Supplementary Information for:

Effect of Anisotropic Confinement on Electronic Structure and Dynamics of Band Edge Excitons in Inorganic Perovskite Nanowires

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Section S1: Additional PL characterization of nanowire bundles



Figure S1: (a) Confocal microscopy PL image of 10 nm nanowire bundles (circled in red), excited at 473 nm. (b) Normalized PL spectra of the bundles in (a), showing homogeneity.



Figure S2: Normalized time-resolved PL (TRPL) of bundles of 10 nm nanowires in solution.

Section S2: Supplementary stroboSCAT Figures



Figure S3: Transverse stroboSCAT profiles of 10 nm nanowire bundle after excitation near a sidewall. The profile expands from a standard deviation of approximately 90 nm initially to 145 nm after 0.4 ns, for a diffusivity of approximately 0.2 cm²/s, substantially smaller than the longitudinal diffusivity. After 0.4 ns the excitations reach the far sidewall, and the profiles no longer provide useful information. Note that the colors correspond to different delay times and the horizontal axis scale is different than in Figure 2e.



Figure S4: stroboSCAT diffusion data from Figure 2f, with an attempted fit to a power law, $D(t) = D_0 t^{\alpha-1}$. The fit is poor.



Figure S5: Measured diffusion decay time as a function of pump laser fluence. If the initial rapid diffusion were an artifact of annihilation, we would expect the decay time to depend on fluence, but that is not seen to be the case.

Section S3: Model of Nanowire Diffusion with Trapping

We start with Equation 2 of the main text, and the following initial conditions: the mobile carriers have a Gaussian distribution with variance σ_0^2 , which is imparted by the pump pulse, and there are no trapped carriers. Make the equations dimensionless by defining σ_0 as the unit of length and $1/k_{fl}$ as the unit of time. The value of σ_0 is measured in the initial distribution, while $\frac{1}{k_{fl}} = 2.1$ ns is taken from the fastest component of the TRPL of 10 nm nanowires (Figure S4). Let $k \equiv k_{tr}/k_{fl}$ be the dimensionless trapping rate, and *D* be the dimensionless diffusivity. The equations are now:

$$\frac{\partial p_m}{\partial t} = D \frac{\partial^2 p_m}{\partial x^2} - p_m - k p_m$$

$$\frac{\partial p_{tr}}{\partial t} = k p_m - p_{tr},$$
(S1)

with initial conditions

$$p_m(x,t=0) = \frac{1}{\sqrt{2\pi}} e^{-x^2/2}$$

$$p_{tr}(x,t=0) = 0.$$
(S2)

Equations S2 can be solved exactly. For mobile carriers, the solution is an expression for ordinary diffusion times a decaying exponential with rate 1+k:

$$p_m(x,t) = \frac{e^{-\frac{x^2}{2(1+2Dt)}}}{\sqrt{2\pi(1+2Dt)}} e^{-(1+k)t} \theta(t),$$
(S3)

where $\theta(t)$ is the Heaviside step function. The equation for trapped carriers can be solved as well, by taking the Fourier transform, re-arranging, and taking the inverse Fourier transform. We find that the result is a convolution between a decaying exponential of rate 1 and the expression $kp_m(x, t)$:

$$p_{tr}(x,t) = \int_{-\infty}^{\infty} k p_m(x,\tau) e^{\tau - t} \theta(t - \tau) d\tau.$$
 (S4)

Plugging in Equation S3 for $p_m(x, t)$ we see that Equation S4 can be solved, but not in a closed form.

$$p_{tr}(x,t) = \frac{\sqrt{k}}{4\sqrt{D}} e^{-t+k/2D} \left[e^{-|x|\sqrt{\frac{k}{D}}} \left(\operatorname{Erf}\left(\frac{\sqrt{\frac{k}{D}}(1+2Dt) - |x|)}{\sqrt{2(1+2Dt)}}\right) - \operatorname{Erf}\left(\frac{\sqrt{\frac{k}{D}} - |x|}{\sqrt{2}}\right) \right) + e^{+|x|\sqrt{\frac{k}{D}}} \left(\operatorname{Erf}\left(\frac{\sqrt{\frac{k}{D}}(1+2Dt) + |x|)}{\sqrt{2(1+2Dt)}}\right) - \operatorname{Erf}\left(\frac{\sqrt{\frac{k}{D}} + |x|}{\sqrt{2}}\right) \right) \right],$$
(S5)

