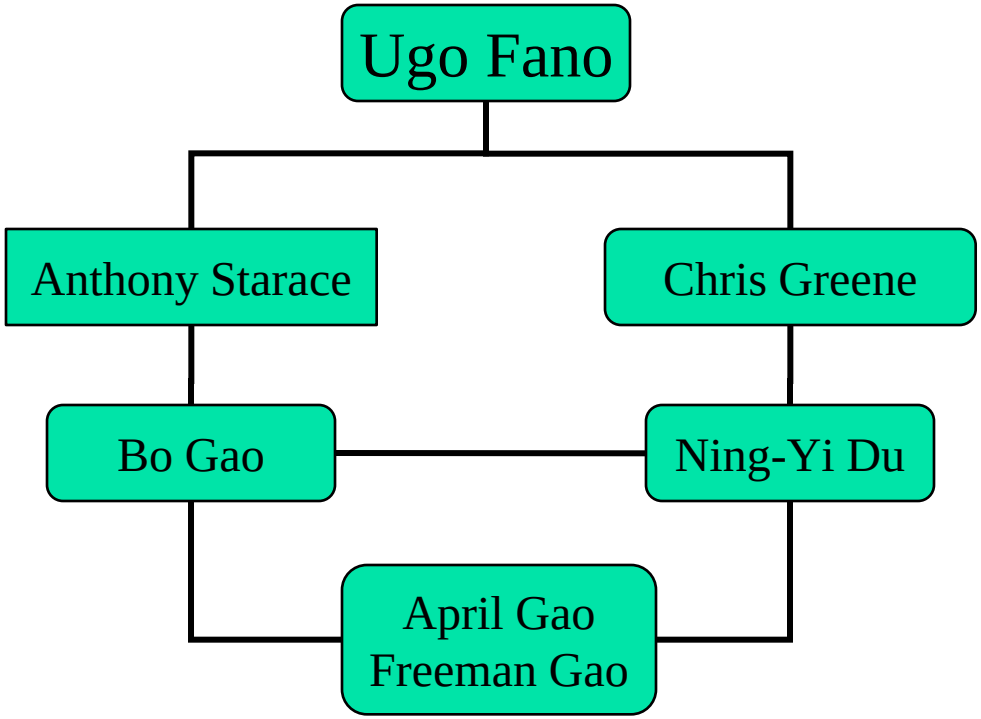
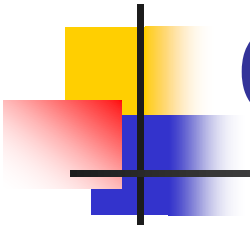
III. Spectroscopy and Ultracold Collisions

- **John Bohn** (JILA): Linking Ultracold Polar Molecules
- **Paul Lett** (NIST): Feshbach Resonances in Photoassociation Spectroscopy
- **Carl Williams** (NIST): From Ultracold Collisions to Quantum Computing
- **Brett Esry** (Kansas State): Ultracold three-body recombination of fermionic atoms
- **Charles Clark** (NIST): Superfluid and Laser Analogies in Degenerate Quantum Gases
- **Christian Jungen** (Orsay): Quantum Defect Theory and ab initio Theory

It’s all in a family.



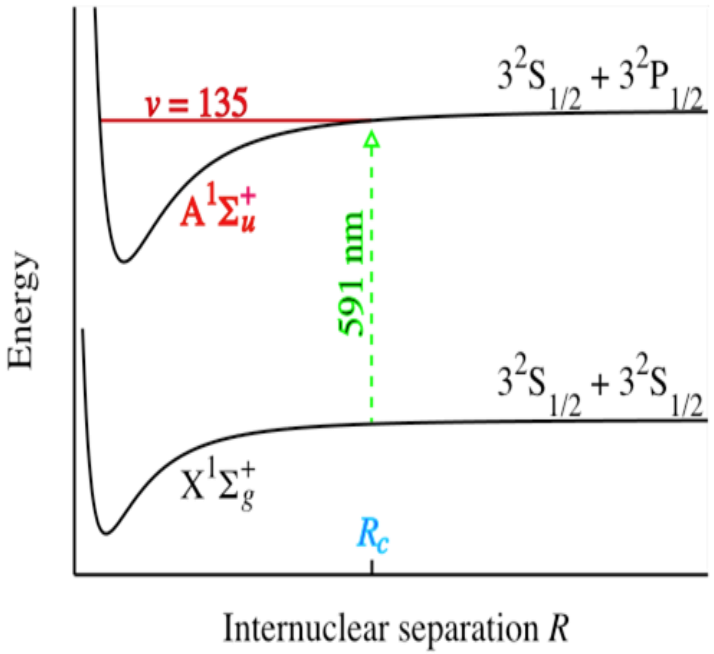


Outline

- Why cold?
- What is quantum-defect theory (QDT)?
- Sample applications in cold-atom physics.

