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The Nature of the Infrared Excess around WD 0950+139

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WD 0950+139 is an intriguing white dwarf because (1) it is the central star (T_{eff} = 110,000 K) of the large (14′ diameter) planetary nebula EGB 6 (Ellis et al. 1984; Liebert et al. 1989); (2) it has strong nebular emission lines (such as [O III], Liebert et al. 1989) associated with a resolved companion at a separation of 0.″18 (Bond et al. 1993); and (3) it has a NIR excess suggestive of the presence of a dM companion (Zuckerman et al. 1990, Fulbright & Liebert 1993). Our new *Spitzer* observations of WD 0950+139 further reveal that the infrared excess extends beyond 35 μm, and has temporal variations on a timescale of a year. Furthermore, our recent ground-based Echelle spectroscopic data reveal a double peaked [O III] line profile indicative of a Keplerian disk structure around the system. In this paper, we will discuss the nature and origin of the infrared excess around WD 0950+139.

The Nature of the Infrared Excess around WD0950+139

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Planetary Nebula EGB 6 = PN G2215+46.3

• EGB 6: a large, faint PN discovered by Bond (see Ellis, Grayson & Bond 1984) on Palomar Sky Survey prints. Ground-based CCD images (Figure 1 below) by Jacoby & van de Steene (1995) and Tweedy & Kwitter (1996) show a brightness enhancement toward the western side of the nebula, suggesting an interaction with the ISM.

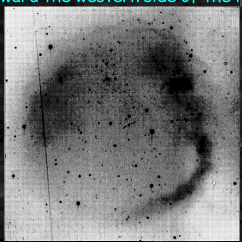

Figure 1 – Hα+[N II] image of EGB 6 by Jacoby & van de Steen(1995). North is to the top and east is to the left with a dimension of 16' on each side. The nebula is fairly spherical on the eastern half, while the western half is distorted and has a strong brightness enhancement on the edge. The nebular dimension is 13'x11'. Assuming a distance of 645 pc and an expansion velocity of 35 km/s, the nebula has a kinematic age of ~6x10⁴ yr. The central star, WD0950+139, is marked.

WD0950+139 = CSPN of EGB 6

• A very hot white dwarf with Teff ~108,390 K, logg ~7.39±0.38, M_*~0.64 M_{sun} at a distance of 645 pc (Liebert et al. 2005)

• Ground-based UBV, Sloan ugriz and GALEX fuv (0.15 μm) and nuv (0.23 μm) photometry can be well fitted with a WD model atmosphere of Teff=110,000 K with an interstellar extinction Av of 0.12 mag (See Figure 2). At distance of 645 pc, the WD luminosity is 72 L_{sun} with a radius of 0.023 R_{sun} (2.55 $R_{\oplus}$).

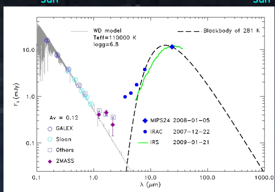

Figure 2 – The SED of the WD0950+139. The infrared excess is evident at λ >1 μm. Spitzer photometry (IRAC and MIPS 24 μm) and IRS low-resolution spectrum were taken ~1 year apart. The temporal variation is real as the associated errors of these measurements are much smaller to account for the difference.

• This WD is found to be associated with a compact emission nebula (Liebert et al. 1989). Ground-based JHK photometry (Zuckerman et al. 1990; Fulbright & Liebert 1993) further revealed a NIR excess suggestive of the presence of a dM companion.

• High-resolution HST images (Bond 2009) resolved the companion (Figure 3, left) at a separation of 0.18" (~116 AU@645pc) and showed that the compact emission nebula is associated with the companion.

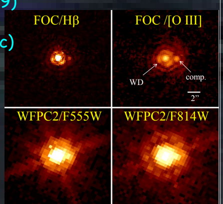

Figure 3 – HST FOC and WFPC2-PC images of WD0950+139. All the images have the same physical scale with N to the top and E to the left.

• Our newly obtained Echelle spectrum (R~30,000 covering 3900 - 7300 A) is shown in Figure 4 (below). Strong lines such as Hα, Hβ, [O III] and He I are spectrally resolved. The FWHM of the lines is ~44 km/s with the base extending from -50km/s to +50km/s.

