Stockholm University

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# New directions in dark matter direct detection

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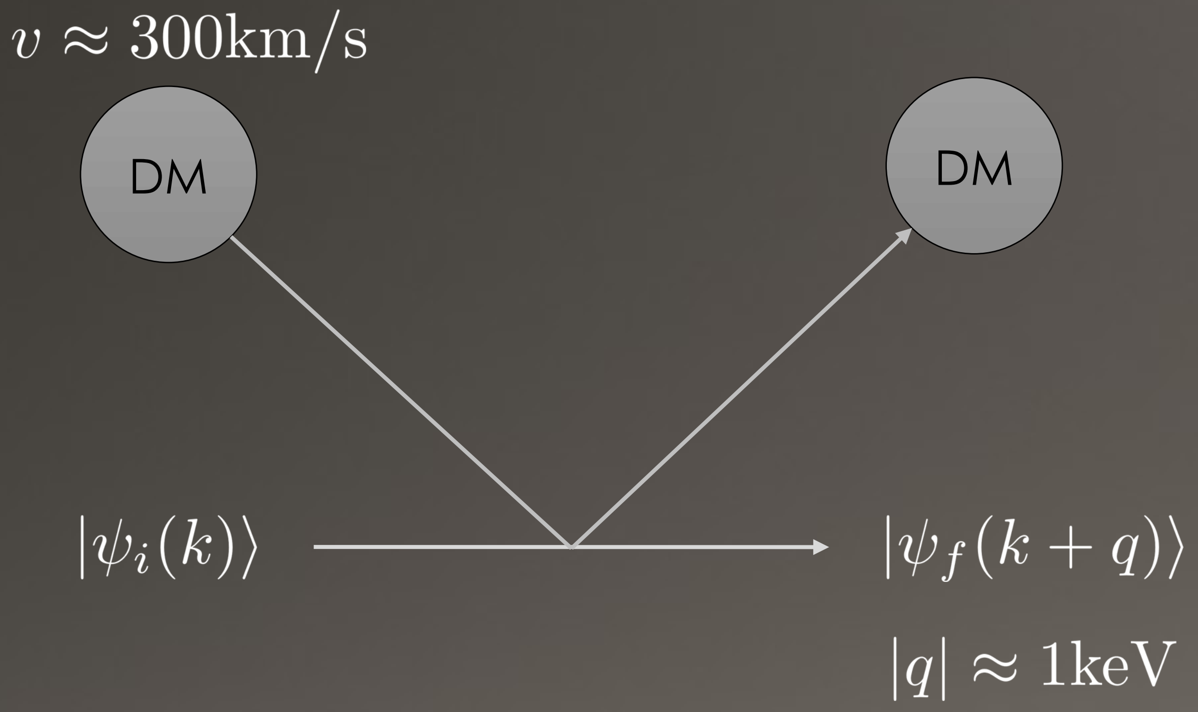
# Light DM-electron scattering



