

Optical observation of flat-band charge dynamics in kagome metal CsCr₆Sb₆Dongwook Kim,^{1,*} Boqin Song^{1,2,*} Zhenzhen Xu¹ Sangjun Han¹ Tianping Ying,² and S. J. Moon^{1,†}¹Department of Physics, Hanyang University, Seoul 04763, Republic of Korea²Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing, China

(Received 31 December 2025; accepted 14 July 2026; published 14 August 2026)

Flat-band systems, where electron kinetic energy is quenched over large regions of momentum space, are predicted to host exotic strongly correlated phenomena. Kagome metals have emerged as a prominent platform for exploring intriguing flat-band physics. Yet, their intrinsic charge dynamics have remained obscured because flat bands in most kagome materials either are located far from the Fermi level (E_F) or coexist with other dispersive bands near the E_F . Here, we report infrared spectroscopy measurements of the kagome metal CsCr₆Sb₆, which features isolated Cr-derived flat bands near the E_F . The optical conductivity spectra $\sigma_1(\omega)$ exhibit a striking power-law behavior proportional to $\omega^{-\alpha}$ with $\alpha \approx 0.26$, significantly deviating from conventional metallic response, where the conductivity falls like ω^{-2} . Above the frustrated magnetic state temperature $T_F \approx 72$ K, the low-energy $\sigma_1(\omega)$ displays incoherent charge dynamics without a well-defined Drude response. Below T_F , the low-energy $\sigma_1(\omega)$ is further suppressed, indicating electron scattering due to the magnetic frustration. Moreover, the spectral weight of $\sigma_1(\omega)$ is redistributed with varying temperature over broad energy scales (~ 4 eV), reflecting strong correlation effects. These findings demonstrate that CsCr₆Sb₆ belongs to the correlated bad metallic systems, which have not been witnessed among other kagome metals.

DOI: [10.1103/tw5d-d9fh](https://doi.org/10.1103/tw5d-d9fh)

I. INTRODUCTION

A flat-band system is characterized by the presence of a dispersionless energy band, where the group velocity of electrons vanishes over large regions of momentum space. Since quenching of kinetic energy enhances the effective strength of the electronic correlations represented by the ratio of the Coulomb interaction (U) to the electronic bandwidth (W), this renders flat-band systems an ideal platform for investigating strongly correlated phenomena. The prominent examples include magnetism [1], fractional Chern insulator phases [2,3], linear-in-temperature resistivity [4], density waves, and unconventional superconductivity [5,6].

In recent years, kagome metals, a class of flat-band systems, have attracted considerable attention owing to the realization of a wide variety of kagome compounds and the flat bands arising directly from the lattice geometry. Within the kagome lattice, the kinetic energy of the electrons between neighboring atomic sites is quenched by quantum destructive interference, resulting in flat bands extending throughout the momentum space [7,8]. In early experimental studies, these flat bands in many kagome metals are located far from the Fermi level (E_F), which hinders direct research on the flat-band physics. Meanwhile, other electronic bands such as Dirac bands and van Hove singularities dominate

the low-energy physics, giving rise to Dirac/Weyl fermions, unconventional superconductivity, and charge ordering [9–14]. Great efforts have led to the discovery of a class of 3d-kagome metals hosting flat bands near the E_F , including YCr₆Ge₆ [15], CoSn [16], CsCr₃Sb₅ [17], Fe₃Sn₂ [18], and Ni₃In [19]. These flat-band kagome metals exhibit a rich variety of quantum phenomena such as magnetism, heavy-fermion behavior, and unconventional superconductivity [16–19], underscoring the role of strong correlations originating from flat bands.

