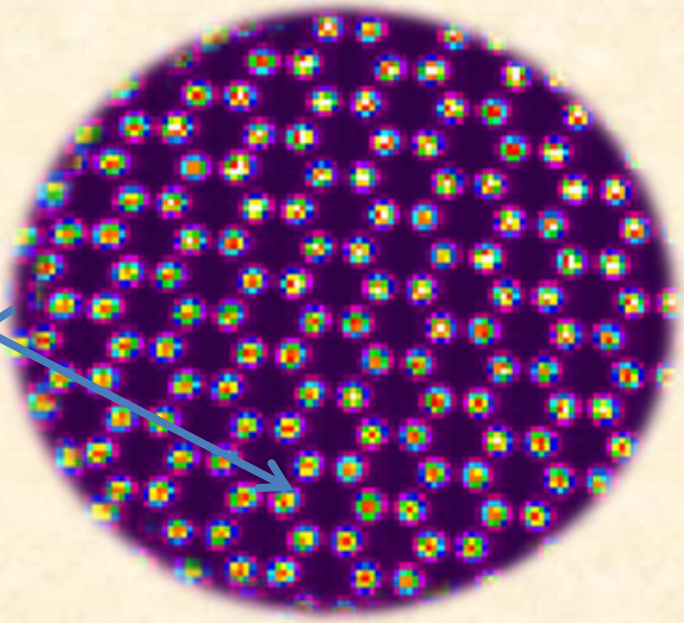
Nixon et al, PRL 106, 223901 (2011), PRL, in press (2012)

- Lasers with random lengths: EVS of random matrices.
- Chaos synchronization.
- Dynamics.


Lucas et. al. (77)