Kinematic Requirement

$$\Delta E = \vec{v}_\chi \cdot \vec{q} - \frac{q^2}{2\mu_{\chi \mathrm{m}}}$$

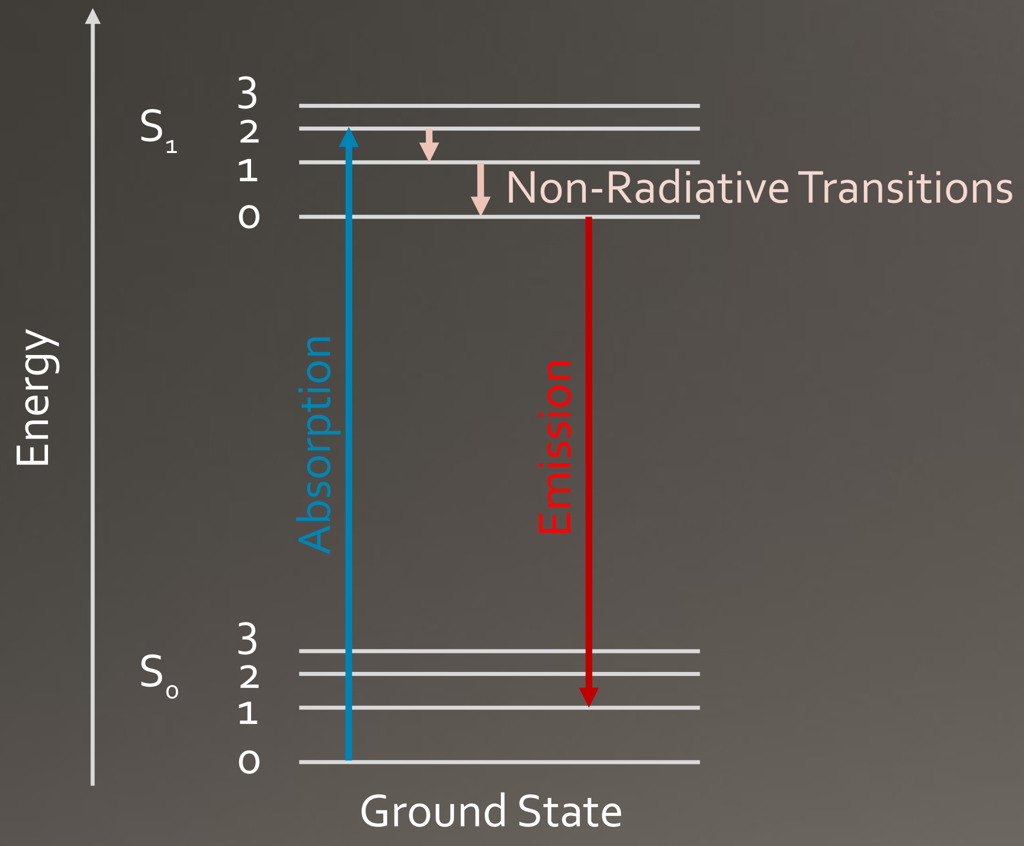
$$\Delta E \sim \mathcal{O}(\text{few eV})$$

What has such transition energies?

- Molecules, Semiconductors

ArXiv:1912.02822 & 2103.08601

# Fluorescence: scintillation

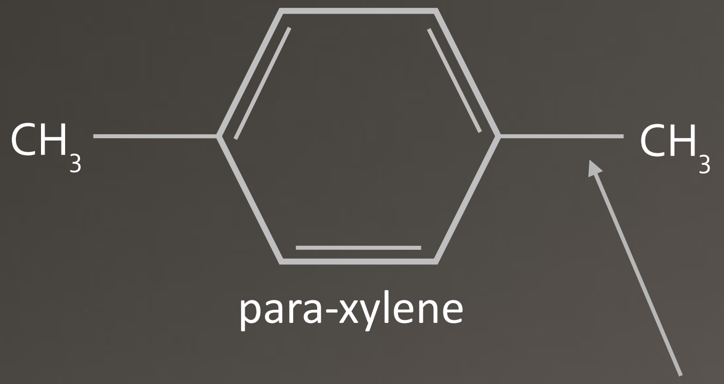


- Absorbtion: Blue photon ($E_A$) promotes electronic transition: $S_0 \rightarrow S_1$ $\Delta J \neq 0$
- Non-Radiative Transition: Internal conversion or vibrational deexcitation
- Emission: Red Photon ($E_E$) emitted as electronic state relaxes back to $S_0$
- $E_E < E_A$

ArXiv:1912.02822 & 2103.08601

# p-xylene (EJ-301)

EJ-301
Solvent: para-xylene
Fluor: 5% by mass



para-xylene

Single σ-bond

- Absorption spectra of p-xylene is well described by slightly perturbed aromatic peaks
- Expected since methyl groups don't affect LCAO at leading order
- Produce perturbation at ~5% level in energy,
  - Benzene HOMO/LUMO gap = 4.9 eV
  - p-xylene HOMO/LUMO gap = 4.7 eV

