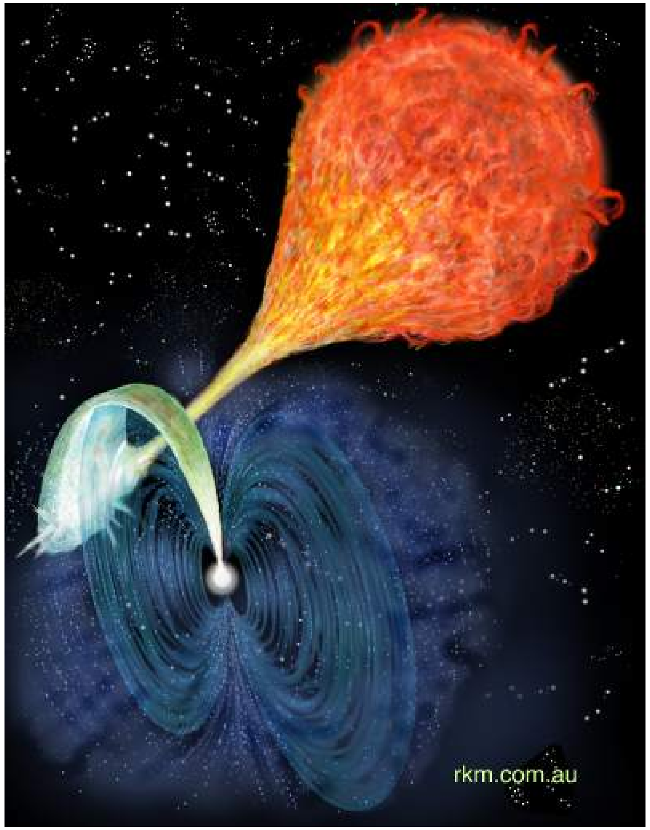
Polars and Intermediate Polars

Christian Lerrahn
<clerrahn@gmx.de>

November 21, 2002
at IAAT Tübingen

Polars



Overview - Polars

- Polars
  - What is a Polar?
  - The Magnetic Field
  - Synchronous Rotation of the Primary
  - Lightcurves
    * Spectra
    * Emission
  - The Accretion
  - The Accretion Region
  - Problems with the Model

What is a Polar?

- subclass of the CVs
- primary is a white dwarf with a strong magnetic field (typically 10-80 MG)
- emission is strongly polarized at optical wavelength (both circularly and linearly)
- no accretion disc
- primary rotates synchronously
- examples: AM Her, AR UMa, ST LMi, VV Pup

The Magnetic Field

- typical field strength of 10-80 MG
- highest-field system: 230 MG (AR UMa)
- probably dipole fields, possibly quadrupole fields

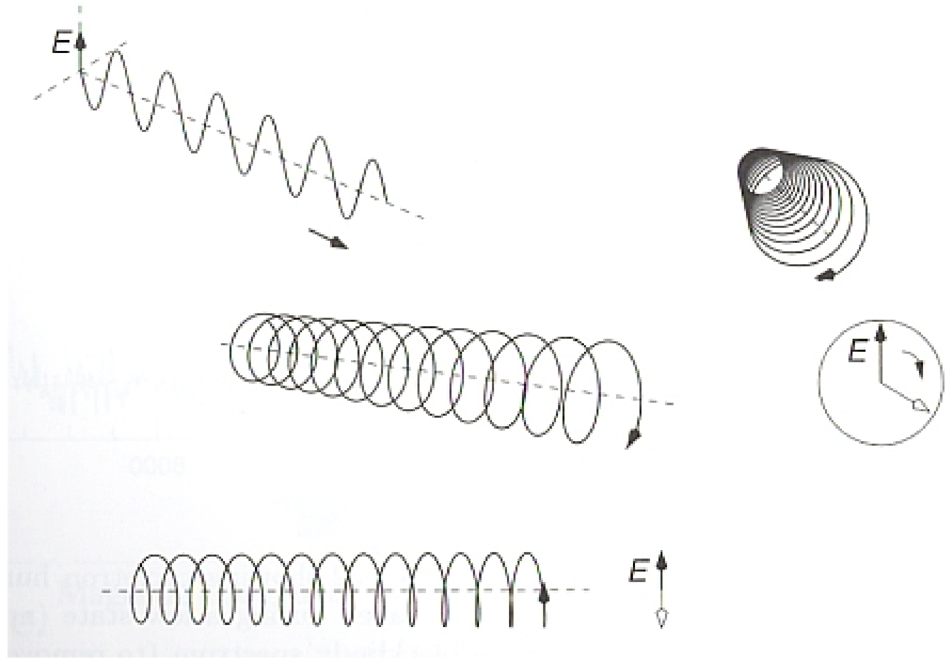


Figure 1: The principle of cyclotron emission *

- Zeeman splitting, cyclotron harmonics, ratio of linear to circular polarization

Synchronous Rotation

- angular momentum of the accretion stream spins up the primary
  $\Rightarrow$ short spin periods expected like those of non-magnetic CVs ($\approx$ 50 s)

- actual spin periods of 1-3 hrs!!!