Intriguingly, these diverse quantum phenomena are not unique to flat-band kagome metals, but appear commonly across other strongly correlated electron systems, including cuprates, ruthenates, iron pnictides, and heavy fermions, suggesting that universal underlying principles could be at play [20,21]. A key to understanding this universality lies in the charge dynamics of the strongly correlated electron systems. The charge localization-delocalization transition is widely observed across the materials platforms in these systems, which can accompany the emergence of quantum phenomena, including heavy-fermion behavior, strange metallicity, and superconductivity [20,21]. Understanding the charge dynamics of these systems is therefore crucial for elucidating the cascade of quantum phenomena commonly found in strongly correlated regimes. The charge dynamics in cuprates, ruthenates, iron pnictides, and heavy fermions have been extensively studied, revealing anomalous behavior that deviates from conventional metallic response. This manifests as fractional power-law behavior and absence of a well-defined Drude response in low-energy optical conductivity spectra [22–27], which are characteristic of non-Fermi liquid (NFL) behavior and incoherent nature of charge carriers.

Flat-band kagome metals also exhibit signatures suggesting similar anomalous charge transport. For instance,

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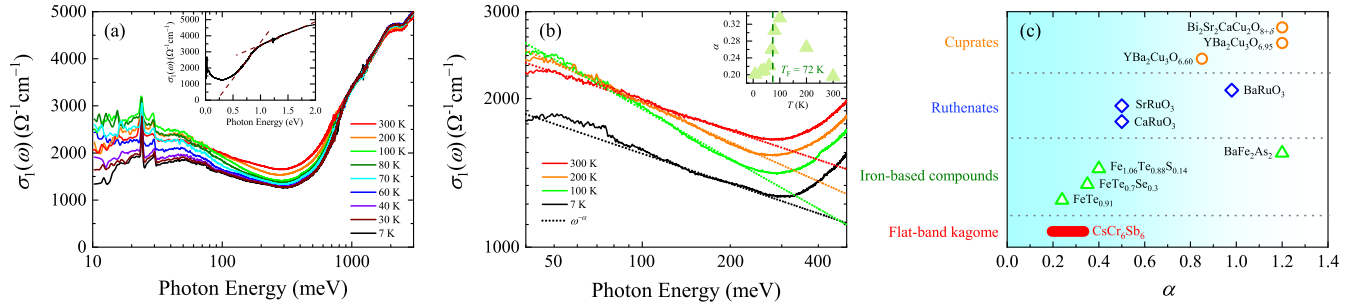


FIG. 1. (a) Optical conductivity spectra $\sigma_1(\omega)$ of CsCr_6Sb_6 below 3 eV. Inset: $\sigma_1(\omega)$ below 2 eV. The dashed lines highlight the linear energy dependence of $\sigma_1(\omega)$. (b) $\sigma_1(\omega)$ below 500 meV at 7, 100, 200, and 300 K. The dotted lines are guidelines for $\omega^{-\alpha}$ dependence. Inset: Temperature dependence of exponent α . The vertical dashed line indicates T_F . (c) Exponent α for CsCr_6Sb_6 (solid symbol) and other representative correlated materials (open symbols). The values of exponent α are obtained from Refs. [26,57] for iron-based compounds, Refs. [27,52,58] for ruthenates, and Ref. [26] for cuprates.

linear-in-temperature resistivity within the kagome plane is observed in CsCr_3Sb_5 under a pressure of about 4 GPa [17] and in Ni_3In at ambient pressure [19], as well as an anomalous scattering rate in Fe_3Sn_2 [18], all hallmarks of NFL physics. YCr_6Ge_6 [15], CoSn [16], and Ni_3In [19] exhibit higher resistivity within the kagome plane than perpendicular to it, in stark contrast to conventional quasi-two-dimensional layered materials where in-plane transport is typically more conductive. This anomalous anisotropy implies the large effective mass and localized nature of flat-band electrons. However, the charge dynamics inherent in flat bands remain enigmatic, as the coexistence of multiple dispersive bands near the E_F in the flat-band kagome metals obscures the flat-band contributions to the charge dynamics.

