

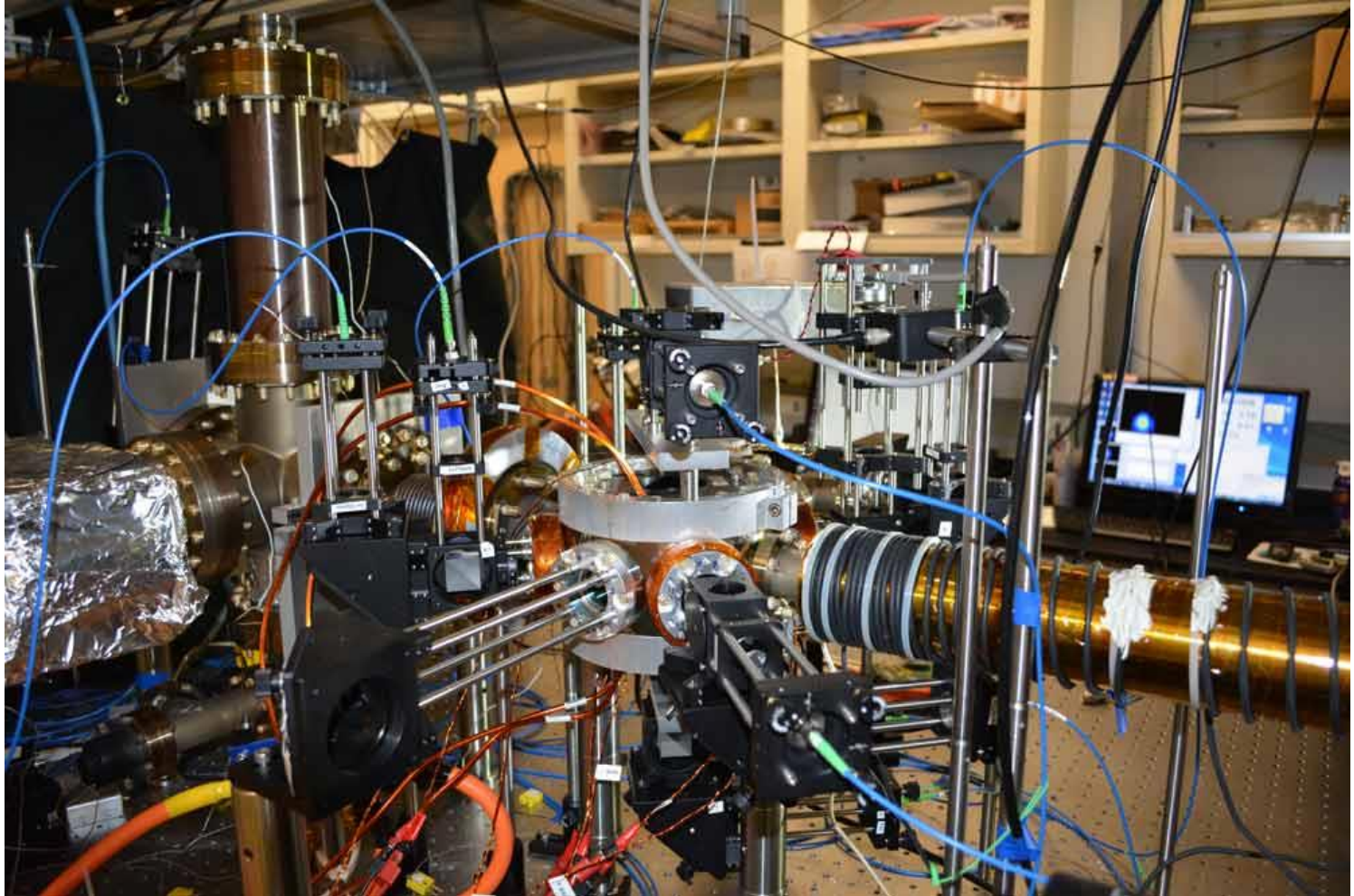
# **Modelo de Dicke y enredamiento a temperatura 0**