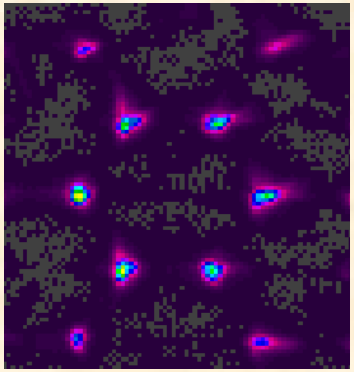
Very large arrays



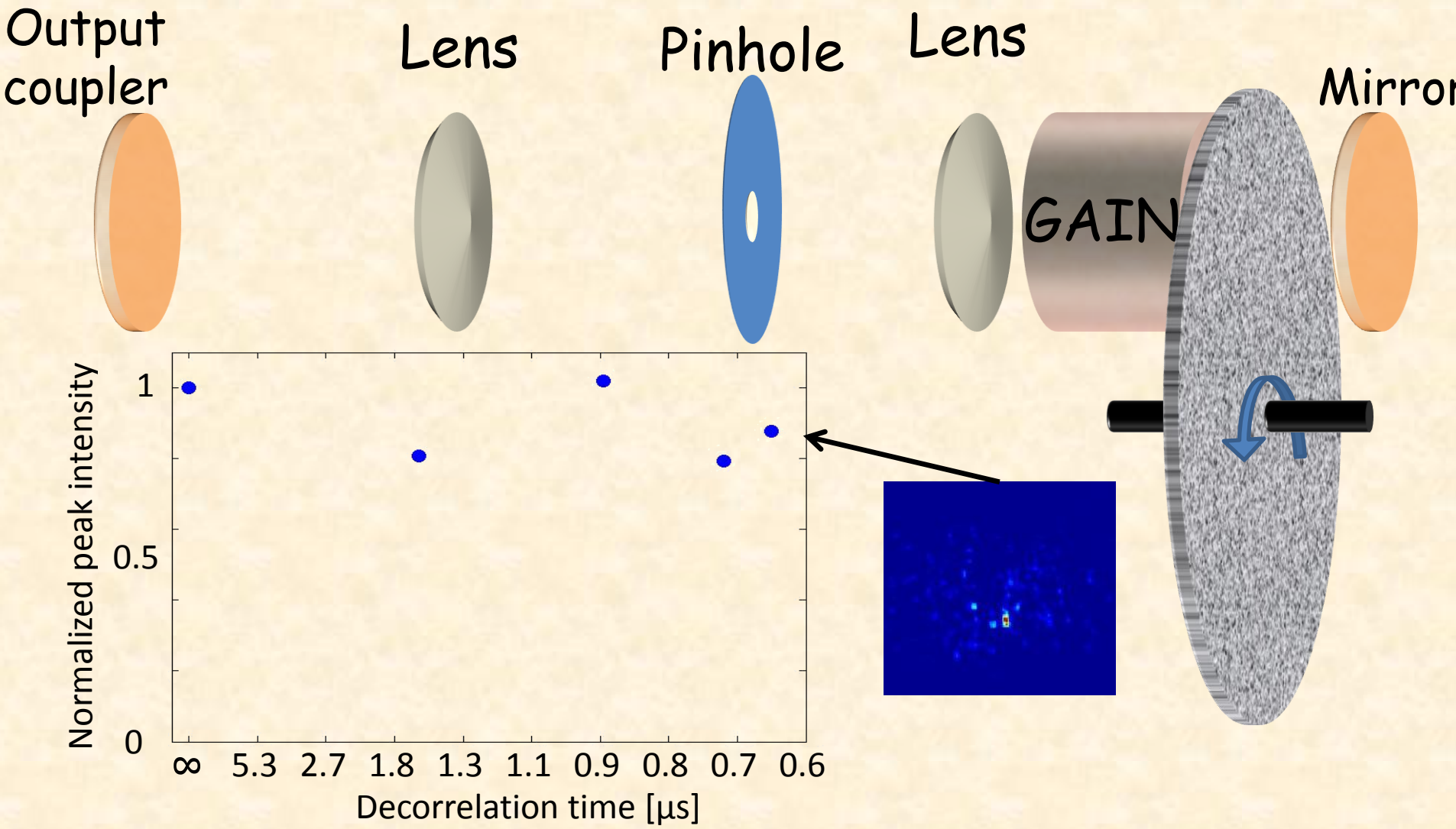


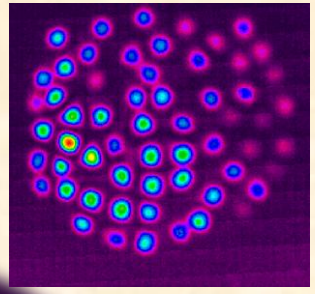
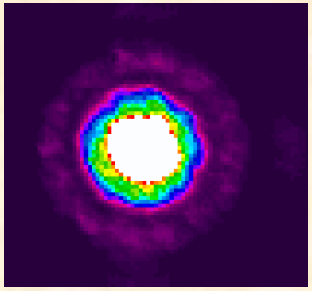
Near Fields

