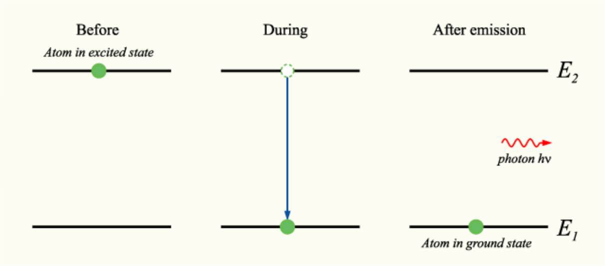
# Understanding the interplay between Pauli blocking, dipolar interactions and atomic motion in a long-lived 2D Fermi gas

# (Spontaneous) radiative decay

Radiative decay one of the most fundamental and ubiquitous processes in nature





- Fireflies
- Laser diodes
- Gamma decay of nuclei
- ...

# Systems of matter and light

**Atom-Light Hamiltonian**

$$H_{\mathrm{M}} + H_{\mathrm{LM}} + H_{\mathrm{L}}$$

**$H_{\mathrm{M}}$**

- Matter fields
- Fermions $c^\dagger$
- Bosons $b^\dagger$
- level structure

**$H_{\mathrm{LM}}$**

- Coupling between Light and Matter

**$H_{\mathrm{L}}$**

- (bosonic) photon modes $a^\dagger$

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**Engineering of AMO systems**

To a large degree all we are doing is manipulating different parts of this

# Atom-Light interaction

**$H_{\mathrm{LM}}$**

$$e^{i\mathbf{q}\hat{\mathbf{R}}}\hat{\sigma}^{+}(\hat{\mathbf{R}})\hat{a}_{\mathbf{q}} + c.c.$$

- couples internal state and motional state of atom to photon field
- describes emission/absorption of photon with momentum $\mathbf{q}$ from/into the field modes

# Atom-Light interaction

## $H_{\mathrm{LM}}$

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- couples internal state and motional state of atom to photon field
- describes emission/absorption of photon with momentum $\mathbf{q}$ from/into the field modes

## Momentum-Kick

- Laser-Cooling
- Momentum resolved scattering

## Internal state

- optical control
- optical potentials
- Stark shifts
- atomic clocks

## Light part

- mode-spectrum
- wave-guides

# Engineering of atom-light coupling

$$H = H_{\mathrm{M}} + H_{\mathrm{L}} + H_{\mathrm{LM}}$$
$$H_{\mathrm{LM}} \sim e^{i\mathbf{q}\hat{\mathbf{R}}}\hat{\sigma}^{+}(\hat{\mathbf{R}})\hat{a}_{\mathbf{q}} + c.c.$$

### Light part

- change field spectrum
- Purcell effect
- **Cavity QED, waveguide QED**

### atomic motional spectrum

- optical potentials
- confinement

### Level Structure

- multi-levels systems
- dressing of internal states
- allowed/forbidden transitions

### Available states

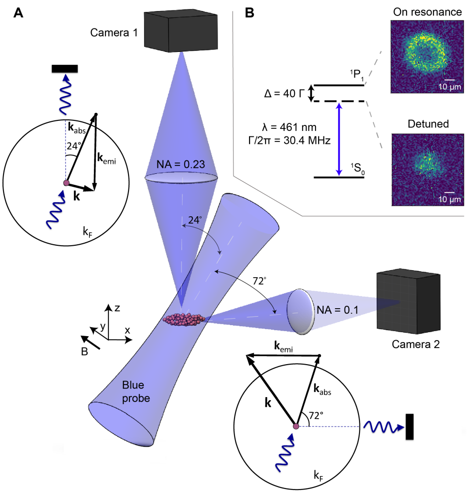
- Quantum-Statistics
- **Pauli blocking**
- Bose enhancement

# Experimental Work

**Recent Experimental Results**

- Observation of reduced light-scattering from atomic ensembles
  - Ye et al, "Pauli blocking of atomic spontaneous decay" (**3.3**.2021)
  - Ketterle et al, "Pauli blocking of light scattering in degenerate fermions" (**11.3**.2021)
  - Kjærgaard et al, "Observation of Pauli blocking in light scattering from quantum degenerate fermions" (**3.3**.2021)