The very recently synthesized flat-band kagome compound CsCr_6Sb_6 [28] offers a unique opportunity to address this challenge. Unlike other flat-band kagome metals, CsCr_6Sb_6 features isolated, nearly dispersionless Cr-based kagome-derived flat bands located in close proximity to the E_F [28,29]. This electronic structure gives rise to a high resistivity and an ultralow carrier density ($\sim 10^{19} \text{ cm}^{-3}$) [28,29], indicating that transport is dominated by flat-band electrons. As temperature decreases, the local moments originating from these flat bands develop as a frustrated magnetic state at $T_F \approx 72 \text{ K}$ [28]. Despite the presence of strong interlayer antiferromagnetic coupling, the local moments maintain the short-range order [28,29], possibly due to the geometrical frustration inherent in the kagome lattice. With further cooling, Kondo screening of the local moments begins, forming the Kondo resonance below $T_K \approx 20 \text{ K}$ [28].

The isolated nature of the flat bands in CsCr_6Sb_6 thus provides an ideal platform to investigate the charge dynamics inherent in flat bands through optical spectroscopy. Here, we investigate the electronic response of CsCr_6Sb_6 single crystal by utilizing infrared spectroscopy. We find that the optical conductivity spectra $\sigma_1(\omega)$ follow a power law proportional to $\omega^{-\alpha}$ ($\alpha \approx 0.26$), which significantly deviates from that of conventional metals, demonstrating NFL transport. At high temperatures above $T_F \approx 72 \text{ K}$, the Drude-like response is not well defined, suggesting incoherent charge dynamics. Below T_F , the low-energy $\sigma_1(\omega)$ is further suppressed, indicating strong scattering of flat-band electrons due to the magnetic frustration. The temperature evolution of $\sigma_1(\omega)$ is also

observed at higher energies, where spectral weight redistribution occurs over broad energy scales centered around $\sim 900 \text{ meV}$ and $\sim 4 \text{ eV}$. These observations demonstrate the dominance of Hund's coupling and U , respectively, placing CsCr_6Sb_6 in the category of strongly correlated systems. Below $T_K \approx 20 \text{ K}$, we observe a pseudogaplike feature at about 15.3 meV, reminiscent of that found in Kondo insulators. Our study demonstrates that the flat band offers a promising playground for investigating the rich physics arising from strong electronic correlations and interplay of charge, spin, and lattice degrees of freedom.

II. RESULTS AND DISCUSSION

The optical conductivity spectra $\sigma_1(\omega)$ of CsCr_6Sb_6 obtained from Kramers-Kronig analysis of the reflectivity spectra are displayed in Fig. 1(a). The reflectivity spectra are shown in the Supplemental Material [30]. Two asymmetric infrared-active phonon modes are observed at about 23 and 29 meV in $\sigma_1(\omega)$, exhibiting anomalous temperature dependences near T_F , indicative of spin-phonon coupling (see the Supplemental Material [30] for details). Overall, $\sigma_1(\omega)$ can be divided into two distinct spectral regions at 300 meV. Above this energy, $\sigma_1(\omega)$ is dominated by interband transitions and exhibits two distinct linear-in- ω regions: one between 600 and 950 meV, and another between 950 meV and 1.8 eV [the inset of Fig. 1(a)]. However, due to the complexity of the electronic band structure of CsCr_6Sb_6 at high energies [47], the origin of the linearity in $\sigma_1(\omega)$ remains elusive and requires further theoretical investigations.

