WZ Sge: Dark Matter in Accretion Disks

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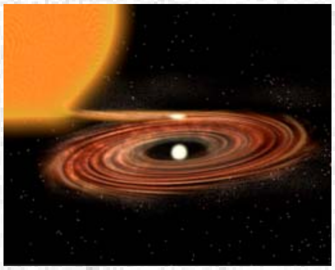
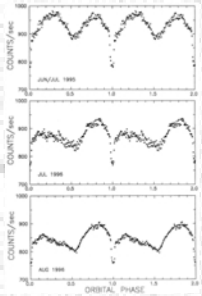
Accretion disks are ubiquitous in astronomy, being present in active galaxies, star and planet formation, galactic and extragalactic black hole and neutron star systems, and in interacting binaries containing white dwarf primaries. We obtained time series Spitzer Space Telescope photometric observations of the short orbital period cataclysmic variable WZ Sge at 4.5 and 8 microns. We also obtained contemporaneous ground-based optical spectroscopy and multi-color photometry. Our light curves reveal that the primary eclipse is still present at these mid-IR wavelengths but its cause is not the same as in the optical and near-IR. The overall implications of our observations are that the gaseous accretion disk observed in the optical and near-IR is surrounded by a much larger, thicker asymmetric outer ring of cool dusty material, invisible in the optical and near-IR. We are able to model the dust disk as being composed of 1 micron dust grains ranging in temperature from 1300K to 500K. Our findings have major implications for both observational and theoretical work on accretion disks including those in AGN and super massive black hole systems as the dust disk is the major light source long-ward of 4 microns..

Introduction

WZ Sge is an 81-minute interacting binary star of the cataclysmic variable type. It consists of a white dwarf primary star having a mass of 0.86 M-sun and a low mass, cool secondary object having a mass of 0.078 M-sun. The primary star is not magnetic and material accreted from the secondary star forms an accretion disk (Steeghs et al., 2007 and Fig. 1). WZ Sge is an eclipsing binary and has been extensively studied in the optical with some work in the near-IR (see Mason et al., 2000). The typical optical primary eclipse (phase 0.0) width is about 8 minutes in length or 0.1 in phase and shows an eclipse of the accretion disk and then the white dwarf (see Fig. 2).





Left: Figure 1 - An artist conception (NOAO/P.Marenfeld) of the current view of systems such as WZ Sge. The primary white dwarf star is surrounded by a hot, gaseous accretion disk. Right: Figure 2 - Typical optical eclipse light curves for WZ Sge obtained by Patterson et al. (1998) in the B photometric band.

Observations

WZ Sge was observed simultaneously at 4.5 (channel 2) and 8.0 (channel 4) microns using the Infrared Array camera (IRAC; Fazio et al. 2004) instrument on the Spitzer space telescope. The observations took place in early July 2007 and lasted for 90 minutes or just over one orbital period for WZ Sge. Spitzer IRAC frames were obtained at 12 second intervals at both wavelengths. Using the Kitt Peak National Observatory 2.1-m and 0.9-m telescopes, we obtained optical spectroscopy and multi-color photometry During the last week in June 2007. The optical observations showed WZ Sge to be in a normal quiescent state with nothing unusual about its eclipse shape or width.

Representative mid-IR images from IRAC are shown in Fig. 3 below while our light curves of WZ Sge are presented in Fig. 4. The 4.5 micron points are unbinned while those for the lower flux level 8.0 micron are binned by 3, to 36 seconds. In contrast to our previous IRAC observations of polars (see Howell et al., 2006, Hoard et al., 2007 and Brinkworth et al., 2007), we did not detect a rising SED from 4.5 to 8 microns. Instead, we find a mid-IR flux distribution that initially appeared consistent with an extended RJ tail of the well known gaseous accretion disk. However, to our surprise, WZ Sge showed deep, broad eclipses in the 4.5 and 8 micron light curves (Fig. 4) indicating that the source of a non-negligible fraction of the mid-IR emission is not circumbinary but within the binary itself.

The primary eclipse is highly structured and much broader than in the optical and near-IR. It lasts for nearly 25 minutes or 1/3 of the binary orbital period, three times longer than in the optical. At the parallax-determined distance of 43 pc for WZ Sge (Harrison et al., 2004), the white dwarf and gaseous accretion disk will contribute essentially nothing to the mid-IR flux. The optically observed gaseous accretion disk tail, roughly following a $\lambda^{-2.3}$ distribution for a sum of blackbodies, should continue to fall in the absence of other flux sources.

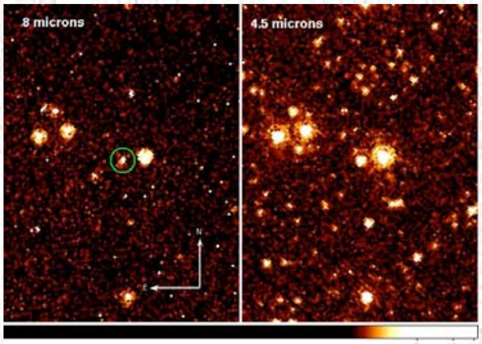


Figure 3 - representative Spitzer pipeline reduced IRAC images of WZ Sge. The green circle marks WZ Sge's position in the 8 micron image. We used five additional stars, common to both images, as comparison sources for stability and error assessment.

