# 1D SPECTRAL MODELING OF ACCRETION DISKS AROUND COMPACT STARS


T. Nagel, S. Hartmann, T. Rauch, K. Werner

Kepler Center for Astro and Particle Physics, Universität Tübingen, Germany

Eberhard Karls Universität Tübingen


## Abstract


AcDc is a NLTE code based on the Tübingen stellar atmosphere code. It computes self-consistently the vertical structure and emergent spectrum of accretion disks. We have applied it to the quantitative spectral analysis of disks in rather different environments: H-rich disks in cataclysmic variables, He-rich disks around white dwarf accretors in AM CVn binaries, C/O/Ne-dominated disks around neutron stars in ultra-compact low-mass X-ray binaries, Fe-dominated supernova fallback disks, and C/N/O/Ca-dominated gaseous debris disks around white dwarfs.


## Introduction

AcDc (Nagel et al., 2004) is based on the radial structure of an $\alpha$-disk (Shakura & Sunyaev, 1973), assuming a stationary, geometrically thin disk. This allows the decoupling of the vertical and radial structures and, together with the assumption of axial symmetry, we can separate the disk into concentric annuli of plane-parallel geometry. In that way the radiative transfer becomes a one-dimensional problem. For each disk ring a depth grid is constructed on which the following set of coupled equations is solved simultaneously under the constraints of particle number and charge conservation:

- radiation-transfer, solved by a short characteristic method
- statistical equilibrium (NLTE rate equations)
- hydrostatic equilibrium between gravitation, gas pressure and radiation pressure
- energy balance between the viscously generated energy and the radiative energy loss

By integrating the spectra of the individual annuli, one obtains a complete disk spectrum. The spectra are Doppler shifted according to the radial component of the Kepler rotation.

## Dwarf Nova Outbursts

Dwarf nova outbursts result from enhanced mass transport through the accretion disk of a cataclysmic variable. We assess the question of whether these outbursts are caused by an enhanced mass transfer from the late-type dwarf onto the WD (mass transfer instability model) or by a thermal instability in the disk (disk instability model, DIM). Our spectral model sequences allow us to distinguish inside-out and outside-in moving heating waves in the disk of SS Cyg, which can be related to symmetric and asymmetric outburst light curves, respectively (Kromer et al., 2007). Our results favor the DIM.

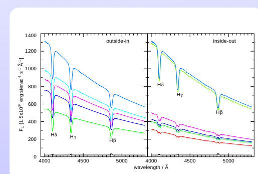


Figure 2: Spectral evolution of an outside-in outburst (left) and an inside-out outburst (right) of SS Cyg (lowermost graphs: cold disk; uppermost graph: full outburst)

## AM CVn Stars

AM CVn stars are close, interacting binary systems with very short orbital periods of $P_{\rm orb} \approx 5-65$ min. Their spectra are dominated by helium lines. The accretor is a white dwarf (WD), whereas the nature of the Roche lobe filling low-mass ($M_2 < 0.1\,M_\odot$) donor is still discussed. It might be a helium WD, a helium star, or the helium-rich core of an evolved secondary. As the disk represents the chemical composition of the donor's atmosphere, the analysis of the disk will help to understand the donor star and the formation of these systems.

We find emission-line spectra for low and absorption-line spectra for high mass-accretion rates. Irradiation of the disk by the primary has almost no influence onto the spectrum. Comparing an observed spectrum of CE 315 with our models we find the qualitatively best match for a 0.8 $M_\odot$ primary and a mass-accretion rate of $10^{-11}\,M_\odot$/yr. The disk shows a strong silicon underabundance confirming the hypothesis that it is a Pop. II object (Nagel et al., 2009).

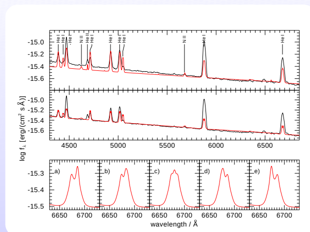


Figure 1: Top: Comparison of CE 315 with a disk model with a boundary layer and a hotspot region. Middle: disk without boundary layer and hotspot, combined with the model spectrum of a WD ($T_{\rm eff} = 20\,000$ K, $\log g = 8.3$), compared with the observed spectrum. Lower panel: Modulation of the He I $\lambda$ 6678 Å line caused by the orbiting hotspot. The position of the hotspot varies from a) moving away from observer to e) moving towards observer. Inclination of all models is 18°.