# Experimental Work II

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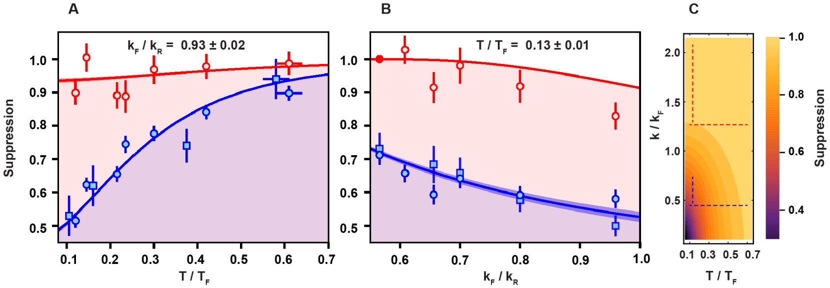
[1] Ye et al (2021)

# Experimental Work II

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1 Ye et al (2021)

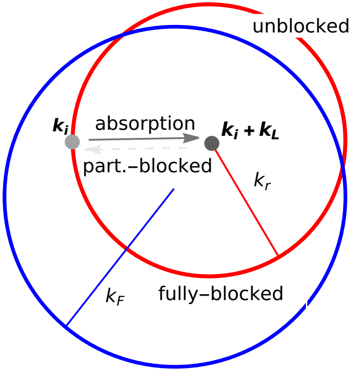
**Missing Piece**

Observation of Pauli blocking/enhanced lifetimes in population measurements

**Challenge**

- Transition/Decay has to be slow to be measured!
- then: motional, interaction and dipolar time-scales are comparable
- $\rightarrow$ need to treat all properly

# Basic idea of Pauli-Blocking of spontaneous decay




**Scenario**

- excited atom in momentum $\mathbf{k}$ embedded in a Fermi-Sea
- decays onto states with $\mathbf{q} = \mathbf{k} + \mathbf{k_r}$
- blocked if state $\mathbf{q}$ occupied

**Consequences**

- Emission is directional

**Relevant Scales**

- Size of Fermi - Sea: $k_F$, $N$
- momentum kick/recoil: ratio $k_r/k_F$

# Non-interacting description

### Basic assumptions

- non-interacting particles
- single excitation
- Fermi sea

### Initial State

- FS with one hole at $\mathbf{k_i}$, and one excitation at $\mathbf{k_i} + \mathbf{k}_L$
- will ignore presence of hole

### Scales

- $k_0$ recoil momentum
- $k_F$ Fermi-momentum
- $\mathbf{k}_L = k_0 \mathbf{e}_x$: excitation "kick" by laser

### Final State

- excitation decays to a momentum on a sphere with radius $k_0$ (weighted by emission pattern of transition)

# Semi-Classics [1]

$$S(\mathbf{k}) = \frac{h^{-3}\int d^3\mathbf{p}d^3\mathbf{q}\, n_{FD,i}(\mathbf{p},\mathbf{q})\,[1 - n_{FD,f}(\mathbf{p} + \hbar(\mathbf{k}+\mathbf{k}_L),\mathbf{q})]}{h^{-3}\int d^3\mathbf{p}d^3\mathbf{q}\, n_i(\mathbf{p},\mathbf{q})}$$

$$M = \int d^2k\, P(\mathbf{k})S(\mathbf{k})$$

$$n_{FD}(\mathbf{p},\mathbf{q}) = \frac{1}{1 + 1/z\, e^{\beta[\sum_i m\omega_i^2 q_i^2/2 + \sum_i p_i^2/(2m)]}}$$

- uses semi-classical phase space formulation
- have to add in dipole-emission pattern $P(\mathbf{k})$ "by-hand"
- **cannot include interactions**

[1] **Thywissen et al. (2009)**, Zoller et al (1998), Busch et al (2009)

# Fundamental Challenge of Interactions

In the regime of strong Pauli blocking interactions are not negligible

**Pauli-Blocking**

**Need:** $k_F/k_0 \gtrsim 1$

**OD Scaling (3D)**

**Want:** $OD = \int dz\, n\, \sigma \ll 1$

$$\sigma \sim \lambda^2 \sim 1/k_0^2$$
$$n \sim k_F^3$$
$$OD \sim k_F (k_F/k_0)^2 \gg 1$$

# Current State of affairs

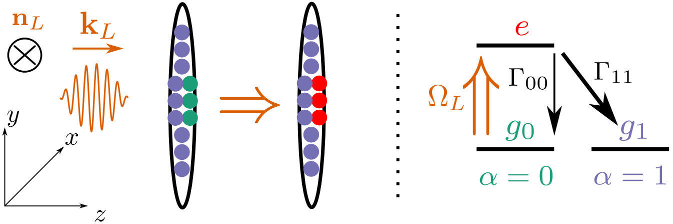
- can describe **non-interacting** Pauli-Blocking
- Strong Pauli blocking $\leftrightarrow$ interacting regime

