Spectral Modeling of AM CVn stars

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Overview

- Modeling of NLTE Accretion Disks
- Non-Stationary vs. Stationary Disks
  → structure
  → spectra
- Preliminary results
- Future Prospects
Modeling of NLTE Accretion Disks

Accretion Disk Code

Assumptions:
- geometrically thin $\alpha$-disk (Shakura & Sunyaev 1973)
- axial symmetry

Division of disk in concentric rings
- plane-parallel radiating slides

Calculate vertical structure and synthetic spectrum
- with $\text{AcDc}$ (Accretion Disk Code, Nagel et al. 2004)
Modeling of NLTE Accretion Disks

Effective Temperature

\[ T_{\text{eff}} = \left[ \frac{3GM_1\dot{M}}{8\pi\sigma R_3^3} \left( 1 - \sqrt{\frac{R_1}{R}} \right) \right]^{1/4} \]

- Radial distribution of effective temperature
- Stationary model

Column mass depth

\[ m(z) = \int_{z}^{\infty} \rho(z') \, dz' \]

- Relationship to geometrical depth
Modeling of NLTE Accretion Disks

Modeling

- Equations of radiative equilibrium
- Equations of hydrostatic equilibrium
- NLTE Populations numbers of the atomic level
- Radiation transfer equation
- Particle number and charge conversation
Modeling of NLTE Accretion Disks

Input

- Mass and radius of central object
- Mass-accretion rate
- Radial extension of accretion disk
- Reynolds number
- Chemical abundance
- Atomic data
- Irradiation
Stationary vs. Non-Stationary

SDSS J141118.31+481257.6

- Long-period AM CVn star
- Low mass-transfer rate system
- Orbital Period: 46 ± 2 minutes
  (Groot et al. 2007)
- Mass of central object: 0.9 solar masses
- Radius of central object: 6720 kilometer
  → mass-radius-relation
Stationary vs. Non-Stationary

Features of Stationary Disks

- Constant mass-accretion-rate all over the disk
  → higher temperature to the innermost rings
  → lower temperature to the outermost rings

- Changing effective temperature
  → hot midplane for the innermost rings
Stationary vs. Non-Stationary

![Graph showing comparison between stationary and non-stationary observations.](image-url)
Stationary vs. Non-Stationary

Features of Non-Stationary Disks

- Changing mass-accretion-rate
  - low mass-accretion at the inside
  - high mass-accretion at the outside

- Equal effective temperature all over the disk
  - different rings look alike
SD vs NSD: Structure

**Temperature**
- $R=0.93 \times 10^9$ cm
- $R=2.40 \times 10^9$ cm
- $R=4.20 \times 10^9$ cm
- $R=9.43 \times 10^9$ cm

**Density**
- $R=0.93 \times 10^9$ cm
- $R=9.43 \times 10^9$ cm
SD vs NSD: Structure

Graph 1: Temperature vs Radius
- $R = 0.94 \times 10^9$ cm
- $R = 2.01 \times 10^9$ cm
- $R = 4.03 \times 10^9$ cm
- $R = 9.41 \times 10^9$ cm

Graph 2: Density vs Radius
- $R = 0.94 \times 10^9$ cm
- $R = 9.41 \times 10^9$ cm

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SD vs NSD: Structure

$\log (T/K)$

$z$ / cm

Distance to central object $r$ / km

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SD vs NSD: Structure

Comparison radial structure

- Stationary Disk:
  → hot midplane
  → higher temperatures to the innermost rings

- Non-Stationary Disk:
  → characteristic vertical temperature structure
  → lower temperatures to the outermost rings
SD vs NSD: Ringspectra

\begin{figure}
\centering
\includegraphics[width=\textwidth]{ringspectra.png}
\end{figure}
SD vs NSD: Ringspectra

![Graph showing SD vs NSD Ringspectra with three sets of data points labeled as stationary and non-stationary. Each set includes measurements for different radii: R = 4.20 \times 10^{10} \text{ cm}, R = 4.03 \times 10^{10} \text{ cm}, R = 2.40 \times 10^{10} \text{ cm}, R = 2.01 \times 10^{10} \text{ cm}, R = 0.93 \times 10^{10} \text{ cm}, R = 0.94 \times 10^{10} \text{ cm}. The abscissa is labeled as \( \lambda \) (Å) and the ordinate as \( \log (F_\lambda / \text{erg} \text{str}^{-1} \text{s}^{-1} \text{Å}^{-1}) \).]
SD vs NSD: Ringspectra