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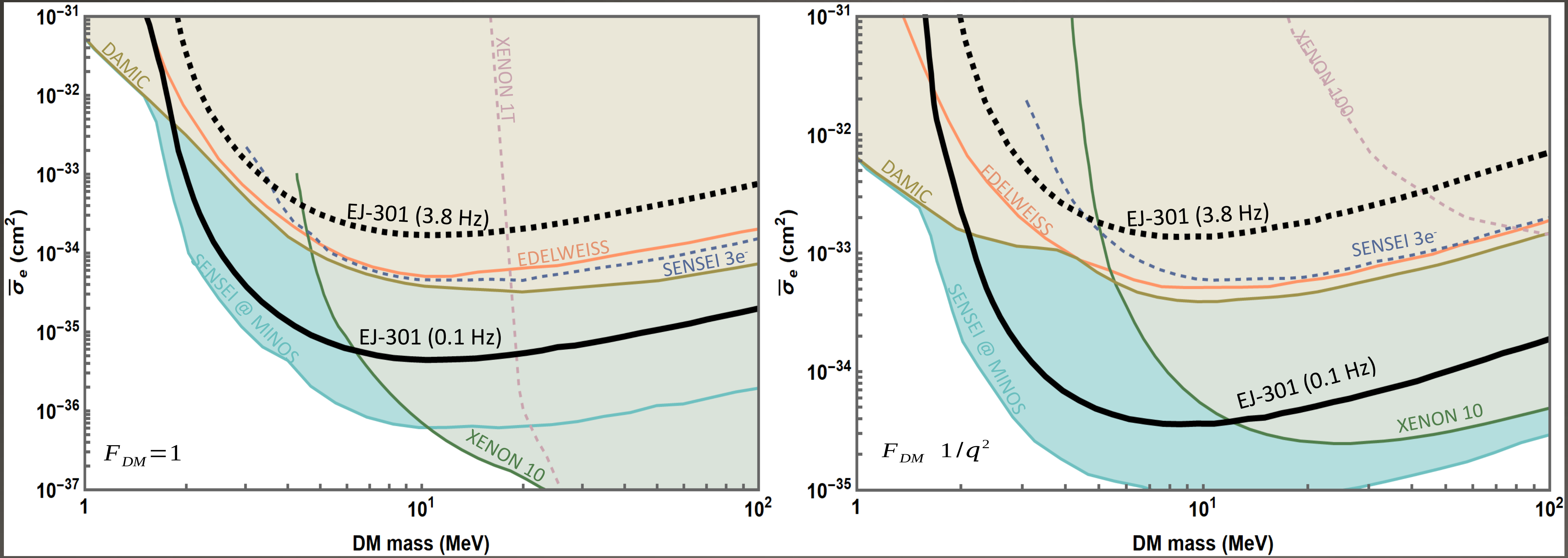
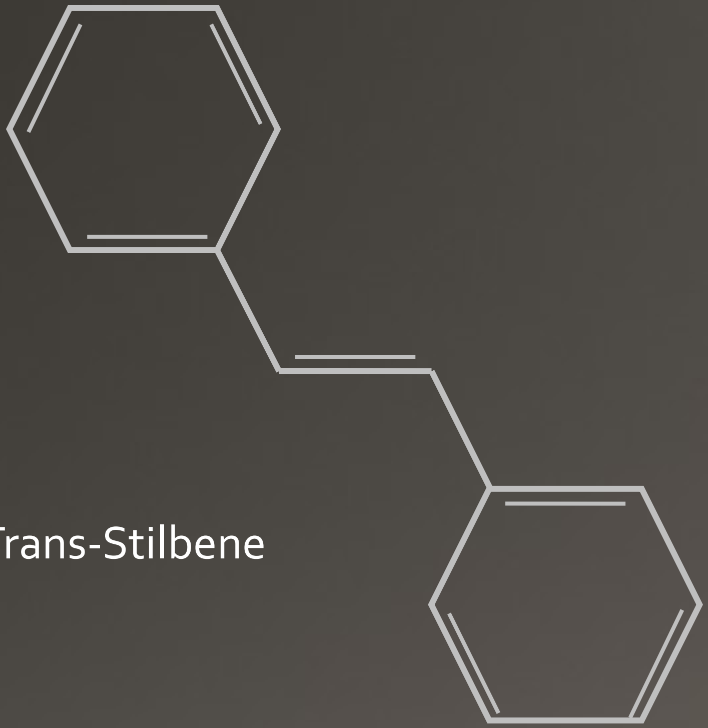
# Results : Liquid EJ-301