- can describe interacting atoms (**without motion**) $\rightarrow$ frozen-atom coupled dipole
- Correct description of Pauli blocking $\leftrightarrow$ motion (momentum-kick)

**Ambitious Goal**

Understand the interplay of **Pauli blocking, dipolar interactions and motion** in quantum degenerate Fermi gases

# Our System/Jun's work II




## Key-Properties

- Strong 2D confinement/Lamb-Dicke
  - no initial momentum kick
  - smaller state space
- $\Lambda$ level structure
  - only 3 internal levels
  - useful $\Gamma_{00}/\Gamma_{11}$-ratio
  - can decouple excited and blocking species

# Our starting point

$$H_{\mathrm{M}} + H_{\mathrm{LM}} + H_{\mathrm{L}}$$

**Main approximation**

- Integrate out light-field
- Born-Markov

**Multi-level dipolar master equation**

$$\dot{\hat{\rho}} = -i\left[\hat{H}, \hat{\rho}\right] + \mathcal{L}(\hat{\rho})$$ [1]

[1] Asier

# ME in real space

$$\hat{H} = -\sum_{\alpha,\beta} \int d\mathbf{r} d\mathbf{r}' \left( \mathbf{d}_\alpha \cdot \mathrm{Re}\, G(\mathbf{r} - \mathbf{r}') \cdot \bar{\mathbf{d}}_\beta \right) \hat{\sigma}_{eg_\alpha}(\mathbf{r})\, \hat{\sigma}_{g_\beta e}(\mathbf{r}') \tag{1}$$

$$\mathcal{L}(\hat{\rho}) = -\sum_{\alpha,\beta} \int d\mathbf{r} d\mathbf{r}' \left( \mathbf{d}_\alpha \cdot \mathrm{Im}\, G(\mathbf{r} - \mathbf{r}') \cdot \bar{\mathbf{d}}_\beta \right) \left( \left\{ \hat{\sigma}_{eg_\alpha}(\mathbf{r}) \hat{\sigma}_{g_\beta e}(\mathbf{r}'), \hat{\rho} \right\} - 2\hat{\sigma}_{g_\beta e}(\mathbf{r}') \hat{\rho} \hat{\sigma}_{eg_\alpha}(\mathbf{r}) \right) \tag{2}$$

$$G(\mathbf{r}) = \frac{3\Gamma}{4} \left\{ [\mathbf{I} - \hat{\mathbf{r}} \otimes \hat{\mathbf{r}}] \frac{e^{ik_0 r}}{k_0 r} [\mathbf{I} - 3\hat{\mathbf{r}} \otimes \hat{\mathbf{r}}] \left[ \frac{i e^{ik_0 r}}{(k_0 r)^2} - \frac{e^{ik_0 r}}{(k_0 r)^3} \right] \right\}, \tag{3}$$

# Deriving ME in momentum space

- Expand ME in single-particle basis $\psi^\dagger(\mathbf{r}) = \sum_{\mathbf{k}} \bar{\phi}_{\mathbf{k}} c_{\mathbf{k}}^\dagger$

**Single particle Basis**

$$\phi_{\mathbf{k}}(x, y, z) = \frac{1}{\sqrt{A}} e^{i(k_x x + k_y y)} \psi_0(z)$$

- only keep "resonant" terms $(ijkl) \rightarrow (ij, ij)$ or $(ijkl) \rightarrow (ij, ji)$
- "spin-model like"

# Expansion in k-basis

$$\hat{H} = \sum_{\alpha,\beta} \sum_{\mathbf{ijkl}} \Delta_{\alpha\beta}^{\mathbf{ij},\mathbf{kl}} \hat{c}_{e,\mathbf{i}}^{\dagger} \hat{c}_{g_\beta,\mathbf{k}}^{\dagger} \hat{c}_{g_\alpha,\mathbf{j}} \hat{c}_{e,\mathbf{l}}, \tag{4}$$

$$\mathcal{L}(\hat{\rho}) = -\sum_{\alpha,\beta} \sum_{\mathbf{ijkl}} \Gamma_{\alpha\beta}^{\mathbf{ij},\mathbf{kl}} \left( \left\{ \hat{\sigma}_{eg_\alpha}^{\mathbf{ij}} \hat{\sigma}_{g_\beta e}^{\mathbf{kl}}, \hat{\rho} \right\} - 2\hat{\sigma}_{g_\beta e}^{\mathbf{kl}} \hat{\rho} \hat{\sigma}_{eg_\alpha}^{\mathbf{ij}} \right), \tag{5}$$

