

Polaritonic quasi-bound states in the continuum in individual van der Waals nanoantennas

Qi Ding,^a Swain Ashutosh,^{b,c} Luca Sortino,^d Thomas Weber,^d Lucca Kühner,^d Stefan A. Maier,^{e,f} Sergey Kruk,^b Yuri Kivshar,^{b,*} Andreas Tittl,^{d,g,*} and Wei Wang^{a,*}

^aSichuan University, College of Physics, Chengdu, China

^bAustralian National University, Research School of Physics, Canberra, Australian Capital Territory, Australia

^cUniversity of Glasgow, School of Physics and Astronomy, Glasgow, United Kingdom

^dLudwig-Maximilians-Universität München, Nano-Institute Munich, Faculty of Physics, Chair in Hybrid Nanosystems, Munich, Germany

^eMonash University Clayton Campus, School of Physics and Astronomy, Melbourne, Victoria, Australia

^fImperial College London, Department of Physics, London, United Kingdom

^gHamburg University of Technology, Institute of Photonics, Hamburg, Germany

Abstract. The study of strong light–matter interaction in van der Waals (vdW) materials is at the forefront of current research in physics and chemistry, and it can be enhanced dramatically by employing optical resonances. Here, we report on the first observation of quasi-bound states in the continuum (qBICs) realized via polaritonic interfering resonances in isolated WS₂ nanodisks. We validate experimentally the existence of polaritonic qBICs driven by the intrinsic coupling of Mie resonances and vdW excitons. We observe exceptionally strong light–matter interaction with a measured Rabi splitting approaching 270 meV – the largest reported value among all transition metal dichalcogenide self-hybridized systems to date. The giant coupling strength stems from qBIC-induced in-plane field enhancement, which strongly interacts with in-plane excitonic dipoles while suppressing radiative losses. Polarization-controlled measurements further demonstrate selective excitation of qBIC through switching incident polarization to specific orthogonal configurations. The observed polarization-dependent coupling provides an additional degree of freedom to control the hybrid states’ spectral characteristics and spatial field distributions. Our demonstrations provide a pathway for engineering high-quality light–matter hybrid states in compact nanostructures, with potential applications in on-chip photonics, polaritonics, and quantum optics.

Keywords: excitons; TMDC; quasi-BIC resonances; polaritons; strong coupling; nanoantennas.

Received Jan. 24, 2026; revised manuscript received Apr. 17, 2026; accepted for publication Jun. 16, 2026; published online Jul. 20, 2026.

© The Authors. Published by SPIE and CLP under a Creative Commons Attribution 4.0 International License. Distribution or reproduction of this work in whole or in part requires full attribution of the original publication, including its DOI.

[DOI: [10.1117/1.AP.8.4.046016](https://doi.org/10.1117/1.AP.8.4.046016)]

1 Introduction

The pursuit of strong light–matter interaction in nanophotonic architectures lies at the heart of polariton physics, where hybridized photonic-electronic states unlock exciting phenomena ranging from Bose-Einstein condensation to low-threshold polariton lasers.¹ Central to this endeavor are transition metal dichalcogenides (TMDCs), which are van der Waals materials hosting tightly bound excitons with exceptional room-temperature

stability (binding energies >200 meV). Their unique valley-tronic properties, combined with tunability via strain, dielectric environment, and electrostatic gating, position TMDCs as versatile platforms for the study of strong light–matter interactions at the nanoscale.² Critically, TMDCs maintain large excitonic oscillator strengths even in ultrathin configurations (10 to 100 nm), enabling direct integration with planar photonic systems while preserving quantum confinement effects.^{3,4}

Realizing strong coupling necessitates concurrent optimization of three parameters: (1) deep subwavelength light confinement to enhance local field intensities, (2) spectral overlap between optical resonances and excitonic transitions, and (3) spatial mode

*Address all correspondence to Yuri Kivshar, yuri.kivshar@anu.edu.au; Andreas Tittl, andreas.tittl@tuhh.de; Wei Wang, w.wang@scu.edu.cn

matching to maximize coupling strengths. Although these conditions have been met in TMDC monolayers coupled to plasmonic nanostructures, photonic crystals, and microcavities, such hybrid systems face intrinsic limitations. Plasmonic platforms suffer from ohmic losses restricting Q -factors, whereas multilayer microcavities demand precise alignment and lack postfabrication tunability.⁵

Recent advances leveraging photonic bound states in the continuum (BICs) address these challenges by offering lossless dielectric confinement with ultrahigh Q -factors and geometrically tunable resonances.^{6–16} Current implementations of TMDC-BIC coupling, however, rely on heterogeneous integration-mechanically transferring exfoliated TMDC layers onto prefabricated all-dielectric metasurfaces (e.g., Si, TiO_2). This approach introduces interfacial defects, strain-induced exciton shifts, and reduced coupling efficiency due to a limited overlap between evanescent metasurface fields and TMDC excitons. The insertion of protective buffer layers such as h-BN, while mitigating environmental degradation, further diminishes field-exciton interaction strength. These constraints highlight the need for monolithic systems that intrinsically unite exciton materials with photonic resonators.

Self-hybridized architectures, where the active material itself forms the photonic cavity, present an elegant solution by eliminating interfacial losses and enabling direct modal overlap.^{17–27} Pioneering work demonstrated this concept in tungsten disulfide (WS_2) metasurfaces supporting symmetry-protected BICs, achieving Rabi splittings of over 110 meV.²¹ Nevertheless, extending this paradigm to standalone subwavelength resonators - a critical step toward scalable quantum emitters and on-chip polaritonic circuits - remains unexplored. Recent theoretical insights suggest that individual dielectric nanoparticles can support quasi-BIC (qBIC) modes through interference between optical modes, combining subwavelength confinement with ultra-high Q factors in lossless systems.^{28–33} Although such isolated quasi-BIC resonators have shown enhanced light-matter interactions^{34–37} and nonlinear processes,^{38–42} their potential for strong light-matter interactions in self-hybridized configurations has not yet been realized.

In this paper, we demonstrate polaritonic qBICs in isolated WS_2 nanodisks via intrinsic coupling of Mie resonances and excitons. Theoretical modeling reveals that interference between two vectorial Mie modes generates photonic qBICs, which hybridize with in-plane excitons to produce anti-crossing features with an approximate 270 meV Rabi splitting—the largest reported in self-hybridized TMDC systems. Experimentally, azimuthally and TE-polarized excitations confirm the existence of polaritonic qBICs. We further reveal that the observed giant energy splitting originates from qBIC-induced in-plane field enhancement, which strongly interacts with excitonic dipoles while suppressing radiative losses. Polarization control enables the selective activation of qBIC, allowing the modulation of hybrid states' spectral properties. We believe that our findings provide a general strategy for engineering high-quality light-matter hybrid states in compact nanostructures, paving the way for advances in nanoscale light manipulation, energy transfer, and sensing technologies.

2 Results and Discussion

The designed system, as shown in Fig. 1(a), consists of a WS_2 nanodisk placed on a multilayered substrate. The substrate is composed of a SiO_2 spacer ($t_2 = 55$ nm), a gold reflector with

a thickness of $t_1 = 100$ nm, and a SiO_2 base layer. As a high-refractive-index nanoresonator, the WS_2 nanodisk can support two vectorial Mie modes when illuminated with an azimuthally polarized beam at normal incidence. Interference between these Mie modes leads to the formation of a Friedrich–Wintgen BIC (FWBIC),³¹ as illustrated in Fig. 1(b) (top panel). The excited FWBIC mode further couples with the intrinsic A excitons of the bulk WS_2 nanodisk, leading to the formation of polaritonic BICs (middle panel). Compared with traditional exciton polaritons (EPs) formed by the coupling of optical modes in nanostructures with excitons in semiconductor materials (bottom panel), the polaritonic BIC in this system emerges through the interference of two vectorial Mie modes, forming a qBIC, which subsequently couples with the intrinsic excitons. One key advantage of this self-hybridized approach is that the qBIC mode is confined within a highly compact isolated nanoresonator, exhibiting extremely strong subwavelength field confinement. This enables highly efficient coupling with the intrinsic exciton, significantly enhancing the strength of light-matter interactions.

In our experiments, we fabricated a series of WS_2 nanodisks with different radii using a combination of electron beam lithography (EBL) and dry etching techniques (see the Appendix for details). Scanning electron microscopy (SEM) images of the nanodisk are shown in the bottom panel of Fig. 1(a) (see also Sec. 1 of the Supplementary Material).

