Polarization Survey for Bright AM CVn Systems

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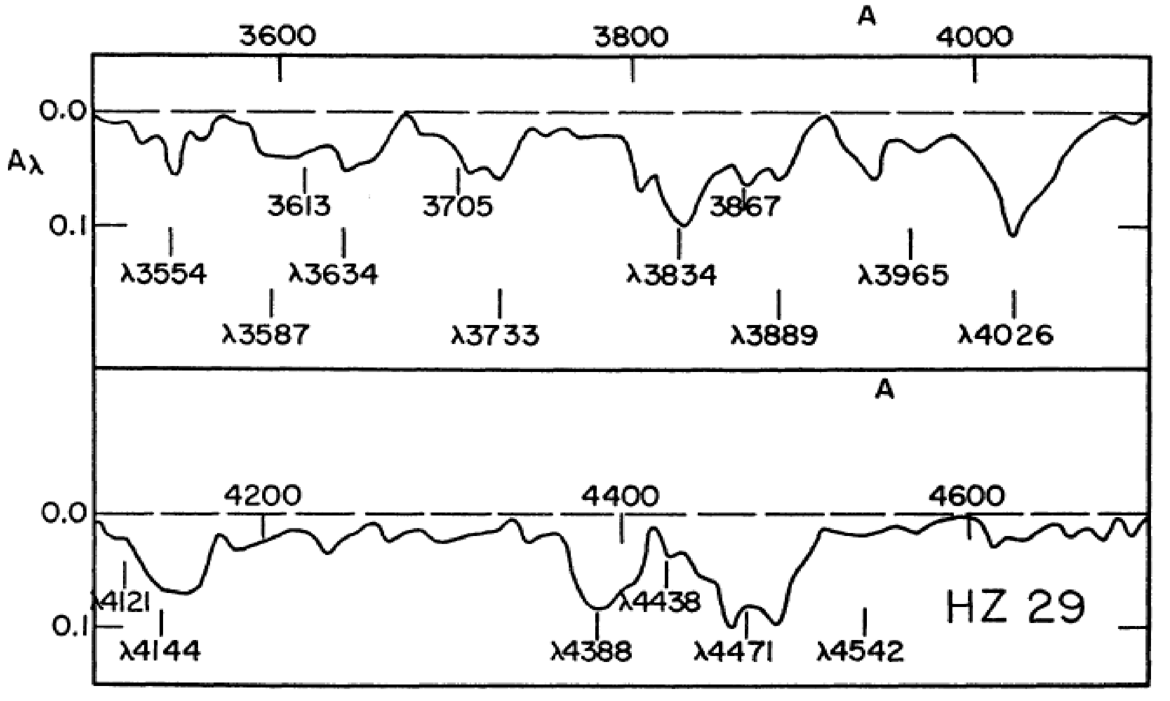
AM Canum Venaticorum stars:

The Greenstein & Matthews (1957) found peculiarly shallow lines in the spectrum of the “DB white dwarf” HZ 9. Smak (1967) found variability at 18 mins and suggested it could be an orbital period.



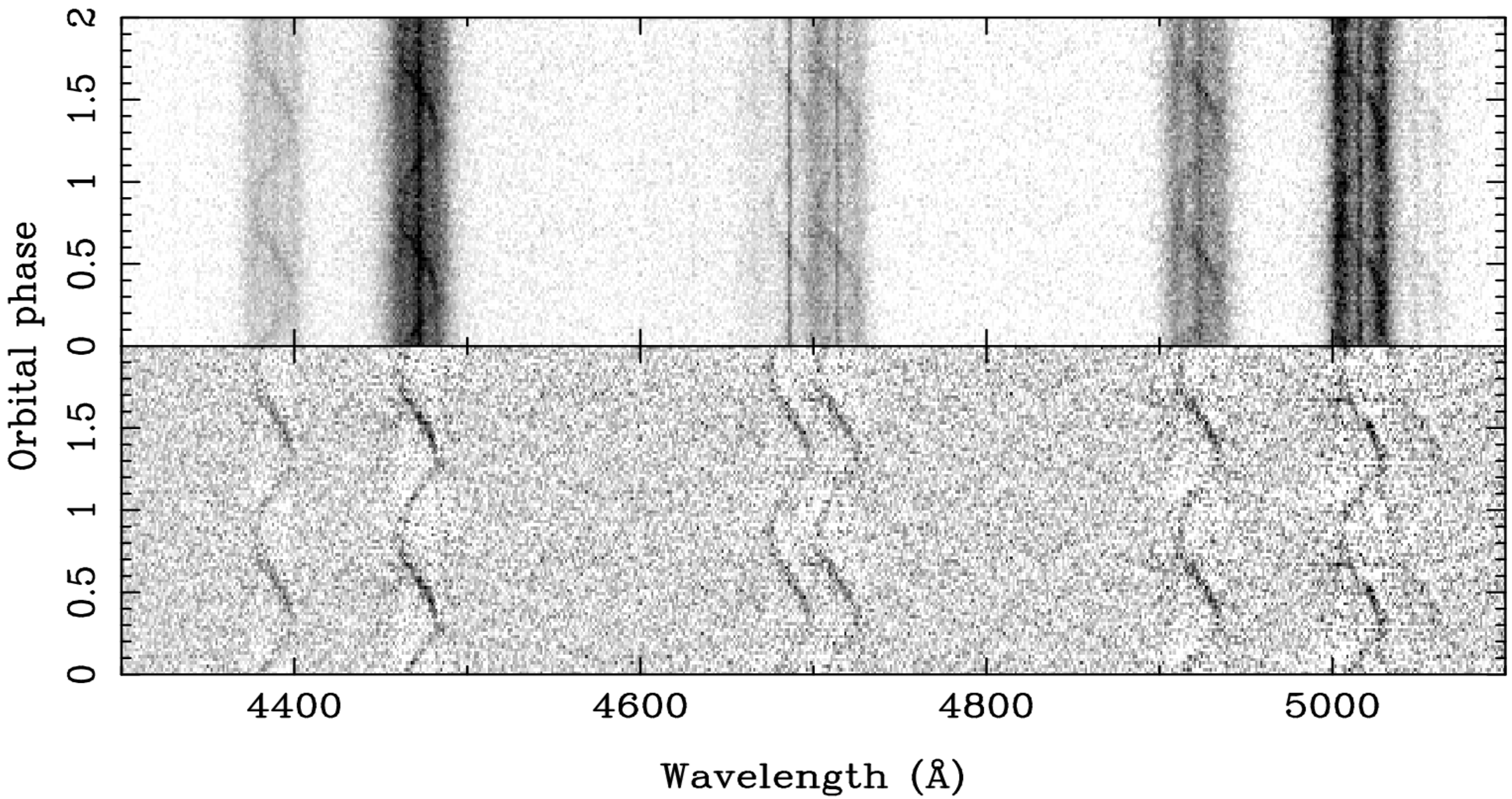
Key properties of AM CVn stars:

- No hydrogen
- Very short periods (5 – 10 to 65 minutes)
- Spectra characteristic of accretion discs
- Weak X-ray emission= AM CVn stars are semi-detached, accreting binary stars in which the donor stars are hydrogen deficient.

The accretors are white dwarfs

To fit within their Roche lobes, the donor stars must be dense, suggesting they may be degenerate too:
“double degenerate” (Faulkner et al 1972).

GP Com, P = 46 mins, trailed spectrum
Marsh (1991)



Some "specifications" of AM Cvn stars:

Total number known: 25 including HM Cnc and V407 Vul

Total number in Galaxy: $3 \times 10^5 – 3 \times 10^6$ (Roelofs et al 2007)

Accreting white dwarfs: M(1) is typically 0.6M(solar)