Far Fields

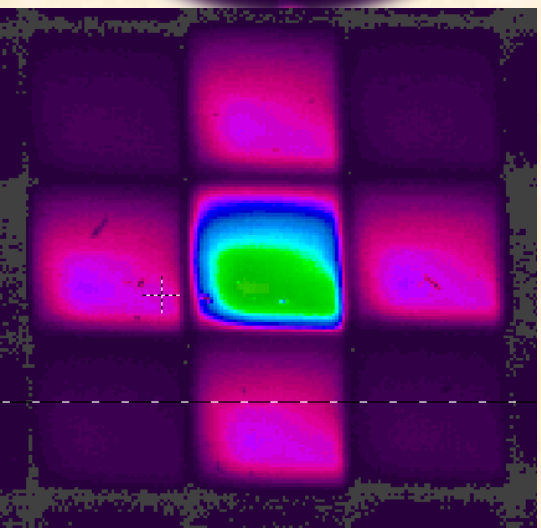
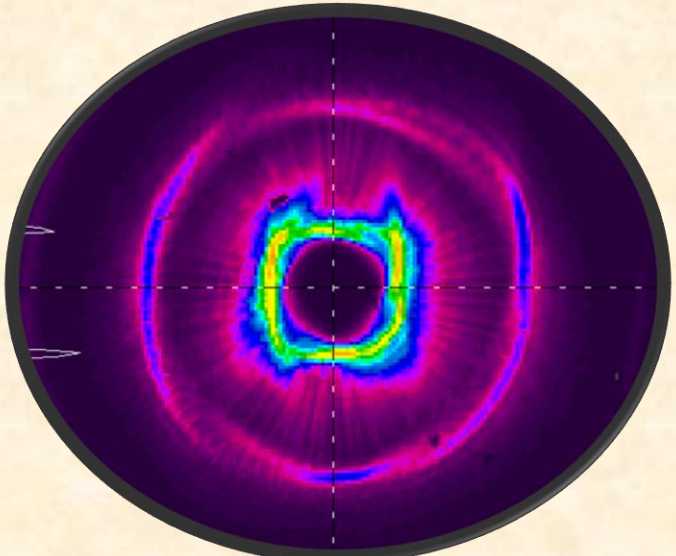
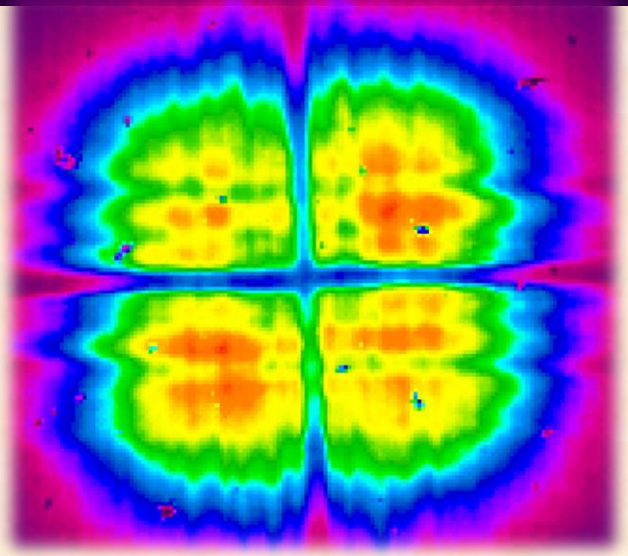