$$\Delta_{\alpha\beta}^{\mathbf{ij},\mathbf{kl}} = \int d\mathbf{r} d\mathbf{r}' \, \bar{\phi}_{\mathbf{i}}(\mathbf{r}) \phi_{\mathbf{j}}(\mathbf{r}) \, \mathrm{Re}\, G_{\alpha\beta}(\mathbf{r} - \mathbf{r}') \, \bar{\phi}_{\mathbf{k}}(\mathbf{r}') \phi_{\mathbf{l}}(\mathbf{r}'), \tag{6}$$

$$\Gamma_{\alpha\beta}^{\mathbf{ij},\mathbf{kl}} = \int d\mathbf{r} d\mathbf{r}' \, \bar{\phi}_{\mathbf{i}}(\mathbf{r}) \phi_{\mathbf{j}}(\mathbf{r}) \, \mathrm{Im}\, G_{\alpha\beta}(\mathbf{r} - \mathbf{r}') \, \bar{\phi}_{\mathbf{k}}(\mathbf{r}') \phi_{\mathbf{l}}(\mathbf{r}'), \tag{7}$$

$$G(\mathbf{r}) = \frac{3\Gamma}{4} \left\{ [\mathbf{I} - \hat{\mathbf{r}} \otimes \hat{\mathbf{r}}] \frac{e^{ik_0 r}}{k_0 r} [\mathbf{I} - 3\hat{\mathbf{r}} \otimes \hat{\mathbf{r}}] \left[ \frac{ie^{ik_0 r}}{(k_0 r)^2} - \frac{e^{ik_0 r}}{(k_0 r)^3} \right] \right\}, \tag{8}$$

# Master equation in momentum space

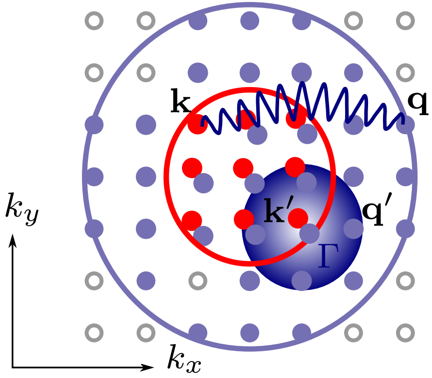
**Multi-level dipolar master equation**

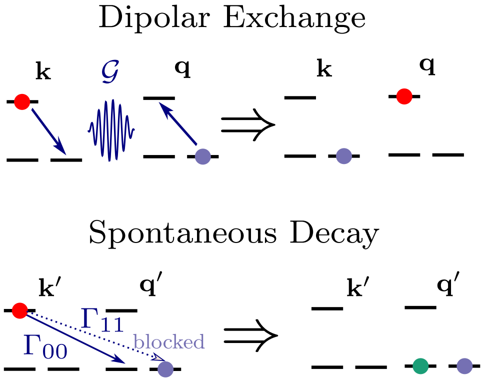
$$\dot{\hat{\rho}} = -i\left[\hat{H}, \hat{\rho}\right] + \mathcal{L}(\hat{\rho})$$

$$\hat{H} = \sum_{\alpha,\beta}\left(\sum_{\mathbf{k},\mathbf{q}} \Delta_{\alpha\beta}^{\mathbf{kk},\mathbf{qq}} \hat{c}_{e,\mathbf{k}}^{\dagger}\hat{c}_{g_\beta,\mathbf{q}}^{\dagger}\hat{c}_{g_\alpha,\mathbf{k}}\hat{c}_{e,\mathbf{q}} + \sum_{\mathbf{k}\neq\mathbf{q}} \Delta_{\alpha\beta}^{\mathbf{kq},\mathbf{qk}} \hat{c}_{e,\mathbf{k}}^{\dagger}\hat{c}_{g_\beta,\mathbf{q}}^{\dagger}\hat{c}_{g_\alpha,\mathbf{q}}\hat{c}_{e,\mathbf{k}}\right) \tag{9}$$

$$\mathcal{L}(\hat{\rho}) = -\sum_{\alpha,\beta}\left(\sum_{\mathbf{k},\mathbf{q}} \Gamma_{\alpha\beta}^{\mathbf{kk},\mathbf{qq}}\left(\left\{\hat{\sigma}_{eg_\alpha}^{\mathbf{kk}}\hat{\sigma}_{g_\beta e}^{\mathbf{qq}}, \hat{\rho}\right\} - 2\hat{\sigma}_{g_\beta e}^{\mathbf{qq}}\hat{\rho}\hat{\sigma}_{eg_\alpha}^{\mathbf{kk}}\right) + \sum_{\mathbf{k}\neq\mathbf{q}} \Gamma_{\alpha\beta}^{\mathbf{kq},\mathbf{qk}}\left(\left\{\hat{\sigma}_{eg_\alpha}^{\mathbf{kq}}\hat{\sigma}_{g_\beta e}^{\mathbf{qk}}, \hat{\rho}\right\} - 2\hat{\sigma}_{g_\beta e}^{\mathbf{qk}}\hat{\rho}\hat{\sigma}_{eg_\alpha}^{\mathbf{kq}}\right)\right) \tag{10}$$