- stationary
- non-stationary

He II 4714
He II 5017
He II 6680
SD vs NSD: Ringspectra

- stationary
- non-stationary

log (F_λ / erg str^{-1} s^{-1} Å^{-1})

He II 4714
He II 5017
He II 6680

λ (Å)
4710 4715 5015 5020 6680
Comparison ring spectra

- **Stationary Disks**
  - \(\rightarrow\) strong emission lines to the radial outside
  - \(\rightarrow\) weak absorption lines to the radial inside

- **Non-stationary Disks**
  - \(\rightarrow\) strong emission lines all over the disk
  - \(\rightarrow\) all rings look alike
Non-Stationary: Spectra

- observation
- non-stationary disk
solar abundance
Non-Stationary: Abundances

Comparison to Observation

- Observation:
  → barely Neon
  → barely Magnesium
  → barely Carbon

- Non-Stationary Disk:
  → reduction to 0.001 times solar

- observation
- non-stationary disk - solar abundance
Non-Stationary: Abundances

- observation
- \([C]=[Ne]=[Mg]=0\), \([Si]=-3\)
- \([C]=[Ne]=[Mg]=-3\), \([Si]=-3\)
Non-Stationary: Abundances

Comparison

- Reduction to 0.001 times solar
  → barely Neon
  → barely Magnesium
  → barely Carbon

- Common feature in AM CVn?
Non-Stationary: Silicon Abundance

- observation
- [Si]=-3
- [Si]=-4

log $F_\lambda$ (erg str$^{-1}$ s$^{-1}$ Å$^{-1}$)

$\lambda$ (Å)

4000 4500 5000 5500 6000 6500 7000
Non-Stationary: Silicon Abundance

Comparison

- Reduction silicon abundance to 0.0001 times solar
  → better agreement with observation

- as well as CE 315
  → Nagel et al. (2009)
Non-Stationary: Boundary Layer

- observation
- no boundary layer
- boundary layer at 20,000 K
- boundary layer at 30,000 K

\[ \log F_\lambda \text{ (erg str}^{-1}s^{-1}\text{Å}^{-1}) \]

\[ \lambda \text{ (Å)} \]

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Non-Stationary: Boundary Layer

Comparison to Observation

- Boundary layer at 30 000 K
  → good agreement with observation

- Hot boundary layer
  → weaker emission lines to red band of spectrum

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Non-Stationary: Inside Boundary

- observation
- inside boundary at 8,740 km
- inside boundary at 10,080 km
- inside boundary at 11,420 km
Non-Stationary: Inside Boundary

Comparison

- Strength of emission lines alters with inside boundary
  → alteration of radiating area

- Shape of emission lines does not significantly alter
  → alteration of velocity is not big enough

- inside boundary at 8740 km
- inside boundary at 11420 km
Non-Stationary: Outside Boundary

- observation
- inside boundary at 94 080 km
- inside boundary at 80 640 km
- inside boundary at 67 200 km
Non-Stationary: Outside Boundary

Comparison

- Strength of emission lines alters with outside boundary
  → alteration of radiating area
- Shape of emission lines alters with outside boundary
  → alteration of velocity is big enough

- outside boundary at 94,080 km
- outside boundary at 67,200 km
Non-Stationary: Preliminary Result

- observation
- best model
Non-Stationary: Object

**SDSS J155252.48+320150.9**

- Long-period AM CVn star
- Low mass-transfer rate system
- Orbital Period: $56.272 \pm 0.005$ minutes
  (Roelofs et al. 2007)
- Mass of central object: 1.0 solar masses
  (Roelofs et al. 2007)
- Spectral twin to J141118.31+481257.6
Non-Stationary: Preliminary Result

- observation
- best model

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Future Prospects

Extension of previous work

- Application to other objects
  - low mass-transfer rate systems
  - AM CVn candidates

- Determination of abundances
  - include more elements (iron group)
  - upper limit of various abundances
  - Determination of genesis scenario
Future Prospects

**Helium Dwarf Nova**

- Non-stationary disk
  → application to low state

- Stationary disk
  → application to high state

- Crossover from stationary to non-stationary disk