Lasing through a Rapidly changing diffuser

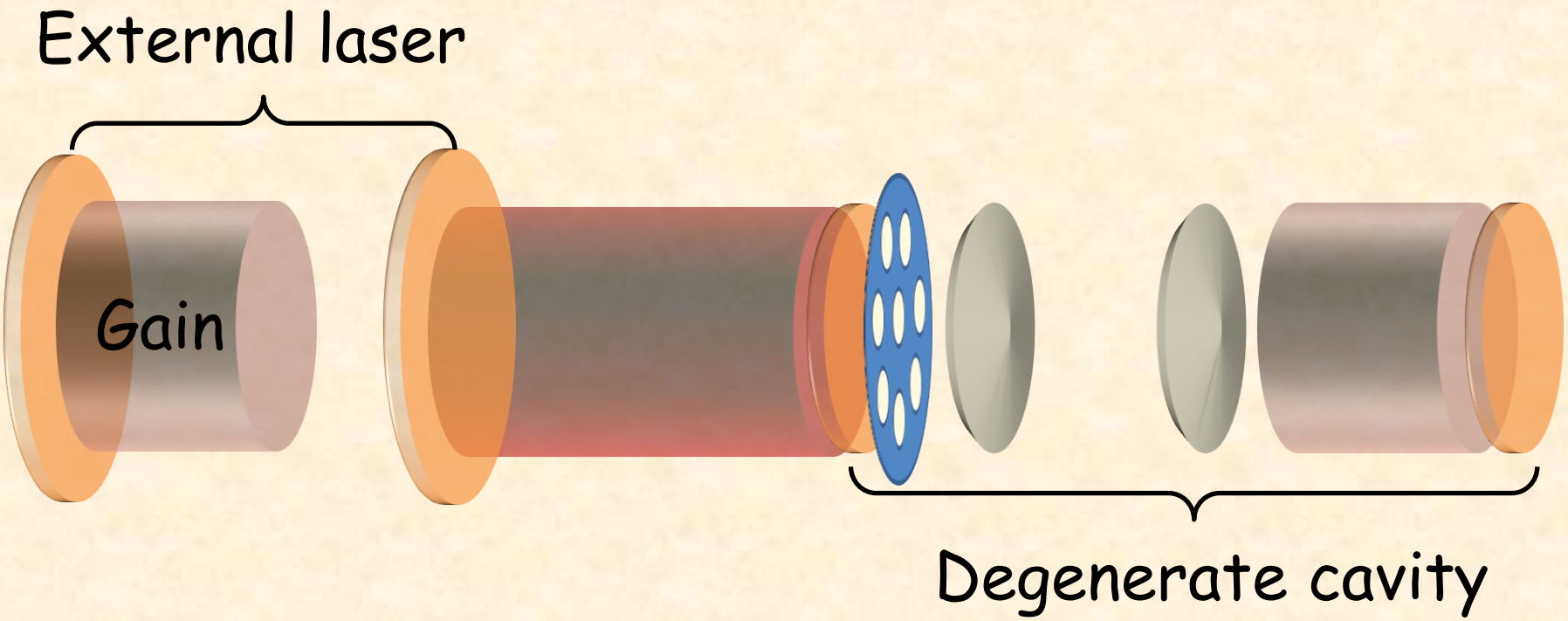


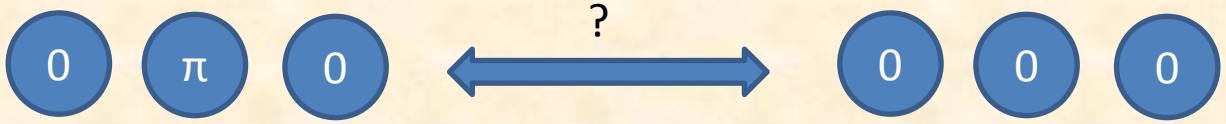



Questions ???

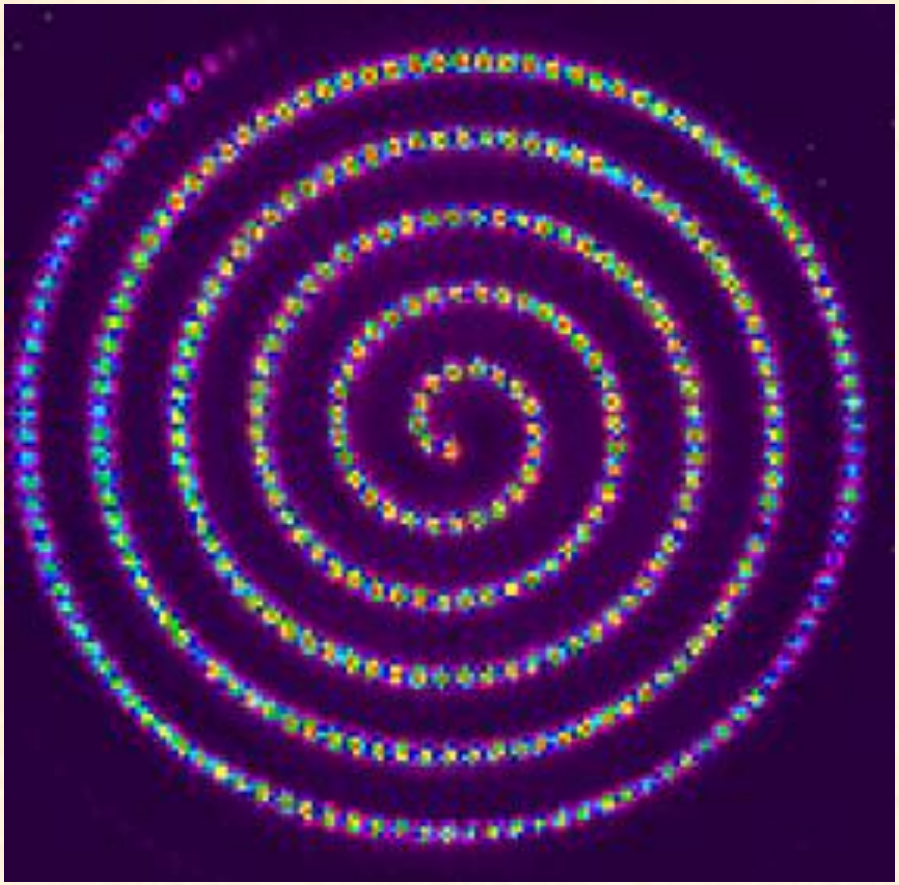
External "field"