# ME in momentum space



# Technical Detail

Ultimately, we'd like to describe a trapped gas

**2D trapped**

- States $|n_x, n_y\rangle$
- $\mathrm{E} = \hbar\omega_\perp(n_x + n_y + 1)$
- $E_F = \hbar\omega_\perp\sqrt{2N}$
- $N$, $\omega_\perp$

**2D Box**

- States $|k_x, k_y\rangle$
- $\mathrm{E} = \hbar(k_x^2 + k_y^2)/(2M)$
- $E_F = \hbar k_F^2/(2M)$
- $N$, Area of box $A$

**Consequences**

- Different density of states
- Need to choose $A$ properly to approximate trapped gas

# Equations of motion

- Focus on momentum diagonal elements $\rho_{\mathbf{qq}}^{\mu\nu} = \left\langle \hat{c}_{\mu,\mathbf{q}}^{\dagger} \hat{c}_{\nu,\mathbf{q}} \right\rangle$

**Key approximation**

Factorise 4 operator products

$$\langle \hat{c}_{\mu,\mathbf{i}}^{\dagger} \hat{c}_{\nu,\mathbf{j}}^{\dagger} \hat{c}_{\mu',\mathbf{k}} \hat{c}_{\nu',\mathbf{l}} \rangle \approx \delta_{\mathbf{il}} \delta_{\mathbf{jk}} \langle \hat{\sigma}_{\mathbf{il}}^{\mu\nu'} \rangle \langle \hat{\sigma}_{\mathbf{jk}}^{\nu\mu'} \rangle - \delta_{\mathbf{ik}} \delta_{\mathbf{jl}} \langle \hat{\sigma}_{\mathbf{ik}}^{\mu\mu'} \rangle \langle \hat{\sigma}_{\mathbf{jl}}^{\nu\nu'} \rangle,$$

**Justification**

- Initial state has no momentum off-diagonal correlations
- valid at short times

# Evolution of the excited state

$$\frac{d\rho^{ee}_{\mathbf{qq}}}{dt} = \sum_{\alpha}\sum_{k} -2(1-\rho^{g_\alpha g_\alpha}_{\mathbf{kk}})\rho^{ee}_{\mathbf{qq}}\Gamma^{\mathbf{kq},\mathbf{qk}}_{\alpha\alpha} \tag{11}$$

$$+\sum_{\alpha,\beta}\sum_{k} i\left(\rho^{eg_\alpha}_{\mathbf{qq}}\rho^{g_\beta e}_{\mathbf{kk}}\mathcal{G}^{\mathbf{qq},\mathbf{kk}}_{\alpha\beta} - \rho^{g_\beta e}_{\mathbf{qq}}\rho^{eg_\alpha}_{\mathbf{kk}}\bar{\mathcal{G}}^{\mathbf{qq},\mathbf{kk}}_{\alpha\beta}\right) \tag{12}$$

**Key Observation**

- First Line → Pauli blocked decay
  - $|e,\mathbf{q},n_{0,z}\rangle \rightarrow |g_\alpha,\mathbf{k},n_{0,z}\rangle$ mediated by $\Gamma^{\mathbf{qk},\mathbf{kq}}_{\alpha\alpha}$
  - Pauli suppressed by $1-\rho^{g_\alpha g_\alpha}_{\mathbf{kk}}$
- Second Line → Super/Sub-radiance and cooperative effects
  - depends on coherences $\rho^{eg_\alpha}$
  - has coherent and incoherent part: $\mathcal{G}^{\mathbf{kk},\mathbf{qq}}_{\alpha\beta} = \Delta^{\mathbf{kk},\mathbf{qq}}_{\alpha\beta} + i\Gamma^{\mathbf{kk},\mathbf{qq}}_{\alpha\beta}$

# Non-interacting Part

**ME**

$$\frac{d\rho^{ee}_{\mathbf{qq}}}{dt} = \sum_{\alpha}\sum_{k} -2(1-\rho^{g_\alpha g_\alpha}_{\mathbf{kk}})\rho^{ee}_{\mathbf{qq}}\Gamma^{\mathbf{kq},\mathbf{qk}}_{\alpha\alpha}$$