- fields will intertwine where they meet and entangle their field lines
  $\Rightarrow$ drag force acting as a torque slowing down the primary
  $\Rightarrow$ sychronization of the primary

- still objects that rotate asynchronously
  - braking torque might be low (larger binary separation, weaker field)
  - asynchronism might be temporary
    (e.g. because of a nova like in V1500 Cyg)

Lightcurves

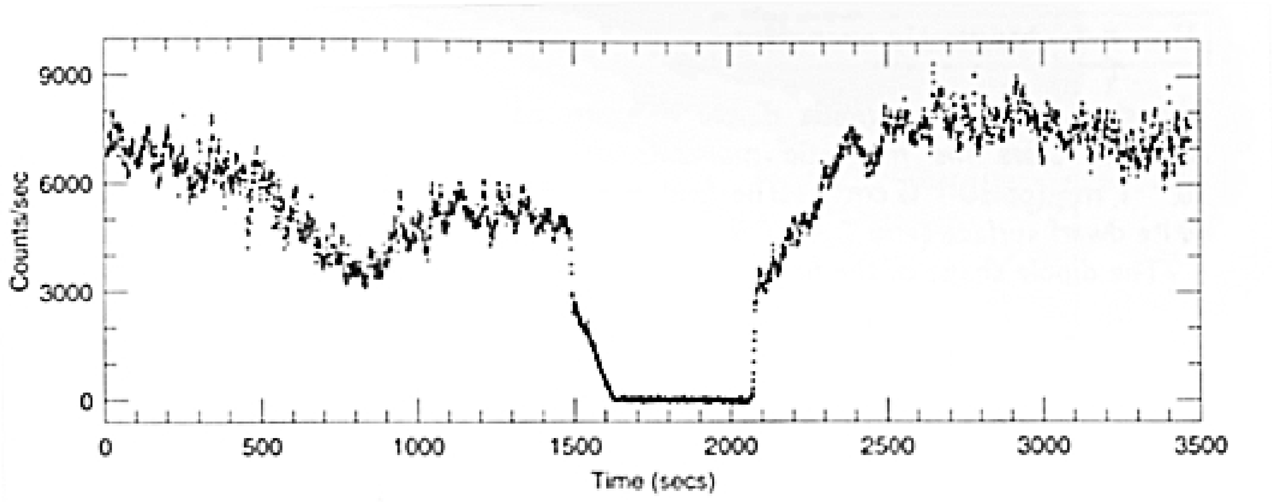


Figure 2: Optical lightcurve of an eclipsing system

Emission

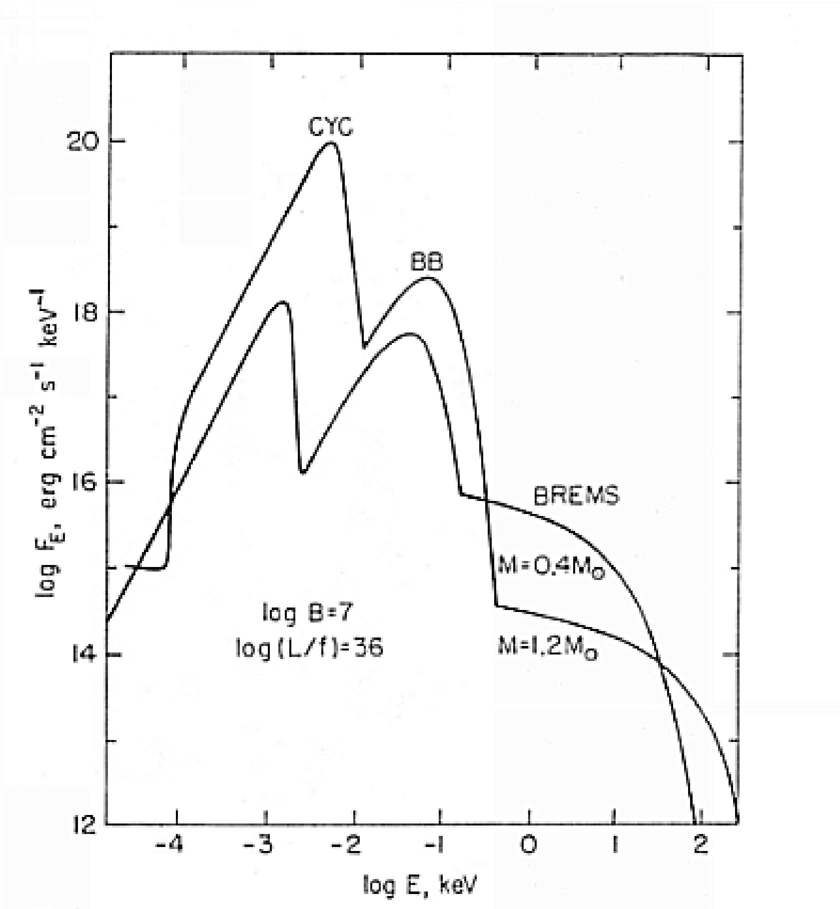


Figure 3: Flux emitted from the accretion region

Emission

- cyclotron emission (CYC) (also see Fig. 1): ionised material spirals around the field lines because of the Lorentz force $F = e\vec{v} \times \vec{B}$
- bremsstrahlung (BREMS): ionised material is slowed down and emits hard X-rays
- black-body radiation (BB): bremsstrahlung emitted towards the white dwarf is reprocessed as a black-body spectrum

