Simulation of energy transport by dark matter scattering in the Sun

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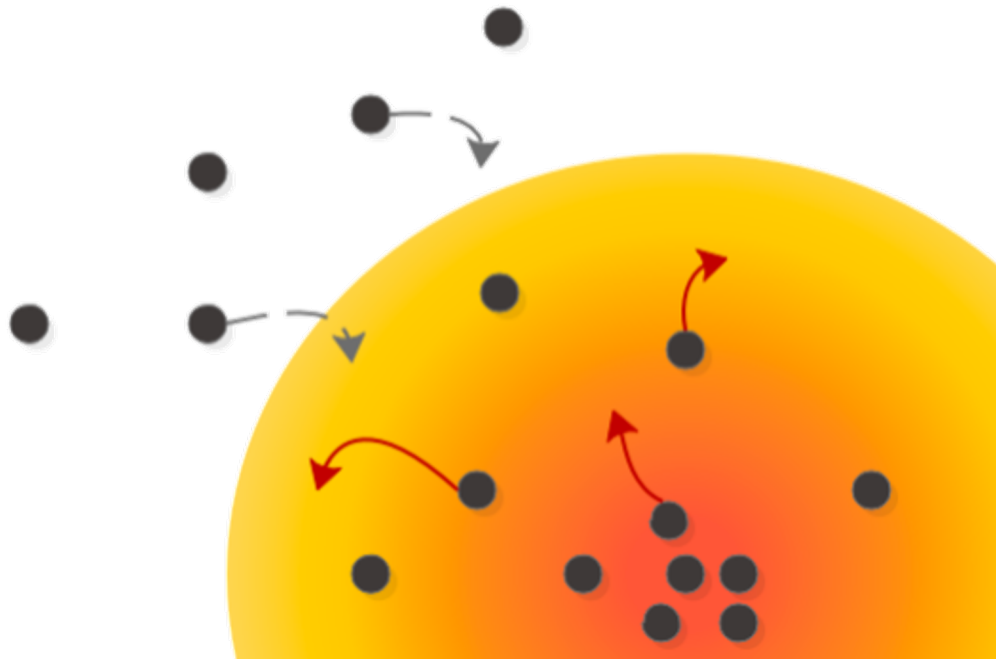
Based on 2111.06895 with S. Ansari, A.C Vincent and P. Scott