Below 300 meV, $\sigma_1(\omega)$ is mostly governed by the intraband response. In the energy range between 80 and 300 meV, $\sigma_1(\omega)$ decays with increasing energy, which is observed consistently across all measured temperatures. The dominance of the intraband response below 300 meV is supported by the density functional theory combined with dynamical mean-field theory (DFT + DMFT) calculations, which show that low-energy electronic structures of CsCr_6Sb_6 are dominated by flat bands near the E_F [47]. Intriguingly, $\sigma_1(\omega)$ decays following a power law proportional to $\omega^{-\alpha}$, where the exponent α shows an unusual temperature dependence [Fig. 1(b)]. Upon cooling above T_F , the exponent α gradually increases from 0.2 to 0.34. On the other hand, the exponent α is suppressed to 0.2

with further cooling below T_F , indicating that the onset of the frustrated magnetic state strongly influences the low-energy optical response. This pronounced temperature dependence indicates that $\sigma_1(\omega)$ below 300 meV is dominated by the intraband response, which is sensitive to scattering mechanisms or magnetic correlations. For example, a recent theoretical study of the t - J model predicts that temperature-dependent magnetic fluctuations induce variations in the power-law exponent of the low-energy optical conductivity [48]. On the other hand, the optical responses associated with the interband transitions generally display negligible temperature dependence [49–51]. The temperature dependence of the exponent α across T_F may indicate which electron-scattering channels, associated with degrees of freedom such as lattice or spin, are dominant. At high temperatures above T_F , the electron-lattice scattering may be dominant. Lowering the temperature toward T_F suppresses this electron-lattice scattering, which induces coherence in charge dynamics. Below T_F , the frustrated magnetic state emerges, and the associated magnetic fluctuations promote spin-flip scattering upon cooling [28,29], suppressing the exponent α from 0.34 to 0.2.

It should be noted that the power-law exponents of $\sigma_1(\omega)$ of the ruthenates, the iron-based superconductors, and the cuprates show little temperature dependence [26,27,52–54]. In CaRuO_3 and SrRuO_3 , the fractional power-law decay with an exponent of about 0.5 is observed at all measured temperatures, i.e., $10 \text{ K} \leq T \leq 500 \text{ K}$ for CaRuO_3 and $40 \text{ K} \leq T \leq 250 \text{ K}$ for SrRuO_3 [27,52]. For $\text{Fe}(\text{Te}, \text{Se})$, the same behavior of the temperature independence of the power-law exponent was found [53,54]. In the cuprates, the fractional power-law decay is shown in the pseudogap phase of the underdoped $\text{YBa}_2\text{Cu}_3\text{O}_{6.60}$ ($\sigma_1(\omega) \propto \omega^{-0.85}$) and in the superconducting state of the optimally doped $\text{YBa}_2\text{Cu}_3\text{O}_{6.95}/\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$ ($\sigma_1(\omega) \propto \omega^{-1.2}$), with the exponents remaining nearly temperature independent [26]. The strong temperature dependence of α in CsCr_6Sb_6 below T_F underscores the close coupling among the charge, spin, and lattice degrees of freedom.

Importantly, the values of the exponent α of CsCr_6Sb_6 are small ($\alpha \approx 0.26$), which clearly deviates from the ω^{-2} dependence observed in conventional metals. Such a slow decay of $\sigma_1(\omega)$ suggests NFL behavior. Other correlated metals, including iron-based compounds, ruthenates, and cuprates, also exhibit a fractional power-law decay of the low-energy optical conductivity $\sigma_1(\omega) \propto \omega^{-\alpha}$, with $\alpha \lesssim 1.2$, as shown in Fig. 1(c) [26,27,52,54–58]. Interestingly, the power-law exponent α of CsCr_6Sb_6 is particularly small and is comparable to that of the Hund's metal ruthenates and iron-based compounds. A theoretical study on the ruthenates and the iron-based compounds demonstrates that stronger Hund's-coupling-induced correlations can lead to smaller power-law exponent α of $\sigma_1(\omega)$ [57]. A recent DFT + DMFT study shows that CsCr_6Sb_6 belongs to Hund's metal [47]: The electronic response of CsCr_6Sb_6 is sensitive to both Hund's coupling and U , with the former playing a more decisive role in the formation of flat bands near E_F , rendering a highly incoherent electronic response [47]. Therefore, the small power-law exponent α of CsCr_6Sb_6 may be closely related to strong correlations and the resulting incoherent charge dynamics induced by Hund's coupling.