## Gaseous Metal Disks around DAZ White Dwarfs

Recently, signatures of a gas disk were discovered in spectra of two DAZ white dwarfs (Gänsicke et al., 2007). We concentrate on one of these, namely SDSS 1228+1040. The spectra display double-peaked emission lines of the Ca II triplet $\lambda\lambda$ 8498, 8542, 8662 Å. H and He emissions are not discovered. It is concluded that the Ca lines stem from a metal-rich Keplerian disk around a single WD.

They can be modeled with a geometrically thin, viscous gas disk ring at a distance of 1.2 $R_\odot$ from the WD, with $T_{\rm eff} = 6\,000$ K and a low surface mass density $\Sigma = 0.3$ g/cm$^2$. The disk is H-deficient (H$\lesssim$1% by mass) and located within the tidal disruption radius ($R_{\rm tidal} = 1.5\,R_\odot$). If one assumes that the disk reaches down to the WD and has a uniform surface density, then its total mass would be $7 \cdot 10^{21}$ g. A rocky asteroid with this mass would have a diameter of about 160 km (Werner et al., 2009).

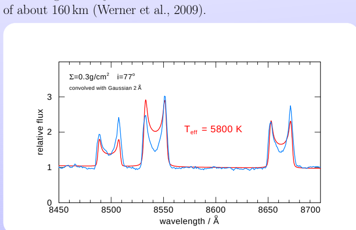


Figure 3: Model fit of the Ca II triplet (red line, $\bar\rho = 0.3$ g/cm², i = 77°) to the spectrum of SDSS 1228+1040 (blue).

## Supernova Fallback Disks

The non-detection of a point source in SN 1987A imposes an upper limit for the optical luminosity of $L_{\rm opt} \approx 2\,L_\odot$. This limits the size of a possible fallback disk around the stellar remnant. Assuming a steady-state thin disk with blackbody emission requires a disk smaller than 100 000 km if the accretion rate is at 30% of the Eddington rate (Graves et al., 2005). With AcDc we have modeled the disk spectrum more realistically. The chemical composition is assumed to be pure Fe or that of a Si-burning ash. It turns out that the observational limit on the disk extension becomes even tighter, namely 70 000 km (Werner et al., 2007).

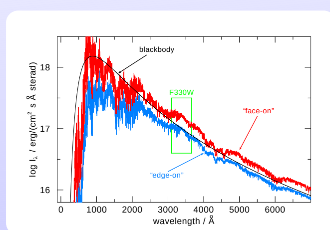


Figure 4: Specific intensity of the disk at a distance $R = 40\,000$ km from the central compact object seen under inclination angles 87° (i.e. almost edge-on) and 18° (i.e. almost face-on). For comparison we also show a blackbody spectrum with $T_{\rm eff}(R) = 33\,000$ K. The rectangle indicates the passband of the HST/ACS filter F330W: The blackbody spectrum systematically underestimates the flux for intermediate inclinations.

## Ultracompact X-ray Binaries

Low-mass X-ray binaries consist of a neutron star or black hole accretor. Of particular interest are ultracompact systems with $P_{\rm orb} < 80$ min, because the donor is probably the core of a stripped WD. This opens up the unique possibility to study the WD interior via an abundance analysis of the disk, which dominates the UV/optical luminosity.

Our models confirm the deficiency of H and He in the disks of two analysed objects. The lack of neon lines suggests that the donor stars are eroded cores of C/O WDs with no excessive Ne overabundance. This contradicts earlier claims of Ne enrichment concluded from X-ray observations of circumbinary material, which was explained by crystallization and fractionation of the WD core.

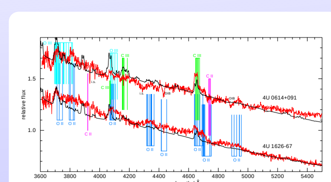


Figure 5: Spectra of 4U0614+091 and 4U1626-67. H and He lines are lacking. Emission lines are identified as O II-III and C II-III. All absorption features are of interstellar origin. Plotted over the two observed spectra is a model spectrum ($\dot M = 2 \cdot 10^{-10}\,M_\odot$/yr, i = 10°, C:O = 50:50) (Werner et al., 2006).

**References**


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