2.1 Formation of Photonic quasi-BIC

To investigate the optical properties of the WS_2 nanodisk system, we performed full-wave simulations using commercial simulation software (COMSOL Multiphysics). In our simulation, we used the dielectric function of WS_2 obtained from experimental ellipsometry measurements,⁴³ as shown in the middle right panel of Fig. 1(a). The details of the real and imaginary parts of the dielectric function are shown in Fig. S5 in the Supplementary Material.

We first consider the nanodisk as a pure high-refractive-index nanoresonator by disabling the A-exciton contribution. For this purpose, we fitted the dielectric function by a sum of Lorentzian oscillators and excluded the contribution of the A exciton. The calculated background dielectric function is shown in Fig. S5(b) (see Sec. 4 of the Supplementary Material for details). Figure 2(a) presents the simulated scattering spectra as a function of the radius r of the nanodisk (100 to 200 nm), with a fixed nanodisk height of $h = 200$ nm. An anti-crossing behavior is clearly visible with the formation of two resonance branches (white lines), which arise from the interference of two vectorial Mie modes. Interestingly, the high-energy branch exhibits a narrow linewidth and a noticeable linewidth variation, whereas the low-energy branch exhibits a negligible variation in linewidth while varying the size of the nanodisks.

To quantitatively analyze the spectral feature of both branches, we further conducted eigenmode calculations to obtain their resonance energies E_{res} and damping rates γ_{res} . Subsequently, the Q factors are given in Fig. 2(b) by calculating the well-established formula $Q_{\text{res}} = E_{\text{res}}/(2\gamma_{\text{res}})$.³⁸ It is evident that the low-energy branch maintains a consistently low Q -factor across all radii (gray line), which is defined as a low- Q (LQ) mode. In contrast, the Q -factor of the high-energy branch (blue line), marked as high- Q (HQ) mode, initially increases with increasing disk radius and reaches a maximum value of ≈ 400 at $r = 140$ nm (red dot), coinciding with a

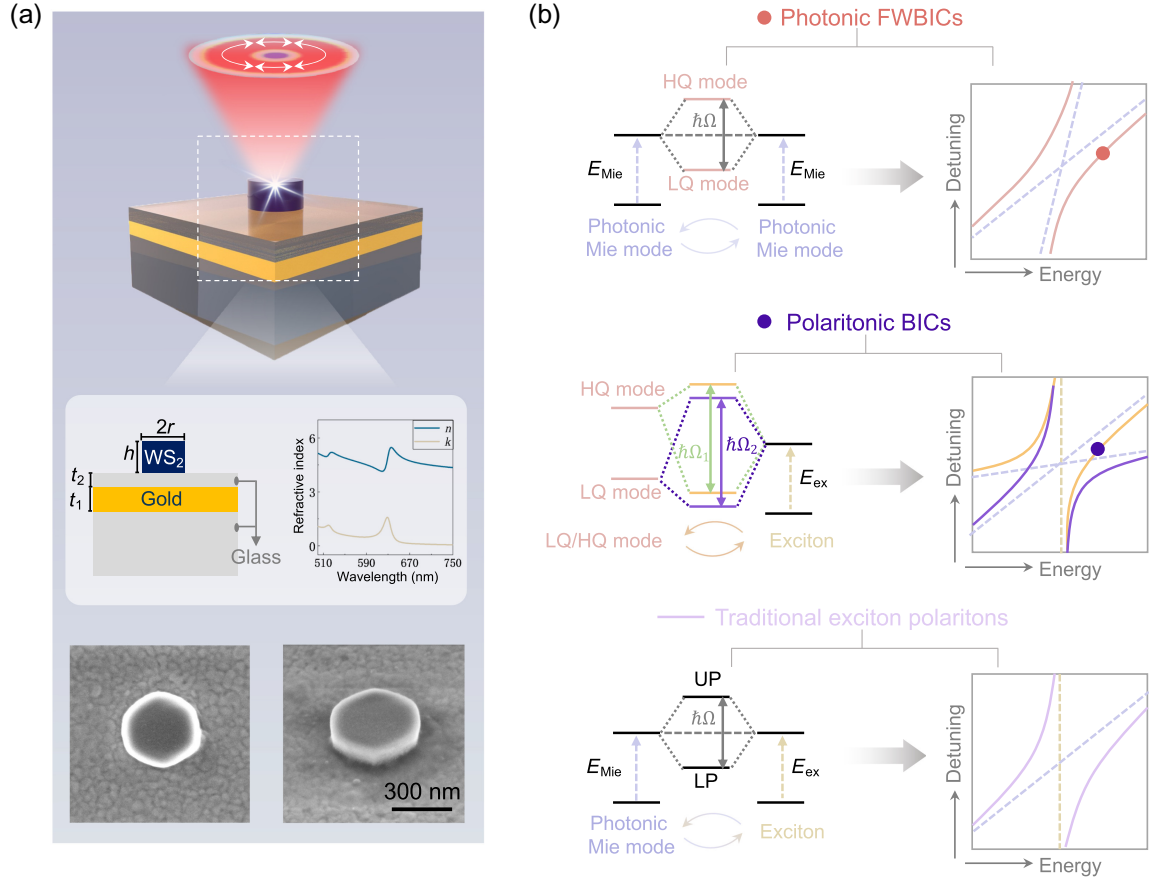


Fig. 1 (a) Sketch of a WS₂ nanodisk placed on a substrate and illuminated by an azimuthally polarized light. Top-view and tilt-view scanning electron microscope (SEM) micrographs of fabricated WS₂ nanodisks are given in the bottom panel. Middle right panel shows the complex refractive index of bulk WS₂ under study. (b) Concept of the formation of a photonic FWBIC (top panel), a polaritonic BIC (middle panel), and an exciton polariton (bottom panel).

divergence in the Fano asymmetry parameter q (see Fig. S3 in the [Supplementary Material](#)). Notably, the thickness of the SiO₂ spacer layer t_2 provides control over the reflection phase,³⁸ further enhancing the destructive interference of the Mie modes in the far field, thereby increasing the Q factor of HQ mode. In this context, t_2 was optimized to maximize the HQ mode performance and the observation of coupling behavior. To quantitatively study the linear optical response of the coupled system, we then describe the system by an effective non-Hermitian Hamiltonian in the form of a 2×2 matrix:⁴⁴

$$H = \hbar \begin{bmatrix} \omega_1 - i\gamma_1 & g \\ g & \omega_2 - i\gamma_2 \end{bmatrix} - i \begin{bmatrix} 0 & \gamma_c \\ \gamma_c & 0 \end{bmatrix}. \quad (1)$$

Here, ω_i and γ_i are the angular frequency and damping rate of the i th mode. g represents the coherent coupling strength. Note that an important cross-damping term γ_c is included to consider the influence of the coupling-induced incoherent interaction process. It is crucial to emphasize that incoherent coupling cannot be neglected in our case. We will show that the simulated optical characteristics of the hybrid system can be well reproduced provided that the terms coherent (g) and incoherent (γ_c) are taken into account.

By solving Eq. (1) with an optimized coupling energy of $\hbar g = 30$ meV and a cross-damping term of $\hbar \gamma_c = 25$ meV, we successfully reproduce both the dispersion [dots in Fig. 2(c)] and the spectral linewidths [dashed lines in Fig. 2(d)] of the two branches obtained from the eigenvalue calculations. The calculated dispersion [white lines in Fig. 2(a) and gray lines in Fig. 2(c)] is further overlaid on the simulated spectra in Fig. 2(a), showing excellent agreement between theory and calculated results, supporting the validity of our model. Further details of the calculation are provided in Sec. 2 of the [Supplementary Material](#).

In this system, the coherent coupling strength $\hbar g$ enables efficient energy exchange between the two Mie resonators. Beyond this coherent interaction, the open nature of the system requires the inclusion of a non-Hermitian cross-damping term $\hbar \gamma_c$. Microscopically, γ_c arises from radiation coupling, where multiple Mie modes radiate into a shared far-field reservoir. According to temporal coupled-mode theory (TCMT),⁴⁵ when such modes coexist within the same environment, their radiation fields interfere coherently rather than decaying independently. This interference, governed by the relative phases of their radiation patterns, gives rise to the off-diagonal elements of the decay matrix. This vacuum-mediated coupling constitutes the fundamental origin of the observed linewidth asymmetry.