Emission

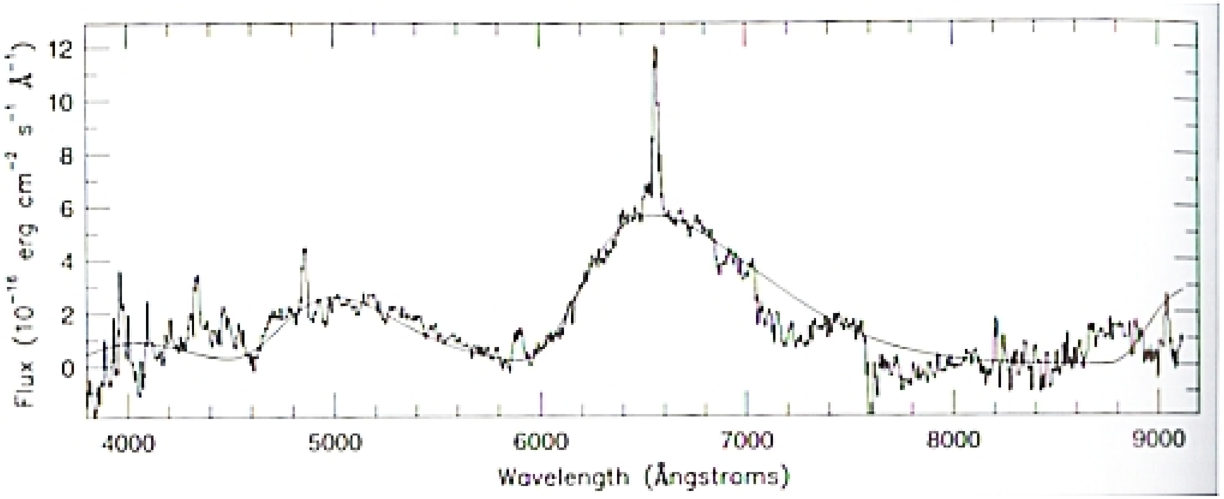


Figure 4: Cyclotron humps in spectrum

Accretion

Observation

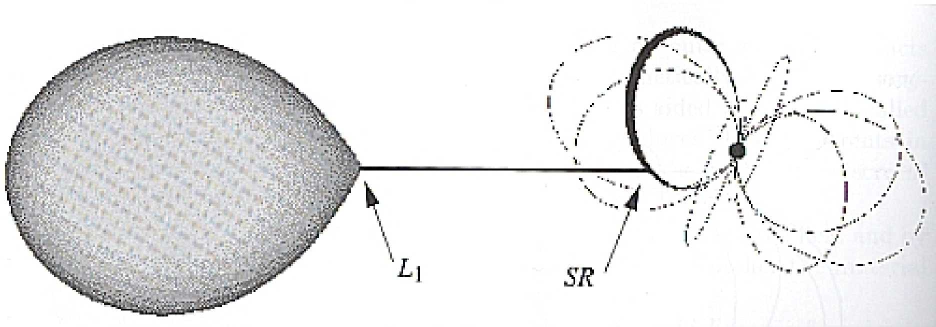


Figure 5: Accretion on a magnetic white dwarf in a CV

Accretion

The Simple Model

- accretion on one pole
- accretion stream starts on a ballistic trajectory and is then forced to follow the field lines
- accreted material forms a shock and an accretion column over the accretion region of the primary

Accretion

Problems with the Simple Model

- “soft X-ray problem”: more soft X-rays than expected
- “reversed soft X-ray mode”: soft X-rays are anti-phased to hard X-rays
- cyclotron emission peaks at red wave-lengths

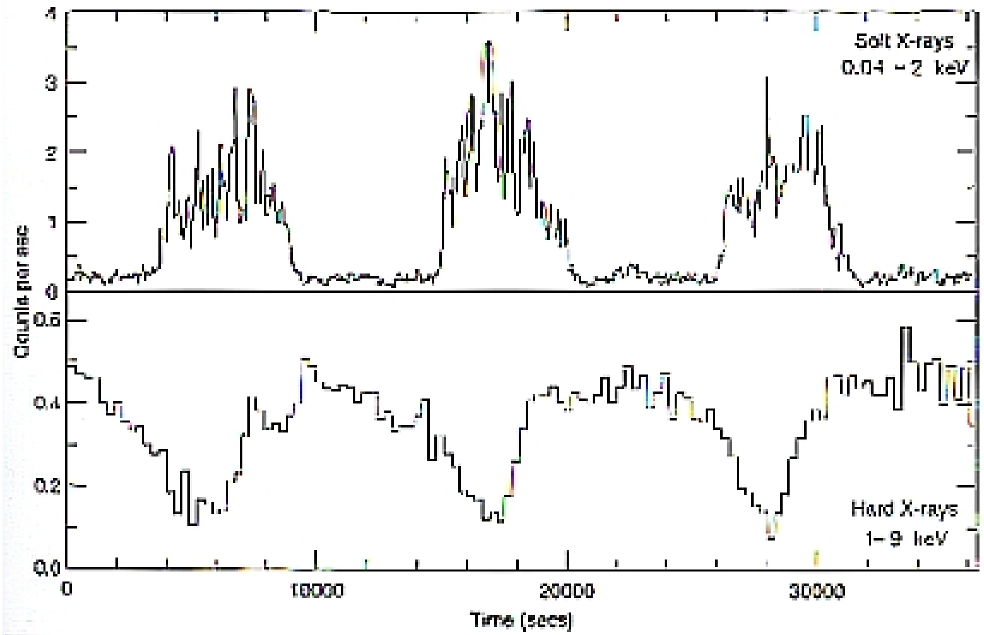


Figure 6: The “reversed X-ray problem”

Accretion

The Solution

- converging field lines squeeze the stream
  $\Rightarrow$ 'blobs' are formed resisting the magnetic pressure longer
  $\Rightarrow$ blobs might reach surface avoiding the shock
  $\Rightarrow$ released X-rays are thermalised by the atmosphere

- accretion on both poles, most blobs going to only one pole
  $\Rightarrow$ soft X-ray emission mainly on one side, hard X-ray mainly on the other

- blobs will reach surface at another point than the 'mist' of matter
  $\Rightarrow$ accretion region is an extended arc