where Erf() is the error function. This is not insightful, but it allows us to plot the total population, $p(x,t) = p_m(x,t) + p_{tr}(x,t)$ and Fit it to a Gaussian, as shown in Figure S8a for parameters *D*=5 and *k*=1 at time *t*=1. We find that a Gaussian fit is appropriate, even for these parameters, which were chosen to accentuate the way in which the model can deviate from a Gaussian. For lower values of the ratio *D/k*, the result is even more Gaussian-like. The profile can be fit to a Gaussian to extract the variance, σ^2 . Plotted as a function of time, we see it fits well to a decaying exponential (Equation 1, main text).



Figure S6: Results of the diffusion trapping model (Equations S1-5). (a) Total exciton profile at time t=1 for parameters D=5 and k=1. Profiles are fit to a Gaussian to extract the variance, which is plotted as a function of time (b) and fit to an exponentially decaying diffusivity (Equation 1, main text).

The model clearly predicts results that look like our observations. Next, we use the fitting results to extract the values of various parameters in the model. The fits shown in Figure S8 return $\sigma_0 = 0.96$ (which is close to the real value of 1), D = 5.7 (which is slightly higher than the real value of 5), and $\tau_d = 0.45$, which is significantly different from the value of $k^{-1} = 1$. We fit the model for many values of D and k in order to create a map between those variables and the measured values, D_0 and τ_d . Dimensionless numbers were converted to real numbers by measuring the initial distribution to get σ_0 and using the lifetime as measured with TRPL to get k_{fl} .

While the intrinsic diffusivity, *D*, is of interest, the trapping rate, k_{tr} , is not so physically meaningful. We convert the trapping rate to a trap density with a second model, described here. We consider a square bundle of *n* by *n* nanowires, each of length *l*. The linear trap density is fixed to be some λ . For each nanowire, the number of traps on that nanowire is drawn from a Poisson distribution of mean $l\lambda$, and the traps are placed randomly along that nanowire. An exciton is initialized at an arbitrary position, and at each time step hops either left or right along its nanowire. With some probability D_r , it may hop in each of the orthogonal directions. This number is ratio of the transverse to the longitudinal diffusivity. Periodic boundary conditions are used. The simulation runs until the exciton encounters a trap. Running many such simulations produces a distribution of trapping times, and hence an average trapping time, $\langle \tau_{tr} \rangle$.

For given values of λ and D_r , 20,000 trajectories were run. The system size was set to n = 30and $l = 20/\lambda$, which was found to be large enough so that the results converged. Figure S9 shows the value of $\langle \tau_{tr} \rangle$ vs. λ on a log-log plot for several values of D_r : in all cases, the data lie on a line of slope -1. This implies that $\langle \tau_{tr} \rangle \propto 1/\lambda$, although the proportionality constant depends on D_r . We estimate D_r using the transverse diffusion measurement, shown in Figure S5. Those data, when fit to Gaussians, indicate a transverse diffusivity of $D_t = 0.22 \pm 0.13 \text{ cm}^2/\text{s}$. The longitudinal intrinsic diffusivity for that same bundle was $D_l = 0.76 \pm 0.09 \text{ cm}^2/\text{s}$, hence $D_r = \frac{D_t}{D_l} = 0.29 \pm 0.17$. Using this value, we can convert the trapping rate to a linear trap density. Eleven nanowire bundles were studied. Box plots of the intrinsic diffusivity, trapping time, and inverse linear trap density are shown in Figure S10.



Figure S7: Results of diffusion simulation to relate mean trapping time to linear trap density. Mean trapping time is plotted vs. linear trap density on a log-log plot, for several values of D_r . Each data set fits well to a line of slope -1.



Figure S8: Box plots of several values measured for each of 11 nanowire bundles: (a) intrinsic longitudinal diffusivity D_0 , (b) trapping time $1/k_{tr}$, and inverse linear trap spacing $1/\lambda$.

Section S4: Supplementary Linear Absorption Figures



Figure S9: (a) A single large nanowire (circled in red), hundreds of nanometers in width and about 20 μ m long. (b) Polarization-resolved absorption spectrum of that nanowire. 0° is defined as parallel to the long axis of the nanowire.