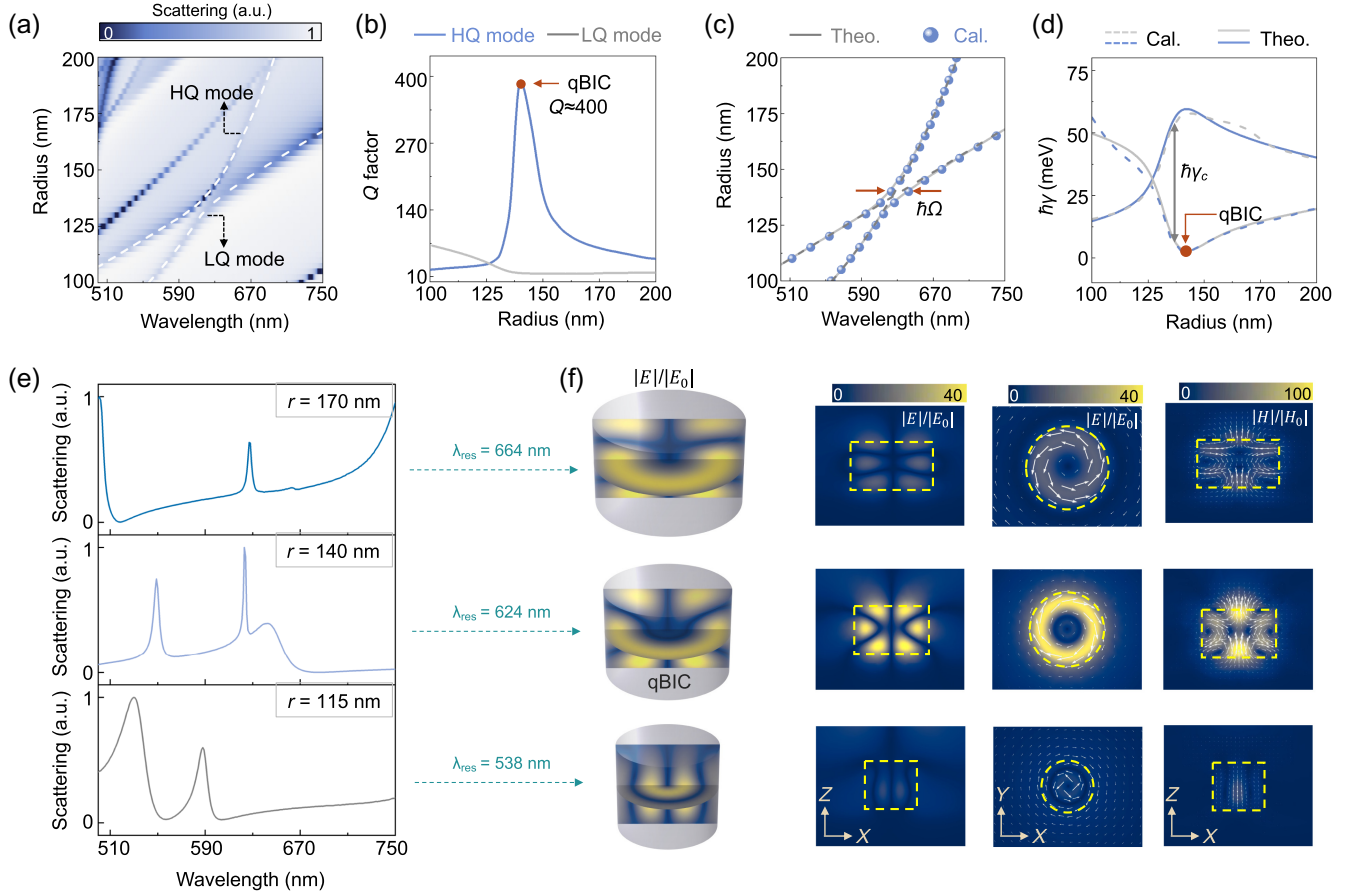


Fig. 2 (a) The calculated normalized scattering spectra as a function of r with background permittivity. Dashed white lines are the calculated high- Q and low- Q modes by the coupling oscillator model. (b) The Q factor versus the radius of the nanodisk of HQ/LQ modes obtained by eigenmode analysis. (c) Calculated mode positions by eigenmodes analysis (dots) and non-Hermitian Hamiltonian (solid lines). The dashed lines mark the two vectorial Mie modes. (d) Simulated (dashed lines) and calculated (solid lines) damping energy of the two interfering optical modes. (e) Three representative normalized scattering spectra extracted from (a). (f) The normalized electric and magnetic field distribution in the nanodisks with different radii at the resonance of the high- Q modes.

When the two photonic Mie modes are tuned in resonance [vertical arrow in Fig. 2(d)], destructive interference between their radiation channels, controlled by γ_c , suppresses the total damping of one hybrid mode while enhancing that of the other. This interference leads to the formation of short-lived (superradiant) and long-lived (subradiant) hybrid states with markedly different decay rates.^{3,46} In particular, energy exchange mediated by vacuum fluctuations induces a subradiant response in the high- Q mode, ultimately resulting in the emergence of a qBIC [red dot in Figs. 2(b) and 2(d)].^{28,29}

2.2 Polaritonic quasi-BIC under Vectorial and Linear Excitations

We now investigate the self-hybridized interaction between the resonant modes and the excitons to explore the formation of polaritonic qBICs. In this case, we include the contribution of the A exciton. Under illumination of an azimuthally polarized light at normal incidence, as depicted in the first panel of Fig. 3(b), the simulated scattering spectra, as shown in the left panel of

Fig. 3(a), show four branches, which are labeled as UP1, UP2, LP1, and LP2, respectively. Moreover, the calculated absorption and extinction spectra also clearly display four branches (Sec. 3 of the [Supplementary Material](#)). This strongly indicates that the LQ and HQ modes (dashed lines) couple individually with the A excitons, rather than forming a three-mode hybridization involving two vectorial Mie modes and the exciton (which would result in three branches). To rigorously extract the intrinsic mode splitting and unequivocally reveal the coherent energy exchange in our open system, we performed direct three-dimensional complex eigenmode calculations. By implementing an auxiliary differential equation (ADE) method, we explicitly treated the dispersive nature of the WS₂ excitons and directly solved for the quasinormal modes (QNMs) of the strongly coupled system.⁴⁷ Based on this eigenmode analysis, the intrinsic Rabi splitting for the HQ-exciton coupling is determined to be $\hbar\Omega_1 = 270$ meV, corresponding to a coherent coupling strength of $\hbar g_1 = 135.5$ meV [right panel of Fig. 3(a)]. For the LQ-exciton coupling, the intrinsic Rabi splitting $\hbar\Omega_2$ is 268 meV ($\hbar g_2 = 134.5$ meV).

