Asymmetric Line Profiles in Spectra of Gaseous Metal Disks Around Single DAZ WDs

Stephan Hartmann
T. Nagel, K. Werner, and T. Rauch

Institute for Astronomy and Astrophysics
Kepler Center for Astro and Particle Physics
Eberhard Karls University of Tübingen, Germany

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Eberhard Karls Universität Tübingen
Institut für Astronomie und Astrophysik

Overview

1. Metal-rich Disks around Solitary DAZ White Dwarfs
   - Discovery and Observations
   - Asymmetric Line Profiles
2. Modeling Disk Geometry
   - Simulations with FARGO
   - AcDc Integration
3. Results
   - Designed Models
   - Calculated Spectra

Disks Around Single WDs

Dust Disks

Dust Disks

- several metal enriched WDs with IR excess, i.e. G 29-38

  (Zuckerman et al., 1987)

  but no cool companions found and short sedimentation time

  (Koester et al. 1997)

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↪ WDs accrete material from surrounding metal-rich dust cloud

  - dust confirmed by Spitzer observations (Reach et al., 1997)
  - dust is located in equatorial plane (Graham et al., 1990)
  - absence of H and He features in disk spectra (Jura, 2003)

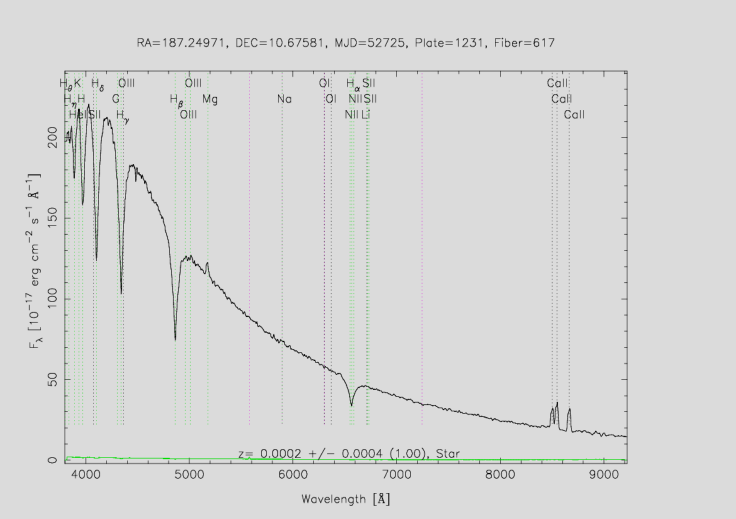
- about 20 similar objects (at the moment)

Disks Around Single WDs
Gas Disks

Gas Disks

- assumed metal-rich gaseous disks for WDs with $T_{\text{eff}} \geq 20\,000\,\text{K}$ (Killic et al., 2006)
- SDSS spectra of five WDs show additional gas disk emission features: (Gänsicke et al., 2006, 2007, 2008, priv. comm.)
  - Ca II $\lambda\lambda$ 8498, 8542, 8662 Å
  - Fe II $\lambda\lambda$ 5018, 5169 Å

Disks Around Single WDs
SDSS J1228+1040



Disks Around Single WDs

Disk's Origin

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Origin of the Disks

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- planetary systems survive last phase of host star's evolution
- gravitational disruption of remnant planetesimals like asteroids
- disk heating process still to be determined (i.e. viscous heating (Werner et al., 2008), Z II region model (Melis et al., 2010))

Asymmetric Line-Profiles

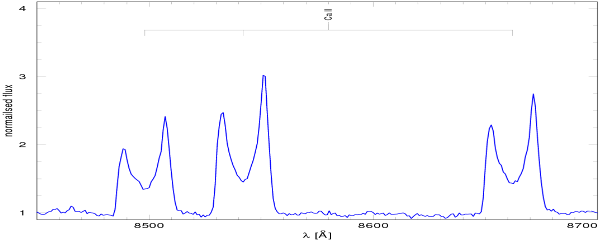


Figure: normalized spectrum of SDSS J1228+1040 (Gänsicke et al., 2008)

Hypothesis

asymmetric Ca II line profiles ⇔ asymmetric disk geometry

Asymmetric Line-Profiles

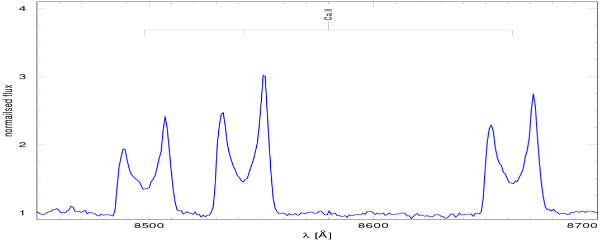


Figure: normalized spectrum of SDSS J1228+1040 (Gänsicke et al., 2008)