Accretion

The Accretion Region

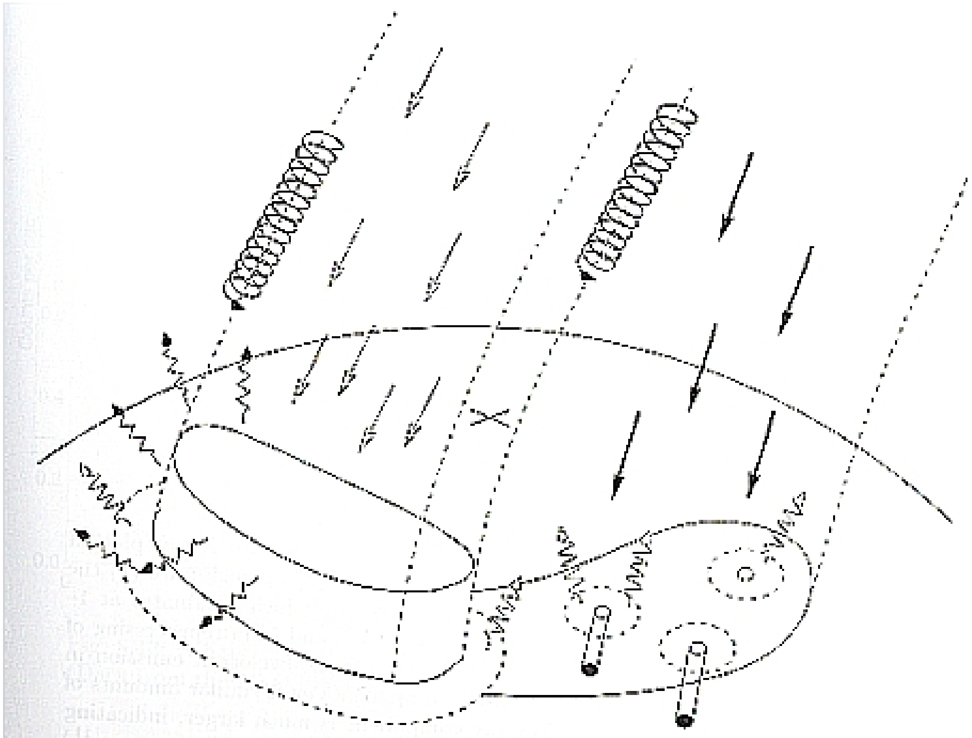
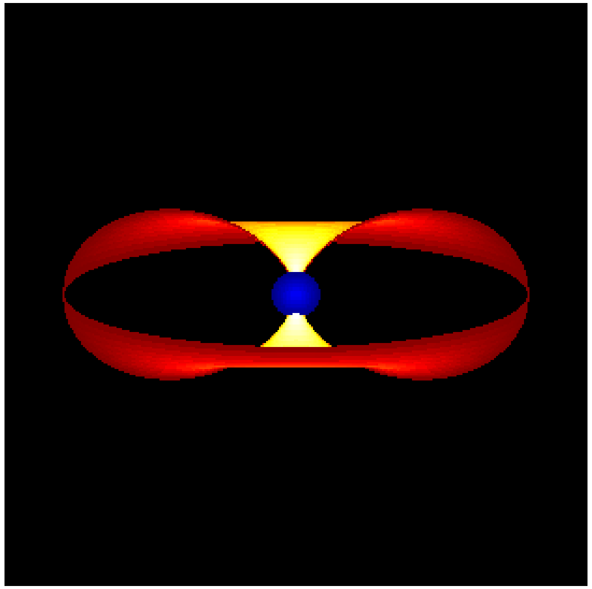


Figure 7: The accretion region

◊

Intermediate Polars



Overview - Intermediate Polars

- Intermediate Polars
  - What is an Intermediate Polar?
  - Discless Accretion
  - Disc-fed Accretion
  - The Accretion Curtain Model
  - Propellers
  - Sidebands

What is an Intermediate Polar?

- subclass of the CVs
- primary is a white dwarf with a medium-strength magnetic field (typically 1-10 MG)
- emission is (usually) not polarized
- truncated or no accretion disc
- primary does not rotate synchronously $\left(\frac{P_{\rm spin}}{P_{\rm orbit}} \approx \frac{1}{10}\right)$
- pulsed X-ray emission
- DQ Her, V2400 Oph, EX Hya, V1025 Cen

Discless Accretion

- blobs are either attracted or repelled (because of electric currents on their surfaces)