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# Motivación

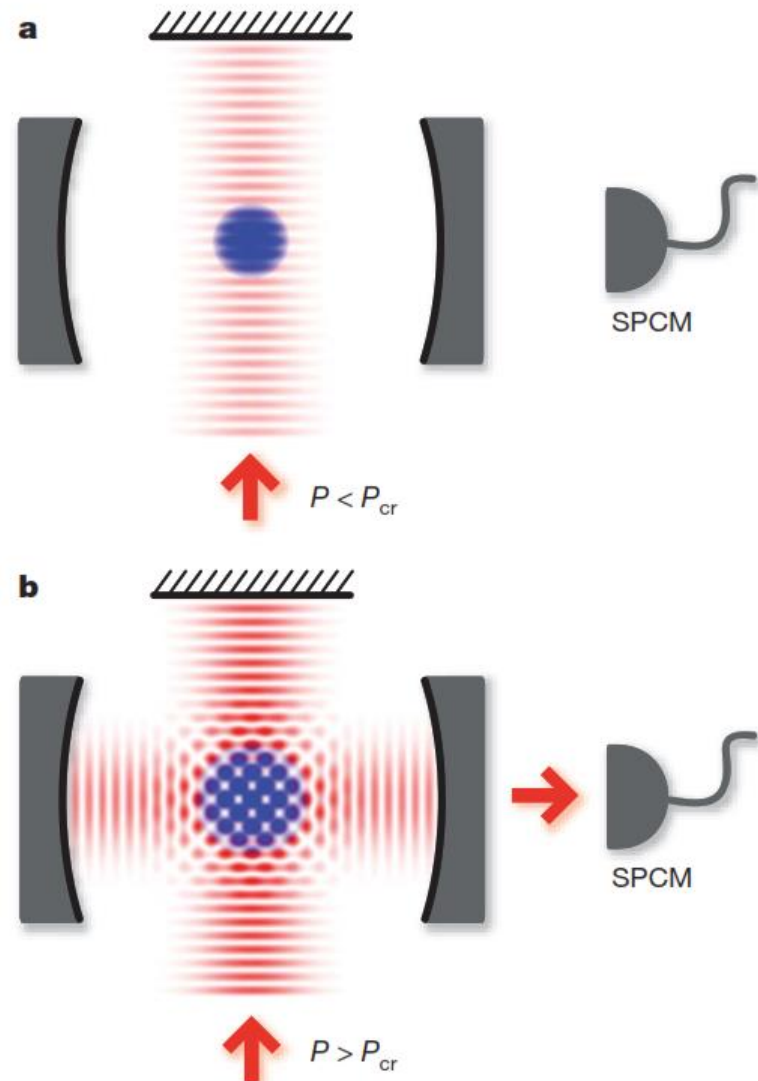
BEC  
Production  
Chamber



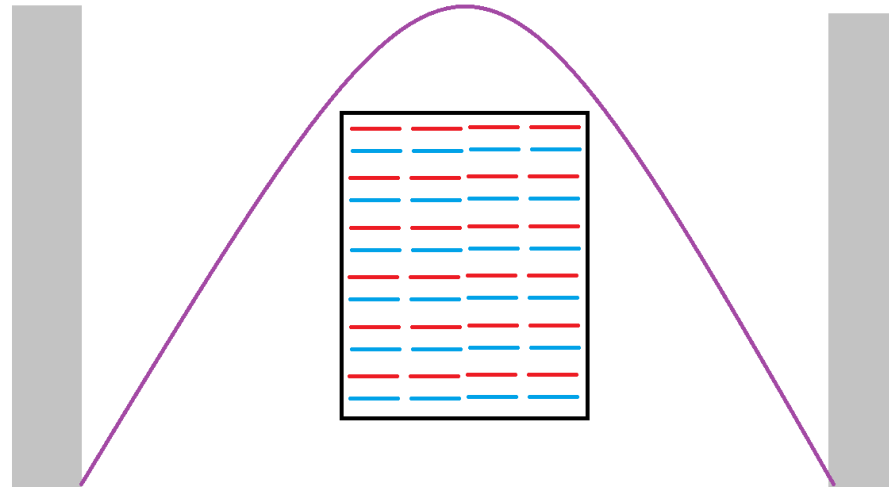
# Motivación

Dicke 1954

Kristian Baumann y  
Tilman Esslinger 2010



# Modelo de Dicke

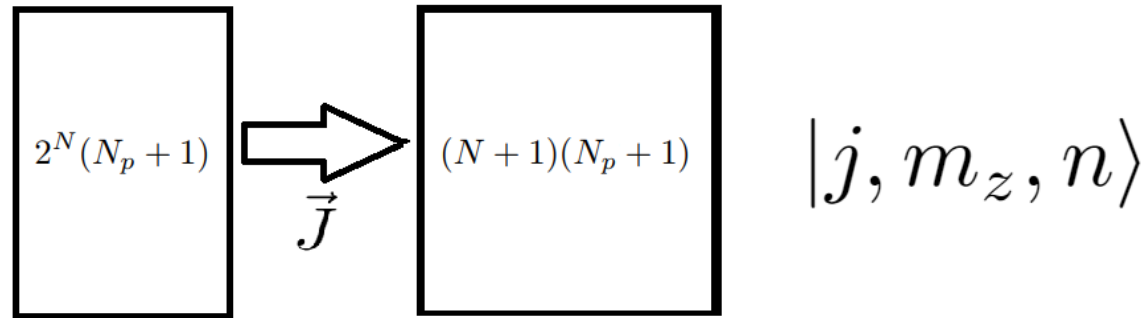


$$\hat{H} = \nu \hat{a}^\dagger \hat{a} + \sum_{j=1}^N \left( \frac{1}{2} \omega_0 \hat{\sigma}_j^z + \frac{\lambda'}{2\sqrt{N}} (\hat{a} + \hat{a}^\dagger) (\hat{\sigma}_j^- + \hat{\sigma}_j^+) \right)$$

# Modelo de Dicke

$$\hat{H} = \nu \hat{a}^\dagger \hat{a} + \sum_{j=1}^N \left( \frac{1}{2} \omega_0 \hat{\sigma}_j^z + \frac{\lambda'}{2\sqrt{N}} (\hat{a} + \hat{a}^\dagger) (\hat{\sigma}_j^- + \hat{\sigma}_j^+) \right)$$

$$\prod_i (|s_i\rangle) \otimes |n\rangle \longrightarrow |j, m\rangle \otimes |n\rangle$$