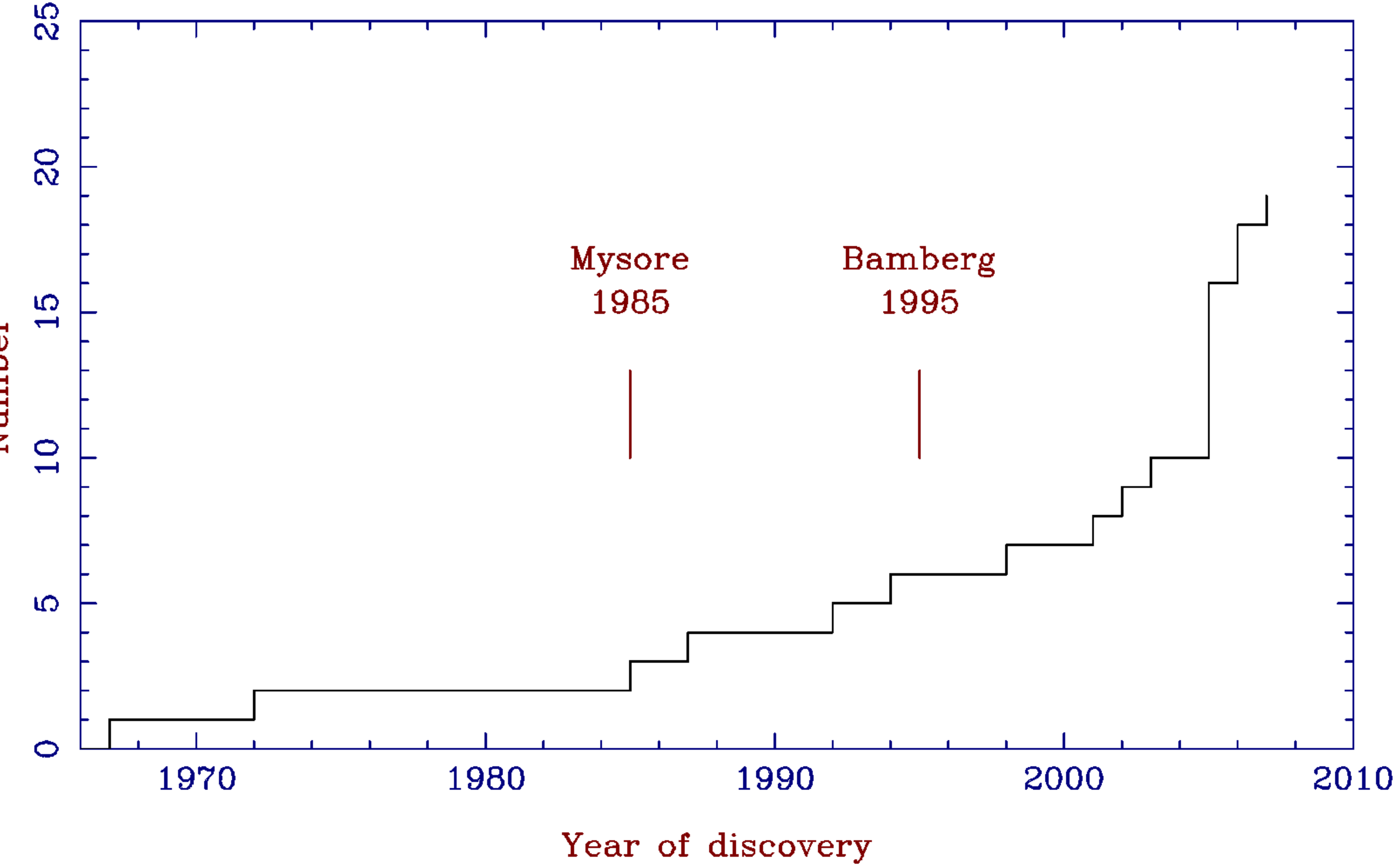
Mass donors: M(2) = 0.015 — 0.15M(solar)

Orbital separations: a = 0.1 — 0.4R(solar)

Accretion Disc size: R(disk) = 0.35a

Mass transfer rates: $\dot{M} = 10^{-12} — 10^{-8}$ M(solar) yr

Absolute magnitudes: M(v) = 5 — 13



11 AM CVn stars have come from the SDSS, the 2QZ survey and supernova cosmology projects. The first eclipsing system, SDSS0926+3624, was found in the SDSS (Anderson et al 2005).

-almost entirely hydrogen deficient=>AM CVn stars differ from most other cataclysmic variables (CVs) in the lack of hydrogen lines from their spectra.

-Both the donor star and accretor star in the binary are degenerate or semi-degenerate objects

-The main reasons to study these binaries are:
(a) their space density is a sensitive test of binary population synthesis models which in turn are input to galactic population models,

(b) they are the strongest known sources of gravitational wave radiation,

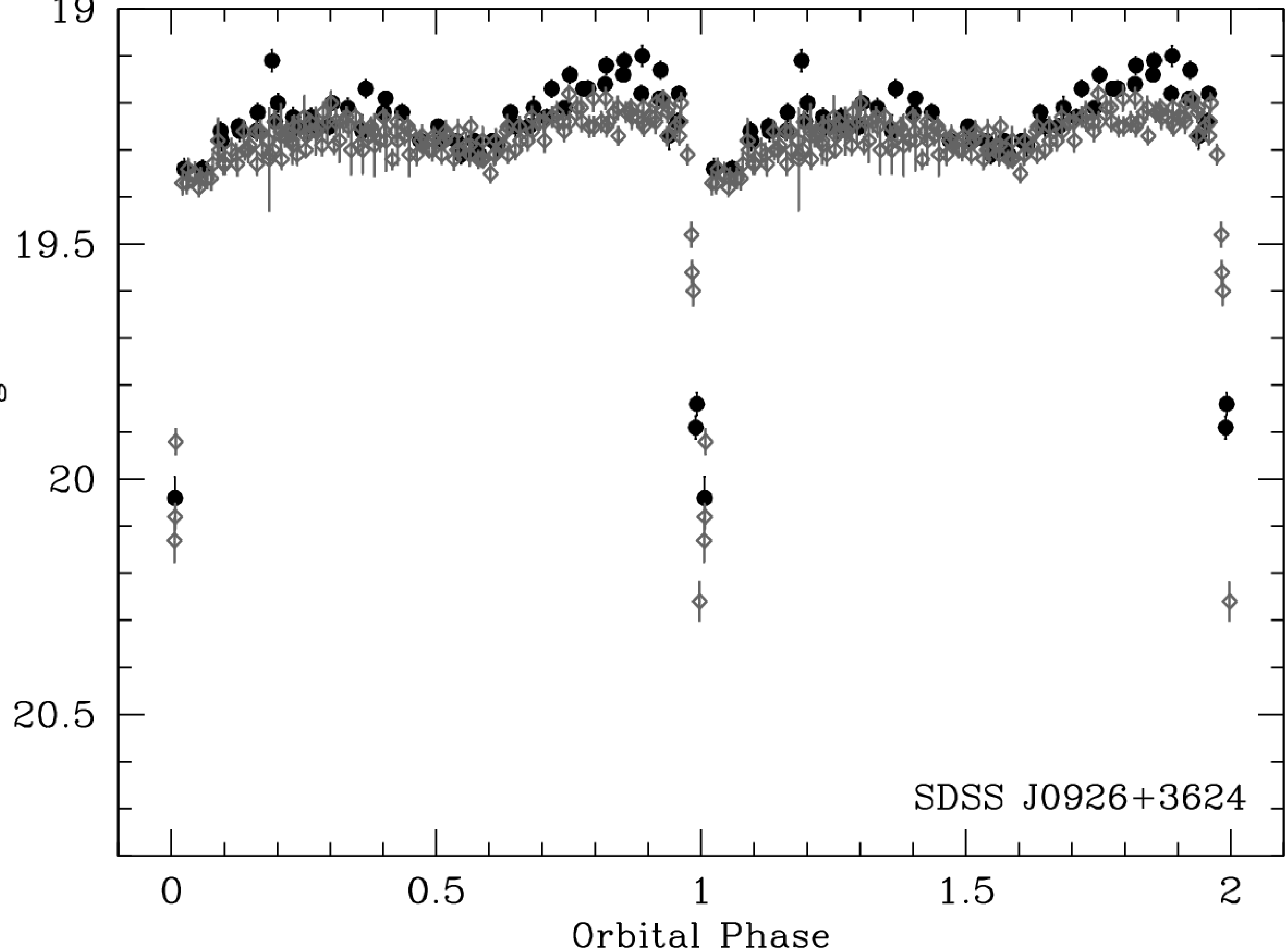
(c) they are the best sources in which to understand hydrogen deficient accretion flows.

Also the first eclipsing AM CVn star, SDSS0926+3624 have been found!
Anderson et al. (2005)

- P = 28 minutes, the only eclipsing AM CVn known

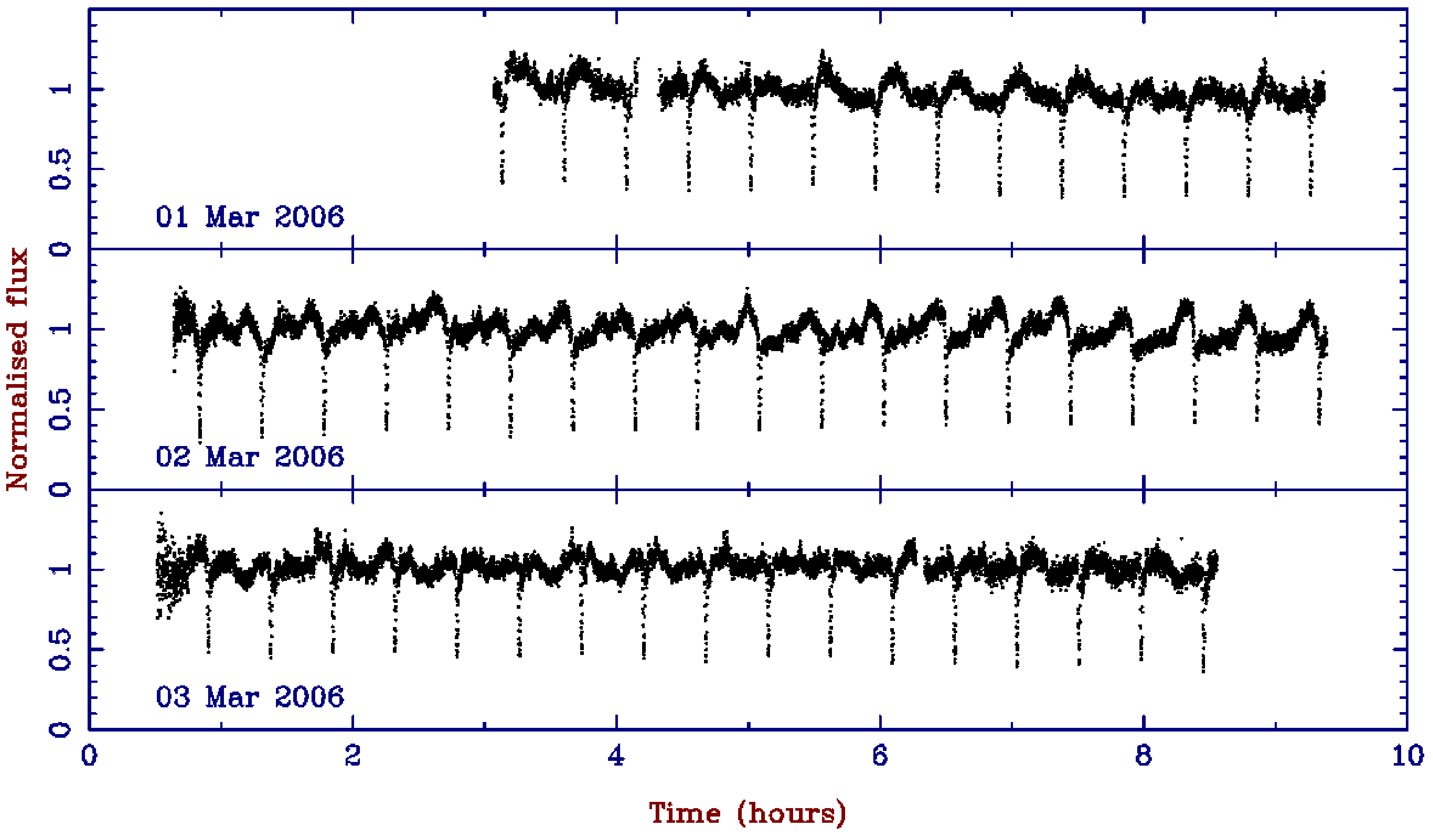
- g' = 19.3 with eclipses that last 1 minute.