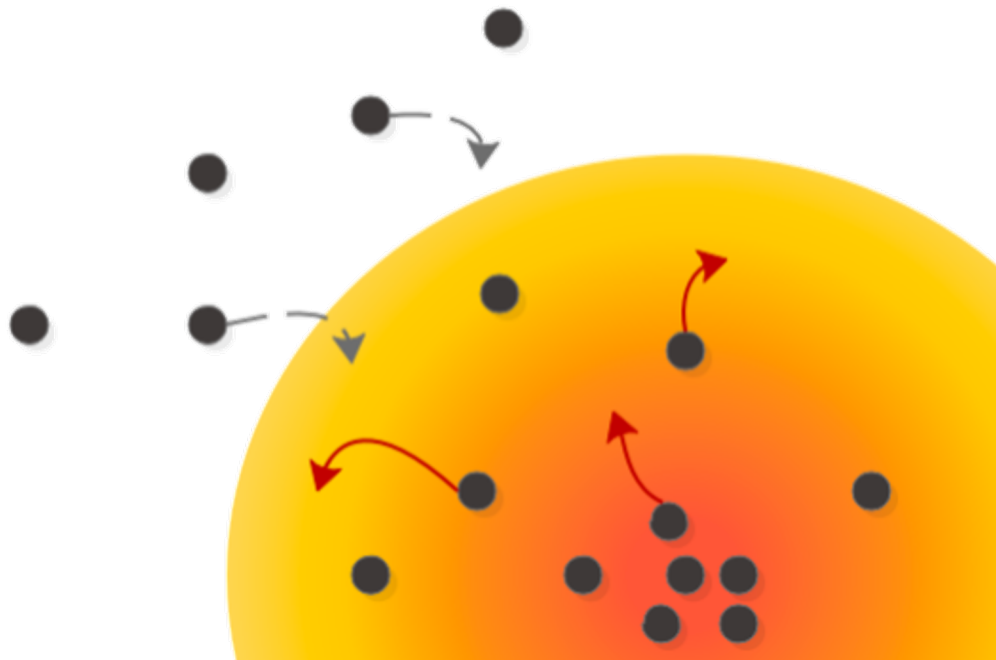


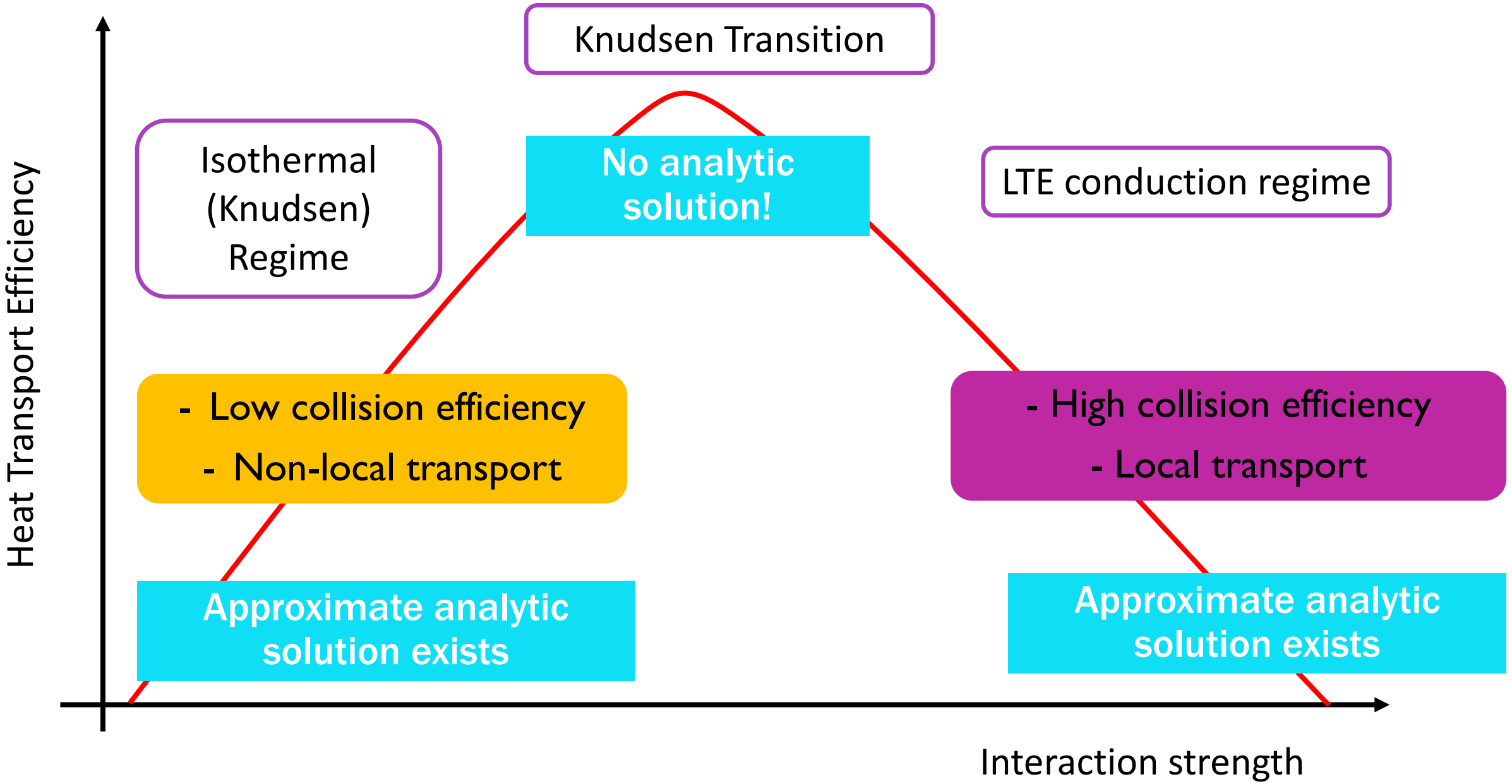
The Idea

- Can use the Sun as a "direct detection experiment"
- (Asymmetric) DM particles can become trapped in the Sun
- Interactions with nuclei conducts heat, modifying internal structure and properties

Probe by

1. Helioseismology
2. Neutrino fluxes




Knudsen Transition
Isothermal (Knudsen) Regime
No analytic solution!
LTE conduction regime
- Low collision efficiency
- Non-local transport
- High collision efficiency
- Local transport
Approximate analytic solution exists
Approximate analytic solution exists
Heat Transport Efficiency
Interaction strength

The existing formalisms:

Spergel & Press

Based on Isothermal "solutions"

VS

Gould & Raffelt

Based on modified LTE "solutions"

1. Use assumptions only valid for one regime
2. Calibrated using a single, simplified simulation done > 30 years ago
3. Only tested for constant interactions

So, is either accurate?