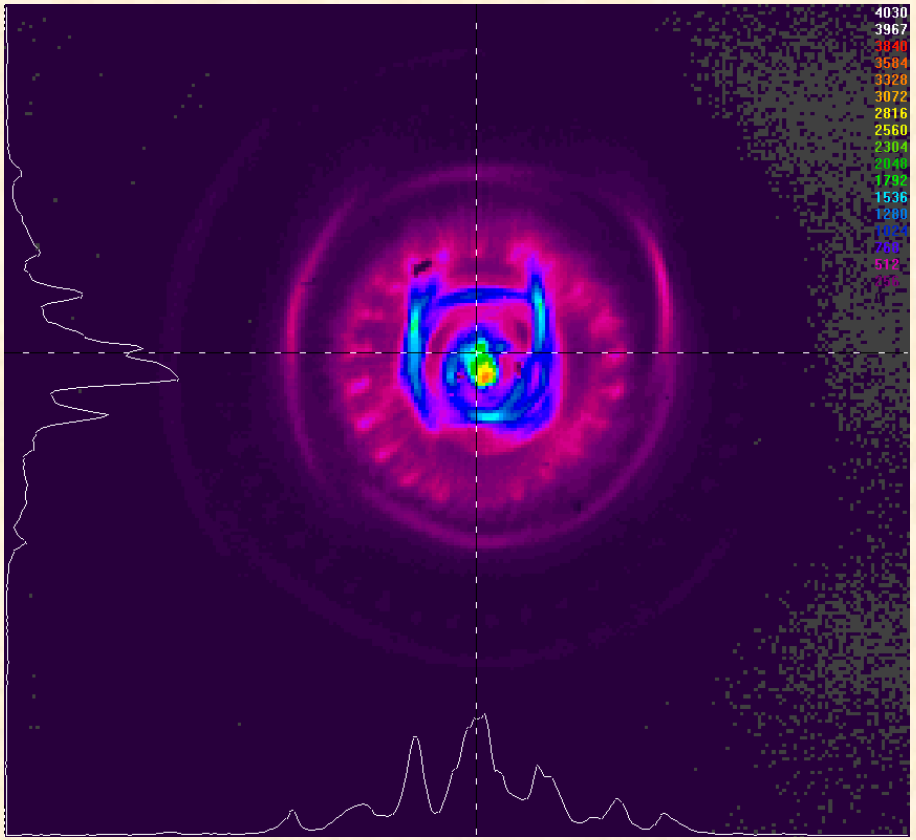


External Field for 1D

Near field spiral

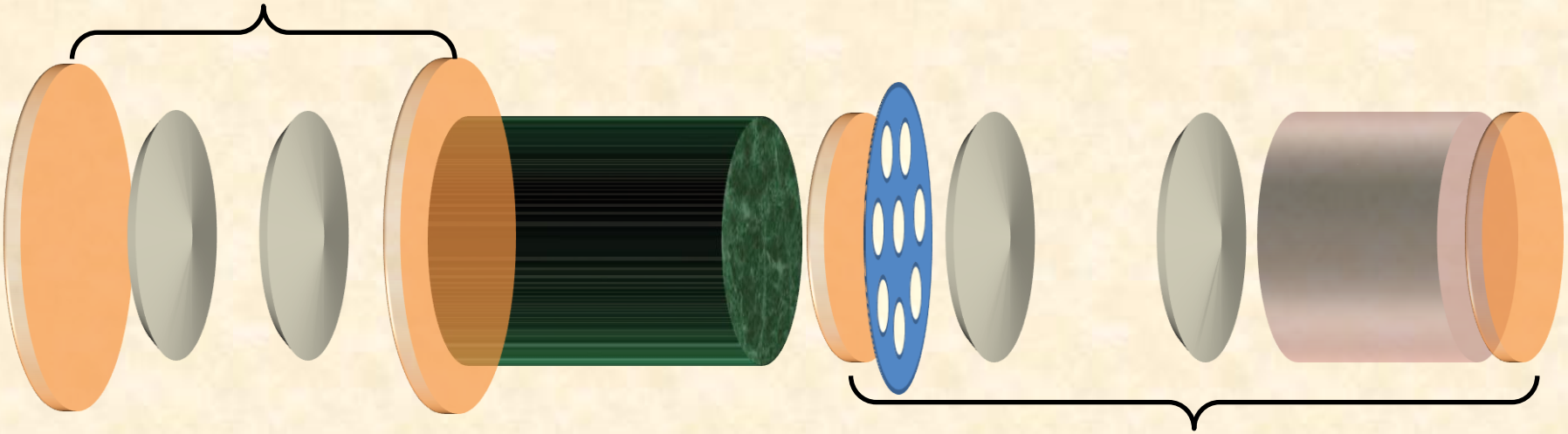


Far field