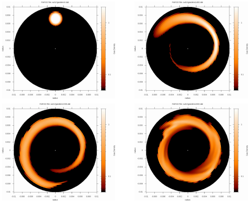
Hypothesis

asymmetric Ca II line profiles ⇔ asymmetric disk geometry

- hydrodynamical disk-evolution code for geometries
- (modified) NLTE accretion-disk code for spectra

FARGO

Simulation Code



FARGO-Code

- **F**ast **A**dvection in **R**otating **G**aseous **O**bjects (**FARGO**) (Masset, 2000)
- hydrodynamical code for sheared fluids, in particular protoplanetary disks

FARGO

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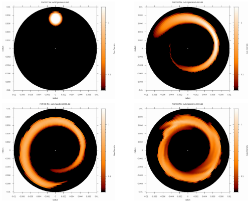

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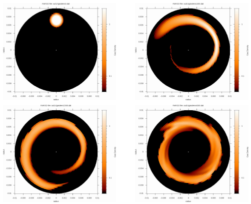

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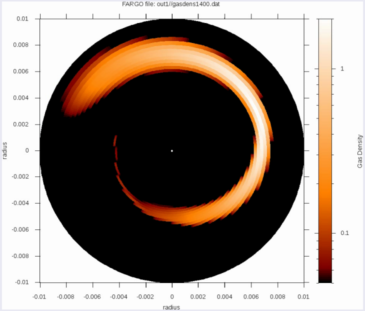
Parameters

- $M_{\mathrm{wd}} = 0.77\,\mathrm{M}_{\odot}$, $R_{\mathrm{wd}} = 7700\,\mathrm{km}$ (Werner et al., 2008)
- $M_{\mathrm{disk}} = 7 \cdot 10^{21}\,\mathrm{g}$, $R_{\mathrm{o}} = 136\,\mathrm{R}_{\mathrm{wd}}$ (Werner et al., 2008)
- $R_{\mathrm{sim}} = 0.01\,\mathrm{AU}\,(\approx 1.5\,\mathrm{R}_{\mathrm{o}})$
- start with gaussian density “blob”

FARGO

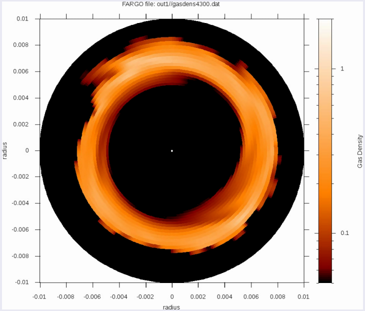
Structures

Spiral-formed Arm



thickness decreases more inwards

Off-centered Disk



out-of-balance circular disk

Accretion Disk code (AcDc)

(Nagel et al., 2004)

Assuming Geometrical Thin α-disk (Shakura & Sunyaev, 1973)

- decoupling of vertical and radial structure

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- decoupling of vertical and radial structure
- disk separation in concentric annuli with
  - $T_{\mathrm{eff}}(R) = \left[\frac{3GM_{\mathrm{wd}}\dot{M}}{8\pi\sigma R^3}\left(1-\sqrt{\frac{R_{\mathrm{wd}}}{R}}\right)\right]^{\frac{1}{4}}$
  - $w\Sigma(R) = \frac{\dot{M}}{3\pi}\left(1-\sqrt{\frac{R_{\mathrm{wd}}}{R}}\right)$

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Simultaneously Solve Set of Equations for Each Annulus

- radiation transfer for the specific Intensity $I(\nu,\mu)$
- hydrostatic equilibrium
- energy conservation for viscously E_{mech} and radiative E_{rad}
- static NLTE rate equation for model atom

Accretion Disk code (AcDc)

Parameters

Parameters for Annuli

- eleven rings with radii $2\,\mathrm{R_{wd}}$ to $136\,\mathrm{R_{wd}}$
- constant surface mass density $\Sigma = 0.3\,\frac{\mathrm{g}}{\mathrm{cm}^2}$
- radial temperature range $T_{\mathrm{eff}}(R) = 6700\,\mathrm{K}$ to $5600\,\mathrm{K}$

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Model Atom Data

- H I-II, C I-IV, O II-IV, Mg I-III, Si I-IV, Ca I-IV
- 223 NLTE levels and 415 lines
- chondrite chemical mixture (%, mass frac.)