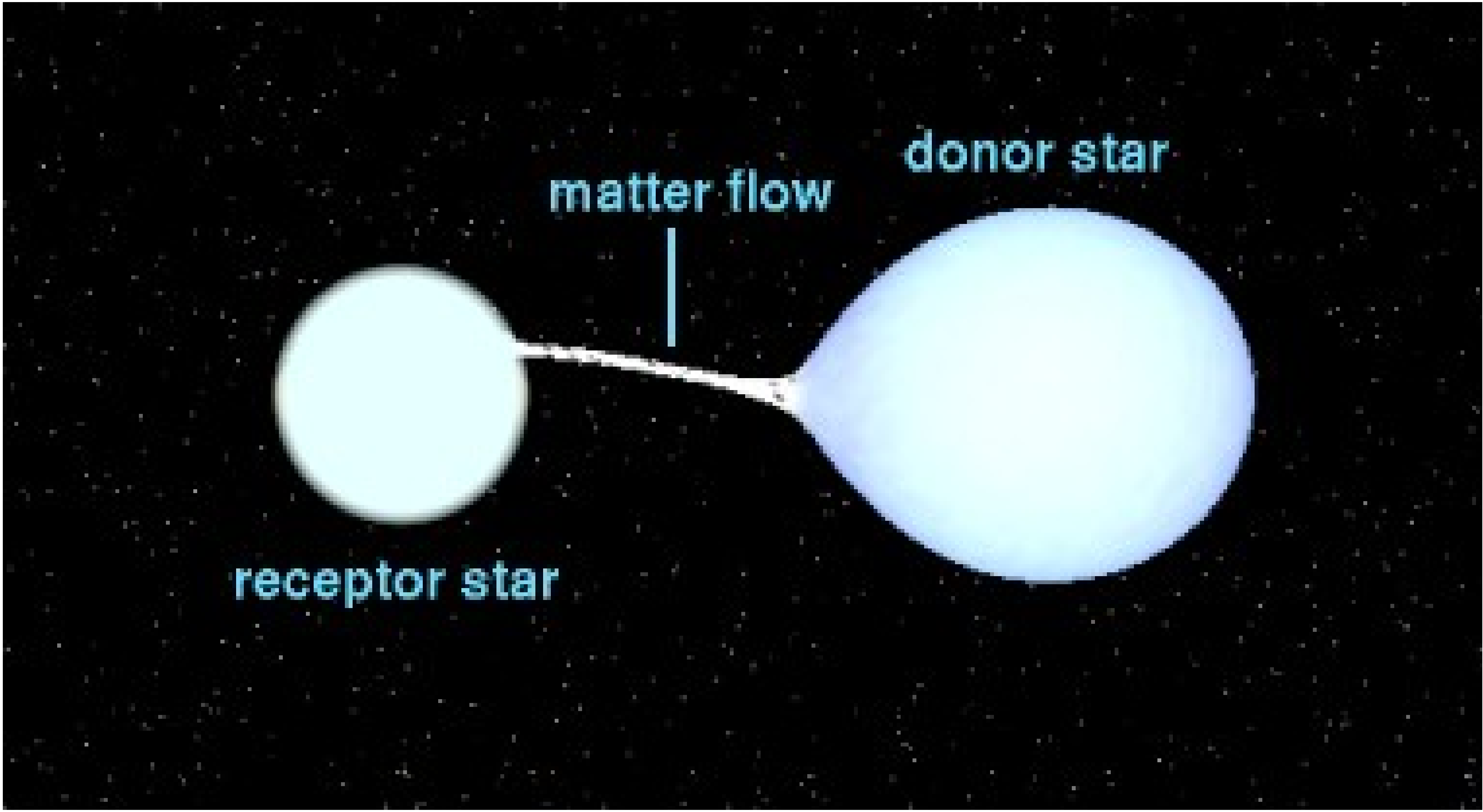
- The first chance to measure component masses directly.

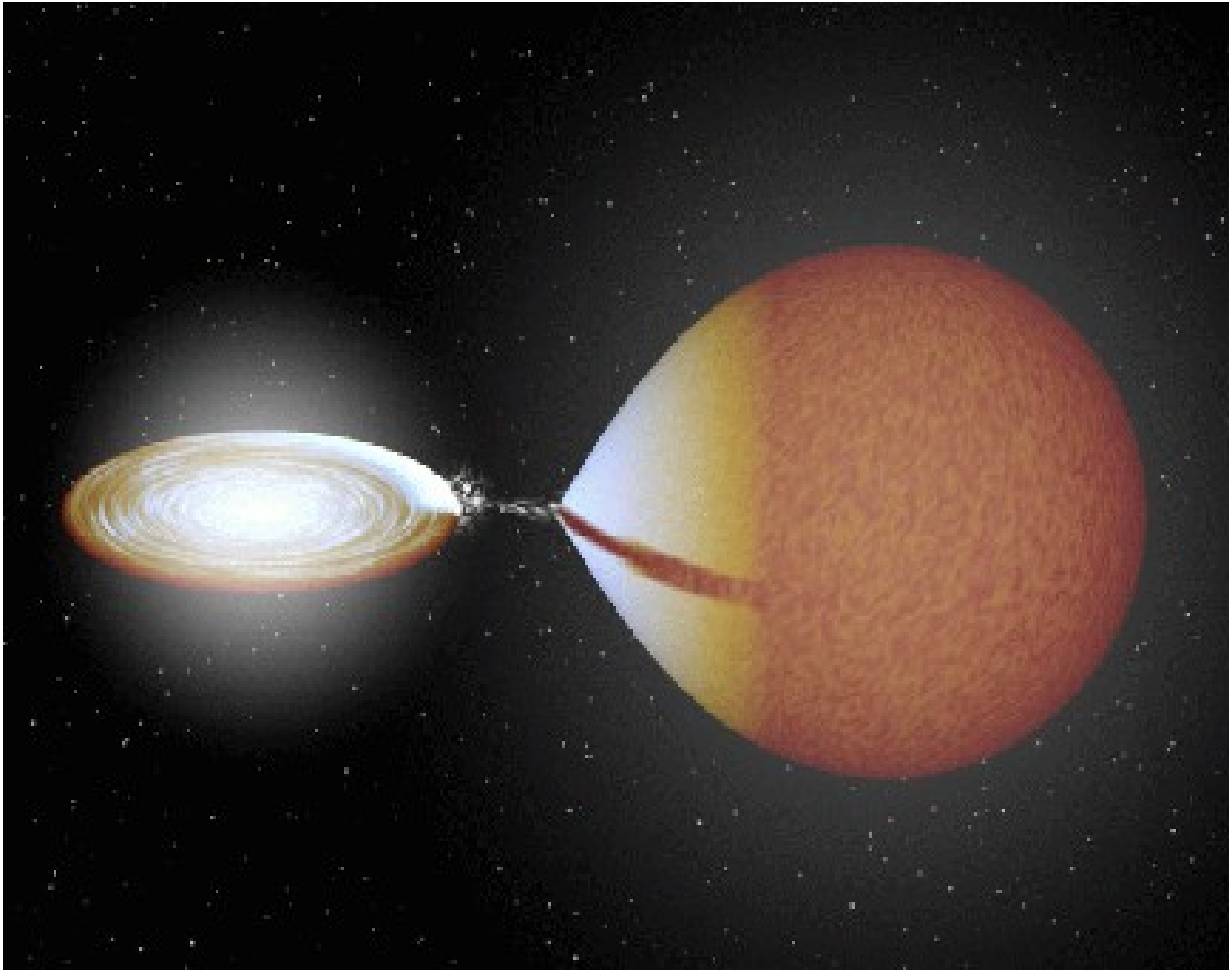


19
19.5
20
20.5
0
0.5
1
1.5
2
Orbital Phase
SDSS J0926+3624

SDSS0926+3624 with 4.2m WHT+ULTRACAM




donor star
matter flow
receptor star



Three ways which are believed to lead to the formation of AM CVn stars:

(i) a double WD system that loses angular momentum via two common envelope (CE) phases and gravitational wave radiation,

(ii) a donor helium star transferring mass onto a WD until it is too low mass to fuse helium and becomes semi-degenerate

(iii) evolution from a Cataclysmic Variable systems (CVs) where the donor has lost enough matter to uncover its helium core.
Magnetic braking allows efficient angular-momentum loss from the orbit and hence a strong shrinkage of the orbit to ultra-short periods.

