Understanding Collisions of Cold Polar Molecules

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Ultracold Molecules are Almost Here

- Novel many body systems of polar molecules predicted, also Bose-Hubbard physics.
- The DeMille group has produced RbCs in its absolute vibrational ground state @ T ~100 **μ**K!!! Collisions within a year?

Current work in progress

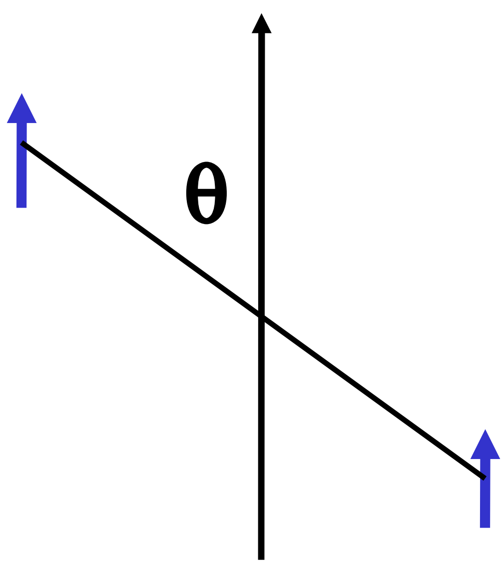
- 2 Body scattering of absolute ground state polar molecules with singlet sigma: current example RbK-RbK (theories and methods will apply for RbCs and LiH).
- Study Energy and Electric field dependence of long range scattering.
- Absolute ground state is a Strong field seeker and there are no **2**-body inelastic processes.
- **Aim**: be first to do FULL 2-body scattering of ultracold POLAR molecules.

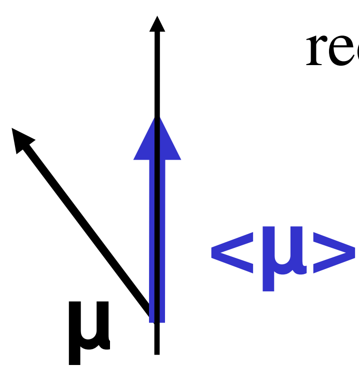
Dipolar Interactions

$$H_{\mu\mu} = \frac{\mu_1 \cdot \mu_2 - 3\hat{R} \cdot \mu_1 \hat{R} \cdot \mu_2}{R^3}$$

$$H_{\mu\mu} \approx \frac{1 - 3\cos^2\theta}{R^3} \langle \mu \rangle^2$$

- Anisotropic!
- Long Range!
- Requires a non-zero field for degenerate channels to be dipole coupled.
- Result: Larger Number of partial waves required AND Many Total Ms required to calculate.