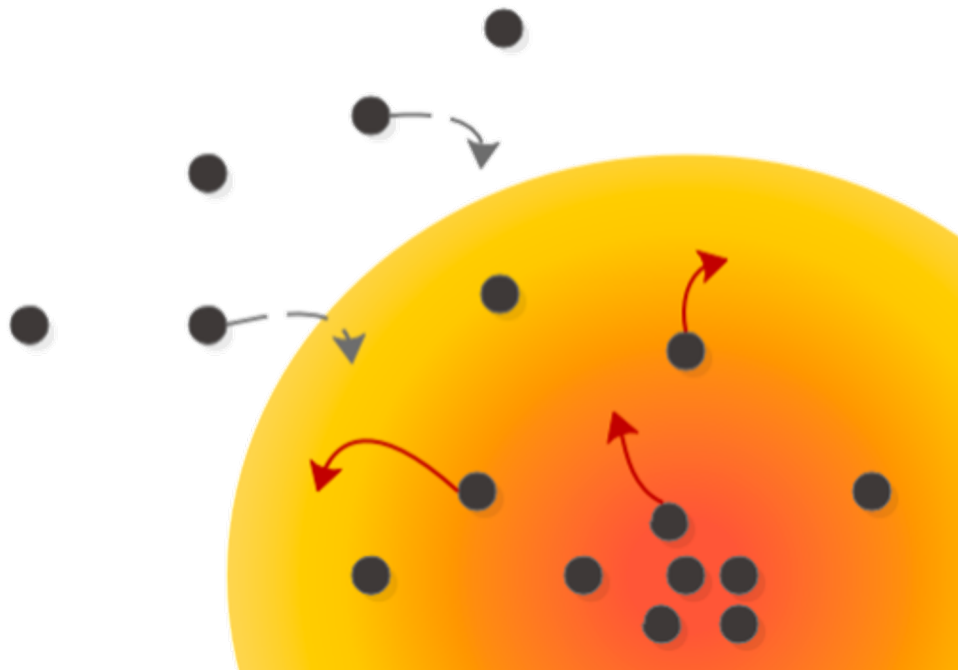
- Simulate chains of 10^7-10^8 DM-nucleon collisions
- Track DM velocity, position and energy transfer at collision points
- Directly extract thermal properties from distributions
- Consider cross sections that depend on relative velocity of DM and nucleon, v_{rel} or momentum transferred, q:

$$\sigma = \sigma_0 \left(\frac{v_{\rm rel}}{v_0} \right)^{2n}$$

$$\sigma = \sigma_0 \left(\frac{q}{q_0} \right)^{2n}$$

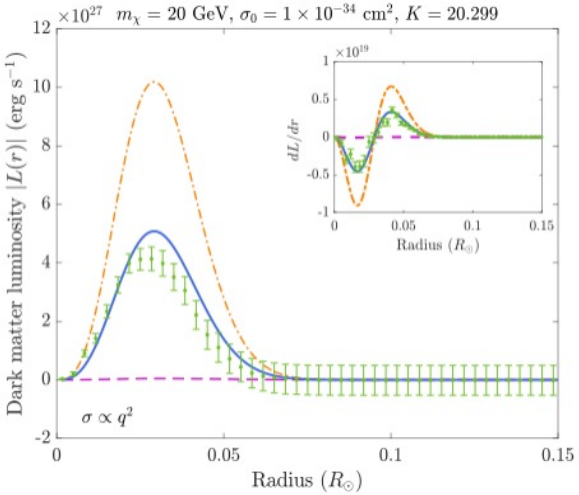
… Monte Carlo!

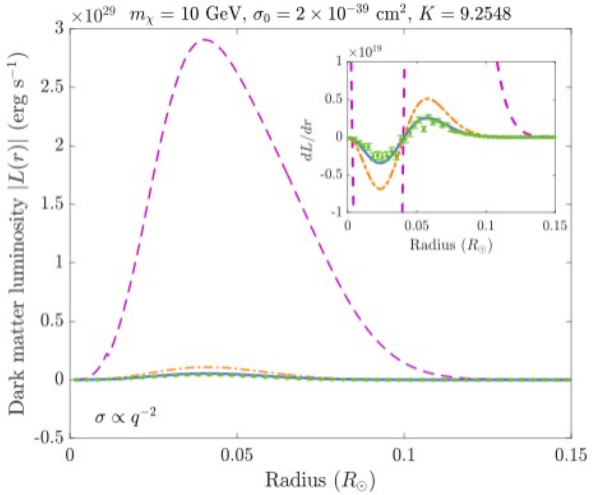
Billions of CPU hrs later….