The magnetic CVs fall into two categories; polars and intermediate polars (IPs). Polars have magnetic field strengths in the range 10-200 MG whilst the IPs are believed to have magnetic fields in the range 1-10 MG.

AM CVn stars and magnetism?

Tout et al (2008) predicts that isolated WDs with magnetic fields higher than 3 MG are formed as a product of a binary system which has undergone a CE-phase and a merger between the two stellar components.

In the case of the double WD formation channel for AM CVn systems we also expect that the accreting WD should have a strong magnetic field in several systems. If the systems follow this model, then one would expect incidence of magnetic fields in AM CVns produced by double degenerate formation to be the same as the incidence of magnetic fields in classical Cvs, i.e. about 25 %..

In the double WD formation channel the separation of the WDs is initially too small for an accretion disk to form. Without the stabilizing effect of an accretion disk, the system must synchronize the spin and orbital periods of two WDs or the systems will merge. It may be the case that this coupling can only be done with a magnetic field (Nelemans et. al. 2001).

Strong magnetic fields have not been definitively detected in any AM CVn system previously.

Attempts to detect a magnetic field have been made in three systems with a tentative detection of a 10MG field is reported in one of them (HM Cnc; Reinsch 2004).

-**A detection of a magnetic field in an AM CVn star would be of exceptional interest as it would represent the first such detection in this class of object.**

-it will reveal the nature of accretion in this class in general and allow the study of magnetically confined accretion of He flows. **The presence of a strong magnetic field would govern the ongoing accretion/mass transfer processes in these systems.**

-A discovery could provide clues as to the origin of AM CVn systems and have implications for the generation and stability of magnetic fields in helium dominated accretion. It would also allow to test whether the distribution of magnetic fields among the AM CVn systems mirrors that of CVs, of which approximately a quarter have detected magnetic fields.

The continuum polarization detected in polars is due to semi-relativistic electrons spiraling around magnetic fields lines resulting in cyclotron emission. If polarization is detected in AM CVns it will also be due to this process.

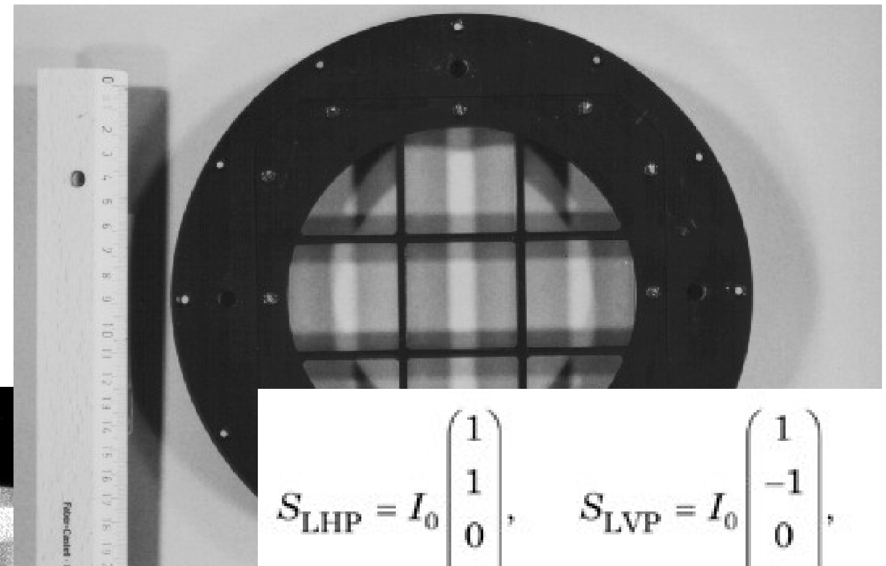
Our circular polarization survey of AM Cvn stars:

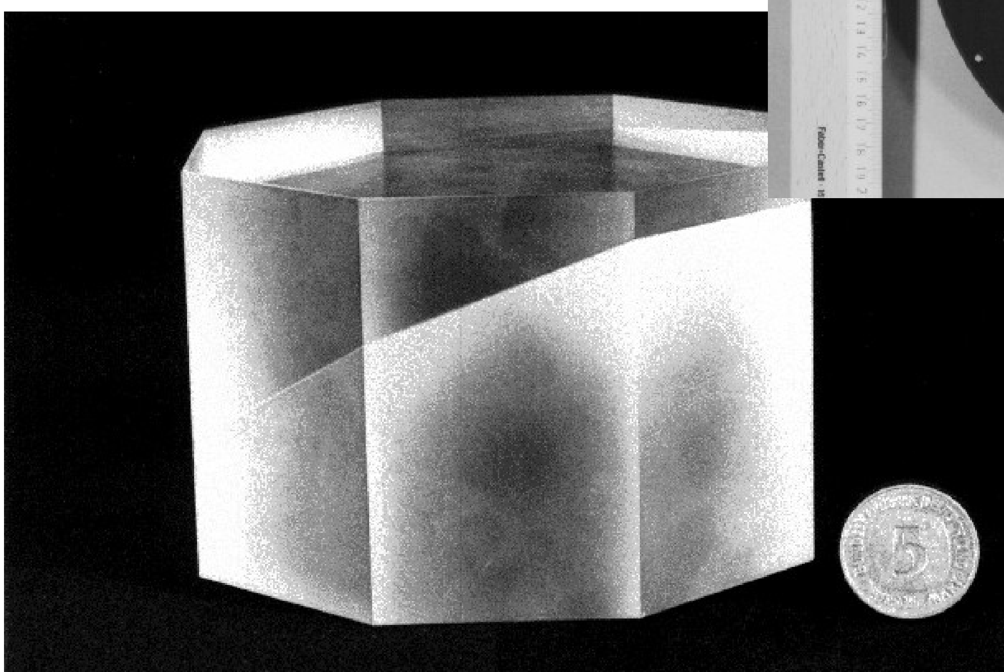
Observing time applied and granted (!) from La Palma observatories (ORM, the Nordic Optical Telescope), and VLT at the ESO in Paranal.

Imaging polarimetry and spectropolarimetry. ALFOSC at the NOT, FORS at the VLT.

Needs high S/N...200-300, and with time resolution of minutes!

POLARIMETRY AS TOOL.

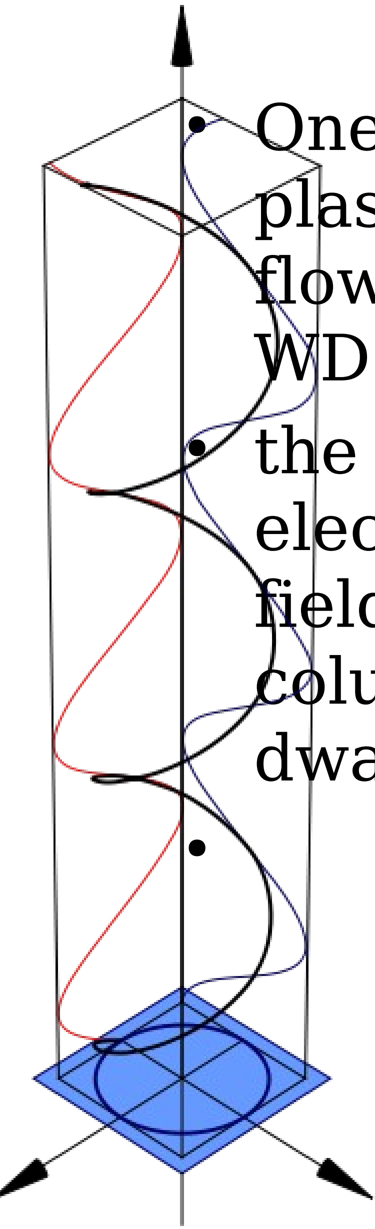




$$S_{\mathrm{LHP}} = I_0\begin{pmatrix}1\\1\\0\\0\end{pmatrix},\quad S_{\mathrm{LVP}} = I_0\begin{pmatrix}1\\-1\\0\\0\end{pmatrix},\quad S_{\mathrm{L+45P}} = I_0\begin{pmatrix}1\\0\\1\\0\end{pmatrix},$$

$$S_{\mathrm{L-45P}} = I_0\begin{pmatrix}1\\0\\-1\\0\end{pmatrix},\quad S_{\mathrm{RCP}} = I_0\begin{pmatrix}1\\0\\0\\1\end{pmatrix},\quad S_{\mathrm{LCP}} = I_0\begin{pmatrix}1\\0\\0\\-1\end{pmatrix},$$