Analysis and Preliminary Model

The mid-IR light curves (Figure 4) suggest that the gaseous accretion disk is surrounded by a large, cool, and highly asymmetric mid-IR emitting disk. This outer ring-like structure is vertically thicker than the gaseous accretion disk and concentrated toward the secondary star covering phases 0.74 to 0.14. Primary eclipse is deeper at 4.5 microns than at 8.0 microns, but the two eclipses have the same width, phasing, and even the same detailed shape. The dip covering phases 0.25 to 0.6 has the same extent as the primary eclipse. Thus, we believe that the primary eclipse is an obscuration of the cool dust ring by the secondary star. Fig. 5 shows an artist concept of the new way we need to view accretion disks; larger in radius and able to block IR light. Our discovery may represent the first observational detection of dusty rings surrounding gaseous accretion disks such as the scaled up dusty torus model for active galaxies.

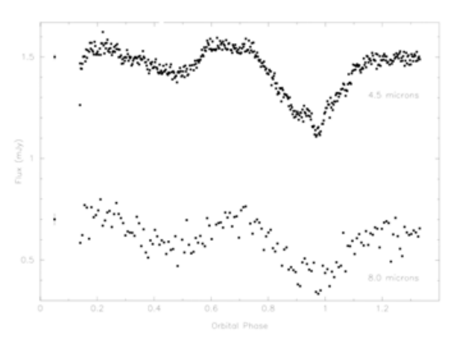


Figure 4 - Spitzer Space Telescope light curves of the interacting binary WZ Sge at 4.5 and 8 microns. The 4.5 microns dataset is shown at its full resolution of 12 seconds per point while the 8.0 micron data have been binned by 3. The two points shown on the far left give the approximate one sigma errors for each dataset. Note the detailed structure in the light curves, particularly near phase 0.0.

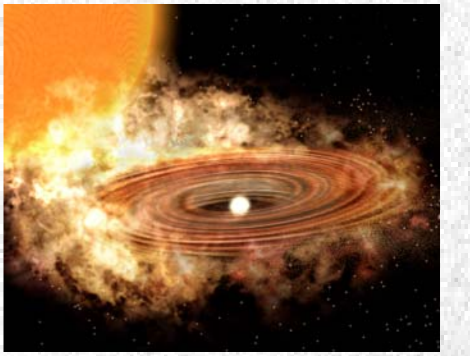


Figure 5 - An artist conception (NOAO/P.Marenfeld) of the new view of accretion disks in systems such as WZ Sge. The primary white dwarf star is surrounded by a hot, gaseous accretion disk observed in the optical and near-IR further surrounded by an asymmetric, thick, cool dust disk.

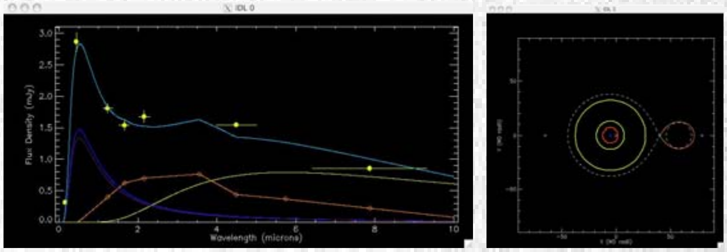


Figure 6 - Preliminary model. (Left) The 10,00K WD (dark blue line), the secondary star (orange line) is a T=1500K, 0.08 Msun L5 star, a T(inner) = 10,000K accretion disk (purple line), and the newly discovered dust disk (yellow line) are plotted.The light blue line is the sum of all components and the yellow dots are observations (HST, 2MASS, Spitzer). The dust disk model is optically thin, composed of 1 micron spherical grains with density of 3 g/cm^3 (i.e. silicates). It is completely invisible (dark) in the optical and near-IR. The total mass in the dust disk is 8e-9 moon masses (about 5.9e17 g = a medium asteroid). The dust disk extends from 9 to 32 Rwd while the gas disk extends to only ~2.4 Rwd. The dust has a temperature of 1300 to 500K from its inner to outer edge and a vertical thickness of at least 0.1 Rwd. (Right) A "top" view of the binary showing the gas disk (red) and newly discovered dust disk (yellow).The dust disk is far less massive than the gas disk but extends to 2-4 times the radius and is the major light source long-ward of 4 microns.

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Refs: Brinkworth, et al., 2007, ApJ, 659,1541; Fazio et al. 2004, ApJS, 154, 10; Harrison et al., 2004, AJ, 127, 460; Hoard et al., 2007, ApJ, 671, 734; Howell et al., 2006, ApJ, 646, L65; Mason et al., MNRAS, 2000, 318, 440; Patterson, et al., 1998, PASP, 110, 403; Steeghs, D., et al., 2007, ApJ, 667, 442