**Semi-Classics**

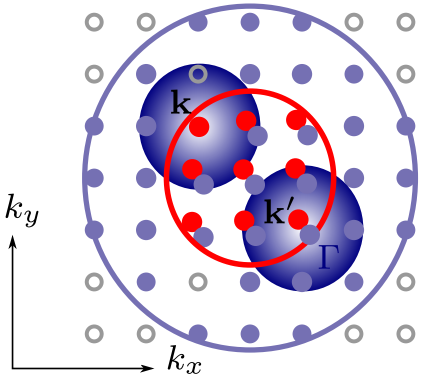
$$\int d^2\mathbf{k}\, n_{FD}(\mathbf{p},\mathbf{r})\left[1-n_{FD}(\mathbf{p}+\hbar\mathbf{k},\mathbf{r})\right]$$

**Advantages**

- valid for multi-level systems
- valid for generic geometries

# Some Intuition

$$\frac{d\rho^{ee}_{\mathbf{qq}}}{dt} = \sum_{\alpha}\sum_{k} -2(1-\rho^{g_\alpha g_\alpha}_{\mathbf{kk}})\rho^{ee}_{\mathbf{qq}}\Gamma^{\mathbf{kq},\mathbf{qk}}_{\alpha\alpha}$$




**Decay process**

- $\Gamma^{\mathbf{kq},\mathbf{qk}}_{\alpha\alpha}$ mediates the decay of an atom $e$ with momentum $\mathbf{k}$
- to $g_\alpha$ at momentum $\mathbf{q}$
- if $|\mathbf{k}-\mathbf{q}| \leq k_0$ (2D)

**Consequences**

- Highly imbalanced FS useful
- high occupation $\rightarrow$ large Pauli blocking
- Dependence on $k_F$ and $T/T_F$
- dimensionality matters!

# Key Quantity of Interest

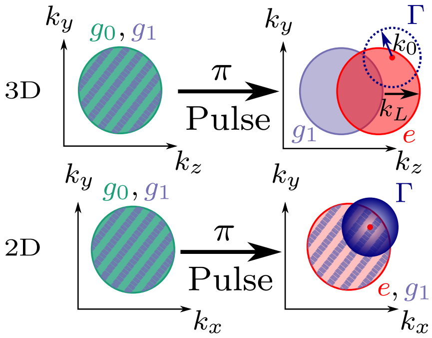
**Effective Decay Rate**

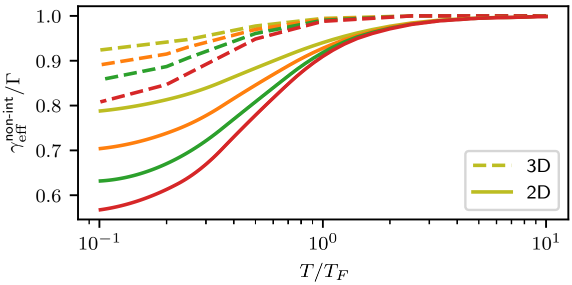
$$\gamma_{\text{eff}} = \lim_{t \to 0} \frac{\dot{N}_{ee}(t)}{N_{ee}(0)}$$

**Advantages**

- removes trivial $N_{ee}$ scaling
- Our approximations are good at $t \to 0$
- simple, single parameter to study
- don't have to care about complex long-time dynamics

# 2D versus 3D

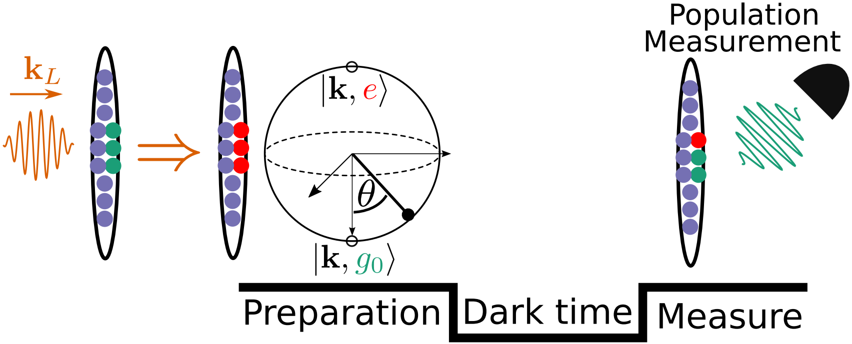



**Why 2D is better**

- no momentum kick in 2D
- mean-occupation higher in 2D due to density of states

# Ramsey Protocol




**Initial State:**

$$\prod_{\mathbf{k}} n_0(\mathbf{k}) \left(\cos(\theta/2)|g_0, \mathbf{k}, n_{0,z}^{FD}\rangle + \sin(\theta/2)|e, \mathbf{k}, n_{0,z}\rangle\right) \otimes \prod_{\mathbf{k}} n_1^{FD}(\mathbf{k})|g_1, \mathbf{k}, n_{0,z}\rangle$$