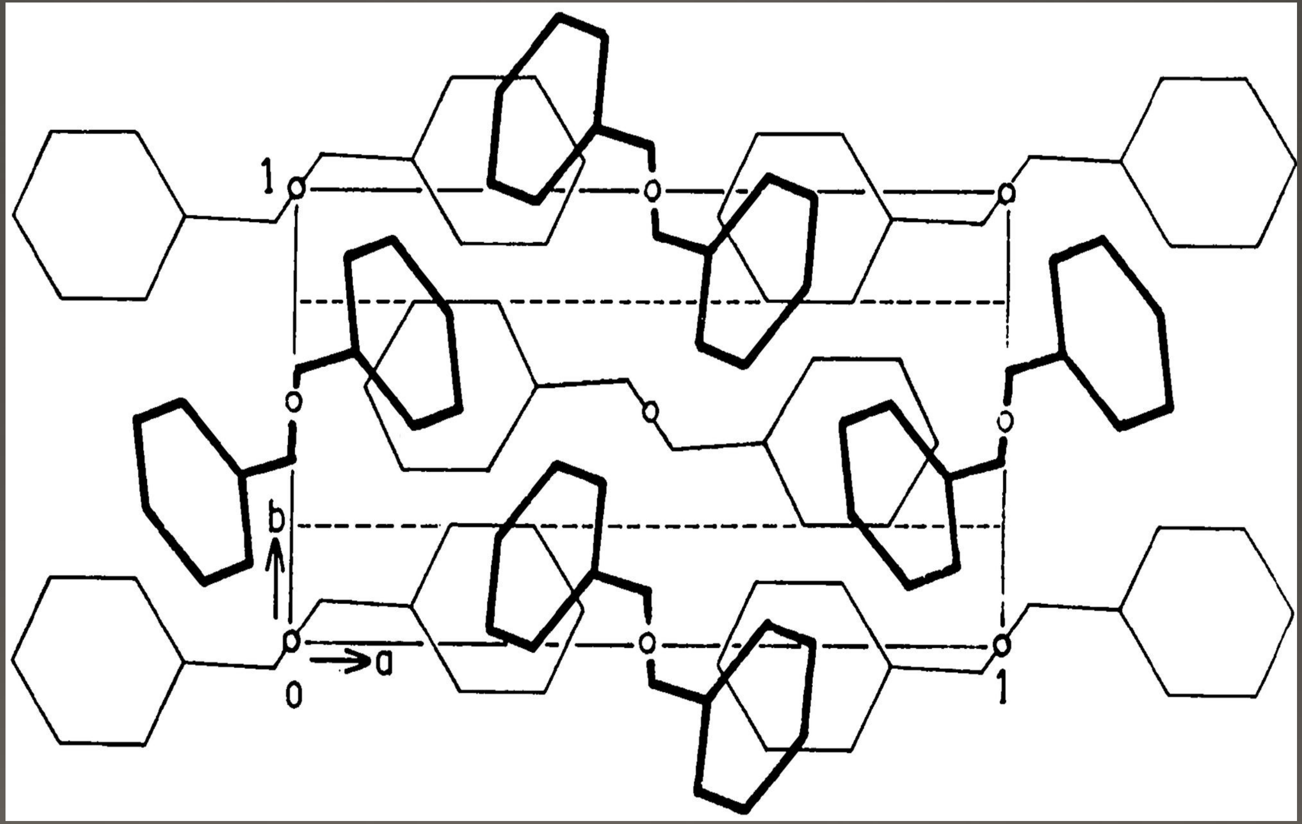


ArXiv:1912.02822 & 2103.08601

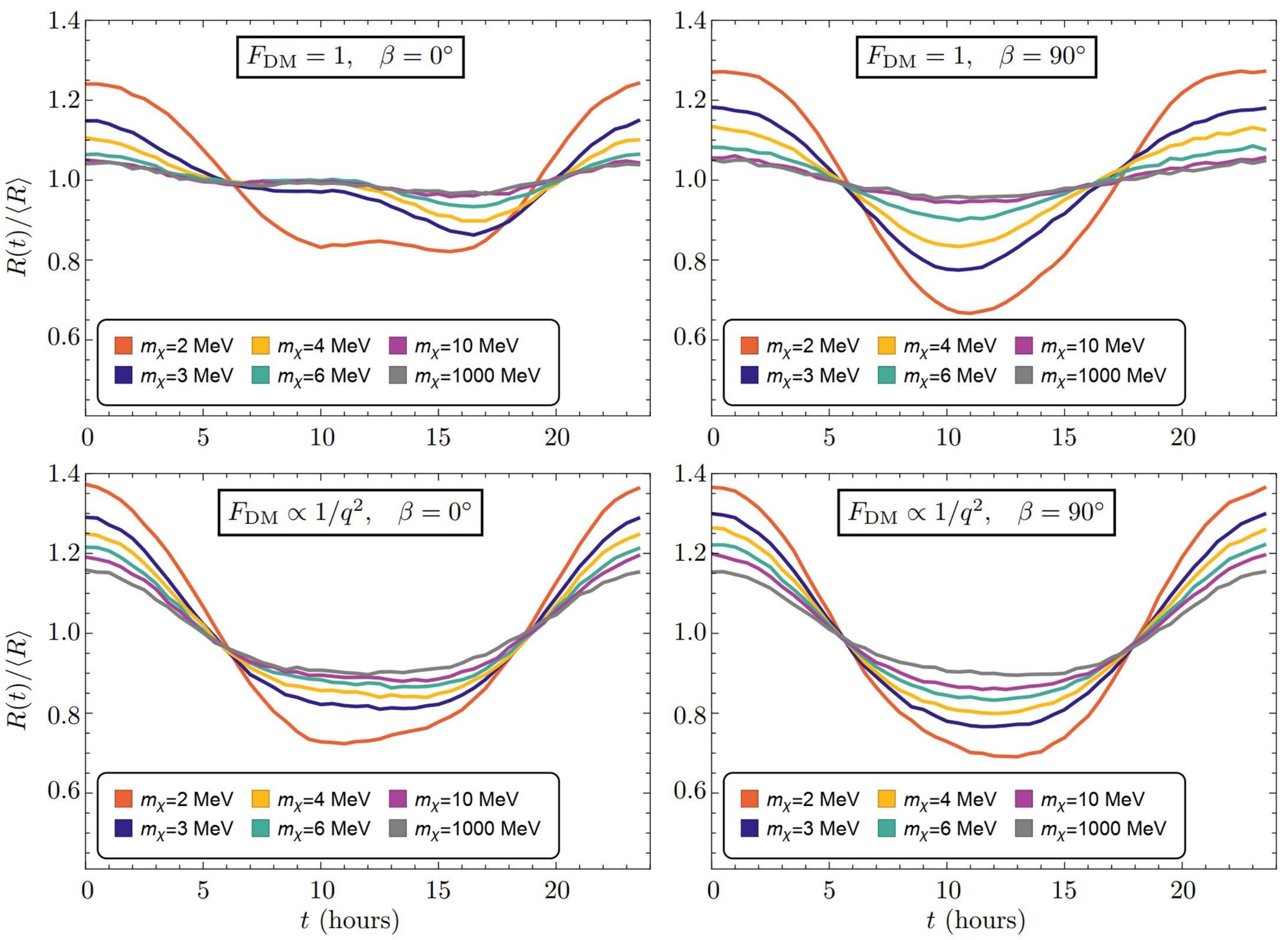
# Trans-Stilbene



Trans-Stilbene



# Daily Modulation



Normalized modulation signals for a variety of DM masses, $m_\chi$ = 2–1000 MeV, for a crystal in $\beta = 0°$ and $\beta = 90°$ orientations. Above 10 MeV, the rate relaxes into a function of time that is nearly independent of the DM mass and with modulation amplitude only mildly dependent on the crystal orientation. The peak-to-trough modulation amplitudes are as large as 60% at low masses and 10% at high masses for $F_{\rm DM} = 1$, increasing to 70% at low masses and 25% at high masses for $F_{\rm DM} = (\alpha m_e/q)^2$.