Figure S10: Normalized TA spectra of 10 nm CsPbBr₃ nanowires in solution, both bundled (solid lines) and isolated (dashed lines), at time delays 1 ps and 10 ps (offset for clarity). The timescales were found to be similar, and the spectra are identical up to a slight red-shift of the ground state bleach upon bundling. This is not surprising given the weak inter-nanowire coupling observed in stroboSCAT measurements.



Figure S11: (a) Evolution association spectra (EAS) of TA measurements on 10 nm $CsPbBr_3$ nanowire bundles in solution. (b) Normalized EAS, in order to accentuate how the shape of the spectrum changes over time.



Figure S12: Inverse of the GSB signal as a function of time, for several pump fluences. Dashed lines guide the eye, and show that the data are roughly linear at early times, indicative of biexciton recombination.

Section S6: Polarization Anisotropy Derivations and Supplementary Figures

Consider light of frequency ω_{ex} incident on a nanowire whose width is much smaller than the wavelength of the light. Let the nanowire have dielectric constant $\epsilon_{nw}(\omega_{ex})$, and the surrounding medium have dielectric constant ϵ_m . As a consequence of Maxwell's equations, the electric field for

light polarized along the short axis of the nanowire is reduced by $2\epsilon_m/(\epsilon_m + \epsilon_{nw}(\omega_{ex}))$.^{1,2} The same is true for light emitted at frequency ω_{em} , so the nanowire excitation and emission can both be cast in the following forms²:

$$P(\omega_{ex}) = 1 + \kappa(\omega_{ex})(\hat{c} \cdot \hat{e}_{ex})$$

$$P(\omega_{em}) = 1 + \kappa(\omega_{em})(\hat{c} \cdot \hat{e}_{em}),$$
(S6)

where \hat{c} is the unit vector along the nanowire axis and \hat{e} is the polarization of the exciting or emitted light. κ has the form

$$\kappa(\omega) = \frac{(\epsilon_m + \epsilon_{nw}(\omega))^2}{4\epsilon_m^2} - 1.$$
(S7)

In order to calculate the intensity for a given configuration, such as I_{HV} , we first fix the directions of \hat{e}_{ex} and \hat{e}_{em} and then take the product $P(\omega_{ex})P(\omega_{em})$. Define the excitation propagation direction as \hat{x} , the emission propagation direction as \hat{y} , and the vertical direction as \hat{z} . Letting the nanowire have orientation given by polar angle θ and azimuthal angle φ , the four intensities are:

$$\begin{split} I_{VV} &= (1 + \kappa_{ex} \cos^2 \theta) (1 + \kappa_{em} \cos^2 \theta) \tag{S8} \\ I_{VH} &= (1 + \kappa_{ex} \cos^2 \theta) (1 + \kappa_{em} \sin^2 \theta \cos^2 \phi) \\ I_{HV} &= (1 + \kappa_{ex} \sin^2 \theta \sin^2 \phi) (1 + \kappa_{em} \cos^2 \theta) \\ I_{HH} &= (1 + \kappa_{ex} \sin^2 \theta \sin^2 \phi) (1 + \kappa_{em} \sin^2 \theta \cos^2 \phi). \end{split}$$

For an isotropic distribution of nanowires we take the average over θ , φ , and easily verify that $I_{VV} \ge I_{VH} = I_{HV} = I_{HH}$. The polarization anisotropy between I_{VV} and I_{VH} is:

$$A_V \equiv \frac{I_{VV} - I_{VH}}{I_{VV} + I_{VH}} = \frac{\kappa_{ex} \kappa_{em}}{15 + 5\kappa_{ex} + 5\kappa_{em} + 2\kappa_{ex} \kappa_{em}}.$$
(S9)

The optical frequency dielectric constant of cyclohexane, which is the solvent we use for unbundled 10 nm nanowires, is 2.02. The optical frequency dielectric constant of CsPbBr₃ is not well known, but computations indicate that it is about 5.³ Using these values we get $\kappa_{ex} = \kappa_{em} = 2.02$ and $A_V = 0.09$. For comparison, the measured value based on the PL peak in Figure 5 is $A_V = 0.14$. Clearly, something else is at work.