- if attracted, disc is formed

- if repelled, torus of matter will be formed but no disc

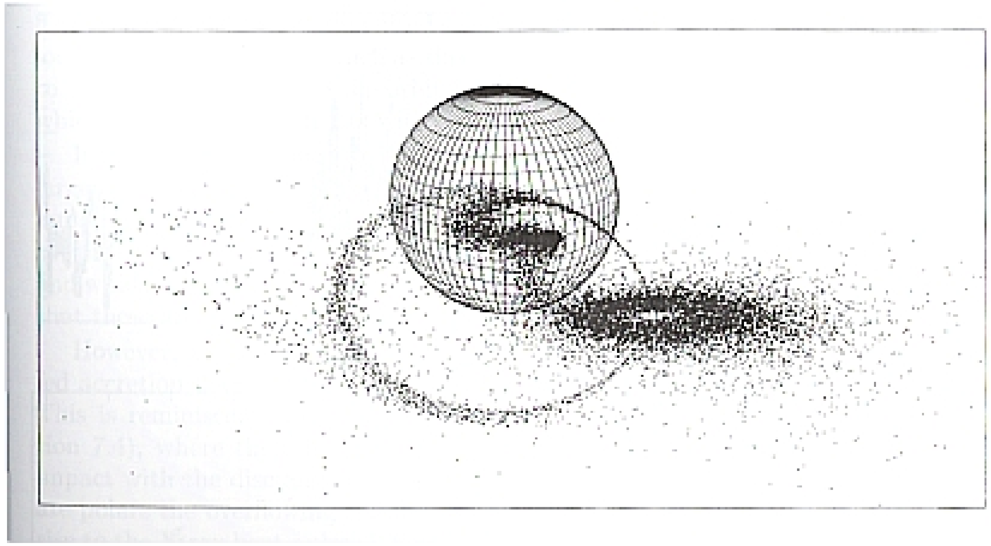


Figure 8: Discless intermediate polar surrounded by a torus of matter

Disc-fed Accretion

- $r_{\text{mag}} < r_{\text{min}}$
- outside the magnetosphere the matter will form a disc
- intermediate case

$$r_{\text{circ}} < r_{\text{mag}} < r_{\text{min}}$$

is pretty much less clear
r_{circ}: circulisation radius (dotted line in fig. 9)