$$M = M_1 + M_2 + M_L$$

Approximations for dipolar Scattering

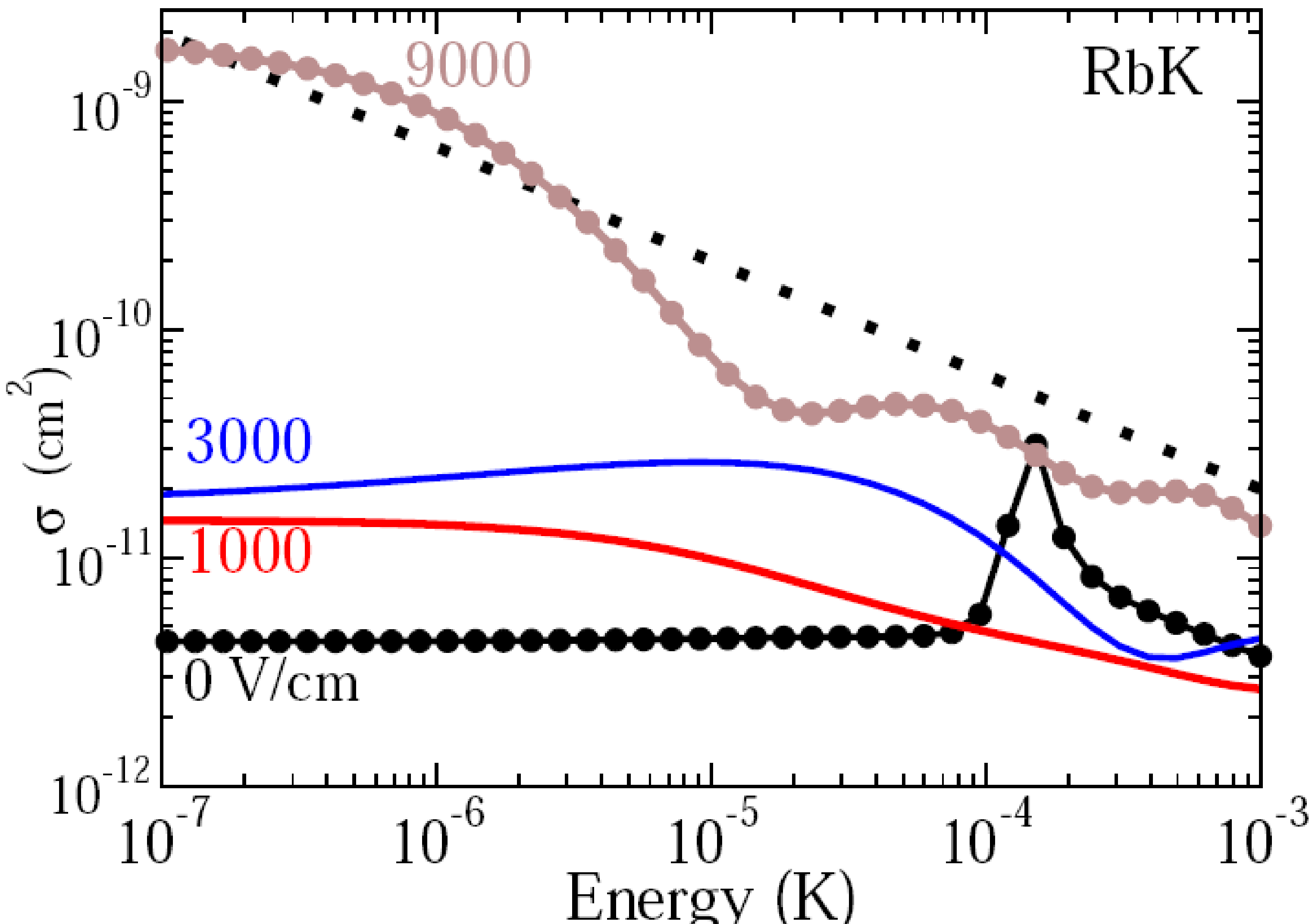
$$\sigma^{Born}_{partial} \propto const$$

$$\sigma^{SC}_{Total} \propto \frac{\langle \mu \rangle^2}{\sqrt{E_{coll}}}$$

$$\sigma^{Quantum}_{partial} \propto \frac{1}{E_{coll}}$$

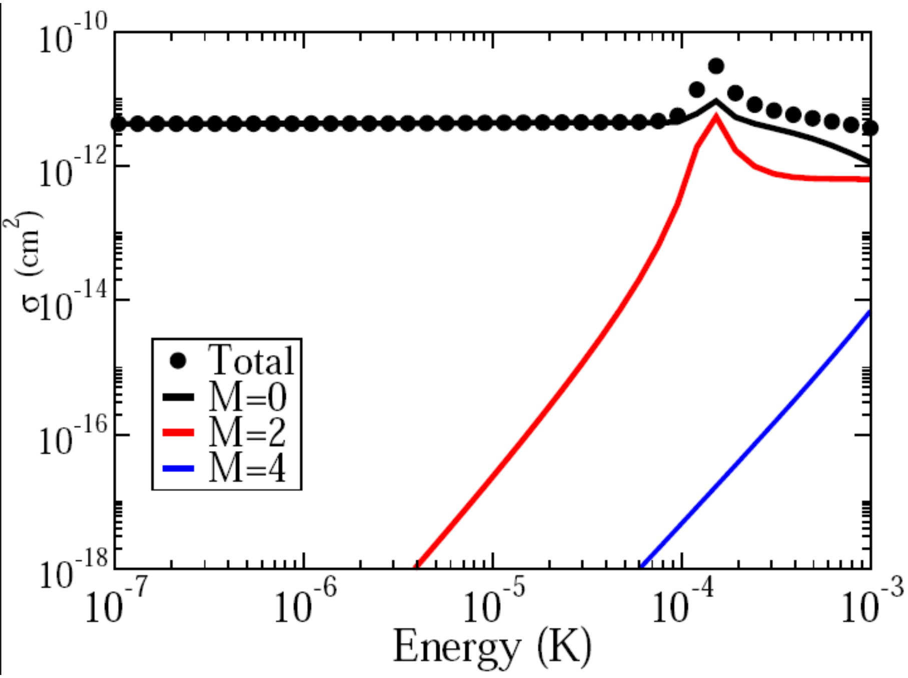
- Born Approximation gives **partial** cross section, Independent of Energy.
- At high energy: Semi-Classical Approximation gives a **total** cross section in terms of physical parameters
- At low energy: Quantum mechanical scattering; Depends on phase shift of a **single** term. Unitarity limit.

