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EM Emission From Tidally Disrupted WDs

A Counterpart to a *LISA* Source

Summary

We model the EM emission from a tidally disrupted $0.55\,M_\odot$ white dwarf (WD) in a bound orbit around a moderately massive ($10^4\,M_\odot$) black hole (BH). With such a combination of masses, the WD is disrupted outside the BH event horizon and produces a distinctive electromagnetic counterpart to the gravitational waves emitted during the inspiral. Both signals will be observable to distances of order 100 Mpc by the next generation of X-ray/optical observatories and the planned *Laser Interferometer Space Antenna* (*LISA*). Thus we will be able to probe the demographics of moderately massive BHs, dynamical interactions in the cores of dwarf galaxies, and the WD equation of state (Sesana et al. 2008). The dynamics of the tidal disruption were simulated with SPH codes and show that the debris settles into a steady, axisymmetric disk six hours after the WD is tidally disrupted and accretion begins after 26 hours. The accretion rate remained steady at $\dot{M} = 2.8 \times 10^{-3}\,\mathrm{M_\odot\,yr^{-1}}$ until our simulations ended, 52 days after the WD is tidally disrupted. We assumed that the potential energy of the accreted material is converted into radiation with an efficiency of 10%, and that this radiation, which has a spectral energy distribution (SED) similar to that of an active galactic nucleus (AGN), illuminates the rest of the disk. With these assumptions, the electromagnetic signature was modeled using the photoionization code *Cloudy*. The optical spectrum is dominated by continuum emission from accretion onto the black hole. There are, however, weak but possibly discernible, X-ray emission lines the strongest of which is the Fe Kα line with an equivalent width of 9-100 eV, depending on the spectral energy distribution of the ionizing radiation.

SPH Simulations

We simulated the dynamics of the tidal disruption with a relativistic SPH code (Laguna et al. 1993) and *GADGET-2* (Springel 2005), to which we added a sink particle with a Paczynsky-Witta potential to represent the BH. For both codes, the artificial viscosity parameter was tuned so the Shakura-Sunyaev viscosity parameter $\alpha \leq 0.1$. In different runs, the WD was represented by 10^4, 5×10^4, and 10^5 particles. The WD was placed just outside the tidal disruption radius and we artificially accelerated the orbital decay due to the emission of gravitational radiation until the WD was disrupted. The debris first formed several rings before differential precession and viscosity spread the material into an elliptical and then circular disk. We followed the evolution of the disk until the inner edge reached the ISCO and accretion began. The accretion rate was steady at 12 times the Eddington limit for the duration of the simulations.