The optical response at lower energies also shows a deviation from conventional metallic behavior. At the highest temperature 300 K, $\sigma_1(\omega)$ becomes suppressed toward zero energy ($\hbar\omega \rightarrow 0$), precluding a well-defined Drude-like response [Fig. 2(a)]. Instead, a broad hump is observed at about 25 meV. As temperature decreases from 300 K to T_F , $\sigma_1(\omega)$ at $\hbar\omega \rightarrow 0$ increases, which renders the broad hump indiscernible. While the broad spectral shape of $\sigma_1(\omega)$ makes it challenging to obtain the quantitative information on the temperature evolution of the hump, it might be related to the so-called localization peak, which is observed in many kagome metals [32,33,35–37,59,60]. The origin of the localization peak in the optical response of kagome metals has been discussed in the framework of the electron-phonon coupling [32,33,35] or the electronic correlations [32,60]. For CsCr_6Sb_6 , the asymmetric line shape of the phonon mode labeled as Ph2 (~ 29 meV) in Fig. S2 of the Supplemental Material [30] at $T > T_F$ may suggest a possible role of the electron-phonon coupling. Alternatively, the origin of the localization peak in CsCr_6Sb_6 may be ascribed to the strong correlations originating from flat bands, where charge fluctuations induced by the long-range U result in transient localization of charge carriers [61–63]. A localization peak in $\sigma_1(\omega)$ of Fe_3Sn_2 is attributed to strongly correlated, localized charge carriers of the flat bands in the vicinity of the E_F [60].

Intriguingly, upon further cooling below T_F , $\sigma_1(\omega)$ below 100 meV is gradually suppressed as shown in Fig. 2(a). This observation reflects that the onset of the frustrated magnetic state plays a crucial role in enhancing the incoherent charge transport. To better understand the role of the frustrated magnetic state in the charge dynamics, we obtained the optical spectral weights (SWs) by integrating $\sigma_1(\omega)$ up to cutoff energy $\hbar\omega_c = 300$ meV, which accommodates the intraband contribution ($\text{SW}(T, \omega_c) = \int_0^{\omega_c} \sigma_1(\omega) d\omega$) [Fig. 2(b)]. The integrated SW is displayed as a function of temperatures in Fig. 2(c). With decreasing temperature above T_F , the SW shows a modest decrease, which may be affected by the decrease in the carrier density [28]. Notably, the SW is suppressed more drastically with further lowering temperature below T_F . One might attribute the faster suppression of the SW to the sharp change in carrier density occurring at T_F . However, the Hall measurements of CsCr_6Sb_6 show no anomalous behavior in the carrier density at T_F [28]. Instead, the sudden suppression of the SW at T_F can be ascribed to the enhanced electron scattering off the localized Cr-3d moments. Such an enhancement of the electron scattering is consistent with the upturns of the resistivity and the onset of negative magnetoresistance below T_F [28,29]. Similar behaviors have been reported in flat-band kagome metal $\text{Sc}_3\text{Mn}_3\text{Al}_7\text{Si}_5$, where the flat-band-induced ferromagnetic fluctuations suppress the Drude peak and enhance the electron scattering rate and resistivity [64]. LiV_2O_4 and carrier-doped CoSn also exhibit enhanced electron scattering from flat-band-induced magnetic fluctuations, which is suppressed by external magnetic field, resulting in negative magnetoresistance [65,66]. Collectively, these examples including CsCr_6Sb_6 indicate that the increased electron scattering off the local moments in the flat-band systems appears to be common, which is attributed to the magnetic fluctuations in the absence of long-range magnetic order.