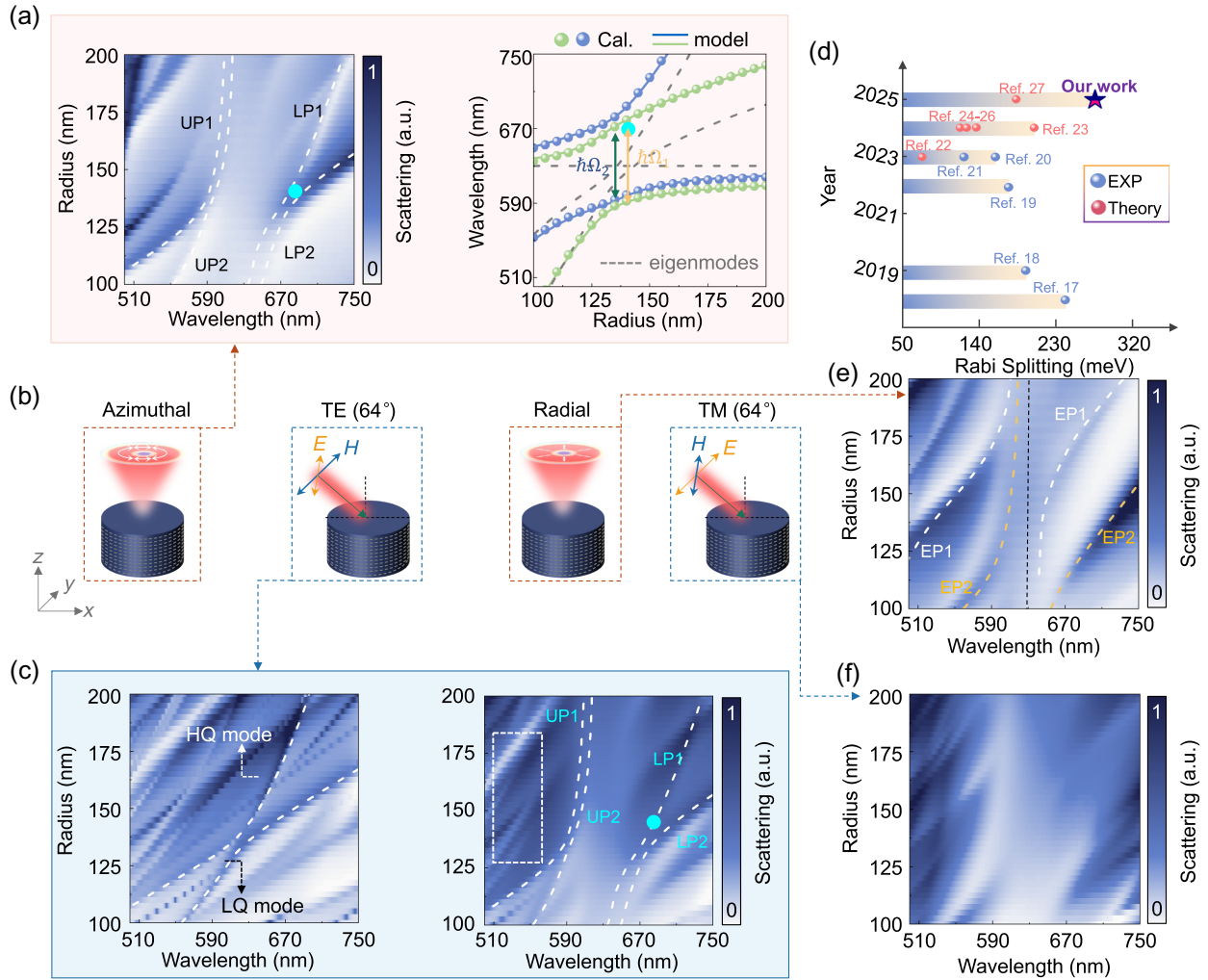


Fig. 3 (a) Simulated normalized scattering spectra (left) of the WS₂ nanodisks under azimuthal incidence with mode positions obtained by eigenvalue calculations (dots) and Hamiltonian (solid lines). (b) Sketches of nanodisks with vectorial and linear excitations. (c) Simulated normalized scattering spectra of the WS₂ nanodisks with background (left) and complete permittivity (right) under TE excitation with an angle of incidence of 64 deg. (d) Literature survey for Rabi splitting in all-dielectric self-hybridized TMDC nanostructures. Panels (e) and (f) show the simulated normalized scattering spectra under radial (e) and TM (f) excitation. In (a) and (c), dashed white lines present the hybrid modes calculated by coupling the oscillator model and the cyan dots mark the polaritonic qBIC. The white rectangle in (c) marks the additional optical modes supported by the nanodisks due to its lower symmetry under TE polarization compared with azimuthal polarization. Dashed lines in (e) are calculated eigenvalues of radial optical modes.

Notably, although phenomenological fitting of the far-field scattering spectra yields a larger apparent splitting (more than 300 meV; see Sec. 3 of the [Supplementary Material](#)) due to Fano interference phase distortions inherent to the qBIC mode, our direct eigenmode calculations rigorously strip away these radiative artifacts to isolate the true intrinsic coupling. Although a comparable Rabi splitting of ~ 300 meV has been achieved using external microcavities and metallic arrays,⁴⁸ our all-dielectric platform demonstrates that a highly competitive splitting (~ 270 meV) can be realized in a single, isolated bulk WS₂ nanoresonator, significantly simplifying fabrication and avoiding substrate- or cavity-dependent constraints.

Furthermore, in this system, the damping rates of the HQ mode and the LQ mode at zero detuning are 2.5 and 51 meV [Fig. 2(d)], respectively. Meanwhile, the damping rate of the A exciton of WS₂ is 26 meV, indicating that both coupled subsystems reach the strong coupling regime.¹ We attribute the giant energy splitting observed in the coupling of the HQ mode and the exciton to the strong electromagnetic field confinement within the nanoresonator. Figure 2(f) shows the near-field distributions at the HQ resonance for nanodisks of three representative sizes, whose scattering spectra are as shown in Fig. 2(e). The electric field distribution exhibits typical qBIC characteristics, as demonstrated in the middle panel. Significantly, this

qBIC mode arises from the interference between two in-plane electric field-dominated Mie resonances (denoted in the top and bottom panels), generating a remarkable ring-like in-plane electric field enhancement. The maximum electric field enhancement factor is above 40, exceeding the localized field intensities reported in most dielectric nanoantennas to date. Notably, this magnetic octupole-dominated qBIC mode simultaneously achieves an exceptional magnetic field enhancement factor exceeding 100, as evidenced in the middle panel. The strong in-plane electric field localization and its distinctive spatial distribution substantially improve the spatial mode matching with in-plane excitons, thereby dramatically enhancing the light-matter coupling efficiency. Due to the exceptional field confinement capability of the qBIC, the HQ mode hybridized with the exciton reaches the largest Rabi splitting observed in all-TMDC self-hybridized systems [Fig. 3(d)]. For a comprehensive comparison, the near-field distribution of the broader LQ resonance is provided in Fig. S6(f) in the [Supplementary Material](#). Although differing significantly in spatial profile and Q factor, both modes exhibit subwavelength confinement within the WS₂ nanodisk, explaining why both subsystems can achieve a comparable Rabi splitting (~ 270 meV).

In our simulations, whereas the presence of a multilayer substrate serves to tune the phase difference between the vectorial Mie modes, the simulated scattering spectra (see Fig. S7 in the [Supplementary Material](#)) for WS₂ nanodisks without a substrate show that the heterogeneous integration involving the WS₂-SiO₂ interface has minimal impact on Rabi splitting. Furthermore, simulations for nanodisks with different substrate thicknesses t_2 confirm that the t_2 value also has a negligible effect on the Rabi splitting between the Mie modes and the excitons. This demonstrates that the primary optical characteristics, governed by shape-dependent Mie resonances, remain largely unaffected by the underlying substrate, thereby preserving the robustness of their emission properties.

Previous studies have demonstrated that FWBICs in a single high-refractive-index dielectric nanoparticle can be excited by both azimuthally polarized light at normal incidence and TE-polarized light at oblique incidence.^{35,39} Accordingly, the polaritonic qBIC can also be excited in the present self-hybridized WS₂ nanoresonator under TE-polarized light. To validate this, we performed size-dependent scattering simulations of the nanodisk with and without A excitons under TE-polarized light at an incidence angle of 64 deg [the second panel of Fig. 3(b)]. Figure 3(c) presents the simulated spectra without A excitons (left panel). The calculated LQ/HQ dispersion (white lines) from Fig. 2(a) was then overlaid on this panel, confirming the successful excitation of the LQ/HQ modes under TE-polarized light illumination. We extracted the spectral width [see Fig. S6(c) in the [Supplementary Material](#)], which agrees well with that for the azimuthal case [Fig. 2(b)]. This confirms the existence of qBIC. We now include the contribution of the A-exciton, and four clear branches (white dashed lines) again appear in the simulated scattering spectra [the right panel of Fig. 3(c)], demonstrating the formation of the polaritonic qBIC (cyan dot).

Notably, the difference between the azimuthal and TE excitation schemes lies in the symmetry of the system. Under TE-polarized excitation, the system exhibits lower symmetry, leading to the presence of additional resonance modes [marked by the white rectangle in Fig. 3(c)]. The presence of these extra modes complicates the identification of characteristic modes in coupled systems and hinders the observation and analysis

of coupling behavior. It is important to note that the advantage of the present single dielectric nanoparticle is highlighted by the fact that polaritonic qBICs can be effectively excited under both azimuthally polarized excitation at normal incidence and TE-polarized light at oblique incidence. The ability to support both excitation configurations provides distinct benefits: under azimuthally polarized excitation at normal incidence, the system preserves ideal rotational symmetry, resulting in fewer unwanted modes, while TE-polarized light at oblique incidence offers a more accessible configuration for optical spectral measurement systems, facilitating setup design and practical implementations. This dual excitation capability thus combines the advantages of symmetry and experimental practicality, making the system more versatile and efficient.

Furthermore, under radially polarized and TM polarized excitations, which are orthogonal to the two previously studied polarization schemes, the optical modes supported by the nanodisk are regular Mie modes without forming qBIC near the WS₂ exciton resonance [see Figs. S6(d) and S6(e) in the [Supplementary Material](#)]. To verify this symmetry-consistent analysis, we simulated the scattering spectra under radially and TM polarized excitation [the third and fourth panels of Fig. 3(b)], as shown in Figs. 3(e) and 3(f). As expected, four EP branches (dashed lines) are clearly visible for the case of radial excitation as a consequence of intrinsic coupling between excitons (vertical dotted line) and two Mie modes, respectively. Under TM excitation, the expected EP branches do not show clearly in the scattering spectrum. This is due to the fact that, under TM excitation, complex Mie eigenmodes [see Fig. S6(d) in the [Supplementary Material](#)] are simultaneously excited, leading to an overlap between the EPs formed by the coupling of these Mie modes with intrinsic excitons, and making it difficult to resolve them clearly.