Why Cold?

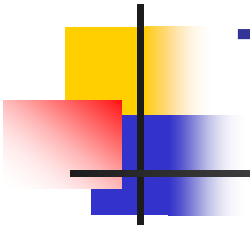
- Energy resolution and Frank-Condon factor (1 GHz ~ 50 mK)
- Ideal starting point to build theories for quantum few-body and quantum many-body problems



What is Quantum Defect Theory: the Math

A second order, linear and homogeneous, differential equation has two linearly independent solutions. And its general solution is a linear superposition of the two.

What is Quantum Defect Theory: the Physics



- A philosophy, a way to look at things
- The energy dependence, and for molecules also the angular momentum dependence, around the threshold is dominated by the long-range interaction
- A method to treat and to relate physics at different length scales

What is Quantum Defect Theory: Sample Implications

For quantum systems with $-C_n/r^n$ types of long-range interaction

- An universal spectrum for each n
- Universal scattering properties for each n
- Getting something for nothing

The Rydberg Formula

Universal spectrum for quantum systems with long-range Coulomb interaction

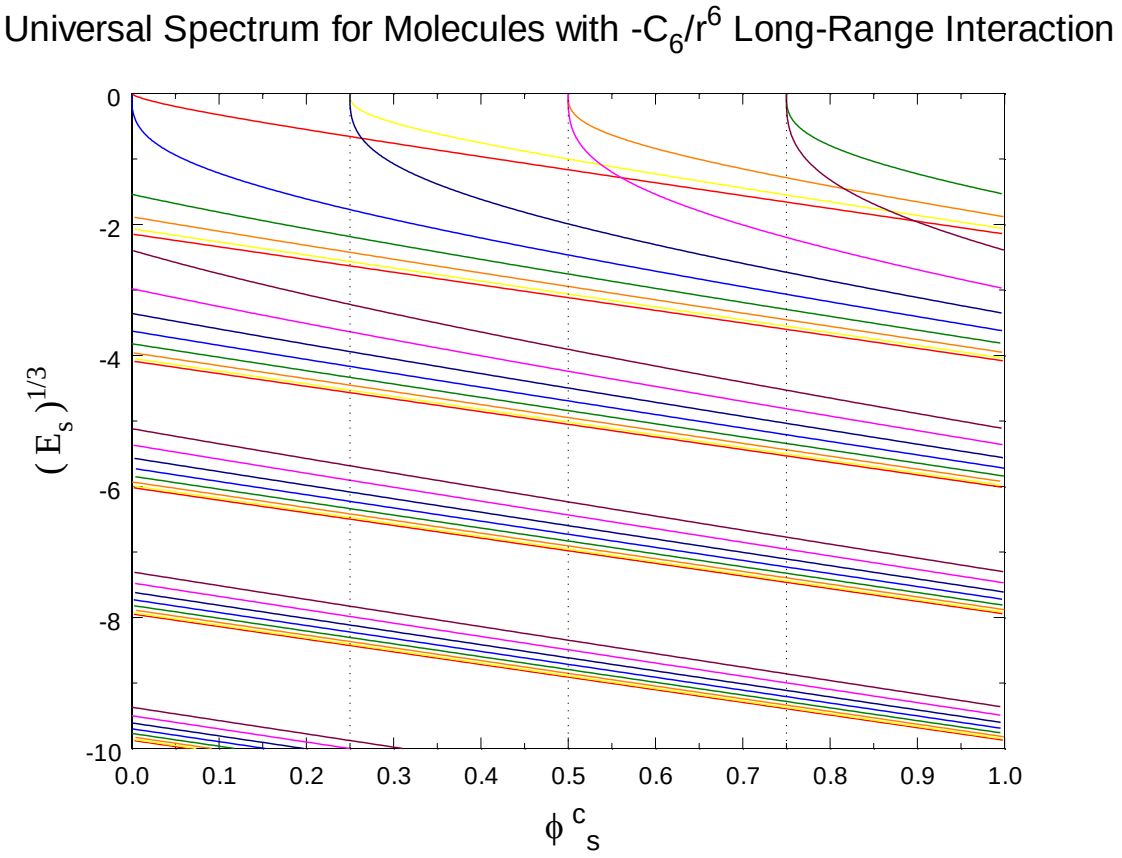
$$E = - Z^2/(n-\mu_l)^2$$

or

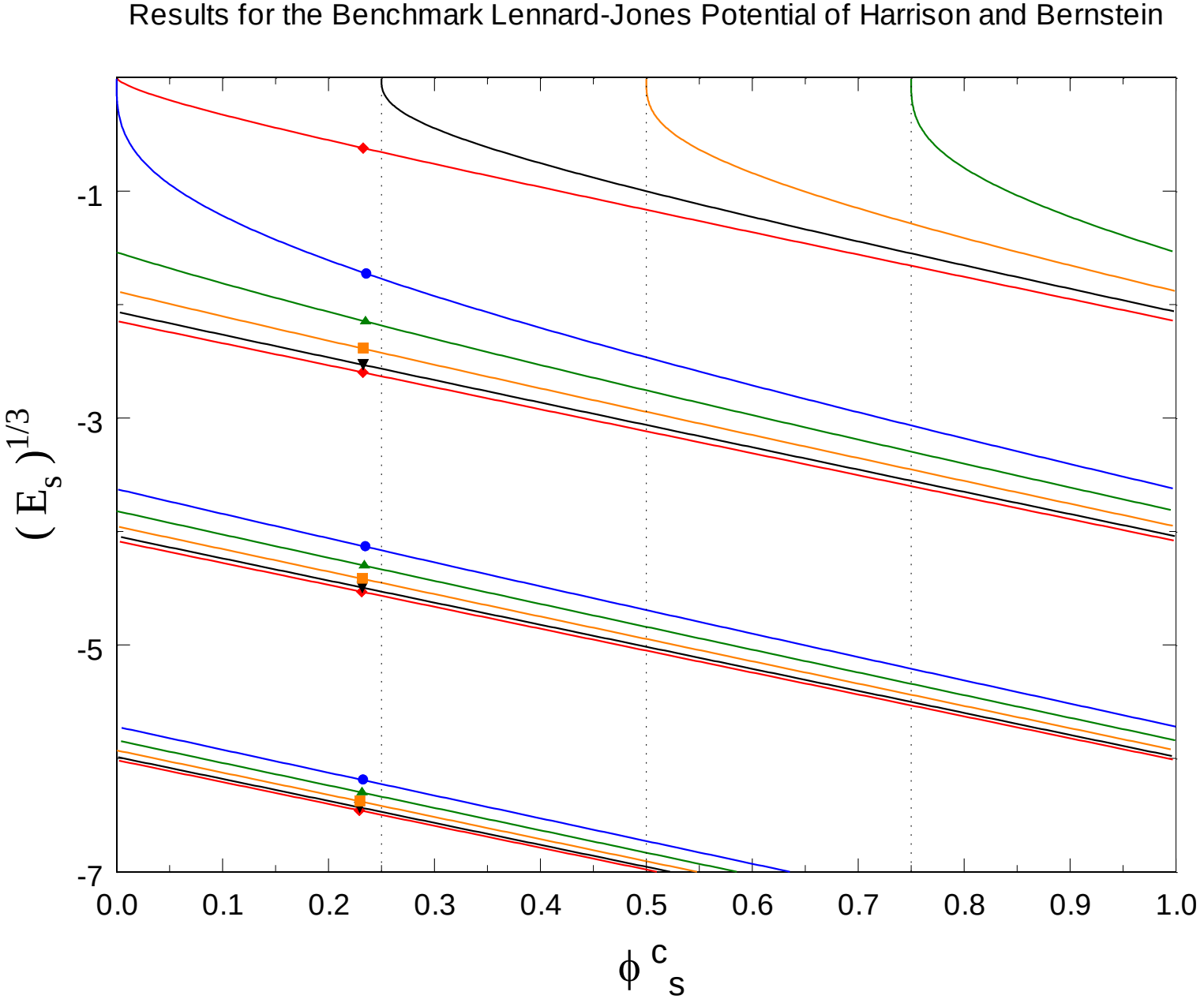
$$E/Z^2 = - 1/(n-\mu_l)^2$$

Universal spectrum (two-body)

- Universal spectrum for diatomic molecules with $-C_6/r^6$ long-range interaction.