Polarimetry of magnetic CVs



- One of the cooling processes of the hot plasma (heated when cool subsonic accretion flow is decelerated near the surface of the WD) is cyclotron emission.
- the cyclotron emission is produced by electrons spiraling down the dipole magnetic field lines and forming an accretion plasma column on top of the magnetic pole of a white dwarf
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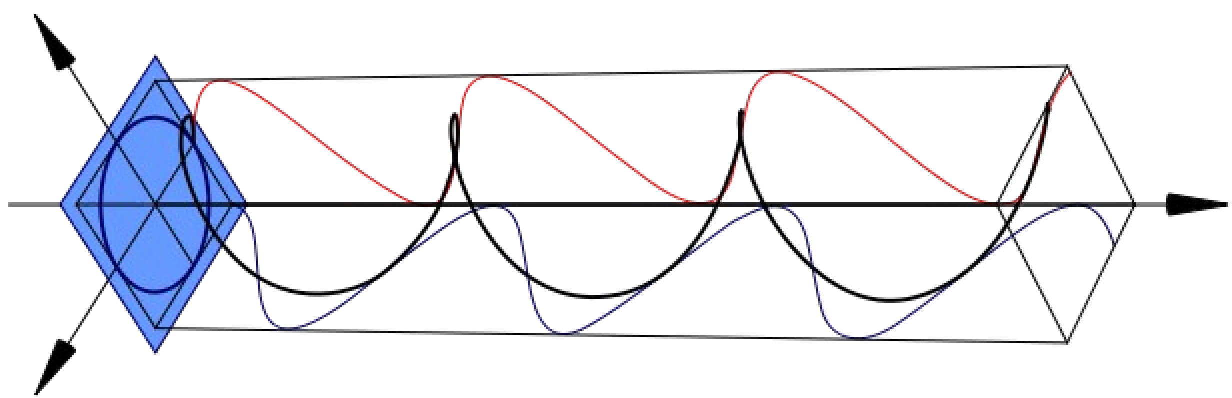
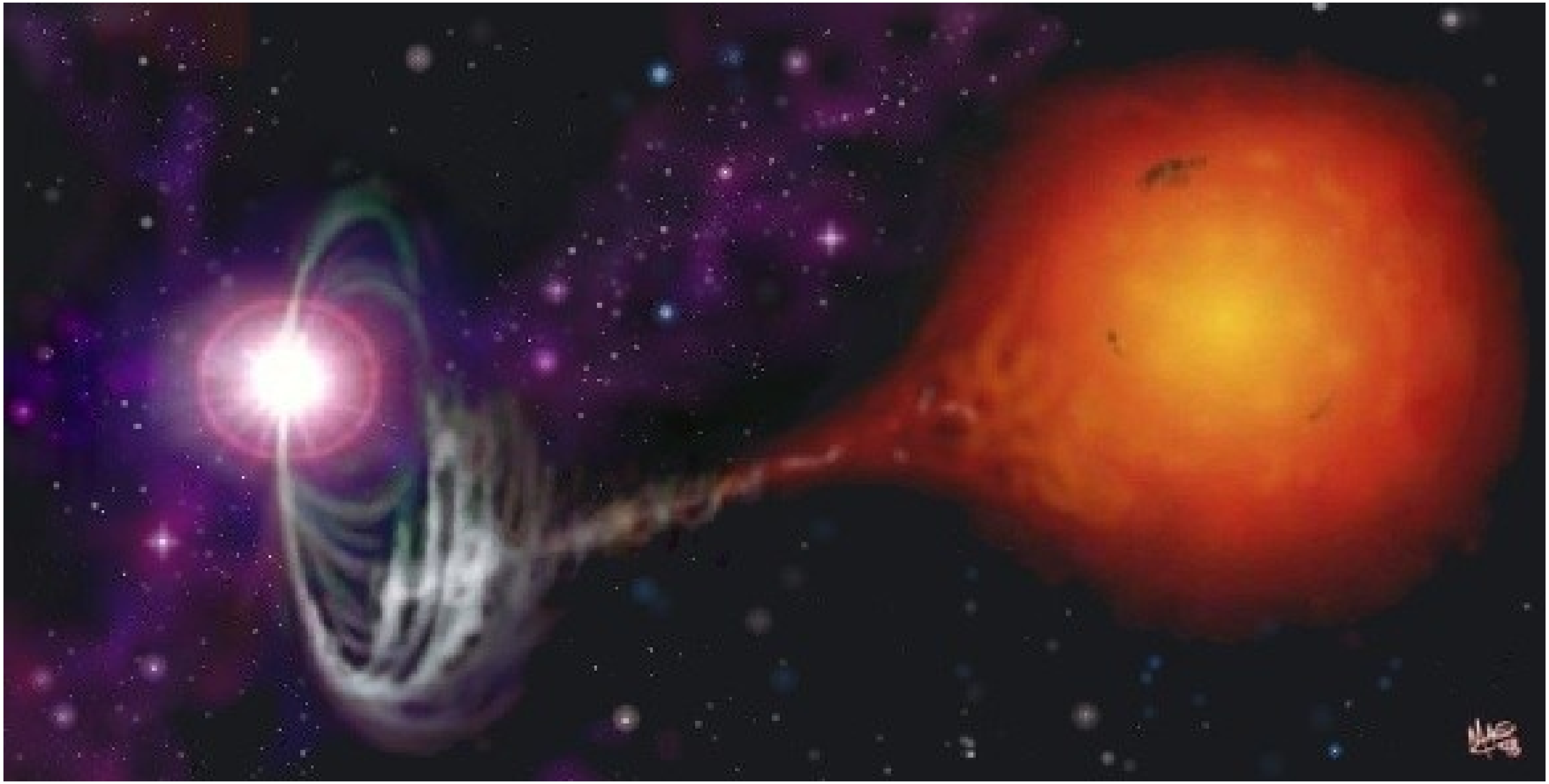


Polar, a strongly magnetic CV

- Strongly magnetic, synchronized, accretion along the magnetic field lines

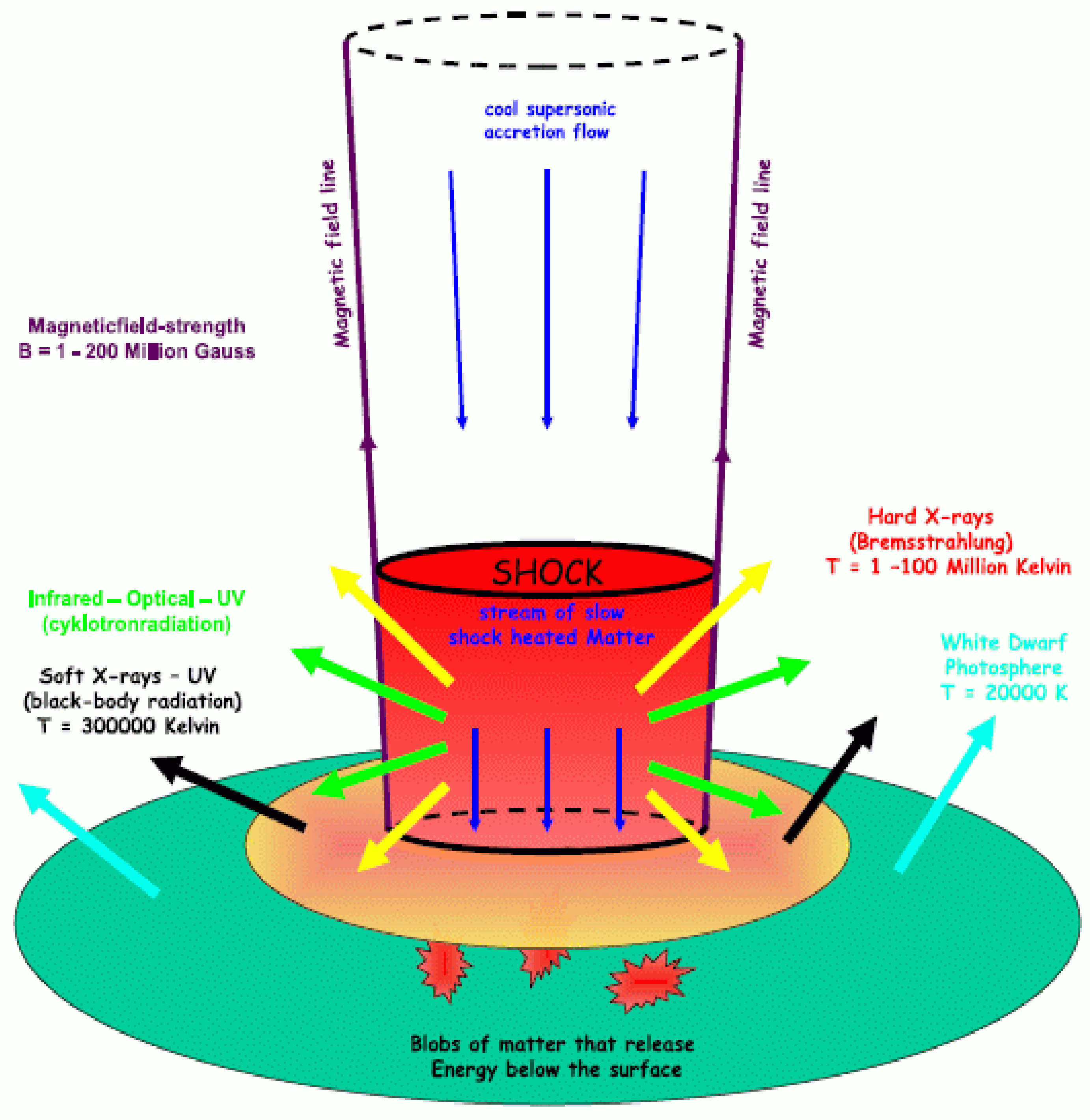


Accretion in mCVs:

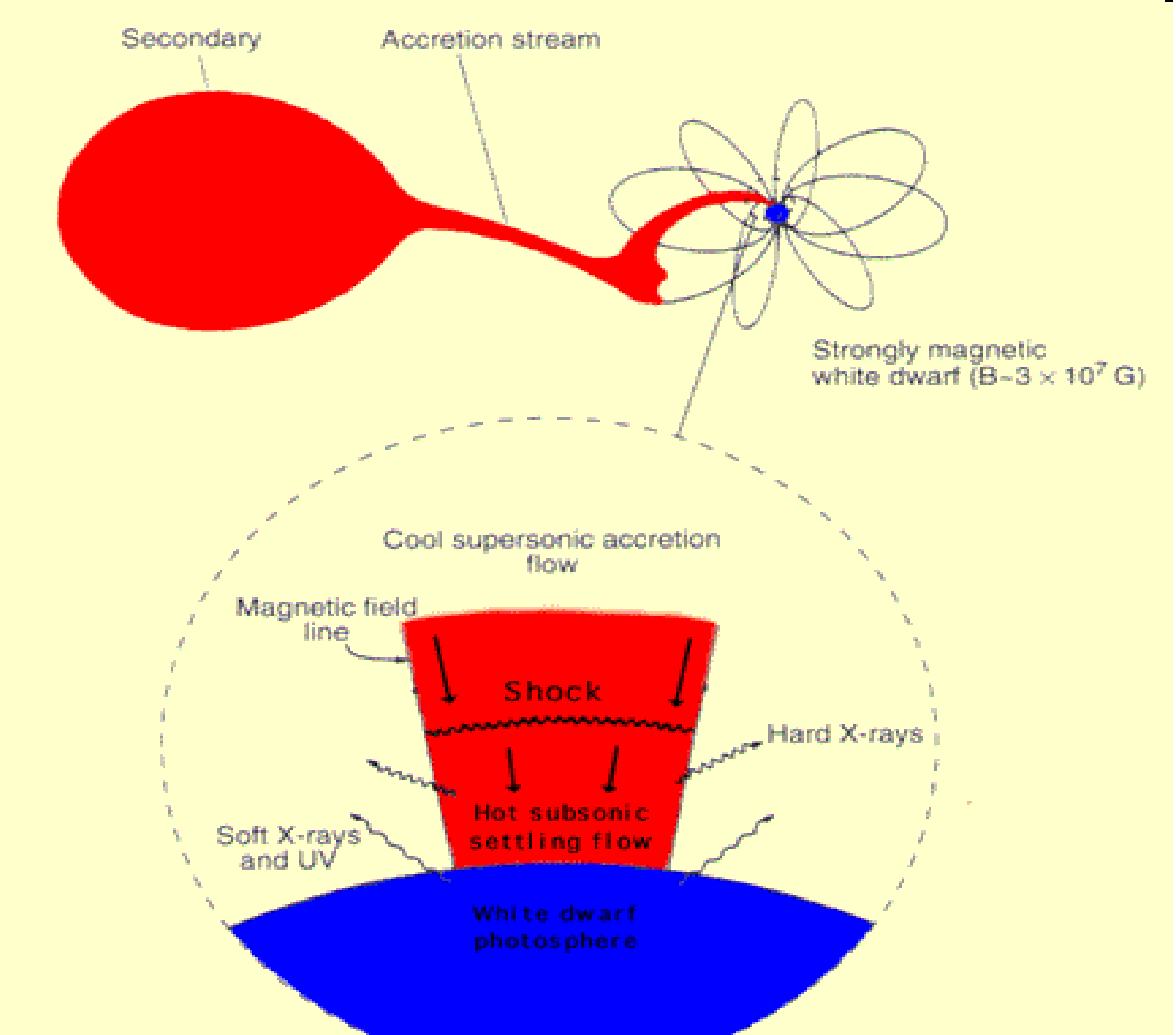
- Plasma flows towards the WD surface along the field lines
- Plasma flow is captured from Keplerian orbit in **coupling region** $\boldsymbol{R_c}$
- $R_c/R_{wd}=[B_p(1+3*\sin^2 theta_d)^{1/2}]^{4/7} *(f/10^{-3})^{2/7} *(M_{wd}/M_{solar})^{-8/21} *(F/(10^{16}\ g\ s^{-1}))^{-2/7}$

f solid angle covered by the stream, *F* mass transfer rate, M_{wd}, R_{wd} mass and radius of the WD, B_p polar field strength oriented an angle $theta_d$ to

- When flowing plasma is decelerated from supersonic speed of 5000 km/s to subsonic speeds, a standing shock is formed above the WD, and **matter is first heavily heated and then cooled**
- ***The most part of the emission we observe in mCVs is products of different cooling processes***



cool supersonic
accretion flow
Magnetic field line
Magnetic field line
Magneticfield-strength
B = 1 - 200 Million Gauss
Hard X-rays
(Bremsstrahlung)
T = 1 -100 Million Kelvin
SHOCK
stream of slow
shock heated Matter
Infrared – Optical – UV
(cyklotronradiation)
White Dwarf
Photosphere
T = 20000 K
Soft X-rays - UV
(black-body radiation)
T = 300000 Kelvin
Blobs of matter that release
Energy below the surface


Secondary
Accretion stream
Strongly magnetic white dwarf (B~3 × 10⁷ G)
Cool supersonic accretion flow
Magnetic field line
Shock
Hard X-rays
Hot subsonic settling flow
Soft X-rays and UV
White dwarf photosphere

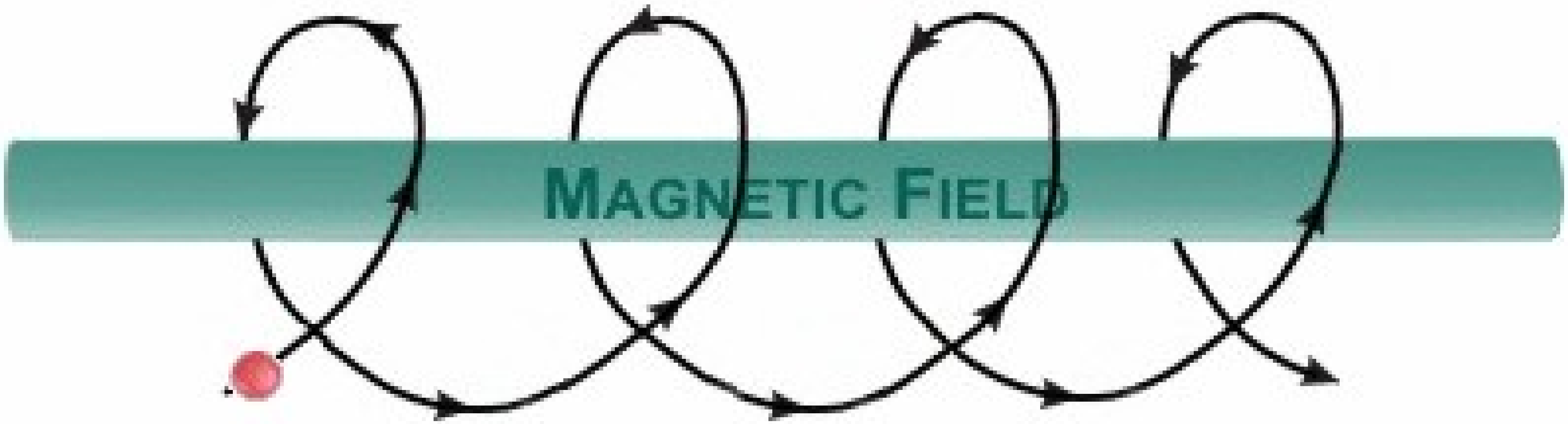
...in infrared and optical this is mostly

cyclotron emission

in polars

...in IPs the situation is not that clear (accretion disk, larger stream etc.)