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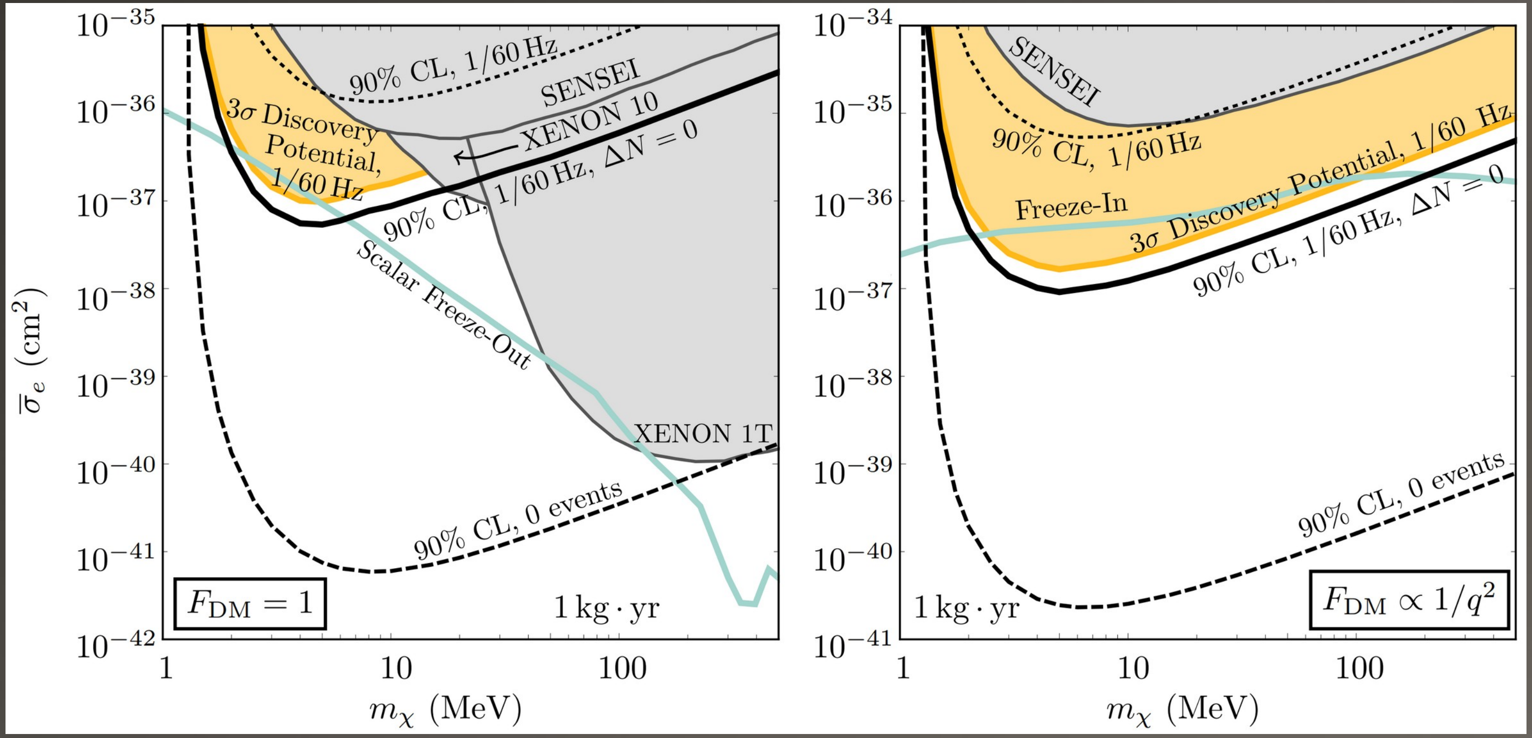
# Sensitivity & Reach: Solid



