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The Critical 9365 Å Diffuse Interstellar Band and C₆₀⁺ Association

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ABSTRACT

The detection of interstellar C₆₀⁺ has been debated for 30 years. The contested attribution of a weaker DIB at 9365 Å was re-evaluated here on the basis of a Pearson correlation relative to 9577 Å, which was previously tied to C₆₀⁺ by diverse collaborations. An assessment of 11 sightlines revealed a high correlation amongst 9365–9577 Å equivalent widths ($r = 0.93 \pm 0.05$), after contamination from an adjacent line was mitigated using both numerical integration and Gaussian fits. In tandem with a recent separate study’s high- r evaluation linking 9577–9632 Å across a sizable baseline: three interrelated DIBs matching C₆₀⁺ laboratory findings were independently reaffirmed (9365, 9577, 9632 Å). Yet further investigations are required to strengthen the case via two other weak DIBs disputedly linked to C₆₀⁺, particularly owing to potential overlapping lines arising from an expansive chemical space (PAHs).

Keywords: Astrochemistry (75)

1. INTRODUCTION

H. W. Kroto (1987) suggested C₆₀⁺ could be associated with diffuse interstellar bands (DIBs). Subsequent experimental and observational research indicated that 9577 and 9632 Å DIBs may be tied to that fullerene (e.g., E. K. Campbell et al. 2015). However, concerns were expressed regarding the attribution (e.g., G. A. Galazutdinov et al. 2021). Recently, a consensus is emerging that those two stronger DIBs are indeed highly correlated and stem from a common carrier (e.g., T. P. Nie et al. 2022; D. Majaess et al. 2025). Yet a convincing connection to the buckminsterfullerene cation remains tenuous when relying merely on two DIBs. Efforts are therefore ongoing to characterize weaker interstellar lines overlapping experimental C₆₀⁺ measurements (9348, 9365, 9428 Å, e.g., E. K.