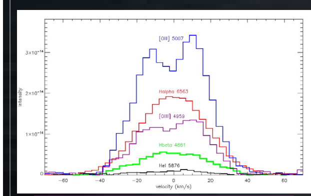

Figure 4 – Echelle spectrum of WD0950+139.

• [O III] lines show a distinct double-peaked profile, which is usually a signpost of a gaseous rotating disk. The separation between the peaks, ±11 km/s, suggests a disk outer radius of 0.5 AU (1.5 AU) if the companion mass is 0.06 (0.2) M_{sun}.

Mid-IR Excess Revealed by Spitzer Observations

• Spitzer images (IRAC 3.6, 4.5, 5.8 and 8 μm and MIPS 24 μm) and Sloan 3-color image are shown in Figure 5 (below).

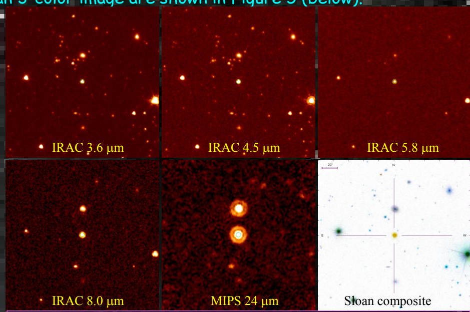

Figure 5 – Spitzer images of WD0950+139 along with the Sloan composite color image. All images are in the same physical dimension with N up and E to the left.

• The WD is detected in all Spitzer images as a point source and the photometry is displayed in Figure 2. The infrared excess (after WD photospheric subtraction) is shown in Figure 6 (below).

• NIR excess can be fitted with a 2000K B.B. or 2000K NextGen model. At a distance of 645 pc, the companion has a luminosity of 0.04 L_{sun}, and a radius of 0.55 R_{sun}.

• Mid-IR excess peaks at ~24 μm with a fractional luminosity (f_d) of ~7x10⁻⁴. For an implied temperature of ~280 K, the emitting area, 0.6 AU², is too big for a stellar object. A dust disk/cloud is needed.

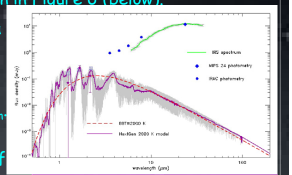

Figure 6 – The infrared excess SED of WD0950+139. The color between 8 and 24 μm suggests a color temperature of ~280 K.

Possible Origins of the IR Excess

• The system is complex: (1) a hot WD, emitting lots of UV photons; (2) an over-luminous companion (116 AU away, T~2000K, R~0.55 R_{sun}) surrounded by a rotating gas disk (R_{out} ~ 0.5-1.5 AU); (3) a dust disk illuminated by both the WD and its companion with location unknown.

• Scenario I (Figure 7)
The dust disk is around the WD, similar to the one around the Helix central star (WD2226-211). The disk is an optically thin debris disk (R_{in}~1 AU, R_{out}~60 AU, astronomical silicates with a_{min}~50 μm and a_{max} of 1000 μm, a total dust mass of 1.3x10⁻² $M_{\oplus}$.

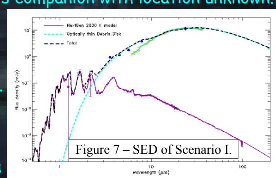

Figure 7 – SED of Scenario I.

• Scenario II (Figure 8)
The dust disk is around the companion and heated by both the WD and its companion. The emission can be approximated as a combination of an opaque ring heated by the companion and an optically thin upper disk layer heated by the WD.

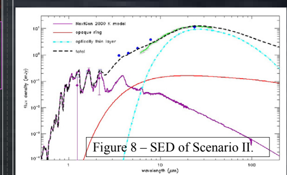

Figure 8 – SED of Scenario II.

The opaque ring has an inner radius of 0.005 AU (~dust sublim. radius) and an outer radius of 0.5 AU (~the Keplerian radius from the [O III] lines). At ~120 AU from the WD, only small grains can emit efficiently at mid-IR. The thin disk atmosphere is composed of 0.1-10 μm amorphous carbon grains.