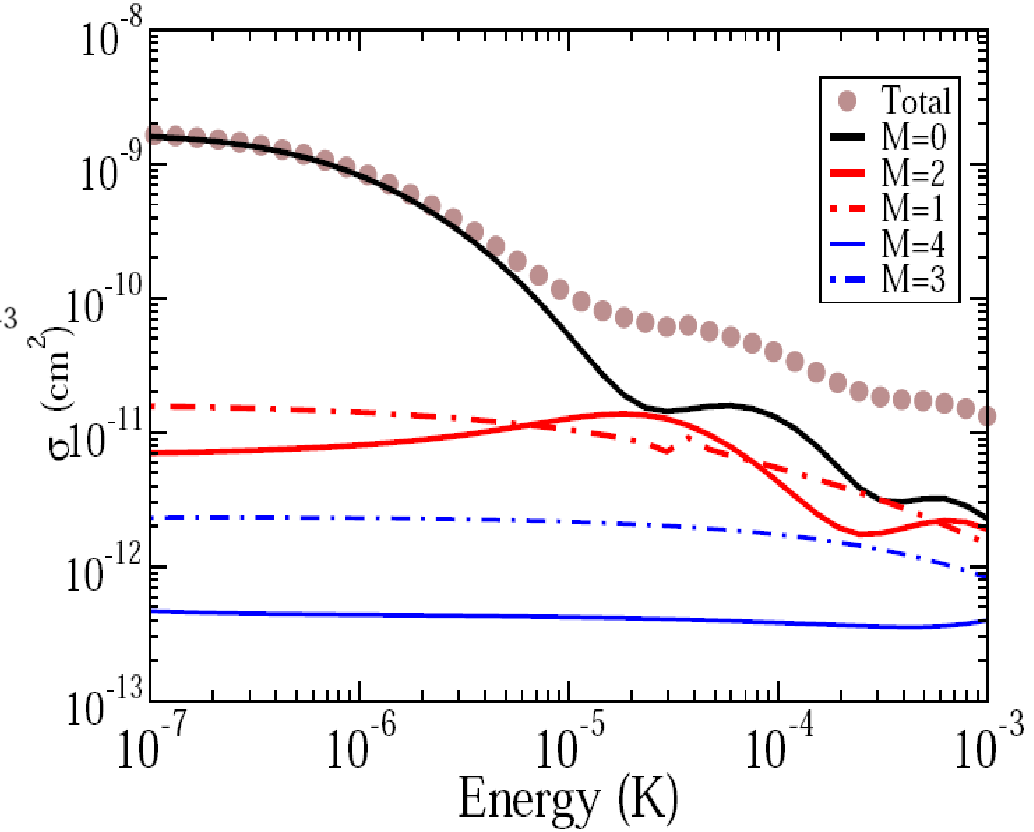
Energy Dependence



Terms in the cross sections:

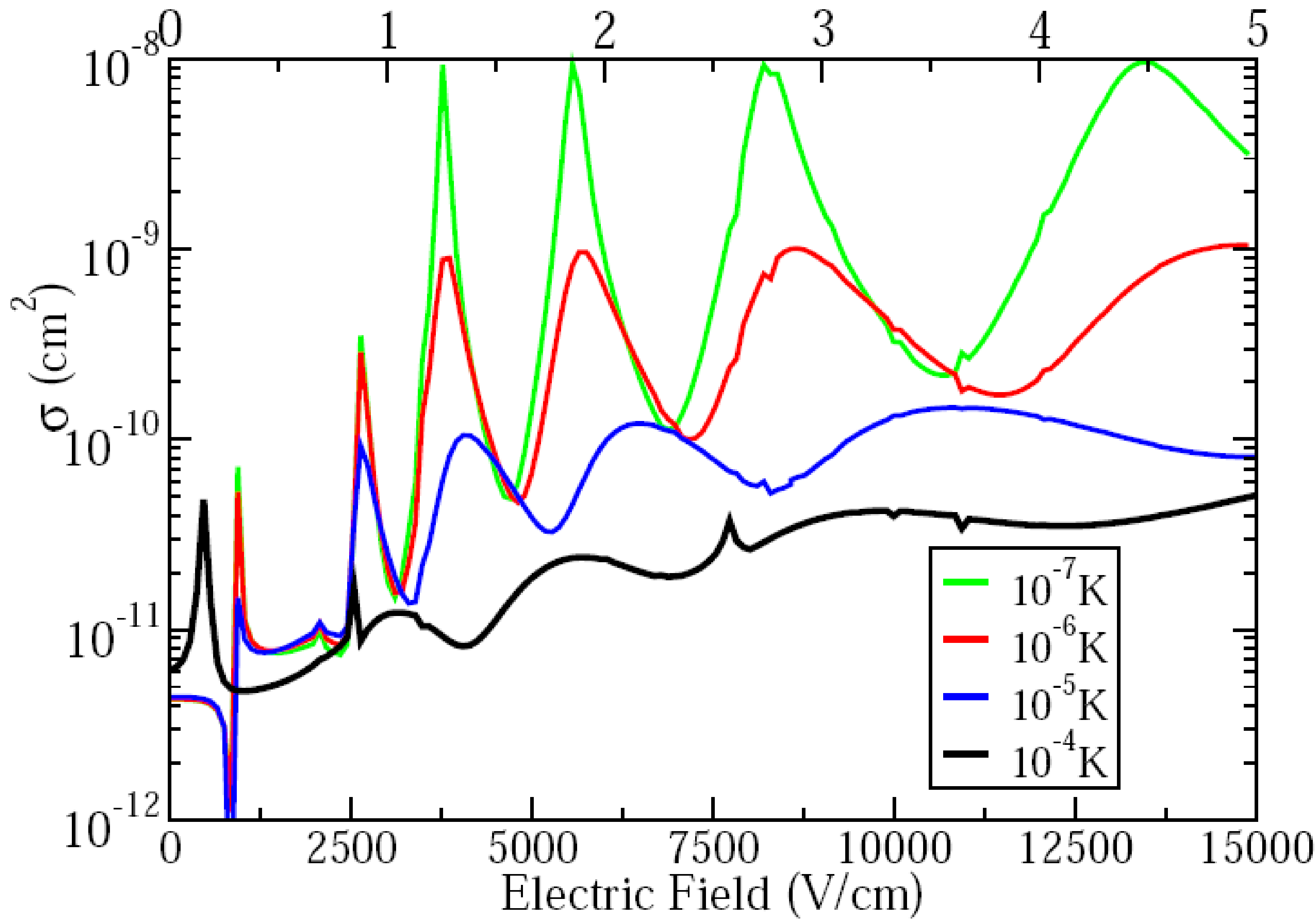
Many total Ms and many partial waves



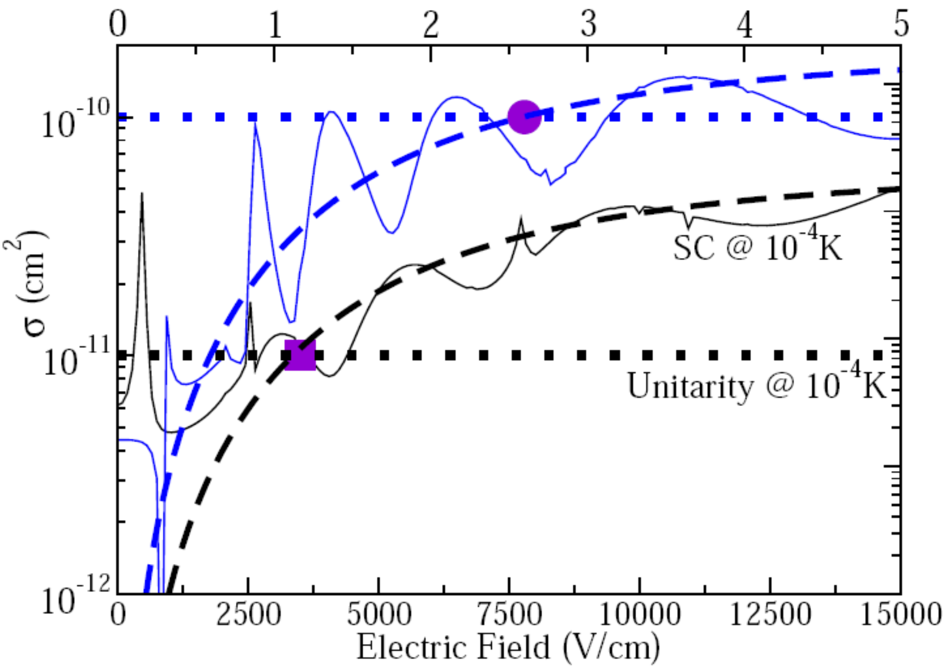