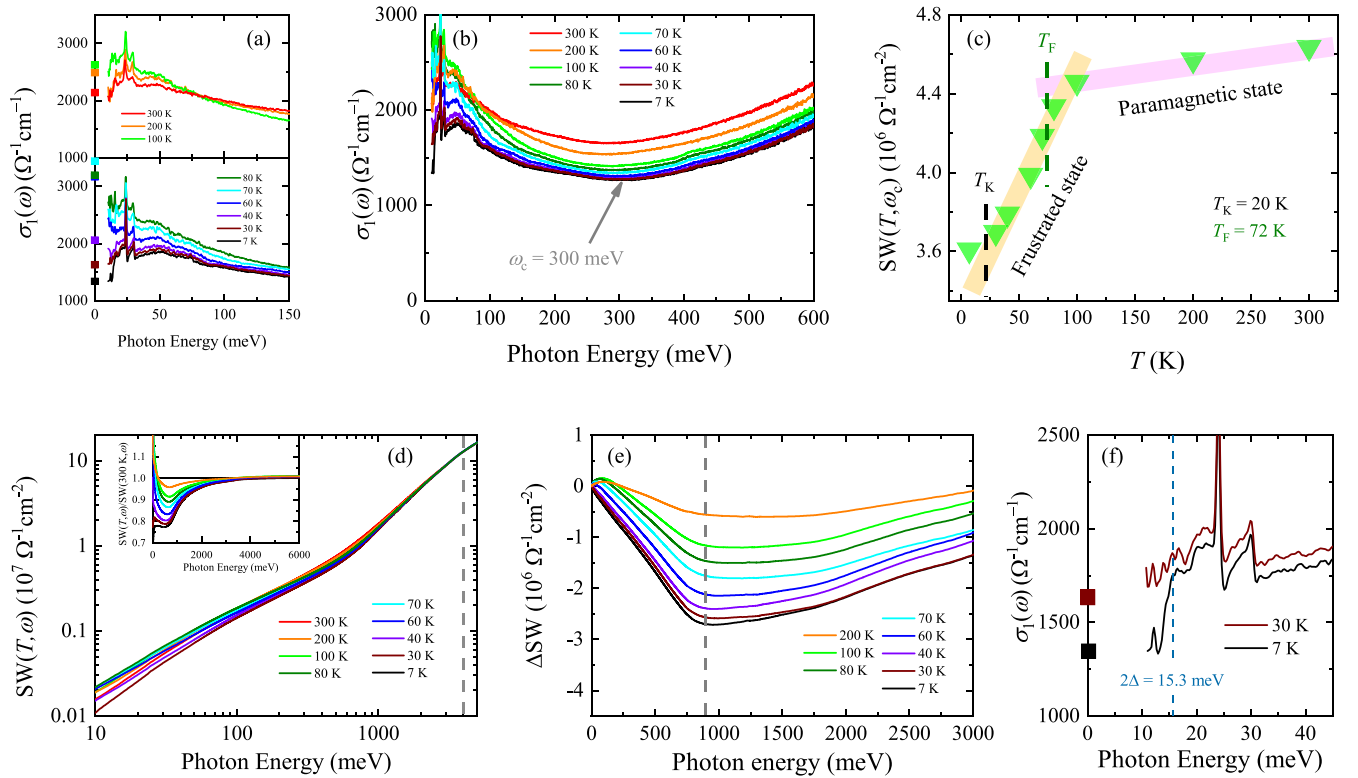


FIG. 2. (a) $\sigma_1(\omega)$ below 150 meV. The solid squares on the y axis represent dc conductivity at different temperatures obtained from the Hagen-Rubens extrapolation of the measured $R(\omega)$ spectra. (b) Temperature-dependent $\sigma_1(\omega)$ below 600 meV. The arrow indicates cutoff energy $\hbar\omega_c = 300$ meV for the calculation of the SW(T, ω_c). (c) Temperature dependence of optical spectral weight SW(T, ω_c). The black and green dashed lines indicate T_K and T_F , respectively. The colored bars highlight slope changes around T_F . (d) Temperature-dependent optical SW(T, ω). The vertical dashed line indicates the energy (~ 4 eV) where the sum rule is satisfied. Inset: Ratio of temperature-dependent optical spectral weight SW(T, ω)/SW(300 K, ω). (e) Temperature dependence of SW changes, $\Delta SW = SW(T) - SW(300 K)$. The vertical dashed line corresponds to $\hbar\omega_c = 900$ meV. (f) $\sigma_1(\omega)$ below 45 meV at 7 and 30 K. The dashed line denotes energy gap of $2\Delta = 15.3$ meV. The solid black and brown squares on the y axis represent dc conductivity at 7 and 30 K, respectively.