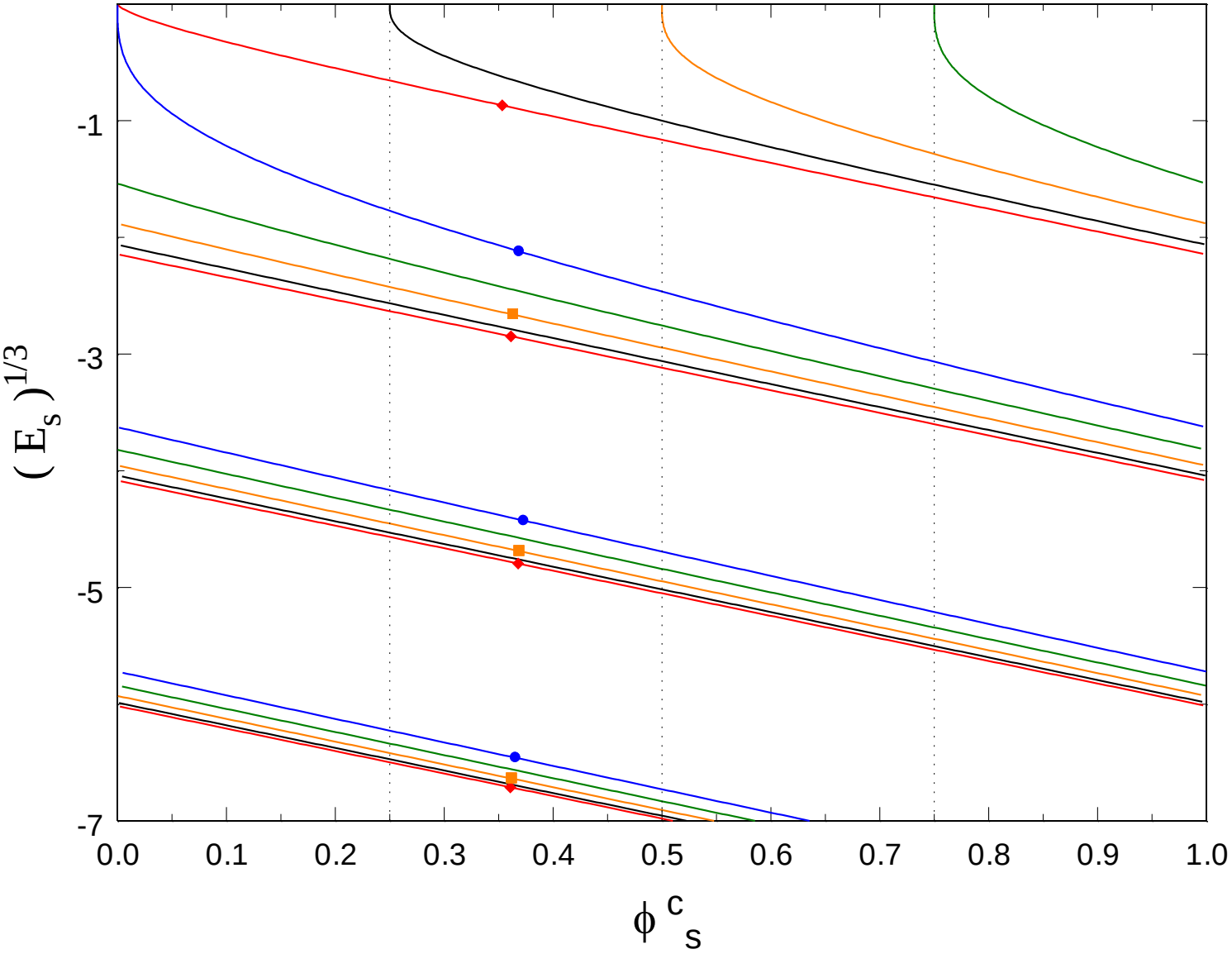


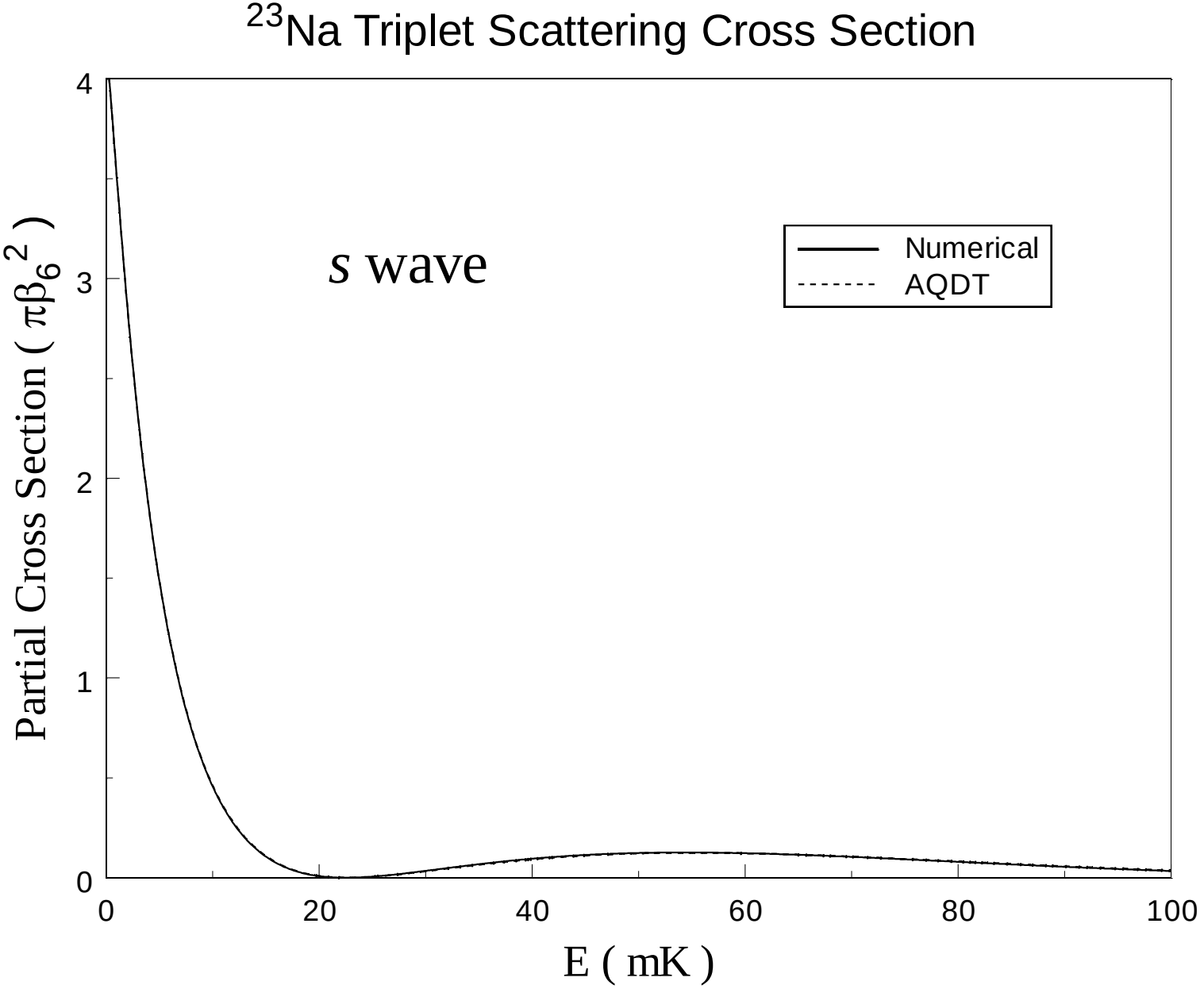
B. Gao, PRA **64**, 010701(R) (2001).


Results for the Benchmark Lennard-Jones Potential of Harrison and Bernstein
-1
-3
-5
-7
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
(E_s)^1/3
φ^c_s

Triplet States of ^{23}Na Dimer

Computed from the potential of T. Laue, *et. al*, Phys. Rev. A **65**, 023412 (2002).




^{23}Na Triplet Scattering Cross Section
s wave
Numerical
AQDT
Partial Cross Section ($\pi\beta_6^2$)
E (mK)
0
1
2
3
4
0
20
40
60
80
100

MQDT for Slow Atomic Collisions

Simple description in terms of a few parameters (the singlet and triplet scattering lengths, and the hyperfine splitting)