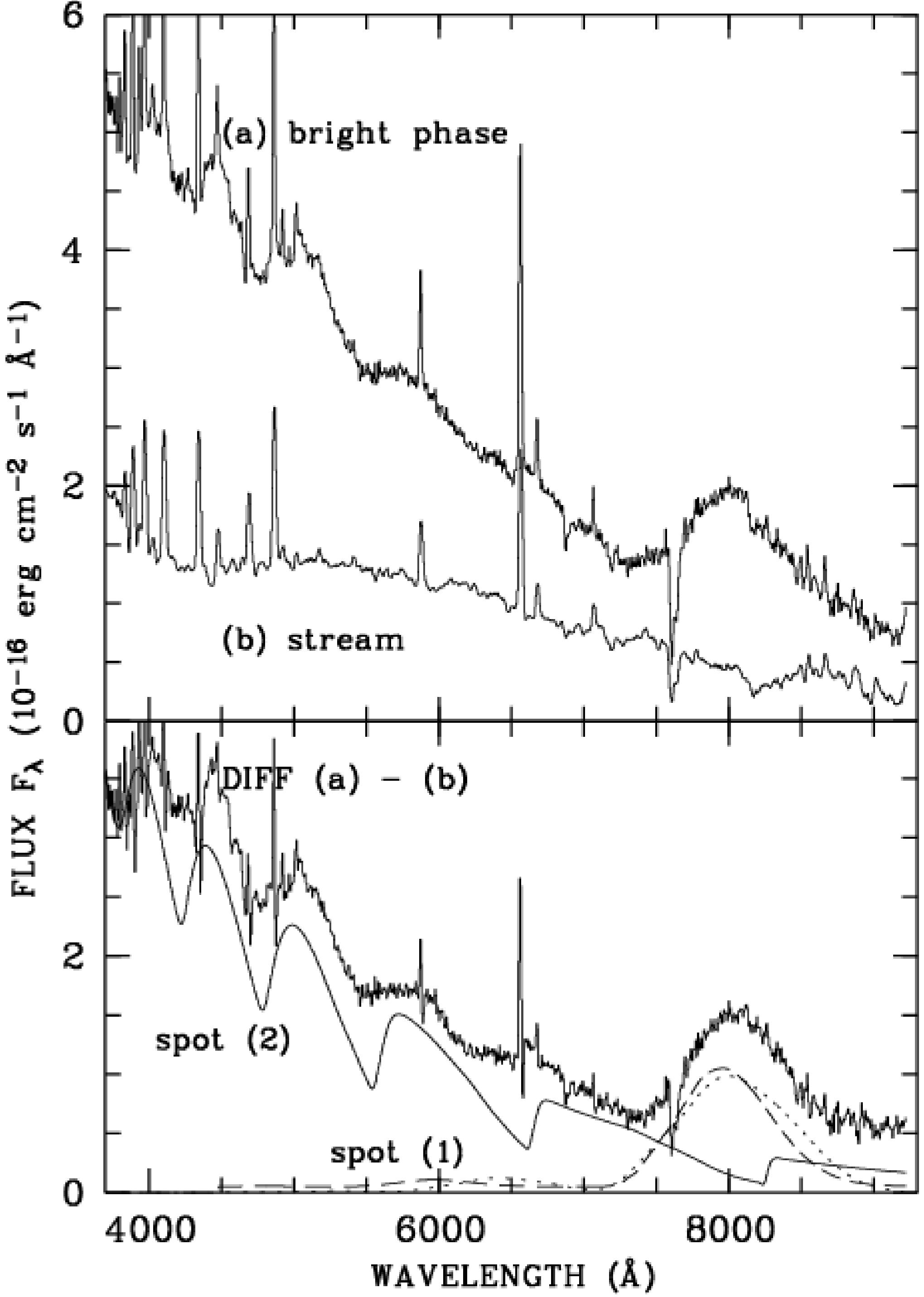
CYCLOTRON EMISSION

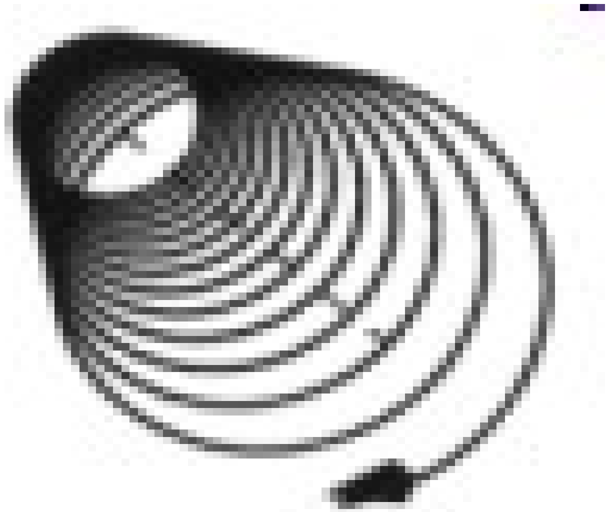


An example of the cyclotron spectrum:

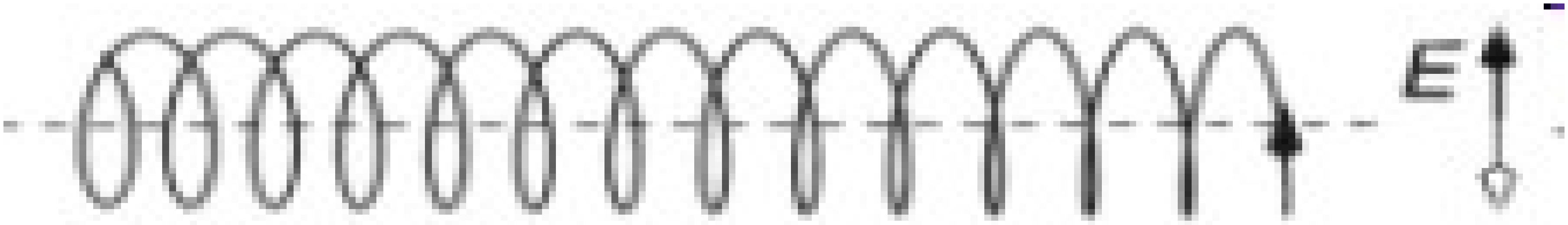
In the upper panel a high-state, bright phase spectrum of a mCV (RBS0206). Lower panel shows the difference spectrum, which is regarded as of pure cyclotron origin.

(*from Schwope et al., 2002, A&A 396, 895-910)*



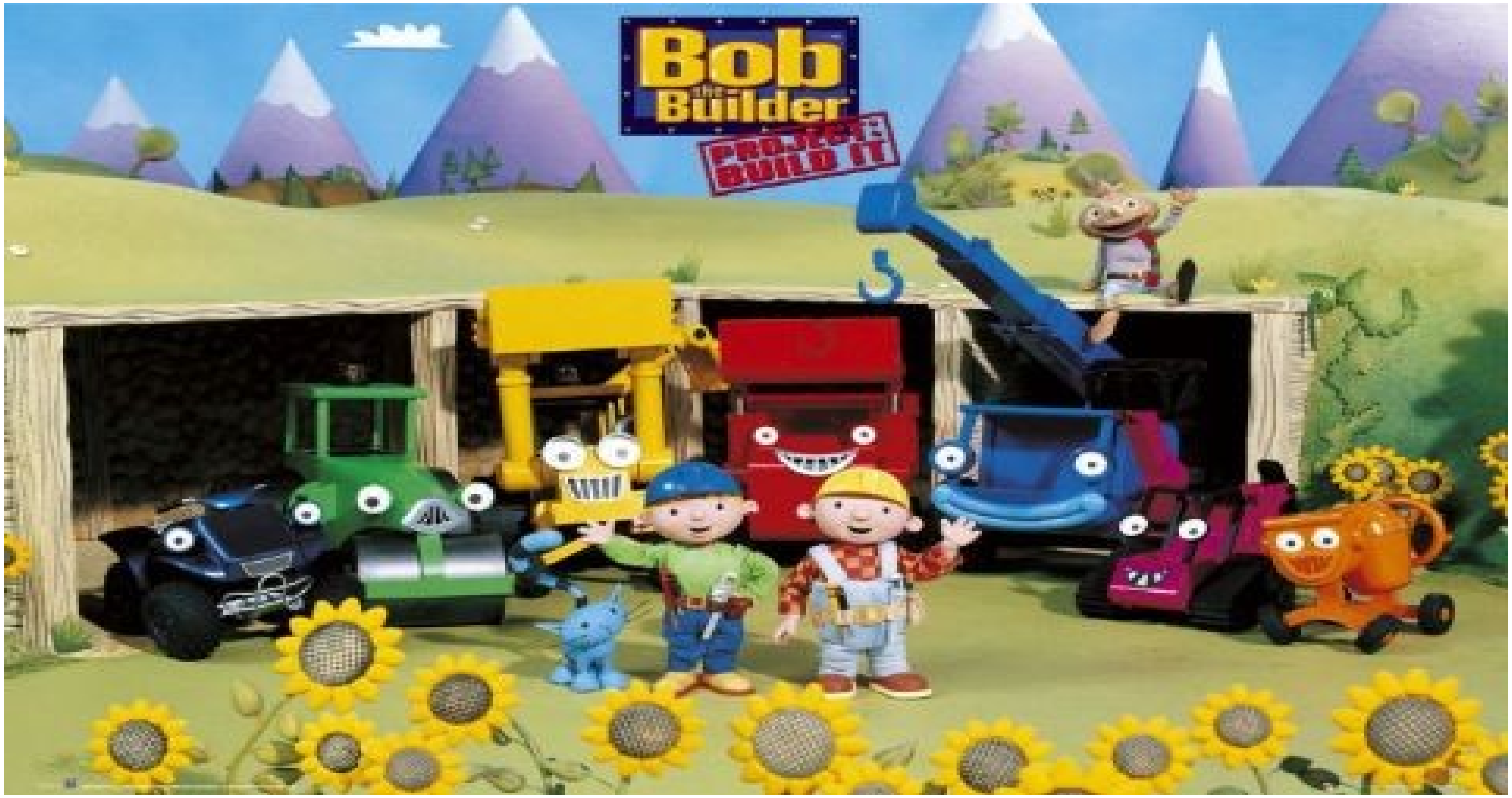


- When we look directly at a field line, the apparent motion is circular, producing circularly polarized photons. *(Image credit: Hellier 2001)*



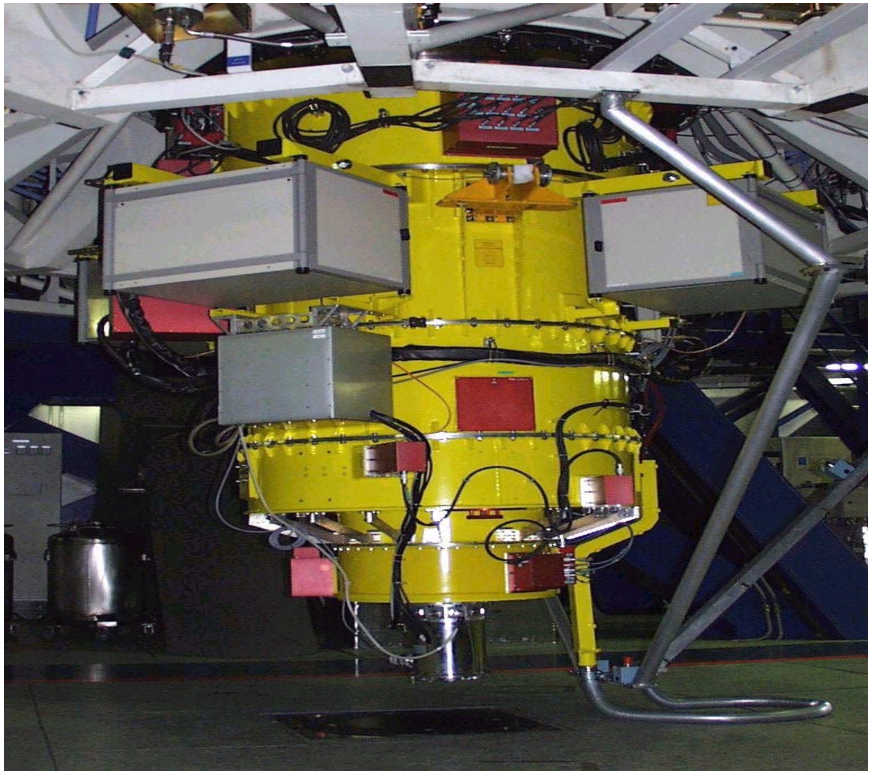
- When the field line is seen side on, an electron spiraling around the field line will appear to be oscillating perpendicularly to the field line. The photons produced by this motion will always have an electric vector in the direction of this oscillation, and so the light is *linearly polarized*. *(Image credit: Hellier 2001)*