As temperature decreases further below $T_K \approx 20$ K, the reduction of the SW becomes less pronounced, reflecting the weakening of the electron scattering. This can be ascribed to the formation of Kondo resonance below T_K , a characteristic behavior of heavy-fermion systems [67,68]. Such a reduction of electron scattering of CsCr₆Sb₆ below T_K is supported by the recent magnetoresistance measurements [28,29] of CsCr₆Sb₆.

A systematic analysis of the SWs over a broader energy range reveals more detailed information about the many-body effects in flat-band kagome systems. Figure 2(d) shows the optical SW obtained from the integration of $\sigma_1(\omega)$ up to 5 eV. We find that the sum rule is satisfied at about 4 eV. With decreasing temperature from 300 down to 7 K, the low-energy SW mostly attributed to the intraband transition is suppressed, and the recovery of the SW is observed up to 4 eV. This trend is more clearly displayed in the ratio of the integrated SW at low temperature SW(T) to the room-temperature value SW(300 K), where the SW ratio reaches unity at about 4 eV [the inset of Fig. 2(d)]. Such a transfer of the low-energy SW over a broad energy range can result from strong correlation on the order of eV, whose energy scale is typically comparable with that of U in Mott-Hubbard systems. The DFT + DMFT calculations suggest the presence of on-site U of about 5 eV in CsCr₆Sb₆ [47]. This energy

scale is comparable to that of other geometrically frustrated d -electron systems with flat bands near E_F , such as CuV₂S₄ [69], Ni₃In [70], and CsCr₃Sb₅ [71]. Furthermore, the SW redistribution in eV scale is the hallmark of strongly correlated d -electron systems, including cuprates [23], $R_{1-x}Ca_xTiO_3$ ($R = La, Pr, Nd, Sm, \text{ and } Y$) [72], LiV₂O₄ [22], and La₄Ni₃O₁₀ [73] as inferred from the optical spectroscopy studies.

It is noteworthy that the temperature dependence of the SW transfer over a broad energy range (~ 4 eV) in CsCr₆Sb₆ shows a distinct characteristic from that observed in conventional Mott-Hubbard systems. In the latter, the SW is generally transferred from high to low energies upon cooling [74], while the SW transfer in CsCr₆Sb₆ occurs in the opposite direction. However, the Mott-Hubbard systems intertwined with additional interactions that tend to localize the charge carriers, such as magnetism, charge order, and Hund's coupling, exhibit the SW transfer from low- to high-energy region with decreasing temperature [75–77]. Since both the short-range antiferromagnetic interactions and Hund's coupling promote carrier localization at low temperatures [78], their combined effects, together with the Mott-Hubbard character of CsCr₆Sb₆, are likely responsible for the unusual temperature dependence of the SW transfer.

The SW transfer in CsCr₆Sb₆ can be further examined across different energy scales. Figure 2(e) displays the

change in the SW relative to the room-temperature value, i.e., $\Delta SW = SW(T) - SW(300\text{ K})$. Notably, ΔSW exhibits a minimum around 900 meV and subsequently exhibits a gradual upturn, which becomes more pronounced at lower temperatures. This behavior indicates that a small fraction of the SW suppressed below 900 meV is transferred to the energy region close to 900 meV. Such an SW transfer from low to high energy in the energy scale of 1 eV is reminiscent of the localization of the charge carriers driven by Hund's coupling [78–80]. Importantly, the energy scale of the turning point is consistent with the Hund's coupling strength (~ 900 meV) estimated from DFT + DMFT calculations of CsCr_6Sb_6 [47], which is comparable to the conventional Hund's coupling energy scale ($J_H \approx 600\text{--}900$ meV), reported in iron-based superconductors [78,79,81].