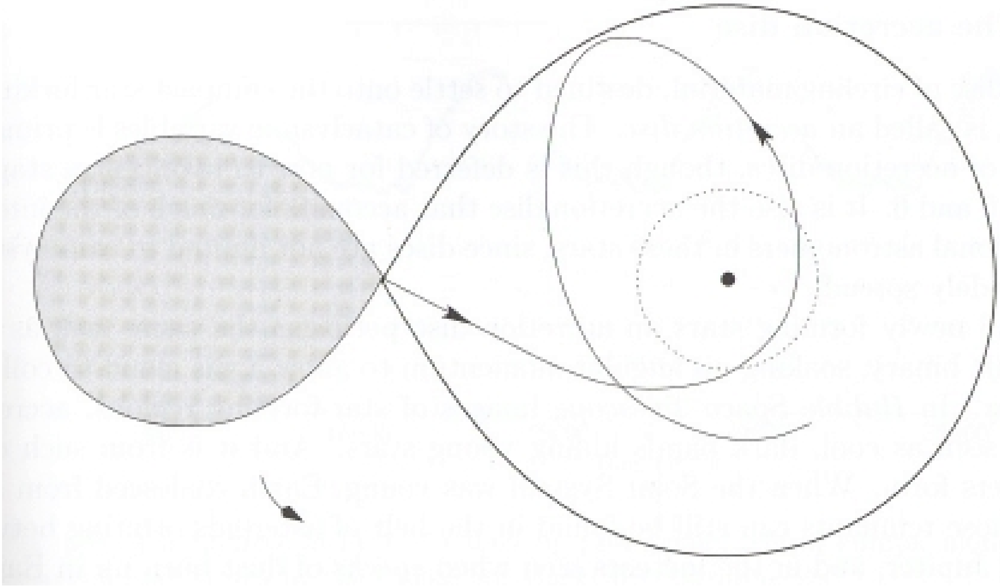


Figure 9: Accretion stream in Roche lobe

- inside the magnetosphere the stream follows the field lines again

Disc-fed Accretion

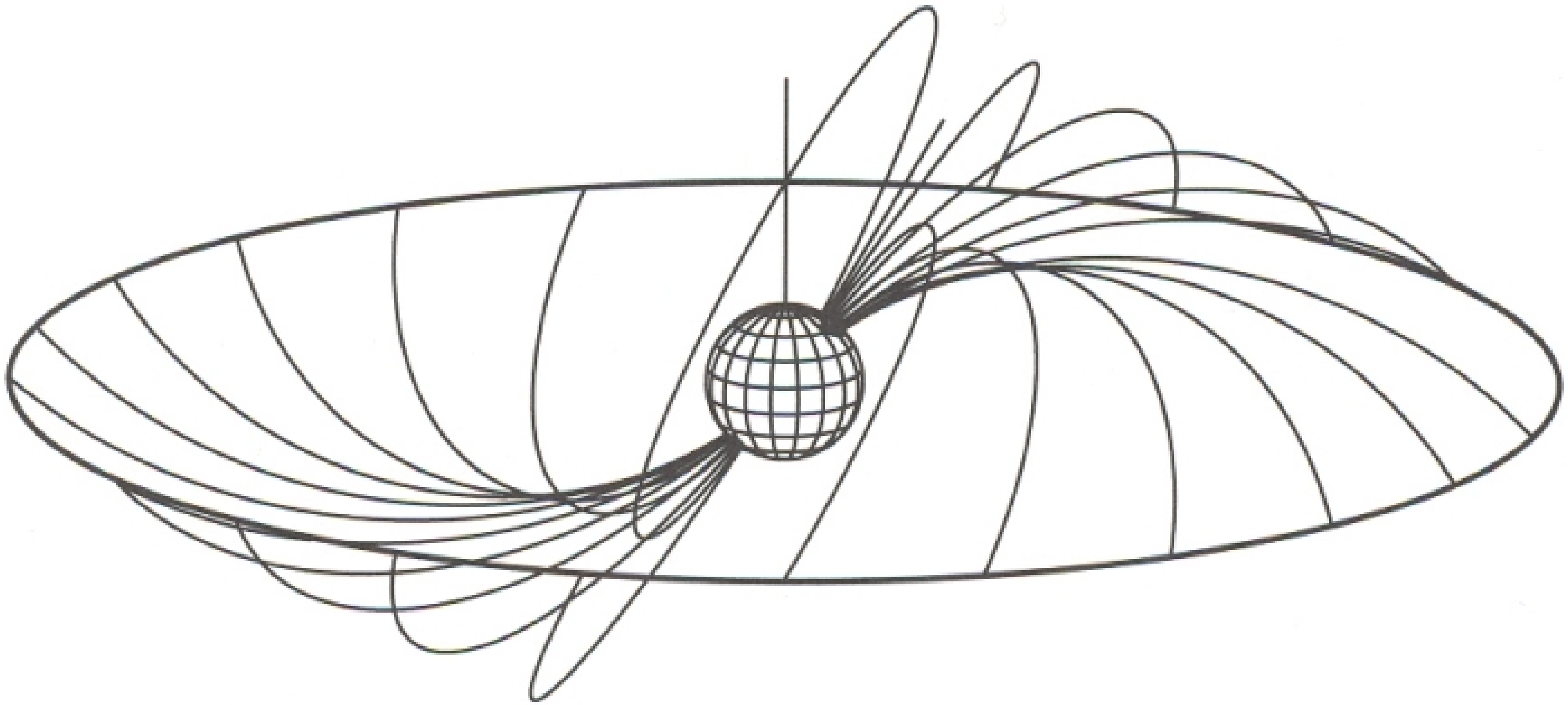


Figure 10: Disc-fed accretion in intermediate polars (animated)

The Accretion Curtain Model

- pulsation although poles cancel each other out in emission
- effects of asymmetric magnetic poles or a significant height of the accretion column too small
- deeper pulsations at lower energies
  $\Rightarrow$ absorption effect

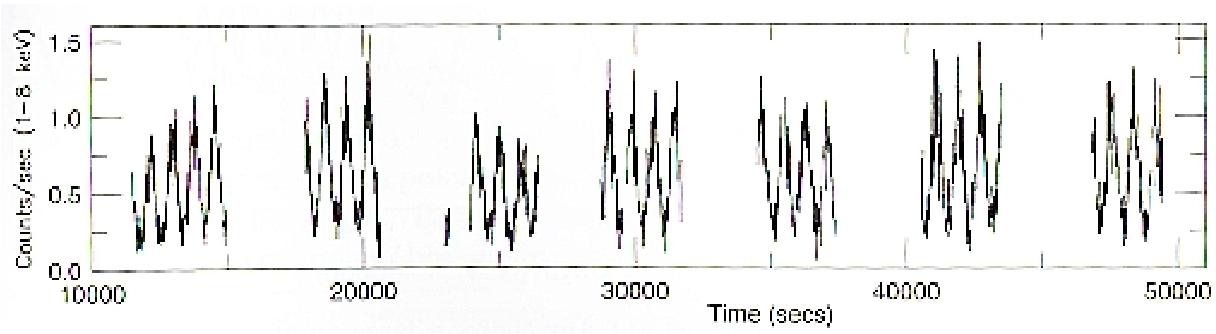


Figure 11: X-ray lightcurve of AO Psc showing 805s-pulsations

The Accretion Curtain Model

- explained by the *accretion curtain model*:
  - stream points towards us $\Rightarrow$ less X-ray is observed
  - stream points away from us $\Rightarrow$ more X-ray is observed

- problem: double-peaked pulsations (e.g in EX Hya)

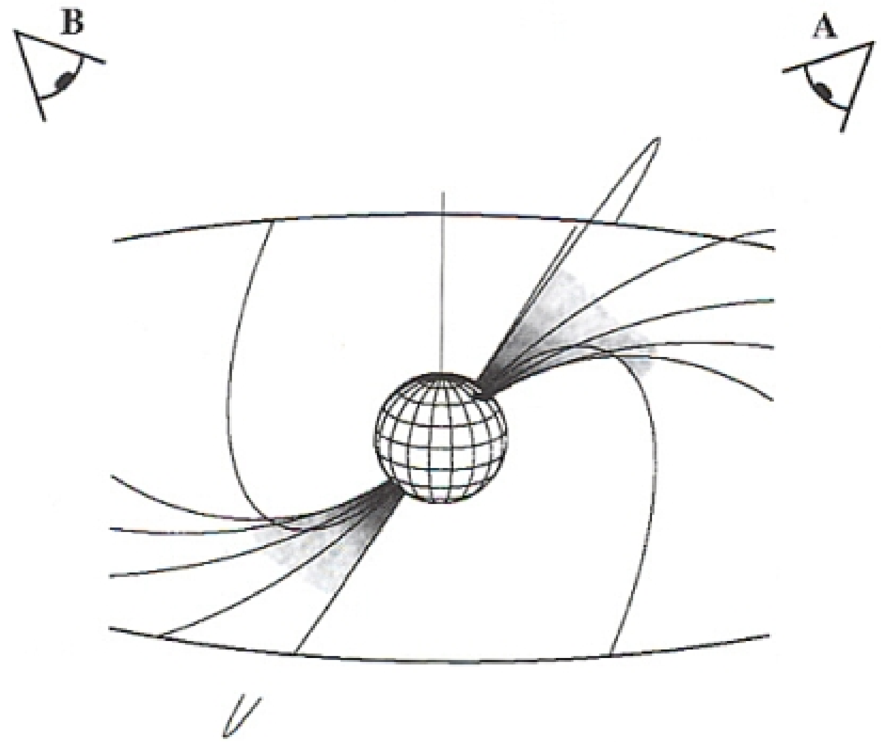


Figure 12: Principle of the accretion curtain model

Propellers

- primary rotates too fast (like in Fig. 13)