The capability of a 1 kg · year t-stilbene experiment to detect or exclude DM models with $F_{\rm DM} = 1$ or $F_{\rm DM} = (\alpha m_e/q)^2$ couplings to electrons, shown with existing limits from SENSEI, XENON 10, and XENON 1T. The dotted and dashed lines show the 90% CL exclusions that can be set from the total number of events, without considering modulation effects, for $R = 1/60\,\mathrm{Hz\,kg^{-1}}$ ($N_{\rm events} \approx 5.26 \times 10^5$) and for $N_{\rm events} = 0$, respectively. The orange shaded regions indicate parameter space that leads to a sufficiently large modulation signal that a 1 kg · year experiment could observe a $3\sigma$ detection, given a total observed rate of $R = 1/60\,\mathrm{Hz\,kg^{-1}}$. The solid black "$\Delta N = 0$" lines show the improved limit that can be set from a null result exhibiting no daily modulation but the same total observed rate.

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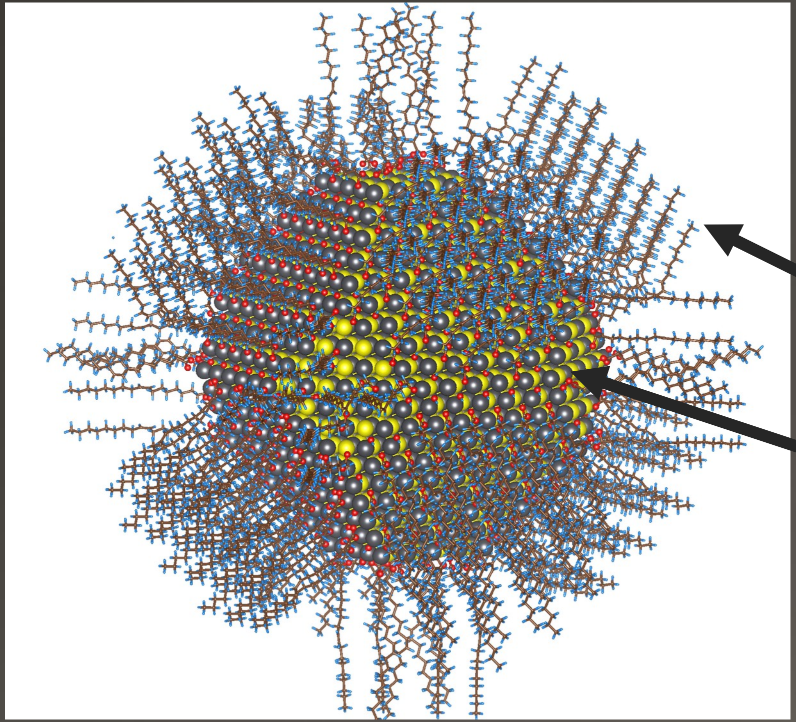
# Anatomy of QDs

Zherebetskyy et al., Science 344, 1380 (2014)