The distinct polarization selectivity can be quantitatively understood through symmetry-based selection rules governed by the $C_{\infty v}$ point group. The excitation efficiency η of a specific mode depends on the overlap integral between the incident field E_{inc} and the induced modal current J_{mode} : $\eta \propto |\int E_{\text{inc}}(r) \cdot J_{\text{mode}}(r) dV|^2$. For a nonzero overlap, the direct product of the irreducible representations of the incident field and the mode must contain the totally symmetric representation A_1 . Under a high-NA objective, the tightly focused radially polarized beam exhibits a strong longitudinal electric field component E_z at the focal center, which transforms as the A_1 representation. This symmetry matches the out-of-plane electric dipole (p_z) mode ($A_1 \otimes A_1 = A_1$), leading to its efficient excitation. In contrast, for azimuthally polarized excitation (discussed previously), the circulating field E_ϕ transforms as A_2 , which matches the symmetry of magnetic multipoles (magnetic dipole/quadrupole/octupole, MD/MQ/MO). To provide a quantitative modal picture, we performed a multipolar decomposition⁴⁹ of the scattering spectra [see Figs. S6(g) and S6(h) in the [Supplementary Material](#)]. The results confirm that under azimuthal excitation, the response is dominated by the magnetic components, while electric contributions are strongly suppressed. Consequently, by simply switching between orthogonal excitation polarizations, our platform allows for active routing between magnetic polaritonic qBIC (via azimuthal excitation) and electric exciton polaritons (via radial excitation). The ability to selectively excite polaritonic qBICs through polarization schemes enables a more precise manipulation of the polaritonic states and enhances the ability to isolate and study specific coupling behaviors, thus offering significant advantages in controlling and tailoring

polaritonic responses of self-hybridized nanoresonators at the single-particle level.

2.3 Experimental Observation of Polaritonic quasi-BIC

To validate the theoretical analysis, dark field spectroscopy was utilized to characterize the optical response of the fabricated WS_2 nanodisk samples. We used two types of microscopic setup to excite samples with tightly focused vectorial polarized light [top panel of Fig. 4(a)] by a dark-field objective with large numerical aperture ($\text{NA} = 0.9$) and linearly polarized light at an angle of incidence $\theta = 64^\circ$ [bottom panel of Fig. 4(a)]. Specifically, for vectorial excitation, an achromatic vortex retarder (AVR) was placed in front of the objective to generate azimuthally/radially polarized light, and the scattered light from the sample was collected collinearly with the incident beam [see Fig. S8(a) in the [Supplementary Material](#)]. For the linear polarization case, an objective mask with a side slit was placed behind the objective, and the dark-field setup was constructed for illumination of a segment of the input outer ring of the dark-field microscope objective [Fig. S8(b) in the [Supplementary Material](#)]. In this case, the incident beam was guided to pass through the side slit so that the sample was illuminated at oblique incidence [Fig. S8(c) in the [Supplementary Material](#)]. The light was then scattered back by the nanodisk and collected from the center of the objective [see the [Appendix](#) for details].

The measured scattering spectra of WS_2 nanodisks under azimuthally polarized and TE-polarized light excitation are given in Figs. 4(b) and 4(d), respectively. The theoretical dispersion relations (white lines) derived from the coupled oscillator model were overlaid onto the measured scattering spectra, revealing a quantitative agreement between measured spectral features and

calculated eigenmode solutions [see Figs. S9(e) and S9(f) in the [Supplementary Material](#) for details], thus confirming the experimental observation of the four polaritonic branches. Polaritonic qBICs, as marked by the cyan dots, were successfully identified around 680 and 685 nm for azimuthal and TE excitation, respectively, which agrees well with the theoretical prediction [Figs. 3(a) and 3(c)]. Here, the slight difference in the resonance positions of the polaritonic qBICs primarily arises from the different sizes of the nanodisks supporting the qBIC under azimuthal and TE excitation conditions, which consequently leads to a shift in the qBIC resonance positions. Specifically, under azimuthal excitation, the qBIC is supported by a nanodisk with a radius of $r = 140$ nm [as shown in Fig. 2(b)], whereas for TE excitation, the qBIC is supported by a nanodisk with a slightly larger radius of $r = 145$ nm [see Fig. S6(c) in the [Supplementary Material](#)]. The variation in nanodisk size directly affects the resonance frequency of the qBIC, as the resonance position is highly sensitive to the dimensions of the nanostructures. Thus, the size-dependent variation in the nanodisk leads to different resonance positions of the polaritonic qBIC in the two excitation scenarios.

The measurements were also conducted using radially polarized and TM polarized excitation, with the resulting scattering spectra presented in Figs. 4(c) and 4(e), respectively. The results in these figures do not exhibit the characteristics of a polaritonic qBIC, which is consistent with the simulated results in Figs. 3(e) and 3(f). In addition, under excitation with vectorial and linearly polarized light, significant differences in the spectra are observed between the two orthogonal polarizations. Consequently, on the basis of the experimental data, we can clearly distinguish whether a polaritonic qBIC is excited.

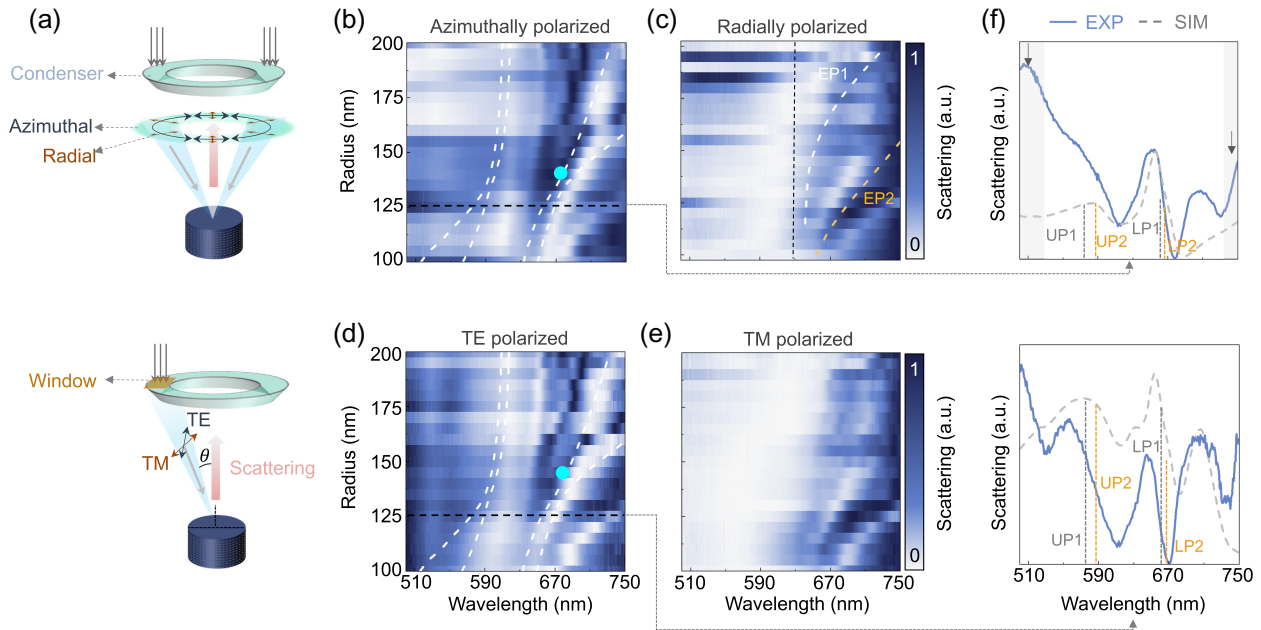


Fig. 4 (a) Schematic of the experimental configuration for scattering measurement under vectorial (top) and linear (bottom) excitation. (b)–(e) Measured normalized scattering spectra of WS_2 nanodisk for (b) azimuthal, (c) radial, (d) TE, and (e) TM excitation. (f) Measured (solid blue) and simulated (dashed gray) scattering spectra for the WS_2 nanodisk with $r = 125$ nm under azimuthal (top) and TE (bottom) excitation using the experimental permittivity. The dashed lines and cyan dots in (b) and (d) denote the calculated dispersion and the polaritonic qBIC, respectively.

Therefore, both the theoretical and experimental results confirm the excitation of polaritonic qBICs under azimuthally polarized and TE-polarized light. The hybridization between excitons and qBICs can be observed more clearly under azimuthal polarization. Furthermore, our findings demonstrate the feasibility of observing self-hybridization behavior under TE-polarized excitation, providing a more convenient approach for the experimental investigations of polaritonic BICs.