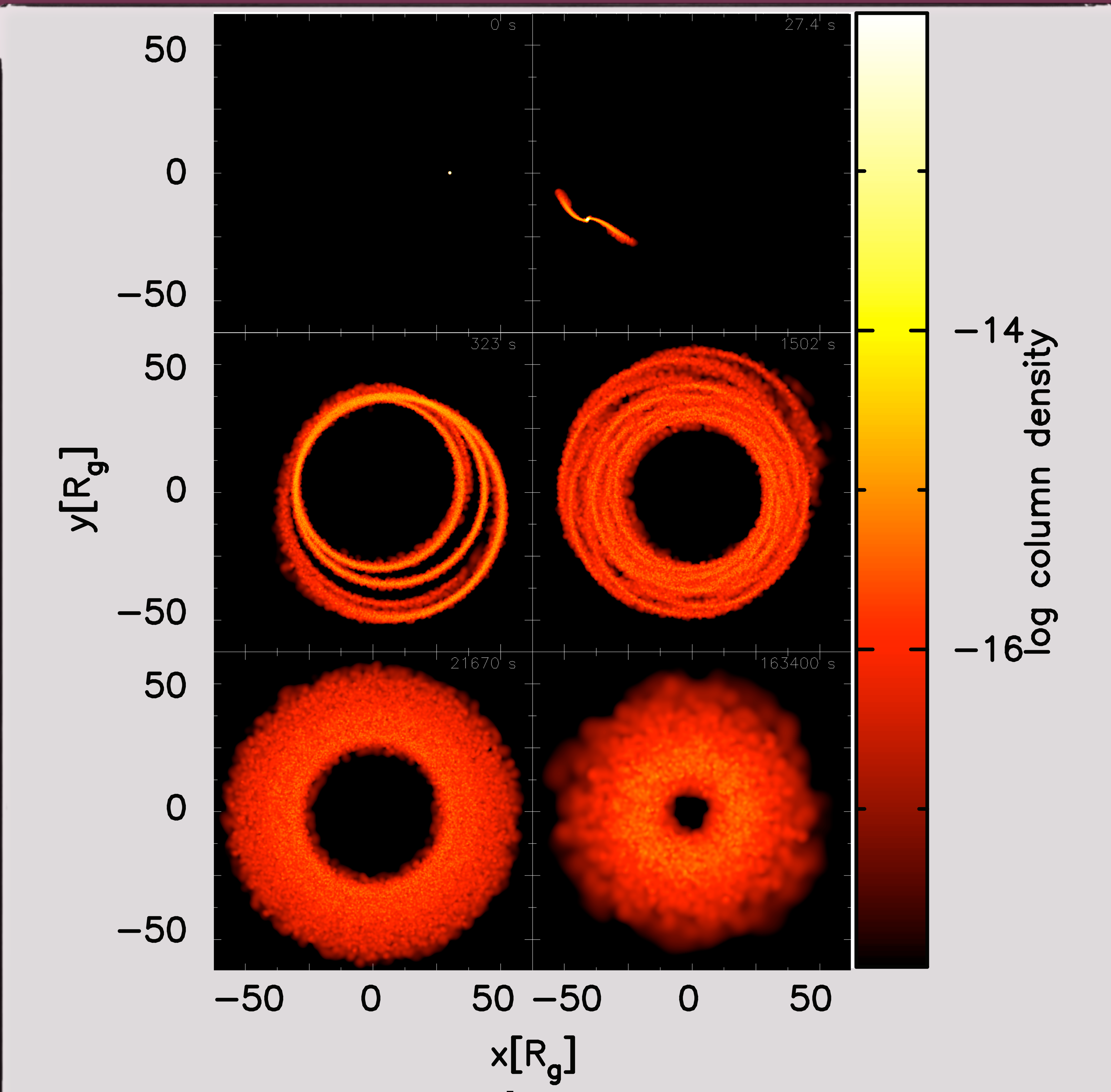

Figure 1 – Snapshots from the 10^5 particle *GADGET-2* simulation showing the major phases of the evolution of the debris disk. The time of each snapshot is given in the upper right hand corner of each figure.

Photoionization Models

The structure of the accretion disk and the accretion rate computed in the SPH simulations were used as the starting point for photoionization models. The SPH simulations follow well the denser parts of the disk but not the atmosphere. Therefore, we fitted an analytic function to the vertical density distribution (following α-disk theory) and extrapolated the density profile of the thin skin to large heights. This skin is ionized by radiation from the top of the nearly spherical inner disk. We modeled the resultant emission from the region bounded by the surfaces where the oxygen ionization parameter is 1000 and the electron-scattering optical depth is 1. The intensity of the incident radiation was normalized to the accretion rate from our dynamical simulations assuming a conversion efficiency of 10%.

The photoionization models were preformed with *Cloudy* (Ferland et al. 1998), using a built in, multicomponent SED, similar to that of an AGN, for the incident radiation. Since the disk is formed from a disrupted WD the mass abundances are: 67% O, 32% C, 1% He and all other elements scaled from their solar values, and 0.001% H.