# Interplay of Pauli blocking and interactions

**EOM**

$$\frac{d\rho^{ee}_{\mathbf{qq}}}{dt} = \sum_{\alpha}\sum_{k} -2(1-\rho^{g_\alpha g_\alpha}_{\mathbf{kk}})\rho^{ee}_{\mathbf{qq}}\Gamma^{\mathbf{kq},\mathbf{qk}}_{\alpha\alpha} + \sum_{\alpha,\beta}\sum_{k} i\left(\rho^{eg_\alpha}_{\mathbf{qq}}\rho^{g_\beta e}_{\mathbf{kk}}\mathcal{G}^{\mathbf{qq},\mathbf{kk}}_{\alpha\beta} - \rho^{g_\beta e}_{\mathbf{qq}}\rho^{eg_\alpha}_{\mathbf{kk}}\bar{\mathcal{G}}^{\mathbf{qq},\mathbf{kk}}_{\alpha\beta}\right)$$

# Interplay of Pauli blocking and interactions

## EOM

$$\frac{d\rho^{ee}_{\mathbf{qq}}}{dt} = \sum_{\alpha}\sum_{k} -2(1-\rho^{g_\alpha g_\alpha}_{\mathbf{kk}})\rho^{ee}_{\mathbf{qq}}\Gamma^{\mathbf{kq},\mathbf{qk}}_{\alpha\alpha} + \sum_{\alpha,\beta}\sum_{k} i\left(\rho^{eg_\alpha}_{\mathbf{qq}}\rho^{g_\beta e}_{\mathbf{kk}}\mathcal{G}^{\mathbf{qq},\mathbf{kk}}_{\alpha\beta} - \rho^{g_\beta e}_{\mathbf{qq}}\rho^{eg_\alpha}_{\mathbf{kk}}\bar{\mathcal{G}}^{\mathbf{qq},\mathbf{kk}}_{\alpha\beta}\right)$$

## Initial State

$$\prod_{\mathbf{k}} n_0(\mathbf{k})\left(\cos(\theta/2)|g_0,\mathbf{k},n^{FD}_{0,z}\rangle + \sin(\theta/2)|e,\mathbf{k},n_{0,z}\rangle\right)\otimes\prod_{\mathbf{k}} n^{FD}_1(\mathbf{k})|g_1,\mathbf{k},n_{0,z}\rangle$$

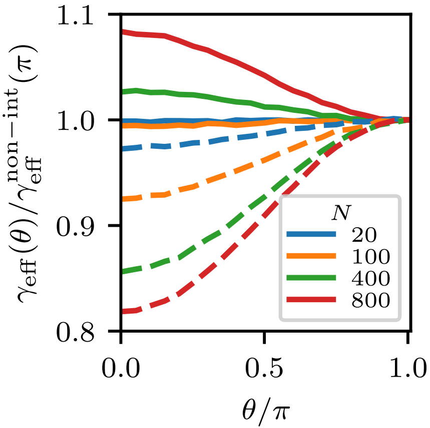
## Pauli-Blocking

$$\rho^{g_0 g_0} \sim \cos(\theta/2)^2$$

## Cooperative Effects

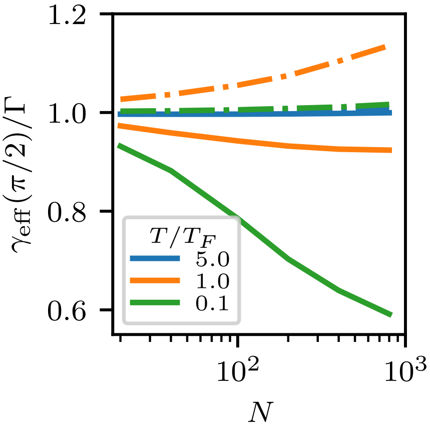
$$\rho^{eg_0}\rho^{g_0 e}/\rho^{ee} \sim \cos(\theta/2)^2$$