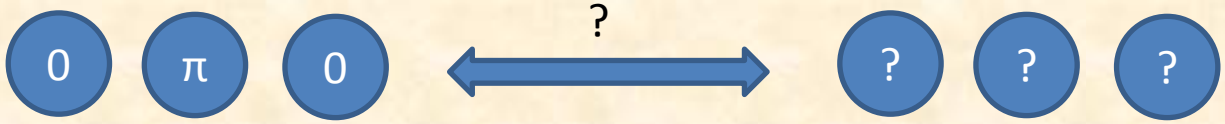


External disordered field

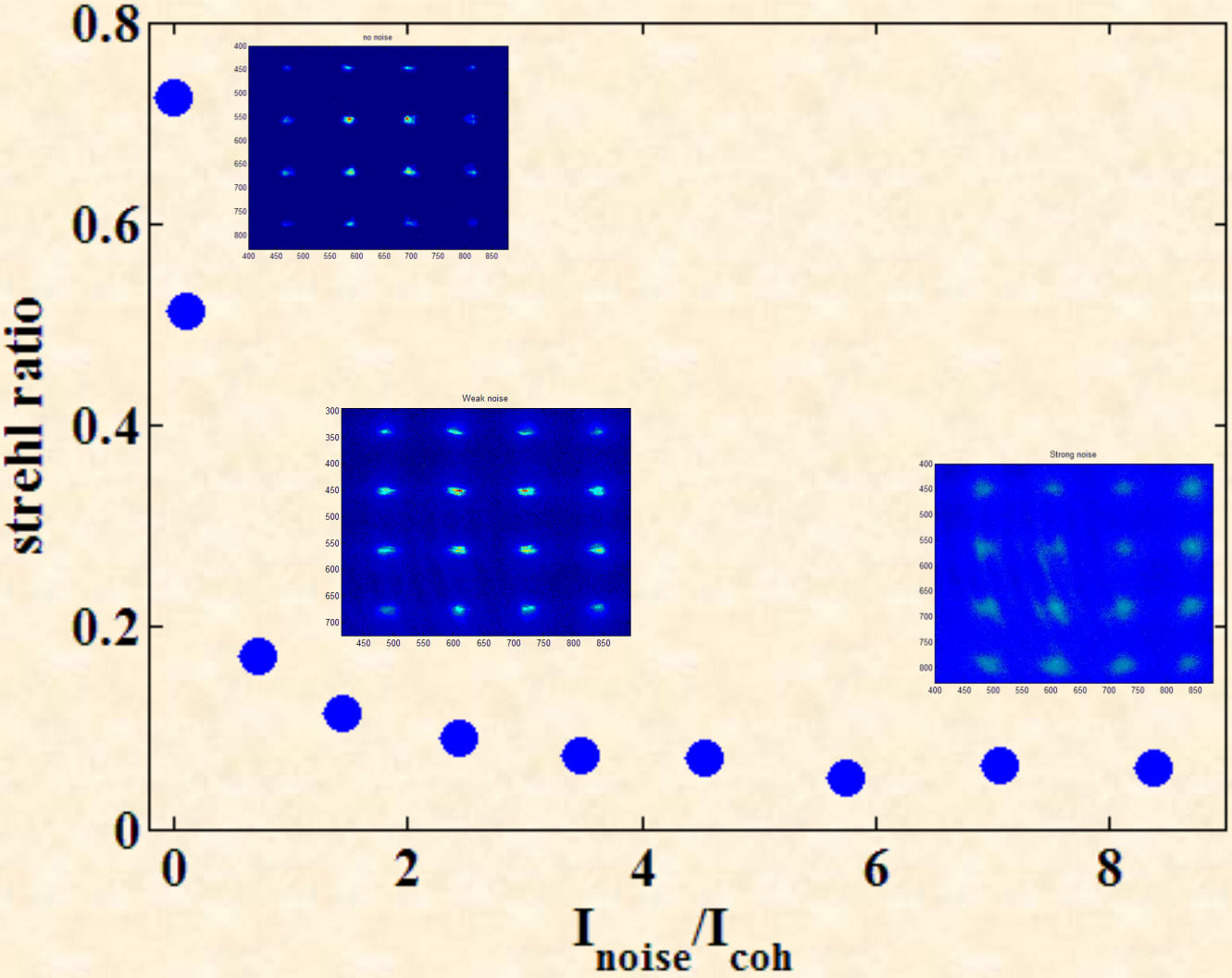
External degenerate laser cavity