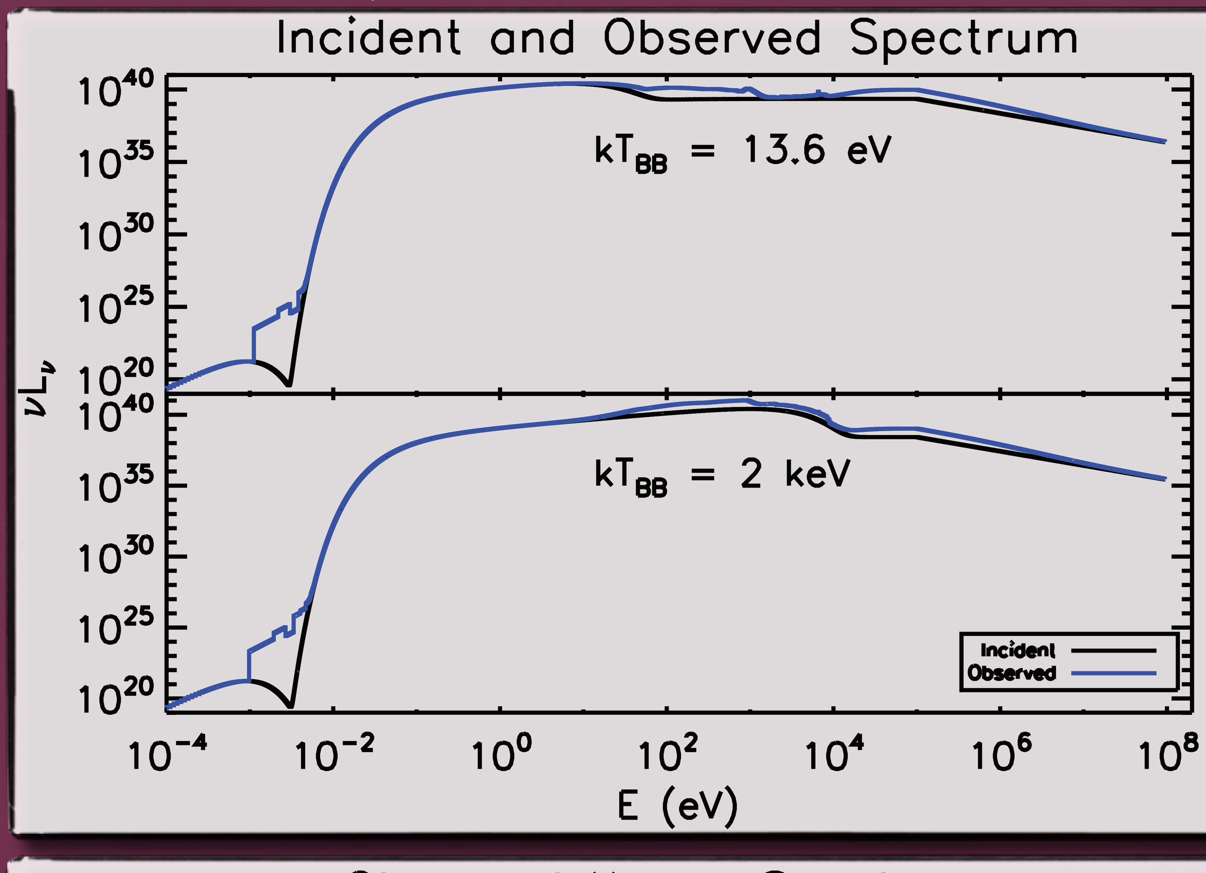

Figure 2 – The photoionization models were run with the peak of the SED at two different energies: 13.6 eV and 2 keV. These energies correspond to the position of the peak in AGNs and X-ray binaries and bracket the range of expected SEDs.