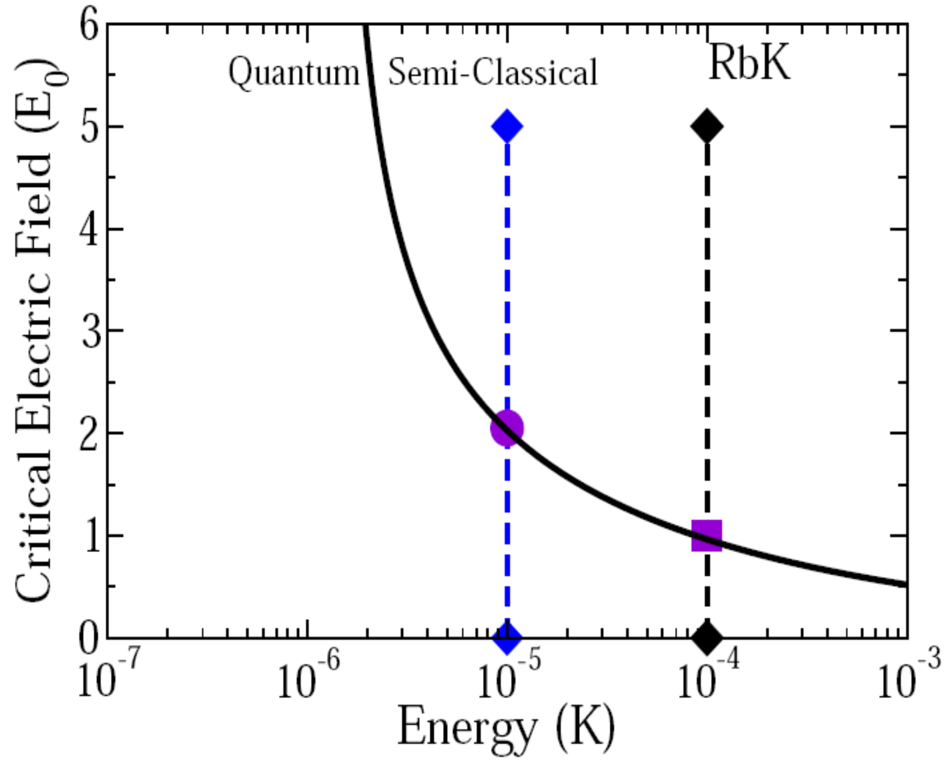
$$M = M_1 + M_2 + M_L$$

Electric Field dependence of total cross section