Although the dispersion trends of the simulated and experimental results are in good agreement, noticeable discrepancies appear in the scattering spectra at high photon energies, particularly in the region highlighted by the white rectangle in Fig. 3(c). These differences are further illustrated by a direct comparison of the scattering spectra for nanodisks with a radius of $r = 125$ nm, as shown in Figs. S9(a) and S9(b) in the [Supplementary Material](#). These discrepancies originate from the fact that the Rabi splitting is sufficiently large that the influence of the B and C excitons of WS₂ on the coupling behavior can no longer be neglected. To account for this effect, we simulated the scattering spectra of the nanodisks using the experimentally measured refractive index [middle right panel in Fig. 1(a)], and the corresponding results are presented in Figs. S9(c) and S9(d) in the [Supplementary Material](#). These simulations confirm that the high-energy polaritonic branches are difficult to observe due to the influence of the B and C excitons. Specifically, these higher-energy exciton backgrounds introduce substantial nonradiative damping and non-Hermitian collective mode repulsion into the system. This directly leads to the dynamic linewidth broadening and the consequent blurring of the upper polariton (UP) branches observed in the experiment. A comprehensive quantitative eigenmode analysis detailing this multiexciton influence and confirming the robustness of the extracted A-exciton coupling strength is provided in Sec. 8 of the [Supplementary Material](#).

To further elucidate the spectral response of the polaritonic qBICs, we compared the simulated scattering spectra (dashed gray curves) with the experimentally measured spectra (solid blue curves) for a nanodisk with a radius of 125 nm, as shown in Fig. 4(f). The results demonstrate good agreement between experiment and theory under both azimuthal and transverse electric (TE) excitation conditions, including the resonance positions of the polaritonic branches and the resonant modes at the critical points, as indicated by the vertical dashed lines. Nevertheless, some discrepancies remain in the spectral responses. These deviations may arise from uncertainties in material parameters (such as refractive index and thickness) as well as fabrication imperfections, which can lead to unintended spectral broadening and slight resonance shifts.

Moreover, it is noteworthy that, in the gray-shaded spectral region [top panel of Fig. 4(f)], a more pronounced discrepancy between the experimental and theoretical spectra is presented under azimuthal excitation. This discrepancy is not observed under TE excitation [bottom panel of Fig. 4(f)]. Such a difference may be attributed to misalignment between the beam center and the geometric center of the nanodisk during azimuthal excitation measurements, which can reduce the overall symmetry of the system and lead to the emergence of unexpected optical modes in the scattering spectra. In contrast, this issue does not affect the TE excitation case, as the symmetry remains preserved.

Figure 5(a) illustrates the illumination configurations for azimuthal and TE excitations. It is evident that under TE excitation,

the system comprising the nanodisk and the electric field of incident light maintains C_2 symmetry. A deviation between the center of the beam and the geometric center of the nanodisk does not break this C_2 symmetry. In contrast, under azimuthal excitation, the system possesses rotational symmetry. Any misalignment between the beam center and the nanodisk's geometric center in this case breaks the rotational symmetry, consequently altering the measured spectral response of the nanodisk. In optical measurements, the misalignment of the incident beam with respect to the geometric center of the nanodisks cannot be completely eliminated. An offset on the order of several hundred nanometers is reasonable in our dark-field microscopic setup.

To quantitatively investigate the influence of this misalignment on the spectral response, we simulated the scattering spectra of the nanodisk at various offset distances. As shown in Fig. 5(b), the scattering spectra exhibit significant differences as the offset increases from 0 to 500 nm, characterized by a slight shift in the polaritonic branches, accompanied by changes in resonance peak amplitudes and the emergence of additional resonance modes. Note that the newly appearing resonance peaks correspond precisely to those observed within the gray region of the experimental spectra in Fig. 4(f). This strongly indicates that the discrepancy between the experimental and simulated scattering spectra in the gray region originates from an inevitable misalignment during the optical measurement of individual nanoparticles. To verify this, we simulated the scattering spectra of nanodisks with both background and experimental permittivity [left and right panels in Fig. 5(c)] by introducing a certain amount of offset between the center of beam and the nanodisk.

Figure 5(c) shows the simulated scattering spectra of nanodisks with both background and experimental permittivity under azimuthal illumination with an offset of 200 nm. To evaluate the influence of offset on the spectral response of the nanodisks, we further plot the simulated spectra (dashed gray curve) for the nanodisk with $r = 125$ nm [marked as dashed black line in the right panel of Fig. 5(c)] together with the experimental spectrum (solid blue curve), as shown in Fig. 5(d). The simulated scattering spectra were found to have improved agreement with the experimental spectra [Fig. 4(f)]. This is due to the fact that the presence of the offset has a negligible impact on the resonance energy of the polaritonic branches and the formation of the polaritonic qBIC although the amplitudes of the polaritonic branches are altered with varying offsets [vertical dashed lines in Fig. 5(b)]. Furthermore, the Mie modes, which were absent in the simulated spectra at shorter and longer wavelengths without offset [gray regions in Fig. 4(f)], now appear and align well with the experimental data. Beyond the tolerance to optical alignment, we also performed a comprehensive quantitative tolerance analysis regarding standard nanofabrication imperfections. As detailed in Sec. 9 of the [Supplementary Material](#), the core polaritonic features, particularly the Rabi splitting, exhibit remarkable robustness against typical experimental uncertainties, including dimensional fluctuations, spacer thickness variations, and crystallographic etching deformations (such as hexagonal faceting). These combined analyses firmly establish the practical reproducibility of the strong coupling regime in our WS₂ nanoresonators.

3 Conclusion

We have presented the first theoretical analysis and related experimental realization of polaritonic qBICs in isolated WS₂

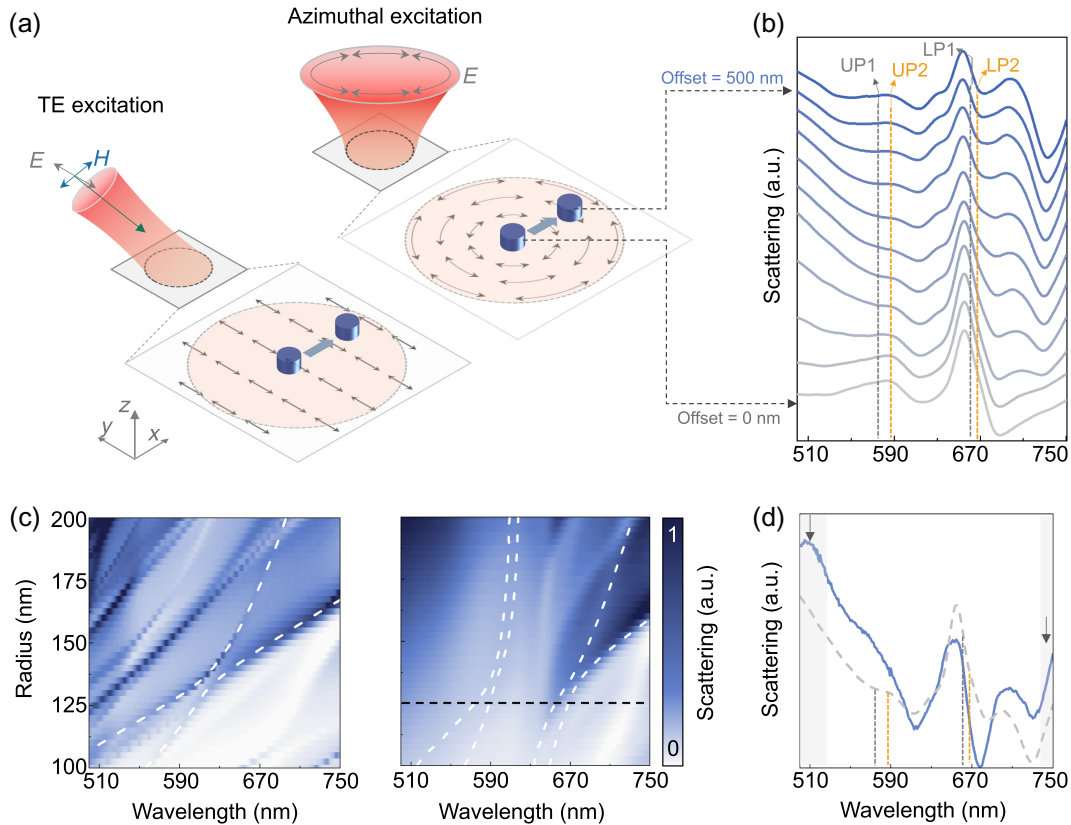


Fig. 5 (a) The polarization diagram of TE and azimuthal excitation. The gray arrows indicate the polarization direction of the electric field and the light red areas are the light spots. (b) Simulated scattering spectrum of a WS_2 nanodisk with a radius of 125 nm, its center offset from the center of the polarization vortex. The offset ranges from 0 to 500 nm in steps of 50 nm, increasing from bottom to top. (c) Simulated scattering spectra of nanodisks with both background and experimental permittivity (left and right panels, respectively), when illuminated by an azimuthally polarized beam whose center is offset by 200 nm from the nanodisk center. (d) Comparison between simulated (dashed line) and experimental (solid line) scattering spectra of a 125 nm radius WS_2 nanodisk with a 200 nm spatial offset.