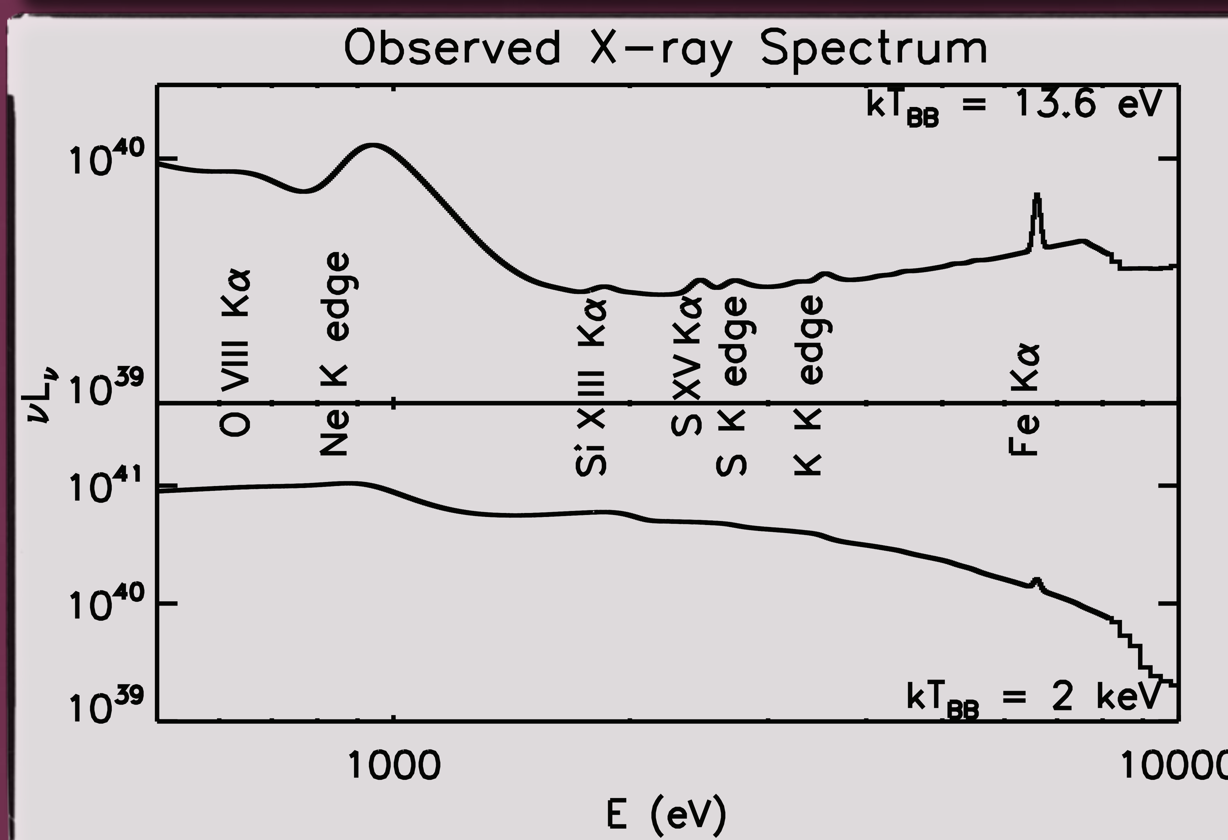

Figure 3 – A simulation accounting for the line response of XMM-Newton and the velocity of the material at these radii generated a line profile resembling a Gaussian with σ_E= 60 eV. The lines and edges in this figure were smoothed accordingly.

Electromagnetic Signature

The EM signature of a WD that has been tidally disrupted by a moderately massive BH is characterized by the following properties:

- An accretion flare with $L_{Bol} = 1.7 \times 10^{43}\,\mathrm{erg\ s^{-1}}$ beginning 26 hours after tidal disruption. Simulations show that the high accretion rate in these systems is steady and not impeded by any dynamical processes.
- With $L_x \sim 10^{41}\ \mathrm{ergs\ s^{-1}}$, the accretion flare will outshine X-ray binaries. The system will maintain a high enough X-ray luminosity to remain distinguishable for ~ 50 years.
- Weak x-ray lines from highly ionized Fe, O, Si, and S:

T_{BB}	O VIII Kα EW	Si XIII Kα EW	S XV Kα EW	Fe Kα EW
13.6 eV	10 eV	12 eV	16 eV	100 eV
2.0 keV	5.0 eV	0.42 eV	1.1 eV	8.7 eV

- A strong Ne K edge

Observers should look in the cores of dwarf elliptical galaxies for an extremely bright, continuum x-ray source.

References

Ferland, G. J. et al. 1998, PASP, 110, 761

Laguna, P. et al. 1993, ApJ, 404, 678

Paczynsky, B., & Wiita, P. J. 1980, A&A, 88, 23

Sesana, A. et al. 2008, MNRAS, 391, 718

Shakura, N. I., & Syunyaev, R. A. 1973, A&A, 24, 337

Springel, V. 2005, MNRAS, 364, 1105