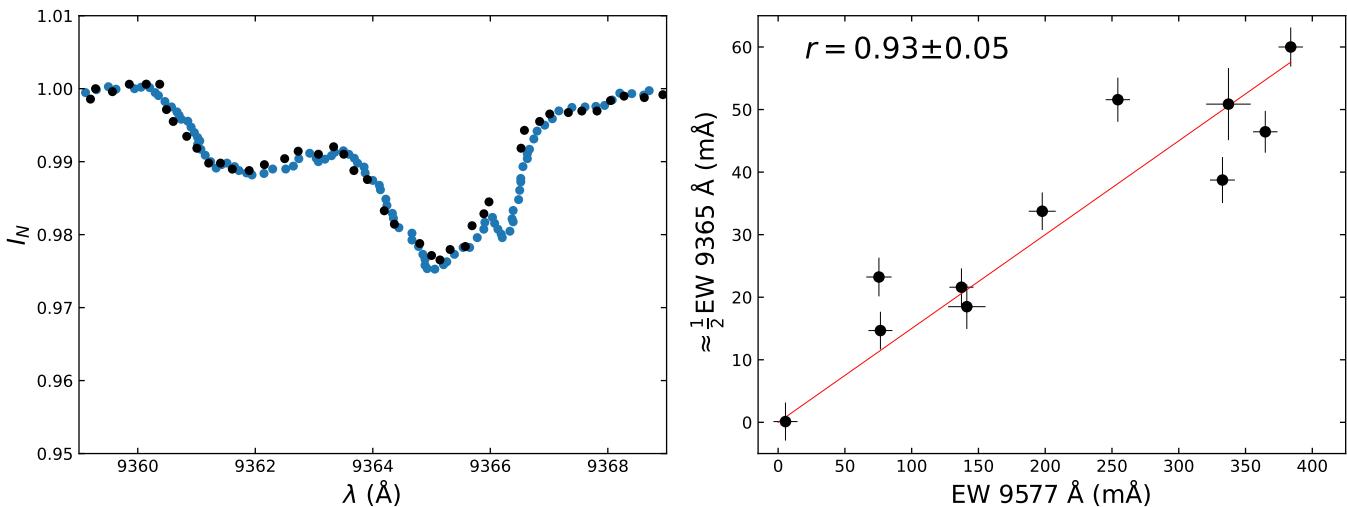


Figure 1. Left, the HD183143 sightline hosts the 9365 Å DIB, and a proximate absorption line at 9362 Å. Data were inferred from spectra displayed in G. A. H. Walker et al. (2015, blue) and G. A. Galazutdinov & J. Krełowski (2017, black dots, and omitting telluric features), and which represent an EW datum (average) in the adjacent right panel. A minor telluric (de)contamination anomaly may exist near 9366.2 Å in the former’s spectrum. Right, 9365 and 9577 Å DIBs are highly correlated ($r = 0.93 \pm 0.05$). The $\approx \frac{1}{2}$ EWs for the 9365 Å DIB represent numerical integration near line center to longer λ , thus mitigating contamination from the adjacent 9362 Å (left). Importantly, a high correlation is confirmed by Gaussian fits ($r \simeq 0.91$).

Campbell et al. 2016; M. A. Cordiner et al. 2019), but importantly those results are contested (G. A. Galazutdinov & J. Krełowski 2017; G. A. Galazutdinov et al. 2021).

In this study, an independent assessment is undertaken regarding whether 9365 and 9577 Å DIBs exhibit Pearson correlated equivalent widths (EW). The investigation is carried out by inspecting spectra presented by G. A. H. Walker et al. (2015, 2016), G. A. Galazutdinov & J. Krełowski (2017), and M. A. Cordiner et al. (2019). Specifically, the following sightlines are revisited: HD168625, HD136239, HD190603, BD+631964, 69 Cyg, HD169454, HD46711, Cyg OB2 5 (VI Cyg 5), Cyg OB2 12 (VI Cyg 12), HD183143, and HD195592 ($n = 11$).

2. ANALYSIS

Wavelength and flux tables for the sightlines are absent from the assessed studies, hence diagrams therein were interpreted using PlotDigitizer. An example of the inferred data is shown in Fig. 1 (left), where generally consistent observations for HD183143 emerge when extracted from spectra displayed by G. A. H. Walker et al. (2015) and G. A. Galazutdinov & J. Krełowski (2017).

Non-parametric numerical integration was favored for EW computations owing to spectral asymmetries and irregularities, which are exacerbated by molecular rotation. Simpson’s approximation was implemented, and the 9365 Å EWs were calculated near⁹ line center to longer wavelengths (i.e., $\approx \frac{1}{2}$ EW), namely to reduce the impact of 9362 Å. The example spectra in Fig. 1 (left) show both 9362 and 9365 Å absorption profiles, whereby the debated DIB linked to C_{60}^+ is 9365 Å. The EW determination for 9577 Å is comparatively uncomplicated relative to 9365 Å. Simpson’s approach was

⁹ $\lambda = 9364.7$ Å.

applied to the full 9577 Å profile. A trapezoid approach was employed to help evaluate uncertainties, as discussed below, and validate the correlation determined together with Gaussian fits.