Having established the manifestation of the many-body effects associated with the flat bands, we discuss the effect of the Kondo screening on $\sigma_1(\omega)$ below T_K . Figure 2(f) presents $\sigma_1(\omega)$ at both 7 K (below T_K) and 30 K (above T_K) below 45 meV. We note that the low-energy $\sigma_1(\omega)$ becomes suppressed below about $2\Delta = 15.3$ meV upon cooling below T_K , indicating the partial gap opening. This observation is consistent with a recent scanning tunneling spectroscopy measurement of CsCr_6Sb_6 , which reports a gap opening near the E_F at 2 K with a magnitude of about 10–15 meV [28]. Although Kondo screening occurs below T_K , the associated spectral change does not follow in a similar manner to that expected for heavy-fermion systems. We do not observe the narrowing of the Drude-like response nor an absorption peak in a finite-energy region, which are conventional signatures of hybridization between f and conduction electrons in heavy-fermion materials [82]. Instead, our observations reveal a pseudogaplike feature, the development of which continuously suppresses the low-energy $\sigma_1(\omega)$. Similar pseudogaplike features have been found in Kondo insulators, where Kondo resonances develop without pronounced Drude-like responses [83–85].

As a final note, our optical observations for CsCr_6Sb_6 , including power-law decay in $\sigma_1(\omega)$, low-energy SW suppression linked to magnetic fluctuations, and broad spectral weight redistribution, are primarily related to the strong correlations induced by geometrical frustration inherent to the in-plane kagome lattice. This is particularly notable given that CsCr_6Sb_6 is a bilayer kagome metal, where the flat bands can be destroyed when the interlayer distance collapses, due to the enhancement of interlayer orbital hybridization. However,

DFT + DMFT calculations have shown that strong electronic correlations prevent the collapse of the interlayer distance, stabilizing it near its experimental value [47]. Consequently, the flat bands near the E_F remain intact, highlighting the minor role of the interlayer coupling in CsCr_6Sb_6 .

III. CONCLUSION

In summary, our infrared spectroscopy study of CsCr_6Sb_6 reveals the intrinsic charge dynamics of kagome flat bands. We observe power-law $\sigma_1(\omega)$ with extremely small exponent, incoherent transport, and SW redistribution over remarkably broad energy scales (~ 4 eV), which are the hallmarks of correlated bad metal behavior. These observations demonstrate that charge dynamics associated with flat bands bears striking similarities to those observed in strongly correlated metallic systems, bridging kagome flat-band systems with the universal physics of strongly correlated electron systems. Below T_K , we observe a pseudogaplike feature at about 15.3 meV, indicating the Kondo-insulating state. Our findings highlight the flat band as a fertile platform for exploring phenomena originating from strong electronic correlations and the intricate coupling among charge, spin, and lattice degrees of freedom.

ACKNOWLEDGMENTS

This research was supported by the National Research Foundation of Korea (NRF) funded by the Korean government (MSIT) (RS-2024-00416036, RS-2026-25492217, RS-2022-00143178), Brain Pool program (RS-2025-25446099), Quantum Simulator Development Project for Materials Innovation through the National Research Foundation of Korea (NRF) funded by the Korean government (MSIT) (RS-2023-NR119931), and National Natural Science Foundation of China (Grant No. 52522201).

DATA AVAILABILITY

The data that support the findings of this article are not publicly available upon publication because it is not technically feasible and/or the cost of preparing, depositing, and hosting the data would be prohibitive within the terms of this research project. The data are available from the authors upon reasonable request.

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