We consider that the absorption and emission TDMs could be anisotropic. For a transition at a given frequency, let the TDM strength be $d_{||}$ for light polarized along the long axis of the nanowire, and d_{\perp} for light polarized along the short axis of the nanowire. We then have:

$$\kappa(\omega) = \frac{d_{||}^2 (\epsilon_m + \epsilon_{nw}(\omega))^2}{4d_{\perp}^2 \epsilon_m^2} - 1.$$
(S10)

If the occupation of band-edge states is non-uniform that would also modify κ , but we do not consider this possibility because the TAM measurements in the main text indicate that the energy shift between states of different polarizations is only about 5 meV, which is small compared to the thermal energy at room temperature.

We also consider orientational anisotropy of the nanowires. Let the orientational distribution be isotropic in φ , but have some polar probability distribution function $f(\theta)$, where the normalization condition is

$$\int_{0}^{\pi/2} f(\theta) \sin \theta d\theta = 1.$$
 (S11)

Define the following moments of the distribution:

$$m_{2} \equiv \int_{0}^{\pi/2} f(\theta) \cos^{2} \theta \sin \theta d\theta$$

$$m_{4} \equiv \int_{0}^{\frac{\pi}{2}} f(\theta) \cos^{4} \theta \sin \theta d\theta.$$
(S12)

For a uniform distribution, $m_2 = 1/3$ and $m_4 = 1/5$.

Combining the two effects described above, we have the following emission intensities:

$$\begin{split} I_{VV} &= 1 + \kappa_{ex}m_2 + \kappa_{em}m_2 + \kappa_{ex}\kappa_{em}m_4 \qquad (S13) \\ I_{VH} &= 1 + \kappa_{ex}m_2 + \kappa_{em}\frac{1 - m_2}{2} + \kappa_{ex}\kappa_{em}\frac{m_2 - m_4}{2} \\ I_{HV} &= 1 + \kappa_{ex}\frac{1 - m_2}{2} + \kappa_{em}m_2 + \kappa_{ex}\kappa_{em}\frac{m_2 - m_4}{2} \\ I_{HH} &= 1 + \kappa_{ex}\frac{1 - m_2}{2} + \kappa_{em}\frac{1 - m_2}{2} + \kappa_{ex}\kappa_{em}\frac{1 - 2m_2 + m_4}{8}. \end{split}$$

We cannot make much progress without knowing something about the orientational distribution, but it is enlightening to consider the anisotropy between I_{VH} and I_{HV} :

$$A_{cross} = \frac{I_{HV} - I_{VH}}{I_{HV} + I_{VH}} = \frac{3(\kappa_{em} - \kappa_{ex})(m_2 - 1/3)}{4 + (\kappa_{em} + \kappa_{ex})(1 + m_2) + 2\kappa_{ex}\kappa_{em}(m_2 - m_4)}.$$
 (S14)

The anisotropy is proportional to both $(\kappa_{em} - \kappa_{ex})$ and also $(m_2 - 1/3)$. Therefore, fluorescence anisotropy between I_{VH} and I_{HV} (which we observe) implies there must be orientational anisotropy **and** there must be a difference between κ for excitation and emission. We do not have enough information to determine the magnitude of this difference, but we can consider possible causes. It could be because ϵ_{nw} is a strong function of frequency, in which case the fact that excitation and emission are at different frequencies would produce different values of κ . However, the amount of anisotropy is uniform in emission frequency, implying that anisotropic TDMs are the cause: $d_{||} \neq d_{\perp}$. We cannot disentangle the effects of absorption and emission anisotropy, however repeating the measurement with 408 nm excitation light (Figure S16) results in a slightly different amount of anisotropy: $A_V = 0.12$. This implies that anisotropy in the absorption TDM is at least partially responsible for our observations.

In order to control for variations in signal strength between the four polarization configurations, a small control molecule (a derivative of triphenylsulfonium) was used. After measuring a PL spectrum of the nanowires, we immediately measured the time-resolved PL of the control molecule for the same excitation and emission polarizations. Because it rotates rapidly, the control molecule should not display any anisotropy in its emission. Any observed anisotropy is therefore due to differences in the excitation or detection efficiency. We found that rotating the laser polarization did not change the PL signal strength for the control molecule but rotating the emission polarizer did change the signal strength because the efficiency of light through the emission monochromator is wavelength- and polarization-dependent. The ratio of the control molecule's PL spectra for a vertically vs. horizontally aligned emission polarizer gives a correction factor, $G(\lambda)$. In the equations above, the intensities I_{HV} and I_{HH} are not the raw counts, but have been scaled by $G(\lambda)$.