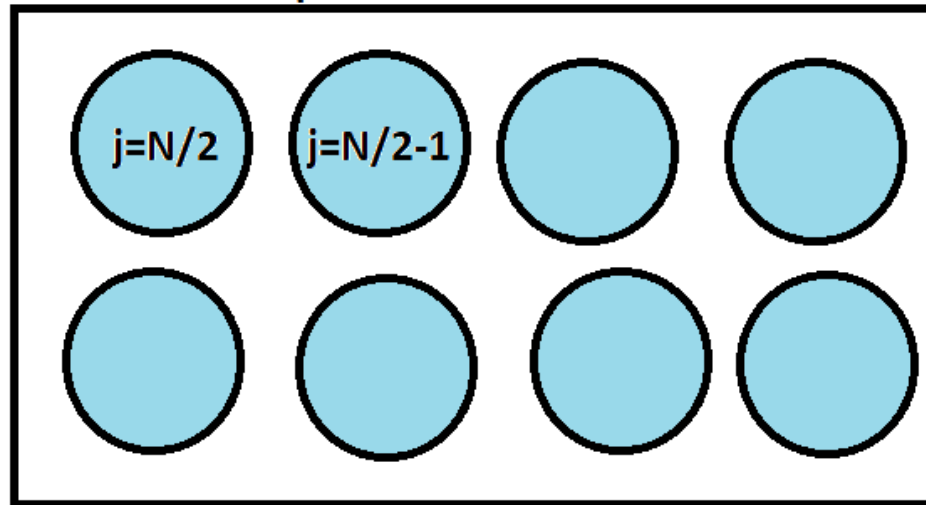
Espacio de Hilbert

$$H = \omega_0 J_z + \omega a^\dagger a + \frac{\lambda}{\sqrt{2j}} (a^\dagger + a) (J_+ + J_-)$$

# Momento angular total

$$J^2 = J_x^2 + J_y^2 + J_z^2 \quad [H, J^2] = 0$$

Espacio de Hilbert



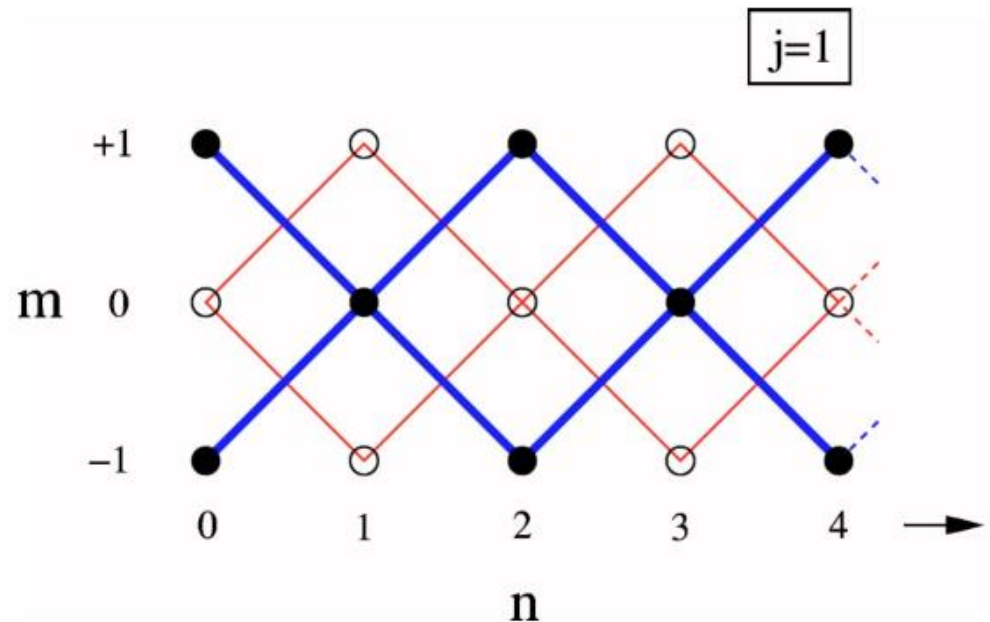
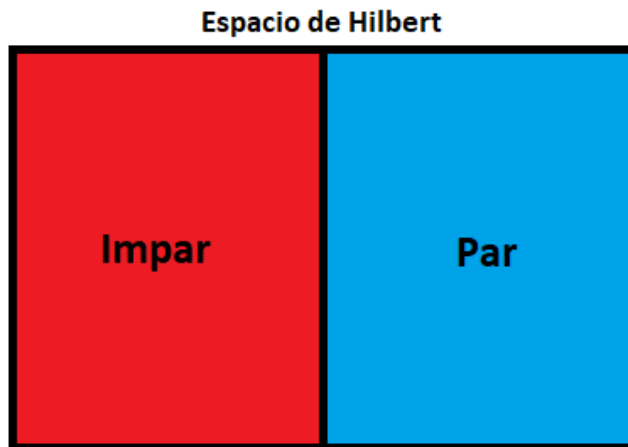
$$H = \omega_0 J_z + \omega a^\dagger a + \frac{\lambda}{\sqrt{2j}} (a^\dagger + a)(J_+ + J_-)$$

