

Accretion on to Magnetic White Dwarfs

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Observations

In some Binary Systems we observe quite interesting features:

- Strongly polarized emission (up to 60 % circular polarisation in the optical)
- Unexpectedly long soft X-Ray component
- Highly variable lightcurves in optical and X-Ray

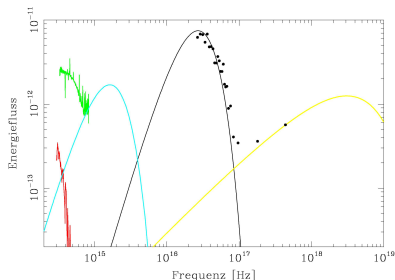
⇒ Strong Influence from a **magnetic field** on the binary system

Example 1 : AM Herculis type

Spectrum of V 393 Pavonis

The νF_ν over ν plot shows :

- Measured optical spectrum (green)
- Measured X-Ray spectrum (black dots)
- Measured optical / IR spectrum from Secondary (red)
- Expected observations from the WD (cyan)
- Blackbody fits (yellow, black line)

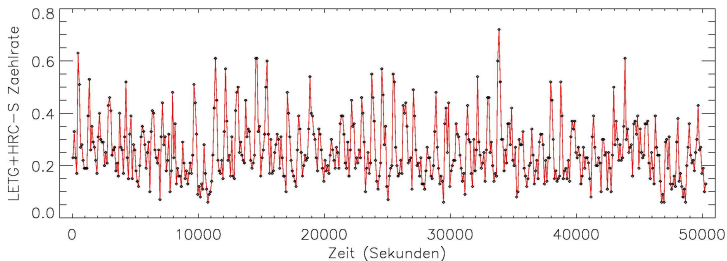


From: V. Burwitz: X-ray and optical properties of ROSAT discovered magnetic cataclysmic variables (1997)

Example 2: PQ Geminorum

RE 0751+14

- Some binary systems show enormous oscillations in their lightcurve:



Observations from Chandra X-Ray Observatory

Where do those effects come from ?

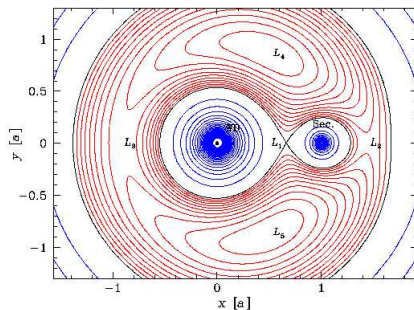
White Dwarf and Secondary

- A system consisting of an accreting white dwarf and a secondary star in close orbit is called **Cataclysmic Variable (CV)**
- The secondary often is a M-class main sequence star of about $0.2 - 0.5 M_{\odot}$
- The white dwarf got more mass and is hotter than the Secondary ($8000 - 60000 K$)
- A small separation is observed in most systems
⇒ high rotation periods

Accretion Stream

- Consists of ionised matter from the secondary
- Accretion happens mostly due to Roche Overflow
- Follows a lightly curved trajectory due to the coriolis force
- Falls on magnetic WD with free-fall velocity:

$$v_{ff} = \sqrt{\frac{2G \cdot M_{WD}}{r}} \approx 2000 - 4000 \frac{\text{km}}{\text{s}}$$



Roche-equipotential-lines for $q=5$ [Kraib]

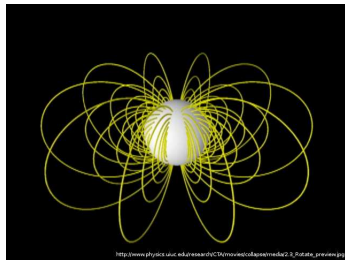
From: <http://www.hs.uni-hamburg.de/DE/Ins/Per/Vrielmann/DLS/roche.gif>

Magnetic Field of the WD

in First Approximation

- Both stars have a magnetic field
- The magnetic flux is roughly conserved during star evolution: $B \cdot R^2 \approx \text{const}$
- \Rightarrow High field strengths up to $\approx 20000 \text{ T}$ (20 MG) near the WD
- Magnetic field is approximated as a Dipole:

$$\vec{B} \approx \frac{\vec{\mu}_D}{r^3}$$



From: http://www.physics.uiuc.edu/research/CTA/movies/collapse/media/2.3_Rotate_preview.jpg

Coupling of Magnetic Field and Accretion Stream

- How do the magnetic field and the accretion stream interact ?
- From plasma physics we obtain the Magnetic Pressure:

$$P_{mag} = \left(\frac{4\pi}{\mu_0} \right) \cdot \frac{B^2}{8\pi} \stackrel{\text{dipol}}{=} \left(\frac{4\pi}{\mu_0} \right) \cdot \frac{\mu^2}{8\pi r^6}$$