Figure S13: Polarized PL spectra of 10 nm diameter nanowires in cyclohexane, 408 nm excitation. The first letter of the legend indicates the polarization of the excitation beam (vertical or horizontal) and the second letter indicates the polarization of the measured emission. The anisotropy between VV and VH is 0.12, which is slightly less than what we measured when exciting at 465 nm, but still more than what we expect from purely electrodynamic effects.

Section S7: Exciton fine structure model

The polarization-resolved linear and non-linear absorption measurements conducted in 10 nm perovskite nanowires (NWs) clearly indicate that the lowest bright exciton level has its transition dipole

moment parallel to the NW axis. This property is similar to observations reported previously on polarization properties of perovskite nanocrystals (NCs) with nominally tetragonal symmetry that have nearly cubic shape.^{4,5} As shown in Sercel et. al.⁶ early interpretations of this level order were based on the unjustified assumption that the tetragonal crystal field that splits the upper conduction band is negative. The fine structure created by the electron hole exchange interaction in cube-shaped CsPbBr₃ perovskite NCs with the correct (positive) sign of crystal field, as determined by calculations using density functional theory, results in a level order not consistent with the experimentally observed fine structure.⁶

Currently there are two viable theoretical models that describe the experimentally observed level structures in nearly cube-shaped CsPbBr₃ perovskite nanocrystals. The first one (the Rashba model)⁷ is connected with the effect of Rashba terms that flips the level ordering in the weak confinement regime,⁶ when the Rashba contribution to the fine structure becomes larger than the exchange contribution. The second model is connected with effect of shape anisotropy via the long-range exchange interaction.⁸

In order to describe the ~5 meV splitting observed in NWs within the Rashba model, we would need to assume that the Rashba coefficient in NWs is ~2 -3 times larger than that required to describe the ~1 meV splitting in excitons in cube-shaped NCs; moreover, the direction of the inversion symmetry breaking would be required to be parallel to the NW axis.

Here we apply the second model, connected with the effect of shape asymmetry in conjunction with long-range exchange, to the case of nanowires. As demonstrated by Nestoklon et. al.,⁸ the long-range exchange interaction acts to create a splitting between the exciton sub-levels when there is a shape asymmetry. To explore this effect for nanowires, we model the NW as a rectangular prism with equal x and y dimensions, $L_x = L_y = L$, but with an unequal z dimension, L_z . As shown by Cho⁹, the long-range exchange energy of a given exciton state, X_i can be written in terms of the Coulomb energy of the polarization associated with the exciton state:

$$H_{X_{i}} = \iint_{V} \left(-\vec{\nabla}_{\vec{r}_{1}} \cdot \vec{P}_{X_{i}}(\vec{r}_{1}) \right)^{*} \frac{1}{\epsilon_{\infty} |\vec{r}_{1} - \vec{r}_{2}|} \left(-\vec{\nabla}_{\vec{r}_{21}} \cdot \vec{P}_{X_{i}}(\vec{r}_{2}) \right).$$
(S15)

Here, the exciton polarization is equal to the transition dipole density [6],

$$\vec{P}_{X_i}(\vec{r}) = -i \; \frac{e\hbar}{m_o E_g} f(\vec{r}, \vec{r}) \vec{p}_{X_i}. \tag{S16}$$

In this expression, $f(\vec{r}_e, \vec{r}_h)$ is the envelope function of the exciton, while \vec{p}_{X_i} is its associated unit-celllevel transition dipole matrix element.⁶ In the expressions above, E_g is the band gap, ϵ_{∞} is the high frequency dielectric constant, and m_0 is the free electron mass. Within the weak confinement regime, we calculate the long-range exchange energy of the exciton states whose transition dipole moment is polarized parallel to the axis of elongation (*z*) of the NW and do the same for the states whose transition dipole moments are perpendicular to the axis of elongation. The envelope function for the ground exciton in the weak confinement regime is written,⁶

$$f(\vec{r}_e, \vec{r}_h) = \phi_{1s}(0) \psi_g(X, Y, Z)$$
 (S17)