# Paridad

$$\Pi = \exp\{i\pi\hat{N}\}$$

$$[H, \Pi] = 0$$

$$\hat{N} = a^\dagger a + J_z + j$$



$$H = \omega_0 J_z + \omega a^\dagger a + \frac{\lambda}{\sqrt{2j}} (a^\dagger + a)(J_+ + J_-)$$



# Estado Base

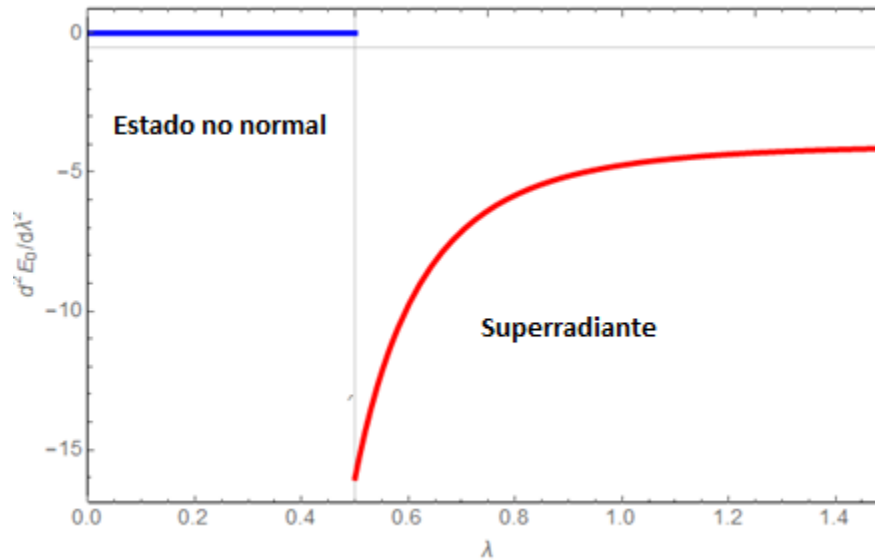
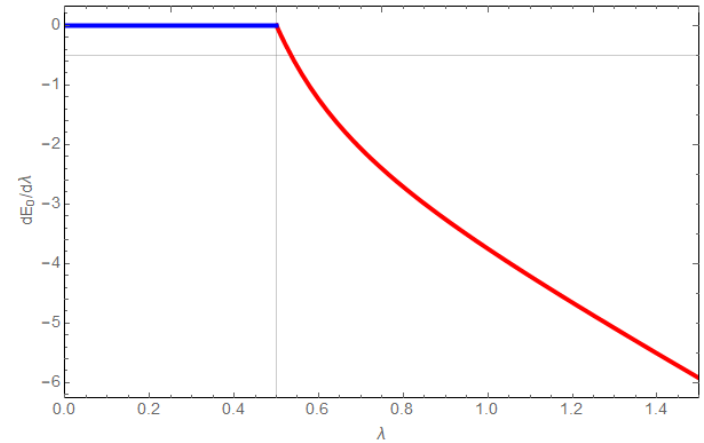
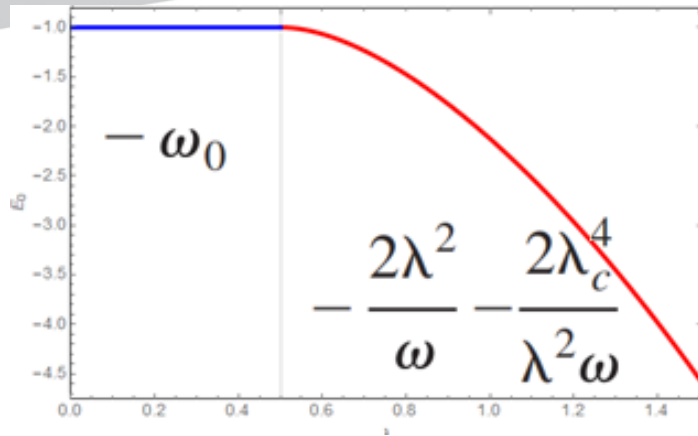
$$j = \frac{N}{2}, \quad m = -\frac{N}{2}$$