- and the Ram Pressure :

$$P_{ram} = \rho \cdot \vec{v}^2 \propto \left[\frac{E_{kin}}{V} \right] \vec{v}$$

- Magnetic Field takes over at:

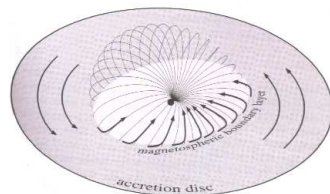
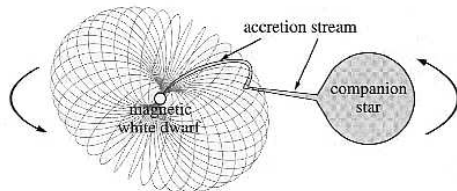
$$P_{ram} \approx P_{mag}$$

- Alfvén Radius:

$$r_a = \left(\frac{\mu^2}{\mu_0} \cdot \frac{1}{2\rho v^2} \right)^{\frac{1}{6}} \stackrel{\text{Mass cons.}}{=} \sqrt[6]{\frac{\mu^2}{\mu_0} \cdot 8\pi^2 \frac{\rho}{M^2}}$$

Visualisation

- For strong magnetic fields of the WD no disc is formed, instead the accretion stream follows the field lines directly
- In some cases a **truncated** accretion disc will form



From: Frank, King, Raine Accretion Power in Astrophysics

Spin Periods and Angular Momentum

- System has an orbital period : P_{orb} ; the WD a spin period : P_{spin}
- Therefore modulations should be observed
- Accretion stream transfers angular momentum to WD

⇒ Spin-up ?

- Consider interaction of magnetic moments of the two stars!

$$(\vec{M} = \vec{m}_m \times \vec{B})$$

- Magnetic moments can **balance** transfer of angular momentum, if interaction is strong enough

Systems with Strong Magnetic Interaction

Polar CV's

In general, systems with strong magnetic field of the WD
($B_{\star} \approx 3 \cdot 10^3 \text{ T}$; $\mu \approx 3 \cdot 10^{24} \frac{\text{T}}{\text{m}^3}$) :

- Synchronise orbital period and spin period of the WD, due to magnetic interaction
- Don't have accretion discs
- Can be identified through strong polarisation in optical wavelength
- Are called **Polars** or AM Her Stars

Systems with Weaker Magnetic Interaction

Intermediate Polar CV's

In general, system with weaker magnetic field show :

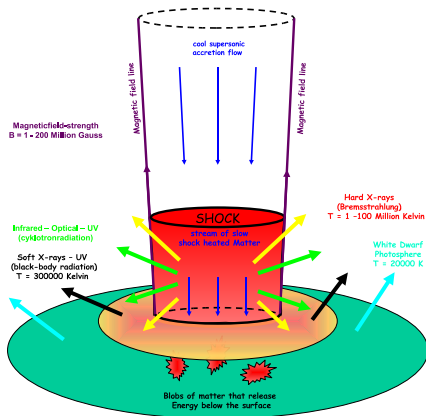
- Low Interaction between magnetic moments
- \Rightarrow Spin Up, due to transfer of angular momentum
- No synchronised state of the rotation periods, but rotation at high velocities
- A truncated accretion disc, as magnetic pressure can't control the plasma far enough

These are called **Intermediate Polars** or DQ Her systems

Standard Model for Accretion Column

Energy Source and Accretion Blob

- Accretion stream is channeled to the magnetic poles on the WD's surface
- Plasma has supersonic speed:
$$V_{plasma} \approx V_{ff} = \sqrt{\frac{2G \cdot M_{WD}}{r}}$$
- Plasma stops where gas pressure equals ram pressure.
- Strong shock due to deceleration, $E_{kin} \rightarrow E_{therm}$
- Heating to $> 10^8 K$



From: V. Burwitz: X-ray and optical properties of ROSAT discovered magnetic cataclysmic variables (1997)

Bremsstrahlung

- Infalling proton encounters electrons of the WD's atmosphere
- Acceleration of charges in electromagnetic fields leads to thermal bremsstrahlung
- Radiation is optical thin, with energies :

$$10 \text{ keV} \leq kT_{Br} \leq kT_{Shock}$$

- \Rightarrow Emission of hard X-Rays
- Most important **cooling mechanism** in most CV's