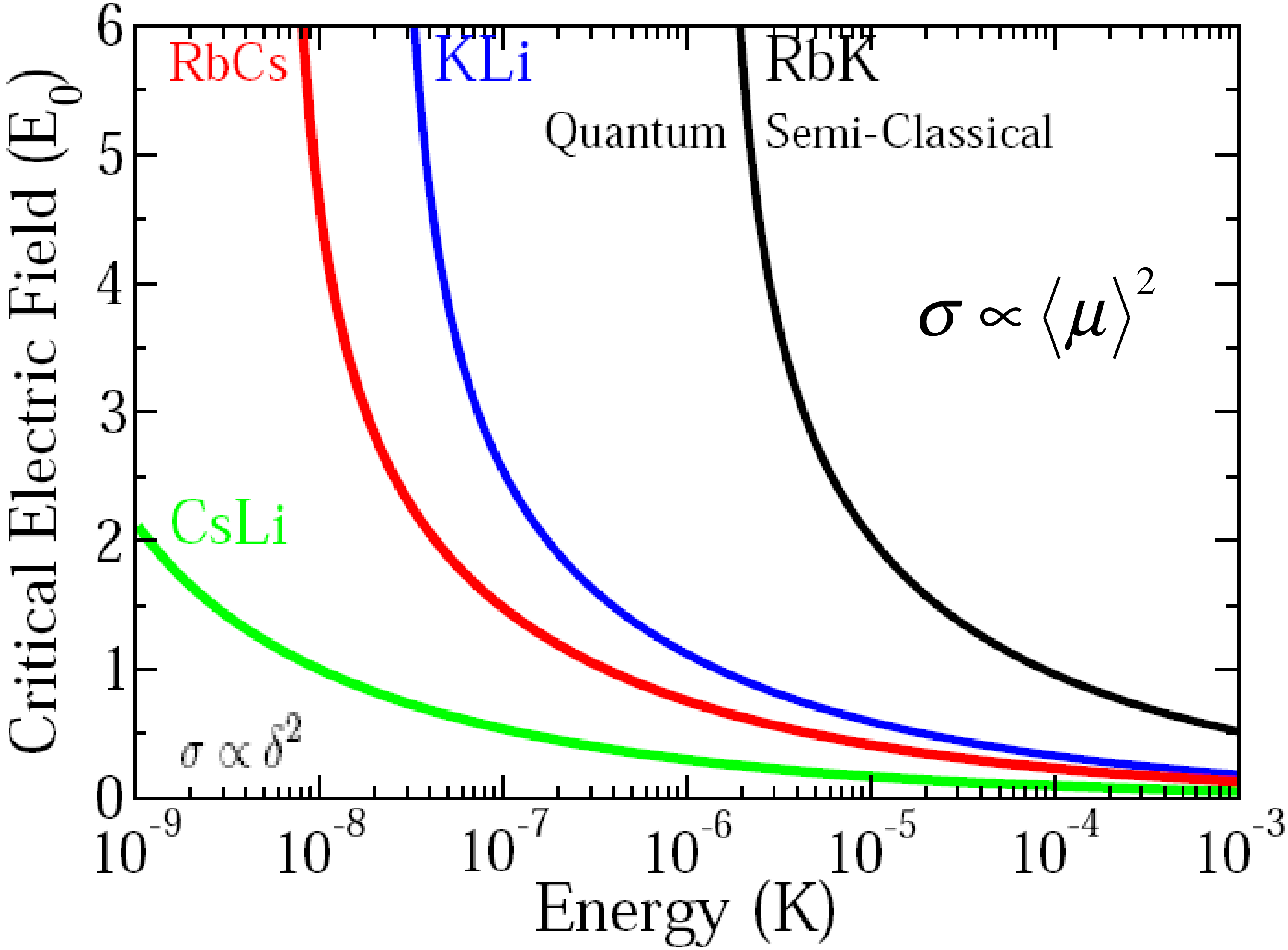
Critical Electric Field:
Semi-classical equals Unitarity Limit