$$|\downarrow\downarrow\downarrow\downarrow \dots \downarrow\rangle \otimes |0\rangle$$

| [2]       | $\lambda < \lambda_c$ | $\lambda > \lambda_c$   |
|-----------|-----------------------|---|
| $E_G / j$ | $-\omega_0$           | $-\frac{2\lambda^2}{\omega} - \frac{2\lambda_c^4}{\lambda^2\omega}$ |

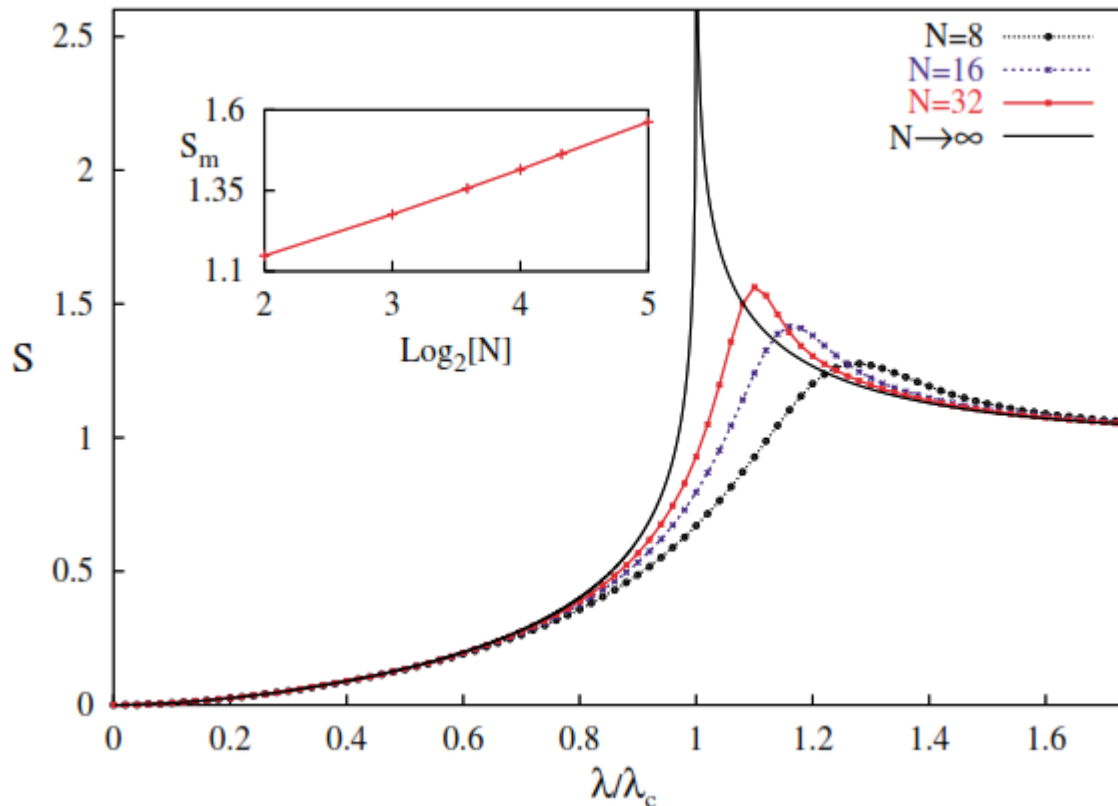
$$H = \omega_0 J_z + \omega a^\dagger a + \frac{\lambda}{\sqrt{2j}} (a^\dagger + a)(J_+ + J_-)$$