Cyclotron Radiation

- Thermal motion makes electrons gyrate around magnetic field lines
- Cyclotron frequency of n-th order : $n \cdot \omega_{cyc} = n \cdot \frac{e \cdot B}{m_e c}$
- Resulting Polarisation is strong evidence for magnetic controlled accretion
- Distance between lines gives magnetic field strength:

$$\omega_{cyc} = \omega_{n+1} - \omega_n = \frac{e \cdot B}{m_e c}$$

- Higher orders in optical - UV, fundamental in IR wavelength

Reprocessed radiation and Line Emission

- Bremsstrahlung heats the WD's surface: $T \approx 10^6 K$
- \Rightarrow Radiation of EUV and Soft X-Rays; (Quasi-) Blackbody Component reprocessed in WD's surface
- UV and X-Rays illuminate Accretion Stream, disc and parts of the Secondary
- \Rightarrow Excitation and photo-ionization of matter

Several emission lines are detected:

- Paschen lines @ near IR
- Balmer, HE 1, HE 2 @ visible
- Lyman L_α , highly ionized C, N and Si @ UV

Photospheric Emission

- The M-class **Secondary** emits in near IR
- Below 4000 K molecular absorption of e.g. TiO , VO and H_2O takes place
- The WD emits in near UV; 8000 – 60000 K
- Typical broadened H and He lines are observed
- In low state Zeeman troughs are observed
- \Rightarrow Determination of magnetic field
- Sometimes the heated photosphere from accretion region up to ≈ 10000 K is seen in UV

Summary of Radiation Processes

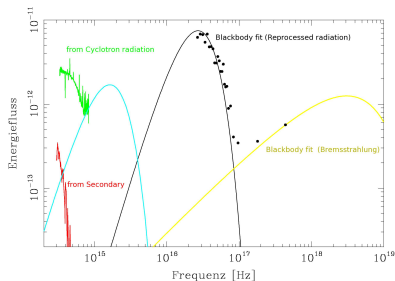
- Thermal Bremsstrahlung → Main cooling process
- Cyclotron radiation → Gives field strength in distance to the WD
- Reprocessed radiation from the WD's surface → Composition of the WD
- Photospheric and line emission → Composition of Secondary and accretion stream
- Zeeman effect in low state gives magnetic field strength @ WD's surface

Comparison of Model and Observations

Energy flux from Polar: V 393 Pavonis

The Model gives us:

- Secondary: Spectrum @ IR - visible
- Cyclotron Radiation @ visible
- Reprocessed Radiation @ soft X-Rays
- Bremsstrahlung @ hard X-Rays

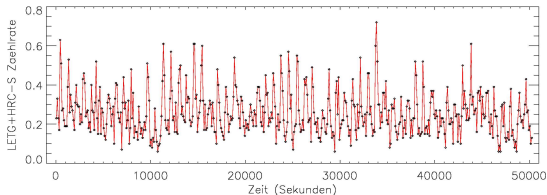


From: V. Burwitz: X-ray and optical properties of ROSAT discovered magnetic cataclysmic variables (1997)

IP : PQ Geminorum (RE 0751+14)

- IP rotates fast; (transfer of angular momentum)
- Accretion onto a small fraction of the surface (magnetic pole)
- \Rightarrow Lighthouse effect

$$\frac{1}{P_{beat}} = \frac{1}{P_{spin}} - \frac{1}{P_{orb}}$$

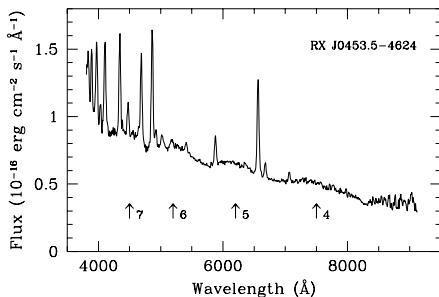


Observations from Chandra X-Ray Observatory

Observations of Cyclotron Radiation

- Cyclotron Radiation is expected
- Calculations show: fundamental frequency is absorbed in accretion column
- Higher orders are seen and give magnetic field strength

$$B = 2\pi \cdot \frac{m_e c^2}{e} \left(\frac{1}{\lambda_{n+1}} - \frac{1}{\lambda_n} \right)$$



From: V. Burwitz: X-ray and optical properties of ROSAT discovered magnetic cataclysmic variables (1997)

Summary

There are two types of cataclysmic variables with non neglectable magnetic field:

- **Polars**, with strong magnetic field, but without accretion disc
- **Intermediate Polars**, with accretion disc, but with weaker magnetic field

further the accretion takes place only on the **magnetic poles** of the White Dwarf. The reprocessed radiation from the poles is seen in soft X-Ray Spectrum.

Literature

- V. Burwitz: X-ray and optical properties of ROSAT discovered magnetic cataclysmic variables (1997)
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