$$E_0 = B/\mu$$

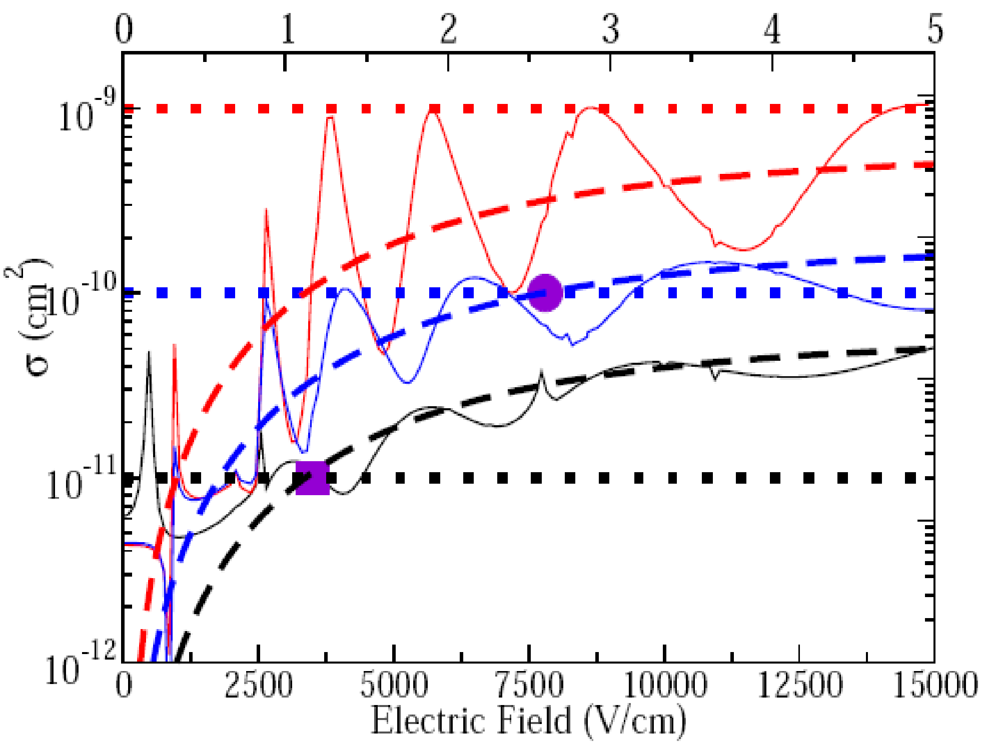
Transition in behavior of Cross section

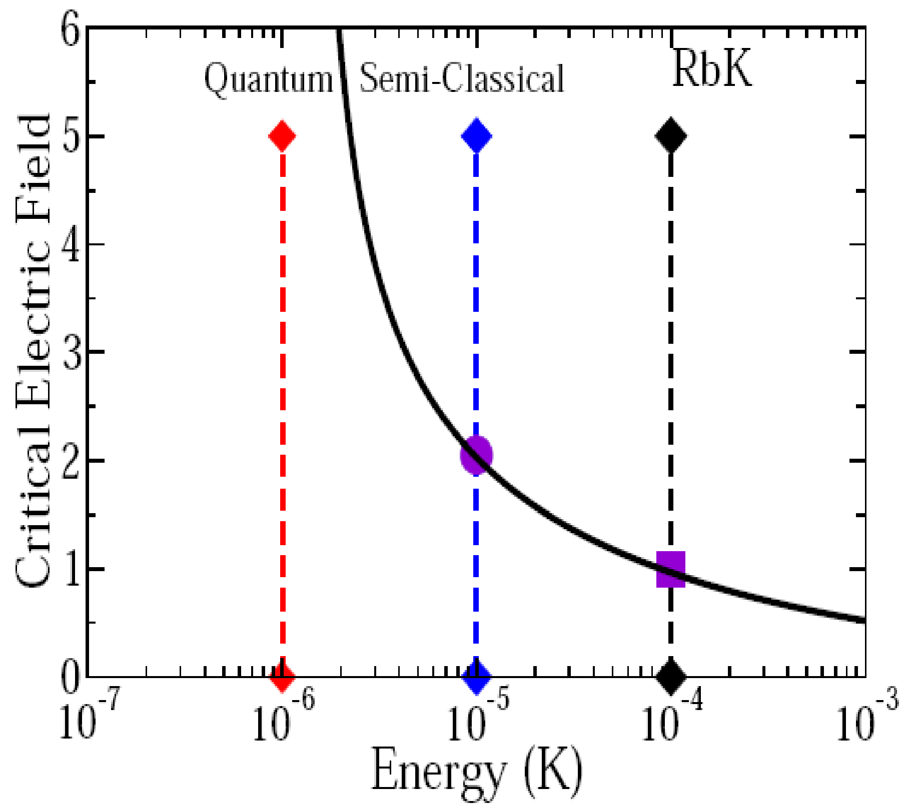


Conclusions

- Polar molecule scattering has dramatic energy dependence in an electric field.
- Transition between quantum and semi-classical scattering can occur at very low energies.
- Interesting implications for many body systems.
- Funding from ACQAO; Computing at VPAC.

Critical Electric Field: Semi-classical equals Unitarity Limit





Transition from semi-classical scaling and Quantum Mechanical scattering depends on Electric Field