# Interplay of Pauli blocking and interactions



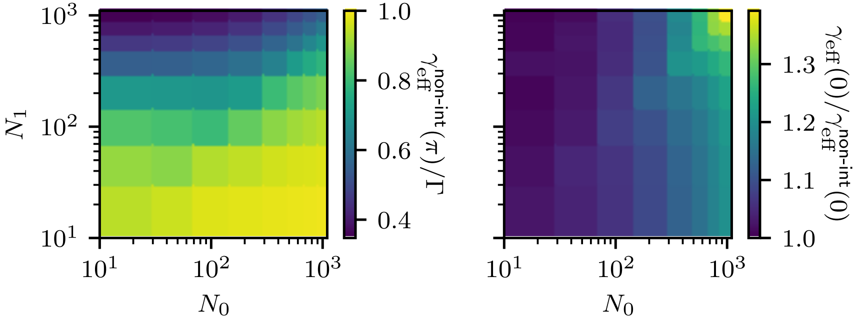

- Non-interacting ME shows stronger Pauli blocking at low $\theta$
- interacting ME shows enhanced decay rate at low $\theta$ (for large enough $N$)

# FA approximation atom versus ME in k-space



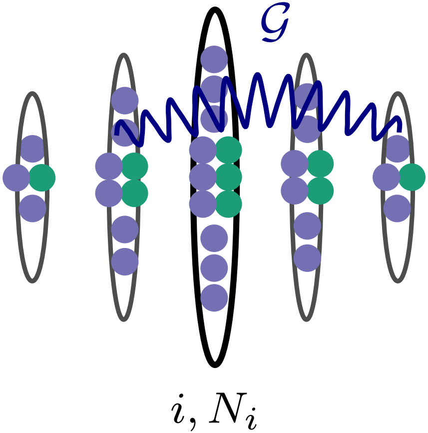

- Frozen atom captures super-radiant enhancement
- fails to capture Pauli blocking

# Role of Imbalance




- Highly imbalanced FS allow strong Pauli blocking
- while minimizing cooperative effects

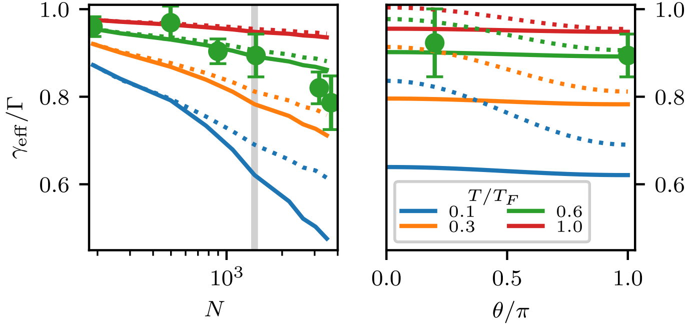
# Extension to 1D lattice




**1D optical lattice**

- Slice 3D gas into stack of 2D pancakes
- Dipolar exchange between pancakes
- Distribution $N_i$ over pancakes $i$
- $T/T_{F,i}$ different in each pancake
- in-plane size different in each pancake

# Comparison with Experiment

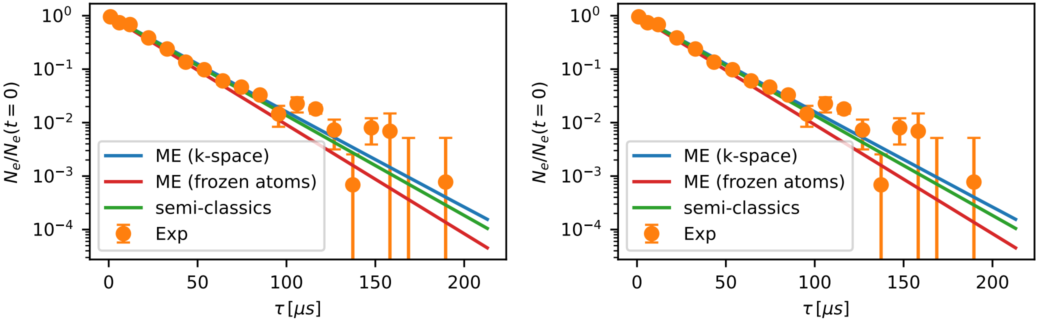



**Exp Parameters**

- $T/T_F = 0.6$
- $N_0 \sim 200$ ,
  $N_1 = 200, \cdots, 3000$
- $\sim 7 - 10$ pancakes

- Theory consistent with experiment in highly imbalanced regime
- weak $\theta$ dependence for imbalanced case $\rightarrow$ interactions not important

# Real-Time Dynamics




- recall: $\Gamma^{-1} \sim 22\mu\mathrm{s}$
- for $t\Gamma \lesssim 3-5$ consistent with single exponential
- $t \to 0$ limit well justified here

# Conclusions

**Summary**

- Developed ME in k-space
- captures Pauli blocking and main cooperative effects
- applicable to multi-level and generic geometries
- consistent with experimental data

**Open Questions**

- Long time behaviour
- Future experiments to conclusively observe this!