  ⇒ energy of the blobs is increased

  ⇒ blobs are expelled and might even leave the system

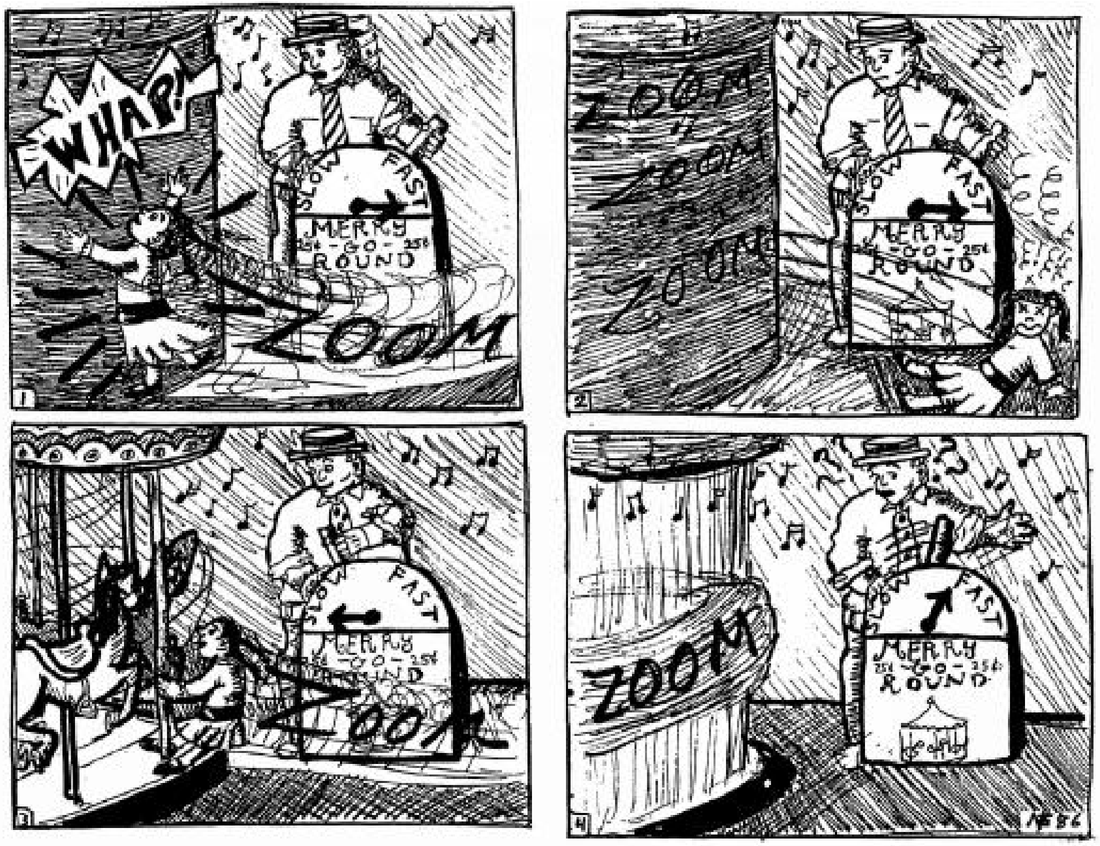


Figure 13: Synchronisation is needed... ;-)