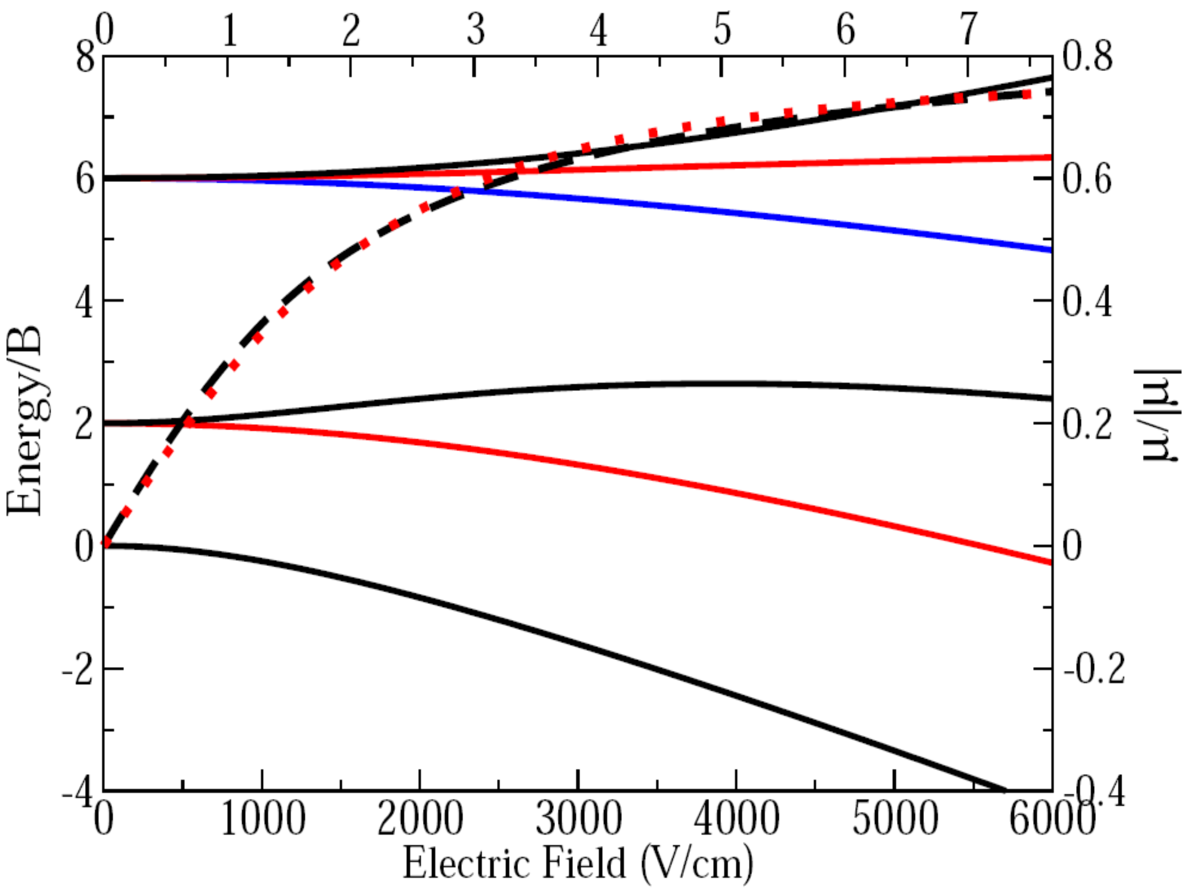
$$\sigma^{SC}_{Total} = \sigma^{Quantum}_{partial}$$

$$x \approx \sqrt{\frac{1.494}{\sqrt{m_r^3 \mu^4 E_{coll}} - 0.223}}$$

$$E_Q \approx \frac{0.045}{m_r^3 \mu^4}$$

- Find Electric Field at which SC equals the Quantum scattering.
- Above this field the scattering will Semi-classical and depends on the molecular parameters; **no single phase parameterizes scattering**.
- Low energy and near zero field scattering will always be dominated by Quantum scattering or **phase dependent**.

Molecular Structure and Stark Effect for Singlet Sigma



$$H_{mol} = BJ(J+1)\delta_{JJ'}$$

$$H_{Stark} \propto \mu E \delta_{JJ'\pm 1}$$

$$H_{mol} \approx H_{Stark} \ @\ E_0$$

$$\frac{\langle \mu \rangle}{\mu} \approx \sqrt{\frac{x^2}{6.7 + x^2}}$$

Little bit of scattering

$$\boldsymbol{M} = \boldsymbol{M}_1 + \boldsymbol{M}_2 + \boldsymbol{M}_L$$

$$\sigma = \sum_{M} \sigma^{(M)}$$

$$\sigma^{(M)} = \sum_{ij} \sigma_{ij}^{(M)}$$

$$\sigma_{ij}^{(M)} = \frac{2\pi}{k^2} \left| \boldsymbol{T}_{ij}^{(M)} \right|^2$$