H	C	O	Mg	Si	Ca
10^{-8}	4.6	65.5	13.5	15.1	1.3

Accretion Disk code (AcDc)

RingRot

RingRot: Surface Integration

- linear interpolation between annuli for $0^\circ \le \varphi \le 360^\circ$
- apply Doppler-shift according to rotation velocity $\Omega_{\mathrm{Kepler}}(R)$

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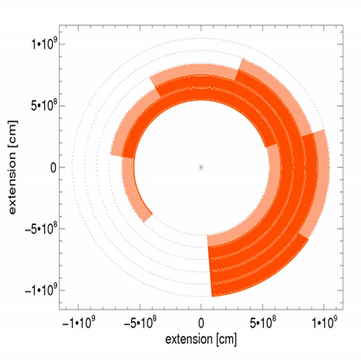
Modified RingRot for Non-axial Symmetry

- construct geometry map according to FARGO simulation
- set flux to zero for not used ring segments
- linear interpolation between annuli for $0° \leq \varphi \leq 360°$
- apply Doppler-shift according to rotation velocity $\Omega_{\text{Kepler}}(R)$

Models

RingRot: Surface Integration

Spiral-formed Arm



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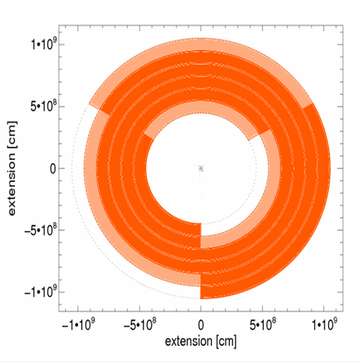
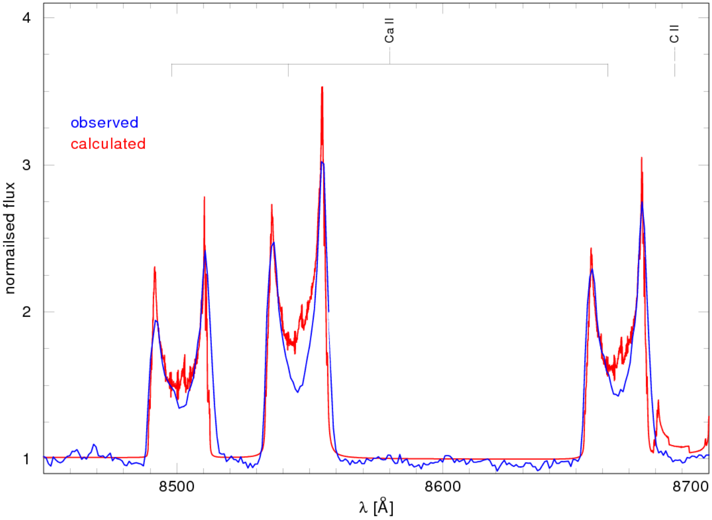


out-of-balance circular disk

Calculated Spectra

Spiral-formed Arm



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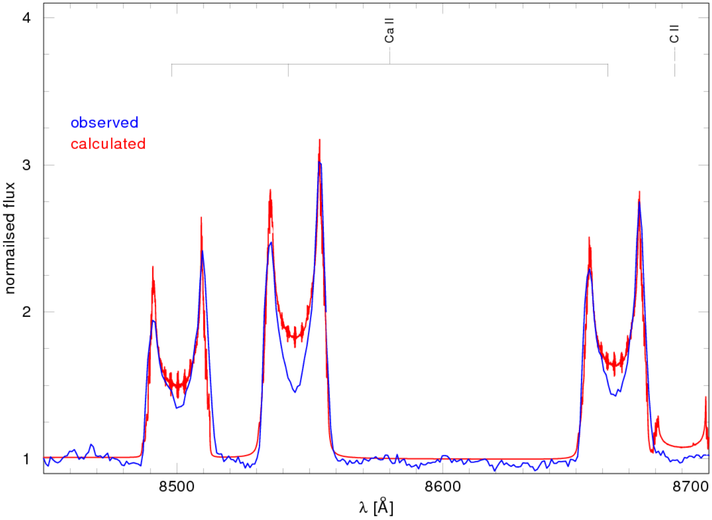

Results

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- flat continuum between lines
  - disk's inner rim $R_{\mathrm{i}} \geq 58\,\mathrm{R_{wd}}$
- asymmetrical line profile is matched
  - but strongly depense on orientation of the thicker region (angle towards line-of-sight)
  - variability reported for two objects (Gänsicke et al., 2008)
- strength of asymmetry should change on long timescale with evolution of geometry

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Thank you for your attention.