Propellers

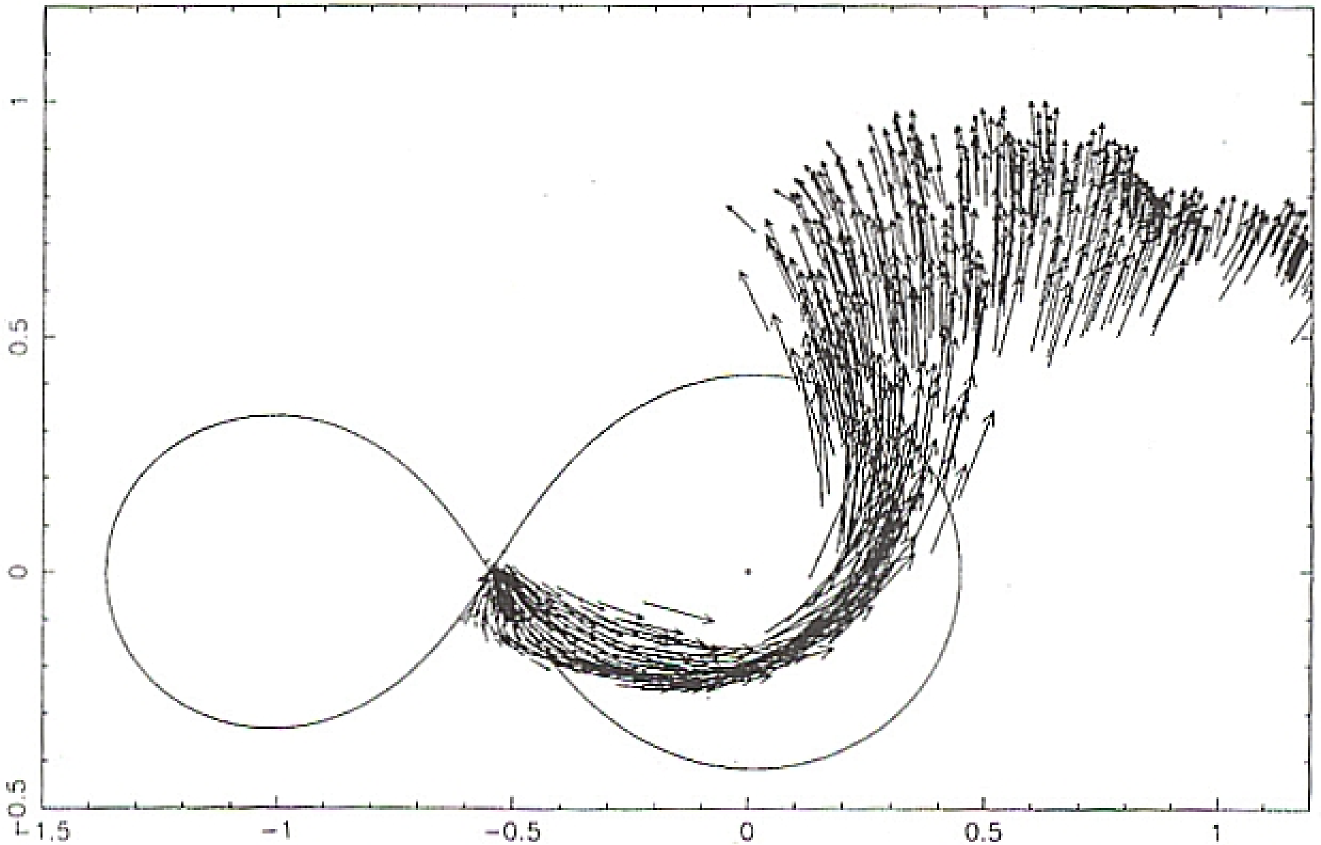


Figure 14: An intermediate polar acting as a propeller

Sidebands

- very often strong beat-cycle pulsations in optical lightcurves
- produced by interaction of spin and orbital cycles
- bright spot re-illuminated after more than one period
- complicated sidebands are possible

$$\omega \pm \Omega \;\; \omega \pm 2\Omega \;\; \omega \pm 3\Omega \;\; ...$$

or even more complicated if more complex amplitude modulation

Sidebands

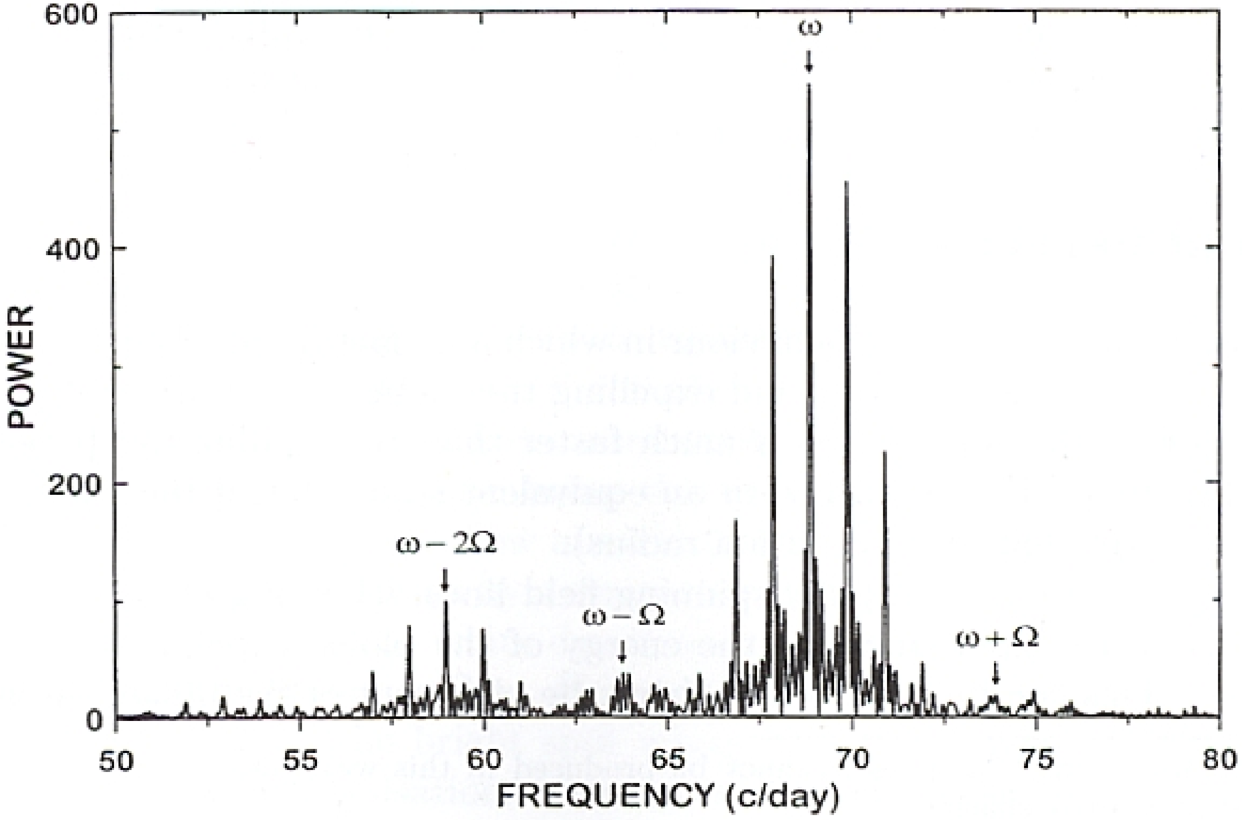


Figure 15: Fourier transform of the optical lightcurve of FO Aqr

References

- C. Hellier, *Cataclysmic variable stars - How and why the vary*, Springer/Praxis, 2001
- M. Cropper, *The Polars*, Space Science Reviews 54, 1990
- J. Patterson, *The DQ Herculis Stars*, Publications of the Astronomical Society of the Pacific 106, 1994
- Movie/picture on page 15 taken from The Open University
- Picture on page 1 taken from the Russel Kightley Media site

Useful related links

- Tool to create OpenGL Animations of CVs
- The MSSL Polar Page