Modelling the reflection effect with irradiated stellar atmospheres in the sdO+dM eclipsing binary: AA Dor

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Hot subdwarfs in the HRD

Heber 2009 ARAA 47 211
Common-Envelope Channels

stable RLOF + CE (mass ratio < 1.2 – 1.5)

stable RLOF

unstable RLOF ----> dynamical mass transfer

common-envelope phase

short-period sdB binary with He WD companion

P_{orb} = 0.1 – 10 days

M_{sdB} = 0.4 – 0.49 M_{sun}

CE only (mass ratio > 1.2 – 1.5)

unstable RLOF ----> dynamical mass transfer

common-envelope phase

short-period sdB binary with MS companion
sdB evolution

Klepp & Rauch
2011 A&A 531 7
Why do astronomers like AA Dor?

- Because it is one of a kind: Bright system (B=10.8 mag), eclipsing, very stable period over 40 years, strong irradiation makes a well measurable reflection effect, clean system: no mass transfer, tidal deformation, no suspected planets around.

Challenges:
- Accurate atmospheric parameters (Klepp & Rauch 2011 A&A 531 7)
- Companion type is still unknown (MS or BD), although the masses are known with high precision ($M_1=0.46\pm0.01$ $M_2=0.079\pm0.002$ $M_\odot$). It is important for CE evolution. (Hoyer et al, 2015 A&A 578 125)
- A very good benchmark system for HW Vir type (pulsating) sdB+MS binaries and irradiated hot-Jupiter systems.

Hilditch et al. 2003 MNRAS 344 644
Disentangled spectra

- Phase resolved spectra (180 sec exposure, 105 spectra over one orbit)
- Combined in radial velocity space and disentangled
- The companion contributes only 3% to the Balmer lines.

Vuckovic et al. 2016
A&A 586 146
Traced metal lines and line profiles

Maja Vuckovic et al.
2016 A&A 586 146

- Orbit integrated spectrum of the irradiated companion
- Numerous emission lines from He-I, C-II, C-III, N-II, O-II, N-II, Mg-II, Si-III, Ca-II
- Balmer emission lines with self-absorption.
Modelling method: Tlusty - Synspec - XTGRID

- **Synspec**: synthetic spectra from Tlusty atmospheres
- **H, He, C, N, O composition**
- **No convection**
- **XTGRID**: interface to Tlusty to perform automated spectral analysis to:
  - model composite spectra binaries (**Tlusty + “template”**)
  - fit multi-wavelength (**uvooir**) observations
  - perform abundance analyses (beyond scaled-solar or alpha-enhanced models)
  - perform spectral classification in large surveys (subdwarfs from LAMOST, **SDSS**)
- **Standard chi-square minimization along the steepest-gradient, plus extras.**
- **Dilution factor is a free parameter**
Geometry

- The system geometry was taken from Hilditch et al. 1996 (MNRAS 279 1380) and Hilditch et al. 2003 (MNRAS 344 644)
- \( R_{sdO} = 0.2 \, R_{\odot} \); \( R_{dM} = 0.11 \, R_{\odot} \); \( sma = 1.45 \, R_{\odot} \)
- \( P = 22597 \, \text{sec} \) (6.3 h)
- No heat transfer on the companion.
- Simple terminator: flux is scaled according to the visible area of the primary's disk over the horizon.
- Three zones with three parallel model atmosphere calculations, one synthetic spectrum.
- The visibility of the zones were calculated for the observed orbital phase range and the relative contributions of the zones were calculated from the model.
Geometry

Current best fit

- Global fit
Structure

- The strong irradiation makes significant structural changes, temperature gradient is inverted.
- The Balmer lines are insensitive to the intrinsic temperature of the companion, but sensitive to the gravity.
- Metal lines are sensitive to both, but the abundances are not known.
- Balmer core-absorption forms high in the atmosphere, but the model predicts too strong absorption.
Structure

- Flat temperature profile plus inversions
- CoolTlusty dM model
- Sphericity: 0.8% expansion at the substellar point
- Suggests sharp structural changes at the terminator. Real? Observed in hot-Jupiters.
- Pressure scale height 8 vs. 130 km
Limb-darkening (brightening)

- A homogeneously irradiated hemisphere did not reproduce the phase profiles.
- A limb-brightening can be observed in all zones, but we see different zones toward the edge of the disk.
Adding all ingredients together
CII (4267 Å) emission line-strength variation over one orbit
CII (4267 Å) line formation on the companion continuum is removed.
HeI (3820 Å) line formation on the companion
Continuum is removed.
Ideas for future work

1. The black-body irradiation must be replaced with the detailed spectrum of the sdO star. A proper treatment of the UV flux must be investigated as weak irradiation cause convergence issues in the NLTE models.

2. Refine the geometry of the irradiation process with details (more zones, elements) in the model and break symmetries to investigate tidal locking. A general model must include the Roche-potentials and surface integration to also get the rotational line profiles.

3. Use photometric constraints in the spectral models to increase consistency and extend the analysis to faint systems with precision photometry already available.
   - Most of the irradiated companions show C and O rich atmospheres. Is it a contamination from a radiatively driven sdO wind?
   - High potential: with such models one can constrain the inclination angle in non-eclipsing binaries and all reflection-effect binaries will become double-lined systems.
Conclusions

- We have spectroscopic observations that are well beyond what our models can predict. This trend will continue in the era of E-ELT. Efforts are needed to bring the models up to the level of these data.

- **AA Dor is a key** system to model development and validation, and to unify the asteroseismology, spectroscopy and light curve analyses of HW Vir systems with pulsating sdB stars.

- Similarly for hot-Jupiters: with AA-Dor-like binaries one can test new methods and reflection/irradiation models already with existing instruments and facilities.

- The “reflection-effect” expression seems to be a loose term, redistribution is more appropriate.
Many thanks to all collaborators

Roy Østensen
Maja Vuckovic
Steven Bloemen
Peter I. Papics