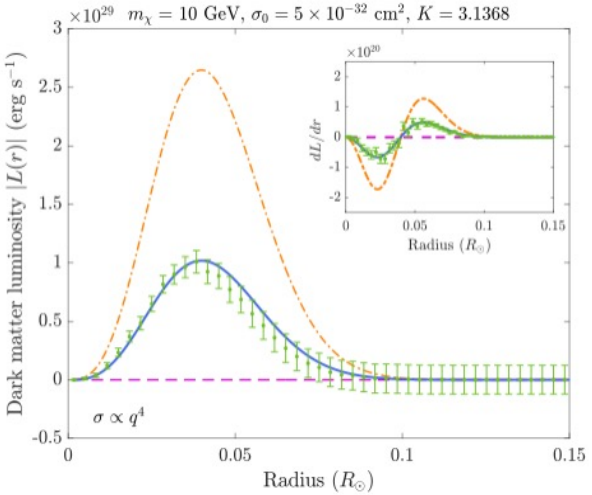


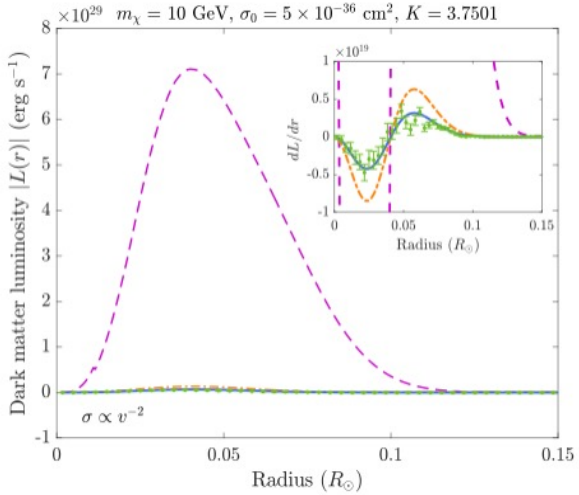
Neither G&R not S&P give a good description!

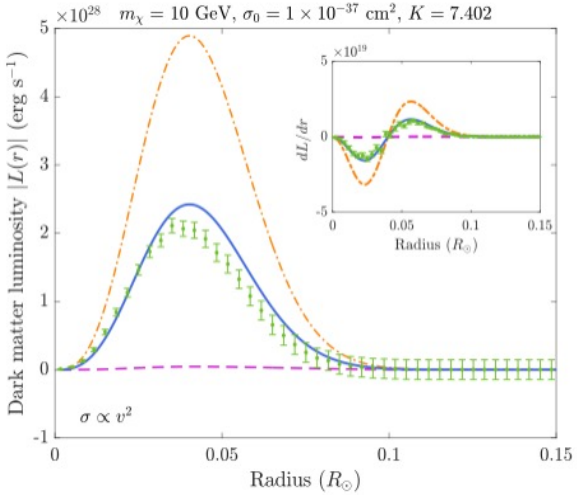
DM Luminosity and Energy Transport (inset) distributions for various interaction types and strengths:

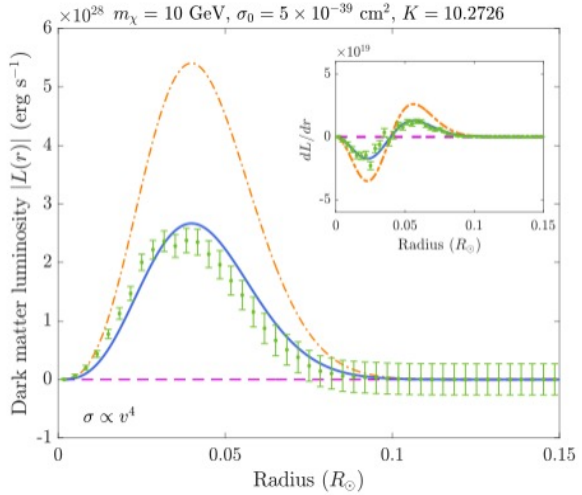












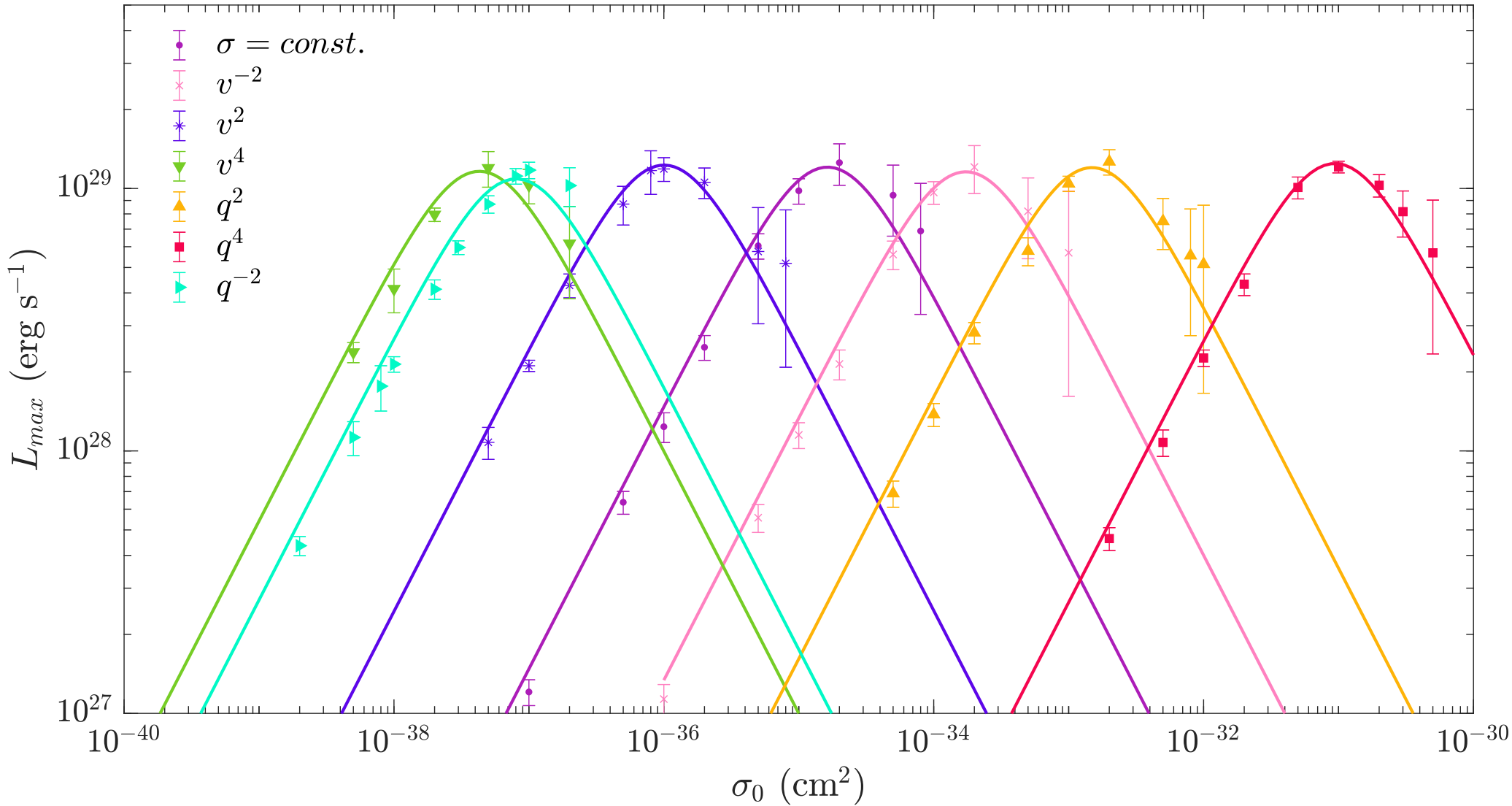
= S & P

= Monte-Carlo

= G&R

= Our scheme

But a simple universal rescaling of S&P scheme works for all interaction types and across all regimes!



Summary

- First direct simulation of DM mediated energy transport in stars performed for non-constant cross-sections
- Neither of the conventional approaches accurately describe DM mediated conduction in realistic simulations
- Simple, universal, rescaling of Spergel & Press formalism accurate for all interaction types and regimes

Can now find new bounds on properties of DM!