Here ϕ_{1s} is the hydrogenic ground state wavefunction in the electron-hole relative coordinate, while ψ_g is the ground center-of-mass envelope function for an exciton confined within a right rectangular prism with dimensions $L_x = L_y = L \neq L_z$. This is given in terms of the exciton's center-of-mass coordinates X, Y, Z as⁶,

$$\psi_g(X,Y,Z) = \left[\frac{8}{L^2 L_z}\right]^{1/2} \cos\left(\frac{\pi X}{L}\right) \cos\left(\frac{\pi Y}{L}\right) \cos\left(\frac{\pi Z}{L_z}\right)$$
(S18)

We find, in agreement with Nestoklon et al.,⁸ that the exciton with a transition dipole moment parallel to the axis of elongation has lower energy than the exciton sublevel whose transition dipole moments are parallel to the short axis.^{6,8} The resulting energies are plotted versus the ratio, L_z/L , between the *z*-dimension of the NW, L_z , and the transverse dimension, *L*, of the NW in Figure S18:



Figure S14: Long range exchange energy for exciton sub-levels in a right rectangular prism of length L_z with transverse dimension L. For $L_z/L > 1$, the exciton sub level with transition dipole moment along z is lower in energy than the exciton sublevels with transversely polarized transition dipole moments. In the limit of large ratio L_z/L , the splitting between the z exciton and the transverse exciton approaches $\hbar\omega_{LT}/2$. When $L_z/L = 1$, the energies of the three exciton sub-levels with transition dipole moments along x, y and z are degenerate and equal to $\hbar\omega_{LT}/3$.

The energy scale of the splitting is the longitudinal-transverse splitting of the bulk exciton, $\hbar\omega_{LT}$ where

$$\hbar\omega_{LT} = \frac{4}{3\epsilon_{\infty}a_x^3} \frac{E_p}{m_0} \left(\frac{\hbar e}{E_g}\right)^2. \tag{S19}$$

In this expression E_p is the Kane energy, E_g is the band gap, ϵ_{∞} is the high frequency dielectric constant, m_0 is the free electron mass and a_x is the exciton Bohr radius. The value of $\hbar\omega_{LT}$ in bulk CsPbBr3 was recently measured as 5.4 meV.¹⁰ This value is consistent with the measured effective mass and inferred exciton Bohr radius for bulk CsPbBr3¹¹ using a high frequency dielectric constant $\epsilon_{\infty} = 4.8.^{12}$

Inspection of Fig. S18 shows that for large aspect ratios, $L_z/L >> 1$, the splitting between the *z* polarized exciton and the transverse excitons approaches $\hbar\omega_{LT}/2$, with the *z*-polarized exciton being lowest in energy, qualitatively consistent with the observed splitting measured in the NW experiments.

The above splitting estimation does not take into account dielectric corrections to the longrange exchange that will drive the transverse exciton energy up by an amount proportional to (κ -1)/(κ +1) owing to image charge effects, while the *z* exciton energy will be unaffected. Here, κ is the ratio of the dielectric constant inside the NW to that of the surrounding medium. Calculating the image charge effect for a cylindrical nanowire,¹³ we estimate a 29% increase in the fine structure splitting for κ =2.5, leading to a total splitting of ~ 3.5 meV. In addition, in the nanowire it is expected that the twodimensional quantum confinement will enhance the exciton binding energy, decreasing the exciton Bohr radius and therefore increasing the value of $\hbar\omega_{LT}$ as shown in Equation S19. In this case, as the exciton binding energy increases and the exciton radius decreases, the exciton is pushed into the weak confinement regime where the splitting is essentially independent of the lateral size.

Our modelling shows that the polarization dependent splitting observed in CsPbBr₃ NWs is qualitatively consistent with splitting due to long-range exchange in conjunction with the shape anisotropy of the NW. DFT calculations indicate that crystal field effects cannot explain the observed polarization dependent splitting.⁶

The magnitude of the splitting observed, 5 meV, is ~ 40% larger than would be expected from the longrange exchange splitting in the weak confinement limit (~ 3.5 meV). This suggests that dielectric confinement effects and the two-dimensional confinement of the exciton in the NW may cause enhancement of the exciton binding energy relative to bulk excitons with a concomitant increase in the long-range exchange splitting energy.

Another explanation could be an increase of the Rashba term's magnitude, or a combination of both effects discussed above.

Supplementary References

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