HD169454, HD183143, and Cyg OB2 5 possess multiple spectra which provide a means of evaluating EW scatter. Data for HD169454 were presented by G. A. H. Walker et al. (2015), G. A. Galazutdinov & J. Krełowski (2017), and M. A. Cordiner et al. (2019). The 9365 Å $\approx \frac{1}{2}$ EWs determined here exhibit a standard deviation of 2 mÅ. For 9577 Å EWs $\sigma = 11$ mÅ. Spectra for HD183143 were published by G. A. H. Walker et al. (2015) and G. A. Galazutdinov & J. Krełowski (2017), and $\sigma = 2$ mÅ for both 9365 and 9577 Å. Lastly, Cyg OB2 5 observations were published by G. A. Galazutdinov & J. Krełowski (2017) and M. A. Cordiner et al. (2019), and the results are $\sigma = 5$ and 14 mÅ for the DIBs, respectively. The average EW for each of those stars was utilized when constructing Fig. 1 (right). In an effort to estimate systematic uncertainties for the entire sample (stars with and without multiple spectra), a base bulk uncertainty was adopted for all stars from means of the aforementioned deviations (i.e., 3 and 9 mÅ for 9365 and 9577 Å accordingly), and subsequently expanded in quadrature with any offset between Simpson and trapezoid integrations for each star. The uncertainties underestimate local effects, and for example note that HD195592 is reputedly a runaway star with bowshock induced γ -rays (M. V. del Valle et al. 2013), which could explain its more deviant nature in Fig. 1 (EW₉₅₇₇ = 254 ± 9 mÅ, and M. A. Cordiner et al. 2019 obtain 251 ± 6 mÅ), in concert with a normalization issue for 9365 Å. Continuum normalization for HD195592 and BD+631964 are uncertain and exhibit potentially spurious shorter-wavelength shoulders (e.g., M. A. Cordiner et al. 2019, their Fig. 2 and discussion therein).

In conclusion, 9365 and 9577 Å are highly correlated (unweighted $r = 0.93 \pm 0.05$, Fig. 1, right). Pertinently, analytic Gaussian fits to 9365 Å provided semi-independent confirmation of the high correlation ($r \simeq 0.91$). Double Gaussians were employed to isolate 9362 Å from the DIB 9365 Å. Moreover, the ensuing observed slope ($m_O = 0.22$, EW₉₃₆₅/EW₉₅₇₇) is similar to indirect comparisons relative to the experimental attenuation ratio (E. K. Campbell & J. P. Maier 2018, $m_L = 0.26$), thereby confirming that specific result of M. A. Cordiner et al. (2019).

Lastly, systematic uncertainties associated with 9362 Å are currently too large to firmly evaluate whether it is correlated with 9365 Å (Fig. 1, left). For example, 9362 Å profiles for Cyg OB2 5 differ between M. A. Cordiner et al. (2019) and G. A. Galazutdinov & J. Krełowski (2017), and that is likewise true for HD169454 (M. A. Cordiner et al. 2019 relative to G. A. H. Walker et al. 2015 and G. A. Galazutdinov & J. Krełowski 2017). Utilizing all data yields $r = 0.36 \pm 0.30$ (9362–9365 Å), and excluding M. A. Cordiner et al. (2019) spectra implies $r \approx 0.67$ (merely $n = 5$).

3. CONCLUSIONS

DIBs at 9365 and 9577 Å feature EWs adhering to a high correlation ($r = 0.93 \pm 0.05$, Fig. 1, right), hence providing additional context relative to an existing and warranted broader C₆₀⁺ debate. The result stems from non-parametric numerical integration and Gaussian fits, where contamination from a nearby absorption line was mitigated (Fig. 1, left). Moreover, when paired with the D. Majaess et al. (2025) high- r determination between 9577–9632 Å DIBs across a notable 650 mÅ baseline¹⁰: three DIBs are now independently reaffirmed as interrelated (9365, 9577, 9632 Å), and as noted previously likewise match experimental C₆₀⁺ conclusions (E. K. Campbell et al. 2015, 2016).

¹⁰ Previous conflicting works each sampled a narrow dynamic range.

Lastly, G. A. Galazutdinov et al. (2021) present pertinent arguments that evidence linking 9348 and 9428 Å DIBs to C_{60}^+ is unconvincing, and this work did not address those two DIBs. Indeed, additional investigations of those two lines are desirable, since unknown PAHs could exhibit three comparable lines to C_{60}^+ , but the probability diminishes substantially when considering five lines (i.e., wavelength and intensity ratios). The current and envisioned analyses could be (in)validated and undertaken using telluric-corrected X-shooter spectra.

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