nanodisks through intrinsic coupling between Mie-type photonic resonances and in-plane exciton transitions. By implementing azimuthally polarized and TE-polarized excitation configurations, we have characterized such hybrid states using polarization-controlled scattering spectroscopy, thereby unambiguously confirming the existence of polaritonic qBIC. We have observed an extraordinary Rabi energy splitting approaching 270 meV, representing a great enhancement compared to the previous demonstrations in other TMDC systems. This record-breaking coupling strength originates from the unique hybridization of qBIC-induced electromagnetic field confinement and exciton oscillator strength—specifically, the in-plane electric field distribution spatially overlaps with excitonic dipoles, while the nonradiative nature of qBIC modes suppresses photon leakage. Polarization-controlled measurements reveal that switching between orthogonal polarizations enables selective excitation of polaritonic qBIC. Such polarization-selective control provides unprecedented spatial and spectral manipulation of polaritonic dispersion without structural modifications. Our findings open avenues for developing room-temperature polariton lasers, nonlinear optical switches, and quantum emitters with enhanced light–matter interactions at the single-particle level.

4 Appendix: Materials and Methods

4.1 Sample Fabrication

Single-crystalline WS_2 flakes were mechanically exfoliated from bulk crystals (HQ graphene) and transferred onto substrates comprising a 100 nm-thick gold layer and a 55 nm thick SiO_2 layer. Then a negative resist layer (ma-N 2403, micro resist) was spin-coated and soft-baked prior to patterning. Electron-beam lithography was performed at 20 kV with a dose of $120 \mu\text{C}/\text{cm}^2$ to define the desired structures. The samples were subsequently subjected to reactive-ion etching to remove the unprotected WS_2 . Finally, the remaining residue was dissolved using a commercial remover, followed by a thorough rinse in water. A sketch of the fabrication process flow is given in Fig. S1 in the [Supplementary Material](#).

4.2 Numerical Simulation

The numerical simulations were conducted in the frequency domain using COMSOL Multiphysics software. All computations were performed for a single nanoresonator of fixed size (200 nm

in height) positioned on a multilayered substrate and enclosed by a perfectly matched layer to simulate an infinite surrounding medium. The material properties, including losses, were obtained from tabulated data for Au in the visible to near-infrared range⁵⁰ and from experimental ellipsometry measurements for bulk WS₂. Discrepancies between the simulated and measured resonant peak positions are likely due to fabrication imperfections, such as the inclination of the disk walls, which were not incorporated into the simulation model.

4.3 Optical Characterization

To perform optical measurements, we designed two experimental setups: vectorial excitation and linear excitation. For vectorial excitation, a liquid crystal polymer-based achromatic vortex retarder (Lbtek) was used to generate a vectorial pump beam from a linearly polarized Gaussian white light source (Olympus TH4-200, Shinjuku-ku, Tokyo, Japan). The pump beam was visualized using a camera (Hikrobot MV-CS050-10UC) in combination with an achromatic lens. The sample was mounted on a three-dimensional translation stage, and the pump beam was focused onto it from the front side using an Olympus objective lens (MPlanFL N, 100 $\times$, 0.90 NA, BD) installed on an Olympus dark field microscope system (BX53M) to achieve a tightly focused beam waist. In the working spectral range, the gold layer acted as a reflective mirror. The reflected signal was collected in the backward direction by the same objective lens (0.90 NA), passed through a nonpolarizing beamsplitter, and was subsequently detected using a CCD (Andor iVac 316) connected to the spectrometer (Zolix Omni- λ 5028i). To obtain the backward scattering spectra, we divided the power spectrum of the reflection from a single nanoparticle (dark-field signal) by the power spectrum of the reflection from the bare substrate (bright-field signal). The resulting spectra were then normalized.

For linear excitation, a linearly polarized Gaussian beam illuminated a segment of the outer ring of the dark-field microscope objective (MPlanFL N, 100 $\times$, 0.90 NA, BD). Figure S8(c) in the [Supplementary Material](#) shows a simplified schematic of the illumination. An incident linear polarization with the electric field oriented toward/away from the lens center thus resulted in the oblique TM-polarized excitation. The electric field oriented perpendicular to the direction of the lens center resulted in TE-polarized excitation. The scattered signal was collected with the central part of the same objective lens. Signal was detected with a spectrometer Ocean Optics QEPro and a camera Trius-SX694 Starlight Xpress camera paired with an infinity-corrected $f = 150$ mm visible achromatic doublet lens.

Disclosures

The authors declare that they have no competing interests.

Code and Data Availability

All data used in the study are available from the corresponding authors upon reasonable request.

Acknowledgments

This work was supported by the Natural Science Foundation of Sichuan Province in China (Grant No. 2024NSFSC0460), Australian Research Council (Grant Nos. DP210101292 and

DE210100679), International Technology Center Indo-Pacific (ITC IPAC) via Army Research Office (Contract FA5209 23C0023), and the European Union (ERC, METANEXT, 101078018). This project was also funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under grant numbers EXC 2089/1–390776260 (Germany's Excellence Strategy) and TI 1063/1 (Emmy Noether Program) and the Center for NanoScience (CeNS).

References

1. M. Hertzog et al., "Strong light-matter interactions: a new direction within chemistry," *Chem. Soc. Rev.* **48**(3), 937–961 (2019).
2. A. M. Berhe et al., "Strong coupling and catenary field enhancement in the hybrid plasmonic metamaterial cavity and TMDC monolayers," *Opto-Electron. Adv.* **7**(5), 230181 (2024).
3. P. Xie et al., "Strong coupling between excitons in a two-dimensional atomic crystal and quasibound states in the continuum in a two-dimensional all-dielectric asymmetric metasurface," *Phys. Rev. B* **104**, 125446 (2021).
4. P. Xie et al., "Strong light-matter interactions in hybrid nanostructures with transition metal dichalcogenides," *J. Opt.* **24**, 093001 (2022).
5. S. Li, Y. Fang, and J. Wang, "Control of light-matter interactions in two-dimensional materials with nanoparticle-on-mirror structures," *Opto-Electron. Sci.* **3**(7), 240011 (2024).
6. C. W. Hsu et al., "Bound states in the continuum," *Nat. Rev. Mater.* **1**(9), 16048 (2016).
7. K. Wang et al., "High-q resonance engineering in momentum space for highly coherent and rainbow-free thermal emission," *Nano Lett.* **25**(9), 3613–3619 (2025).
8. J. Fan et al., "Hybrid bound states in the continuum in terahertz metasurfaces," *Opto-Electron. Sci.* **2**(4), 230006 (2023).
9. L. Nan et al., "Angular dispersion suppression in deeply subwavelength phonon polariton bound states in the continuum metasurfaces," *Nat. Photonics* **19**, 615–623 (2025).
10. L. Sortino et al., "Atomic-layer assembly of ultrathin optical cavities in van der Waals heterostructure metasurfaces," *Nat. Photonics* **19**, 825–832 (2025).
11. A. Aigner et al., "Optical control of resonances in temporally symmetry-broken metasurfaces," *Nature* **644**(8078), 896–902 (2025).
12. R. Berté et al., "All-optical permittivity-asymmetric quasi-bound states in the continuum," *Light Sci. Appl.* **14**(1), 185 (2025).
13. H. He et al., "Spectro-polarimetric detection enabled by multidimensional metasurface with quasi-bound states in the continuum," *Opto-Electron. Adv.* **8**(10), 250015 (2025).
14. W. Hu et al., "Optofluidic refractometric sensor based on quasi-bound states in the continuum in all-dielectric metasurface," *Opto-Electron. Eng.* **50**(9), 230124 (2023).
15. K. L. Koshelev et al., "Bound states in the continuum in photonic structures," *Phys.-Usp.* **66**, 494–517 (2023).
16. S. I. Azzam and A. V. Kildishev, "Photonic bound states in the continuum: from basics to applications," *Adv. Opt. Mater.* **9**, 2001469 (2021).
17. B. Munkhbat et al., "Self-hybridized exciton-polaritons in multilayers of transition metal dichalcogenides for efficient light absorption," *ACS Photonics* **6**(1), 139–147 (2018).
18. R. Verre et al., "Transition metal dichalcogenide nanodisks as high-index dielectric mie nanoresonators," *Nat. Nanotechnol.* **14**(7), 679–683 (2019).
19. F. Shen et al., "Transition metal dichalcogenide metaphotonic and self-coupled polaritonic platform grown by chemical vapor deposition," *Nat. Commun.* **13**(1), 5597 (2022).
20. P. G. Zotev et al., "Van der Waals materials for applications in nanophotonics," *Laser Photonics Rev.* **17**(8), 2200957 (2023).