$$\overrightarrow{\phantom{R \sim 10}}$$

$$R \sim 10 \text{ nm}$$

$$R << a_0 \sim 20 \text{ nm}$$

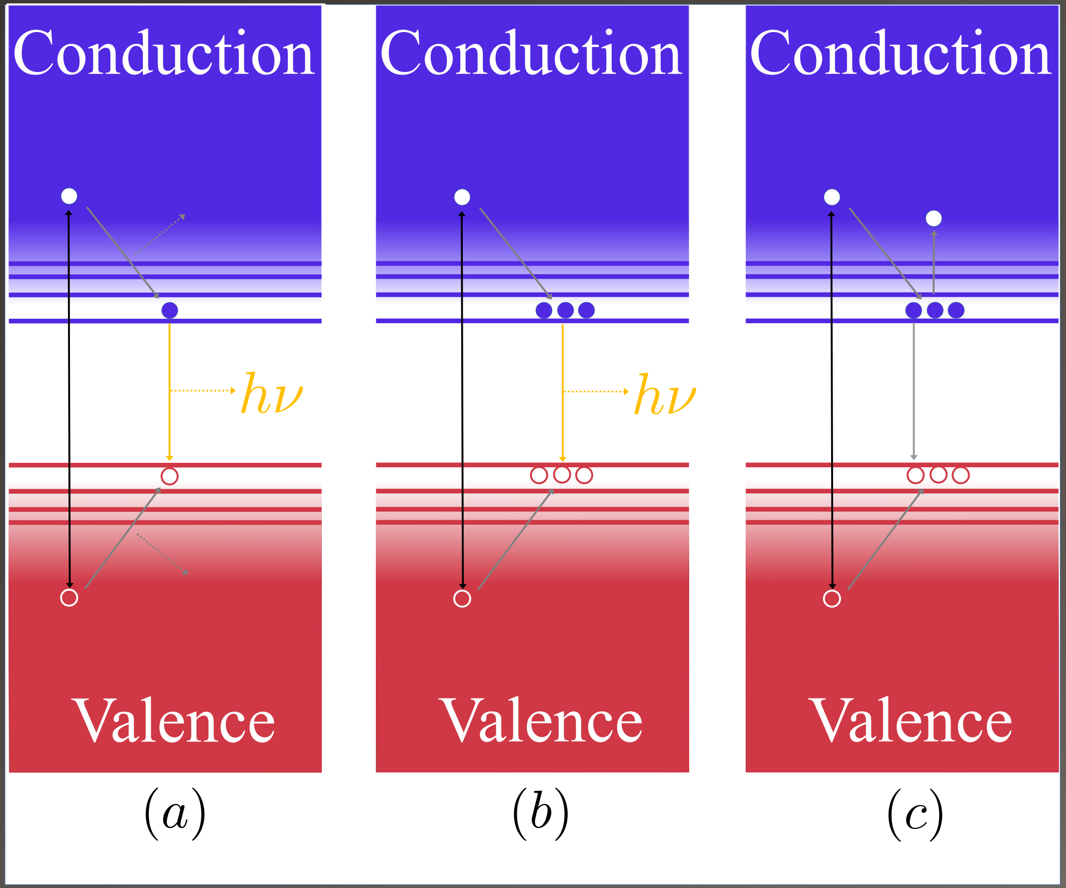
$$E_{\text{confinement}} = \frac{\hbar^2 \pi^2}{2R^2}\left(\frac{1}{m_e} + \frac{1}{m_h}\right) = \frac{\hbar^2 \pi^2}{2m^* R^2}$$

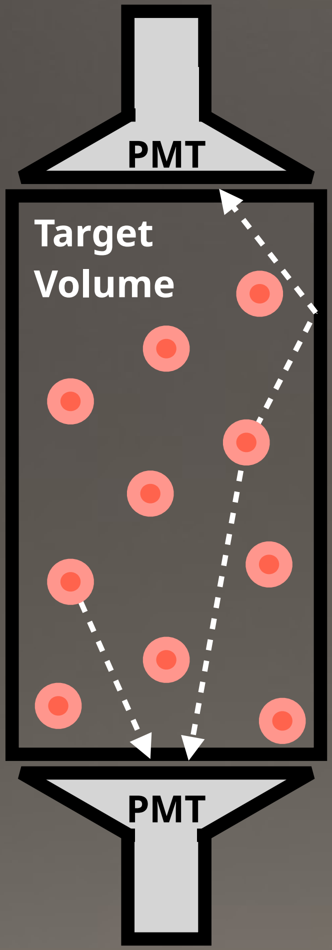
$$\begin{aligned} E &= E_{\text{bandgap}} + E_{\text{confinement}} \\ &= E_{\text{bandgap}} + \frac{\hbar^2 \pi^2}{2m^* R^2} \end{aligned}$$

Stabilizing ligands

Small semiconductor crystal (e.g. PbS, a = 0.5nm)

# Excitations in QD: Quick review





- Absorbtion: (b) Creation of a “hot” exciton – an electron/hole pair with energy significantly larger than the bandgap
- Non-Radiative Transition: (b) MEG – multi-exciton generation when energy is greater than twice the bandgap. Creates several band-edge excitons.
- Emission: (b) Radiative recombination of severalband-edge excitons producing several coincident photons

ArXiv:1912.02822 & 2103.08601

# QDs sensitivity