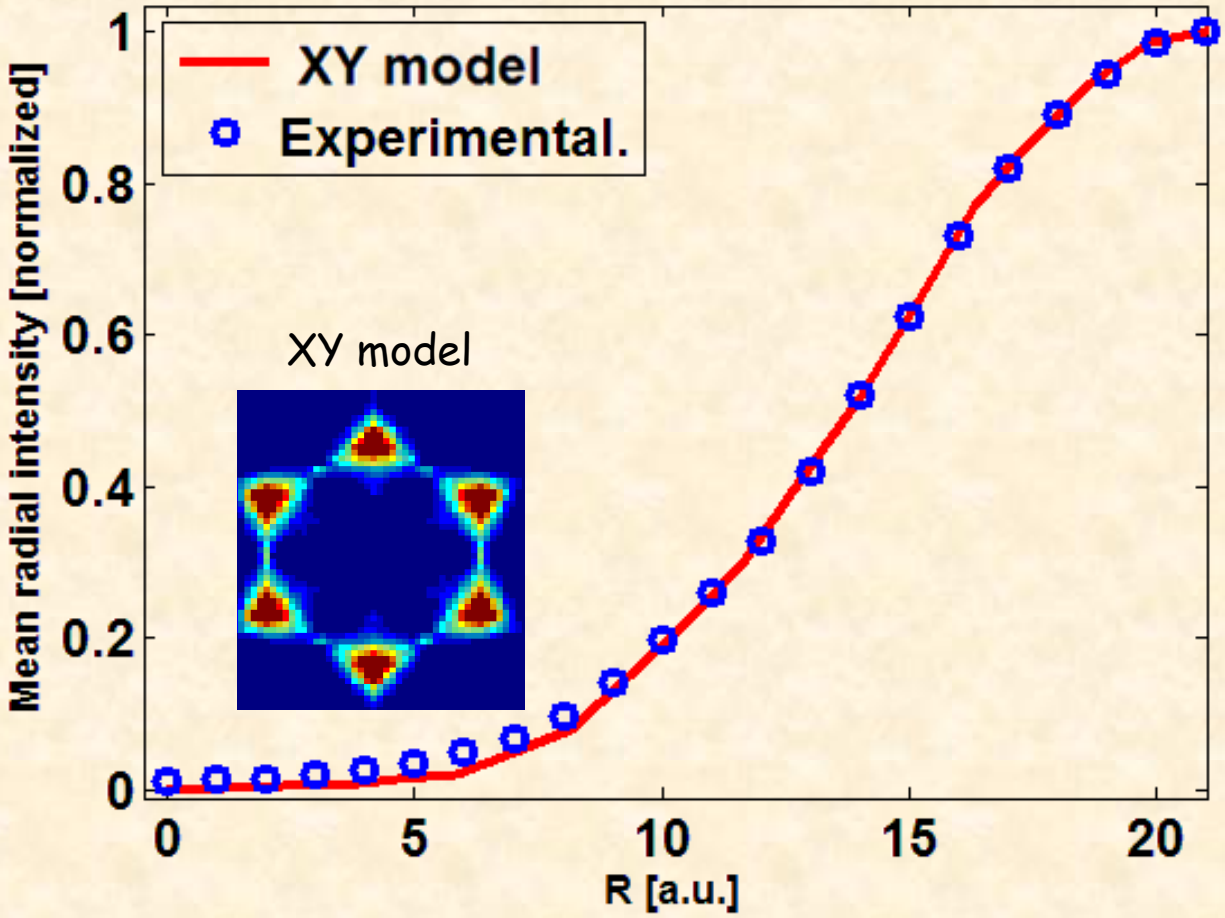
Degenerate cavity



Effects of finite "temperature" in square array

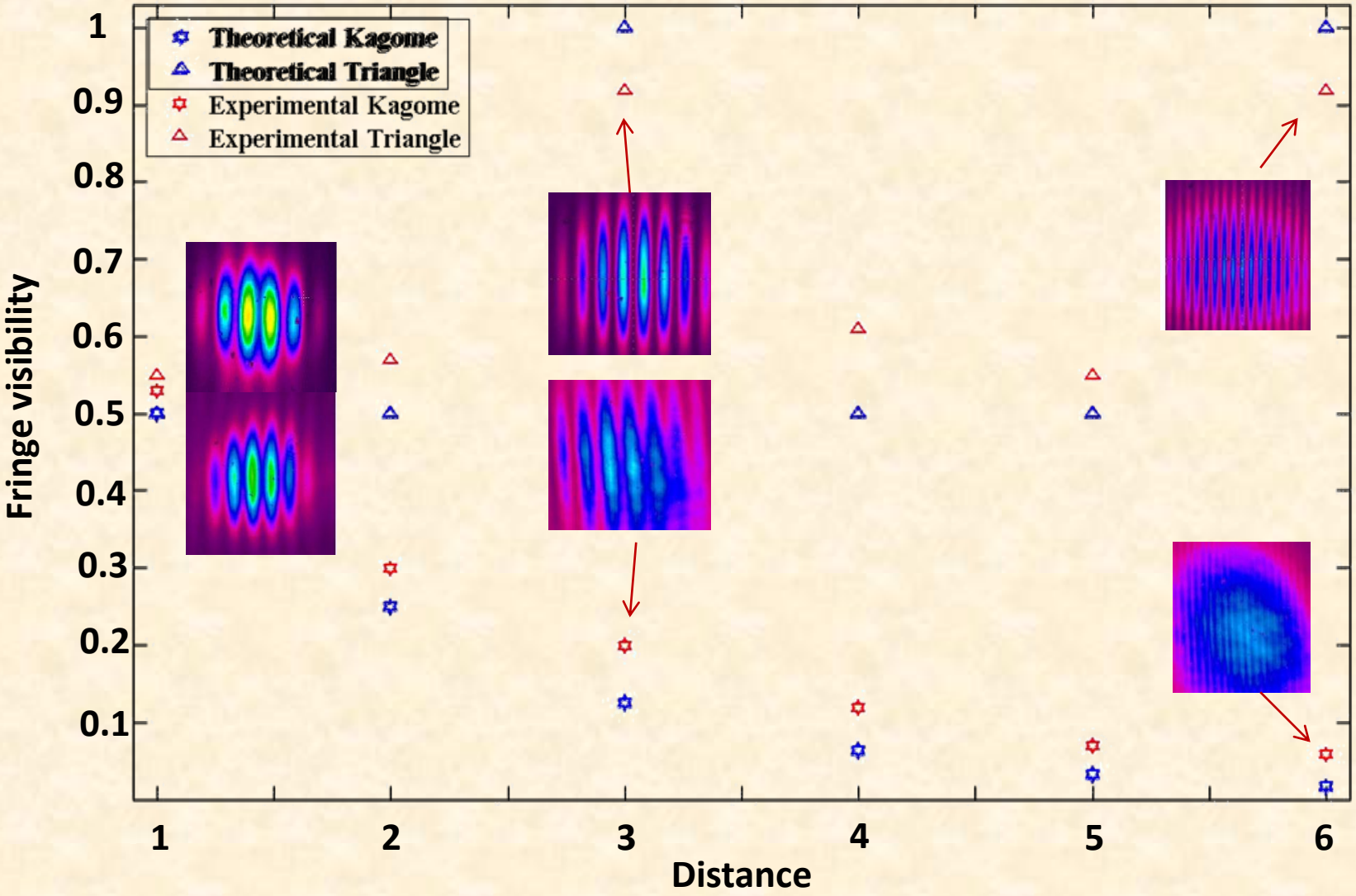


Is it a true "ground state"?



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

Short range phase ordering



Next Nearest Neighbor Coupling