21. T. Weber et al., "Intrinsic strong light-matter coupling with self-hybridized bound states in the continuum in van der Waals metasurfaces," *Nat. Mater.* **22**(8), 970–976 (2023).
22. S. You et al., "Strong light-matter interactions of exciton in bulk WS₂ and a toroidal dipole resonance," *Opt. Lett.* **48**(6), 1530–1533 (2023).
23. Q. Ding et al., "Tunable intrinsic strong light-matter coupling in transition metal dichalcogenide nanoresonators," *Opt. Lett.* **49**(11), 3122–3125 (2024).
24. S. Shen et al., "Manipulation of intrinsic light-matter interaction in a single self-hybridizing WS₂ nanodisk," *Phys. Rev. B* **110**(15), 155422 (2024).
25. S. Shen et al., "Directional light emission from WS₂ monolayer driven by self-hybridized van der Waals nanoresonator," *Phys. Rev. B* **109**(15), 155405 (2024).
26. H. Zhou et al., "Photonic spin-controlled self-hybridized exciton-polaritons in WS₂ metasurfaces driven by chiral quasibound states in the continuum," *Phys. Rev. B* **109**(12), 125201 (2024).
27. L. Yue et al., "Intrinsic strong self-hybrid coupling empowered by Brillouin zone folding-induced high-*Q* quasibound modes in van der Waals metasurfaces," *Phys. Rev. B* **111**(4), 045412 (2025).
28. M. V. Rybin et al., "High-*q* supercavity modes in subwavelength dielectric resonators," *Phys. Rev. Lett.* **119**(24), 243901 (2017).
29. A. A. Bogdanov et al., "Bound states in the continuum and Fano resonances in the strong mode coupling regime," *Adv. Photonics* **1**(1), 016001 (2019).
30. L. Mercadé, A. Barreda, and A. Martínez, "Dispersive optomechanics of supercavity modes in high-index disks," *Opt. Lett.* **45**(18), 5238–5241 (2020).
31. M. Odit et al., "Observation of supercavity modes in subwavelength dielectric resonators," *Adv. Mater.* **33**(1), 2003804 (2020).
32. L. Huang et al., "Pushing the limit of high-*Q* mode of a single dielectric nanocavity," *Adv. Photonics* **3**(1), 016004 (2021).
33. M. R. Nurrahman et al., "Broadband generation of quasi bound-state-in-continuum modes using subwavelength truncated cone resonators," *Opt. Lett.* **48**(11), 2837–2840 (2023).
34. Q. Ding et al., "Strong coupling of excitons in a two-dimensional atomic crystal with quasi-bound state in the continuum supported by a single nanoparticle," *Appl. Phys. Lett.* **126**(8), 081703 (2025).
35. V. Mylnikov et al., "Lasing action in single subwavelength particles supporting supercavity modes," *ACS Nano* **14**(6), 7338–7346 (2020).
36. S. Jia, Z. Li, and J. Chen, "Brightening single-photon emitters by combining an ultrathin metallic antenna and a silicon quasi-bic antenna," *Chin. Phys. B* **31**(1), 014209 (2022).
37. L. Liu et al., "Heterogeneously integrated quantum-dot emitters efficiently driven by a quasi-BIC-supporting dielectric nanoresonator," *Photonics Res.* **10**(8), 1971–1977 (2022).
38. K. Koshelev et al., "Subwavelength dielectric resonators for nonlinear nanophotonics," *Science* **367**(6475), 288–292 (2020).
39. A. Zalogina et al., "High-harmonic generation from a subwavelength dielectric resonator," *Sci. Adv.* **9**(17), eadg2655 (2023).
40. L. Carletti et al., "High-harmonic generation at the nanoscale boosted by bound states in the continuum," *Phys. Rev. Res.* **1**(2), 023016 (2019).
41. I. Volkovskaya et al., "Multipolar second-harmonic generation from high-*Q* quasi-BIC states in subwavelength resonators," *Nanophotonics* **9**(12), 3953–3963 (2020).
42. M. Panmai et al., "Highly efficient nonlinear optical emission from a subwavelength crystalline silicon cuboid mediated by supercavity mode," *Nat. Commun.* **13**(1), 2749 (2022).
43. A. A. Vyshnevyy et al., "Van der Waals materials for overcoming fundamental limitations in photonic integrated circuitry," *Nano Lett.* **23**(17), 8057–8064 (2023).
44. P. Xie et al., "Strong coupling of resonant metasurfaces with epsilon-near-zero guided modes," *Nano Lett.* **24**(29), 9027–9033 (2024).
45. S. Fan, W. Suh, and J. D. Joannopoulos, "Temporal coupled-mode theory for the Fano resonance in optical resonators," *J. Opt. Soc. Am. A* **20**, 569–572 (2003).
46. W. Wang et al., "Interplay between strong coupling and radiative damping of excitons and surface plasmon polaritons in hybrid nanostructures," *ACS Nano* **8**(1), 1056–1064 (2014).
47. P. Lalanne et al., "Light interaction with photonic and plasmonic resonances," *Laser Photonics Rev.* **12**(5), 1700113 (2018).
48. B. Li et al., "Large Rabi splitting obtained in Ag-WS₂ strong-coupling heterostructure with optical microcavity at room temperature," *Opto-Electron. Adv.* **2**(5), 190008 (2019).
49. A. B. Evlyukhin and B. N. Chichkov, "Multipole decompositions for directional light scattering," *Phys. Rev. B* **100**, 125415 (2019).
50. A. D. Rakić et al., "Optical properties of metallic films for vertical-cavity optoelectronic devices," *Appl. Opt.* **37**, 5271–5283 (1998).
51. E. Melik-Gaykazyan et al., "From Fano to quasi-BIC resonances in individual dielectric nanoantennas," *Nano Lett.* **21**(4), 1765–1771 (2021).
52. F. Alpeggiani et al., "Quasinormal-mode expansion of the scattering matrix," *Phys. Rev. X* **7**, 021035 (2017).
53. S. Wang et al., "Coherent coupling of WS₂ monolayers with metallic photonic nanostructures at room temperature," *Nano Lett.* **16**(7), 4368–4374 (2016).
54. Y. Li et al., "Measurement of the optical dielectric function of monolayer transition-metal dichalcogenides: MoS₂, MoSe₂, WS₂, and WSe₂," *Phys. Rev. B* **90**, 205422 (2014).

Qi Ding is currently a PhD student in the College of Physics at Sichuan University, China. His current research interests focus on strong light-matter interactions in two-dimensional transition metal dichalcogenides, particularly exploring quasi-bound states in the continuum and tunable intrinsic polaritonic coupling in nanoresonators and van der Waals nanoantennas.

Yuri Kivshar received his PhD in 1984 from the Institute of Low Temperature Physics and Engineering in Kharkov, Ukraine. After 1989, he was a visiting researcher at the Complutense University in Madrid (Spain) and then Humboldt Research Fellow in Duesseldorf (Germany). In 1993 he moved to Australia, where he is currently Distinguished Professor at the Australian National University. His research interests include nonlinear physics, nonlinear optics, and resonant metaphotonics.

Andreas Tittl is a full professor and director of the Institute of Photonics at the Hamburg University of Technology (TUHH). His group aims to push the limits of light-matter coupling through advances in optical metasurfaces, spanning BIC-driven photonic systems with ultrahigh quality factors, van der Waals heterostructures for polaritonics and quantum emission, and optofluidic sensing for clinical diagnostics. He received his PhD in physics from the University of Stuttgart, was a postdoctoral researcher and Fellow at EPFL, and served as professor of experimental physics at LMU Munich before joining TUHH.

Wei Wang is a professor in the College of Physics at Sichuan University, China. His research interests are mainly focused on nanophotonics, metasurfaces, photonic crystals, bound states in the continuum, momentum-space topological optics, and structured light field manipulation.

Biographies of the other authors are not available.