# Transición de fase

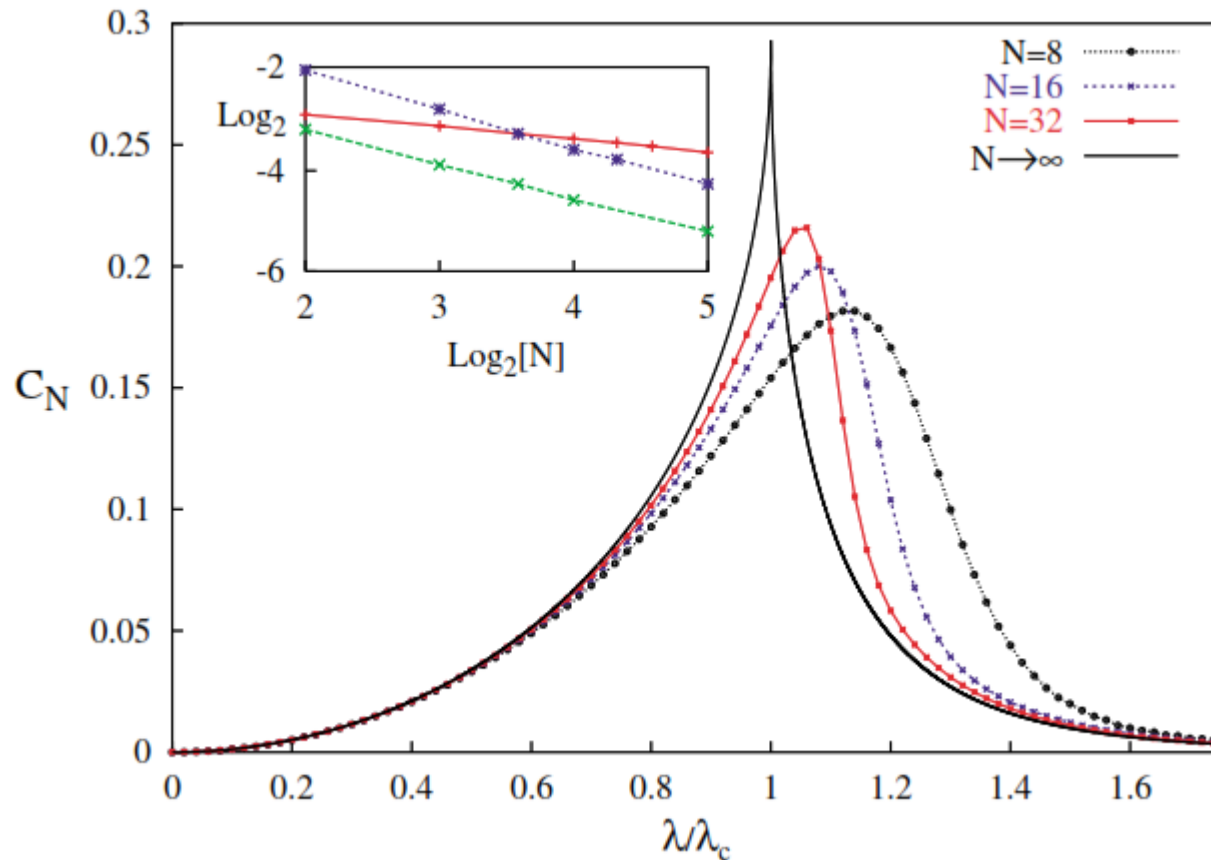


# Entropía

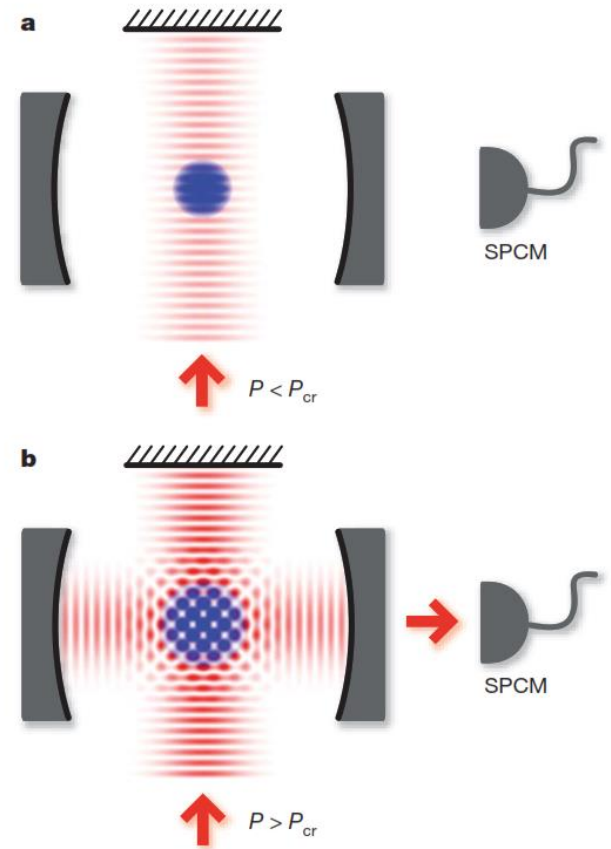
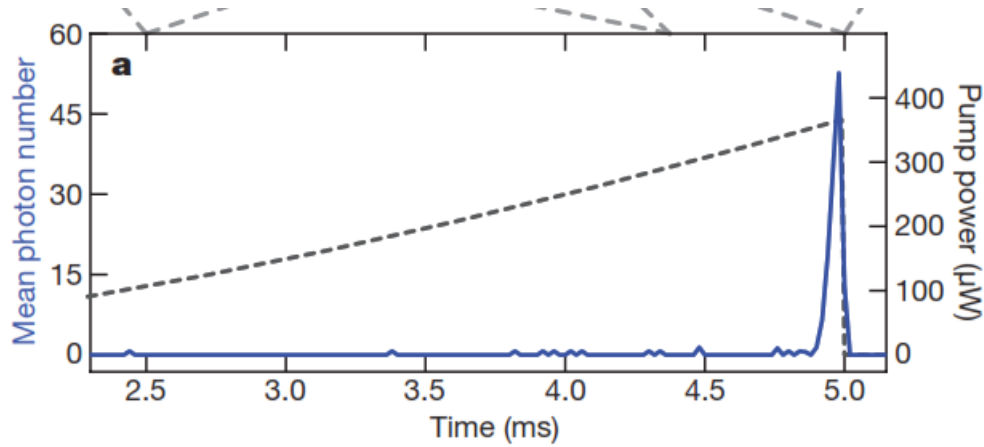
$$S_N = -\text{tr} \{ \hat{\rho}_A \log(\hat{\rho}_A) \}, \quad \hat{\rho}_A = \text{tr}_B \{ |\psi\rangle \langle \psi| \}$$



# Enredamiento



# Experimento



# Conclusiones y perspectiva

- El modelo de Dicke experimentalmente puede proveer una facilidad para la computación cuántica.
- Este modelo otorga nuevos medios para investigar sistemas con comportamiento colectivo.
- Un primer objetivo experimental podría ser caracterizar la evolución temporal del sistema en la fase super radiante.

- **[1]** Baumann et al. - Dicke quantum phase transition with a superfluid gas in an optical cavity- Nature
- **[2]** Brandes et al.- Entanglement and the Phase Transition in Single-Mode Superradiance
- **[3]** Lambert, et al.- Entanglement and the Phase Transition in Single-Mode Superradiance