Tools for polarimetry



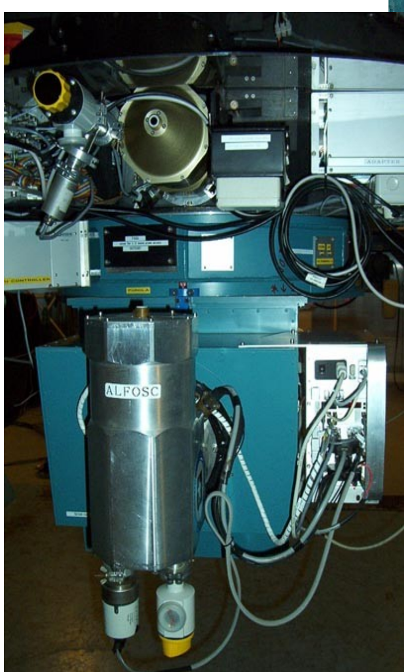
ESO, Cerro Paranal:

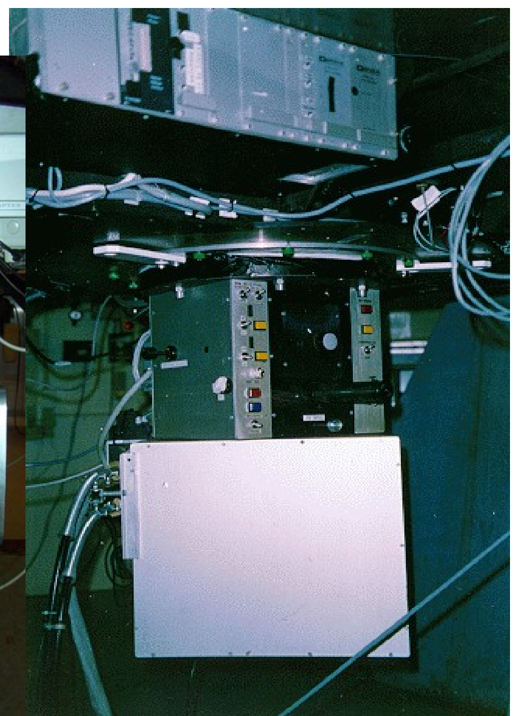
- **VLT: FORS**



Nordic Optical Telescope, ORM, La Palma:

Turpol & ALFOSC





Polarization as a tool..

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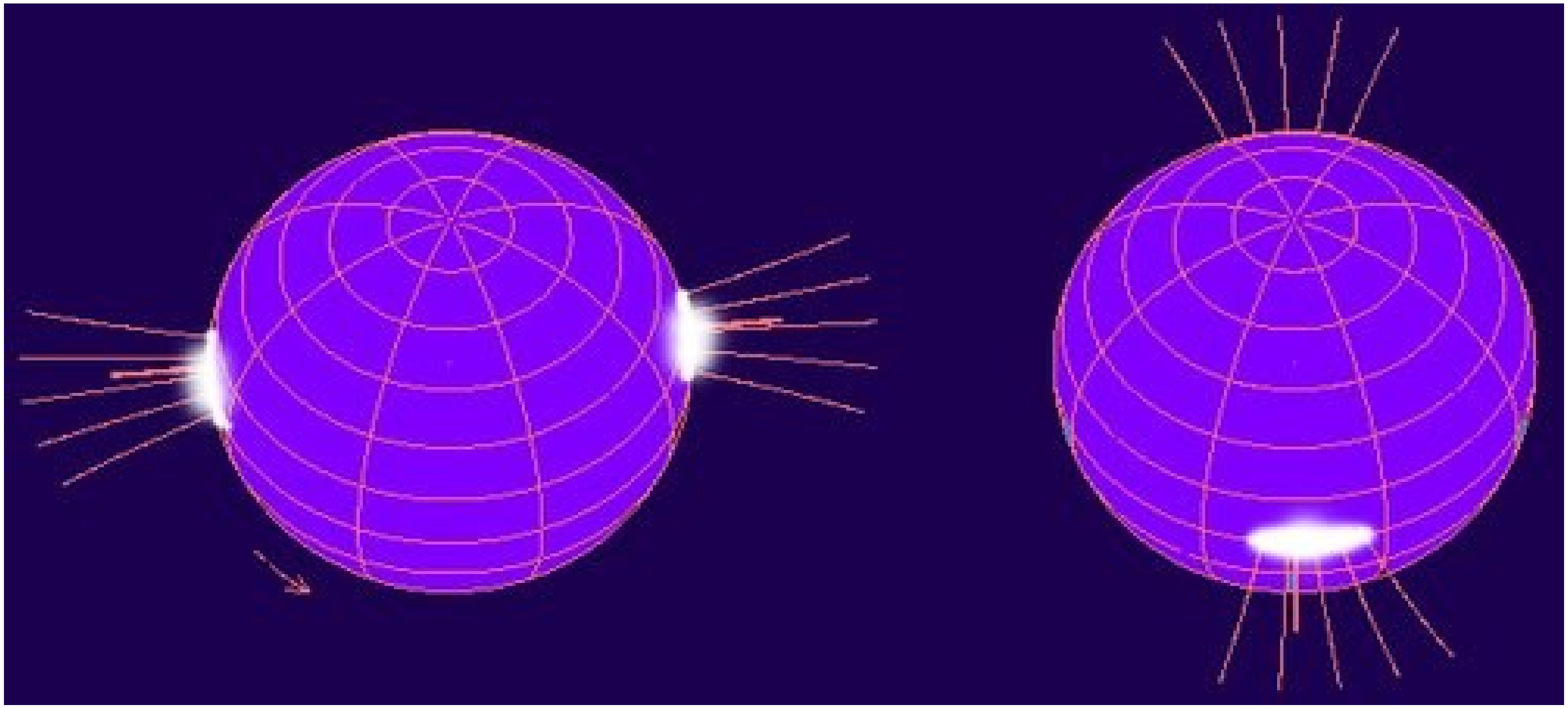
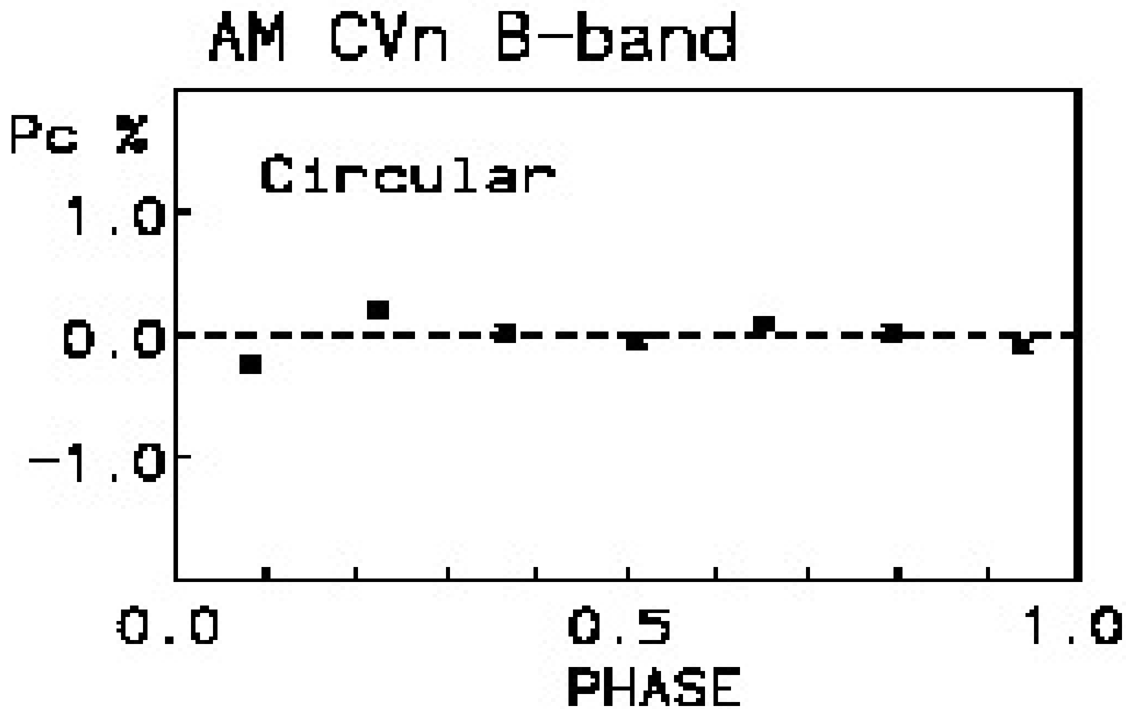
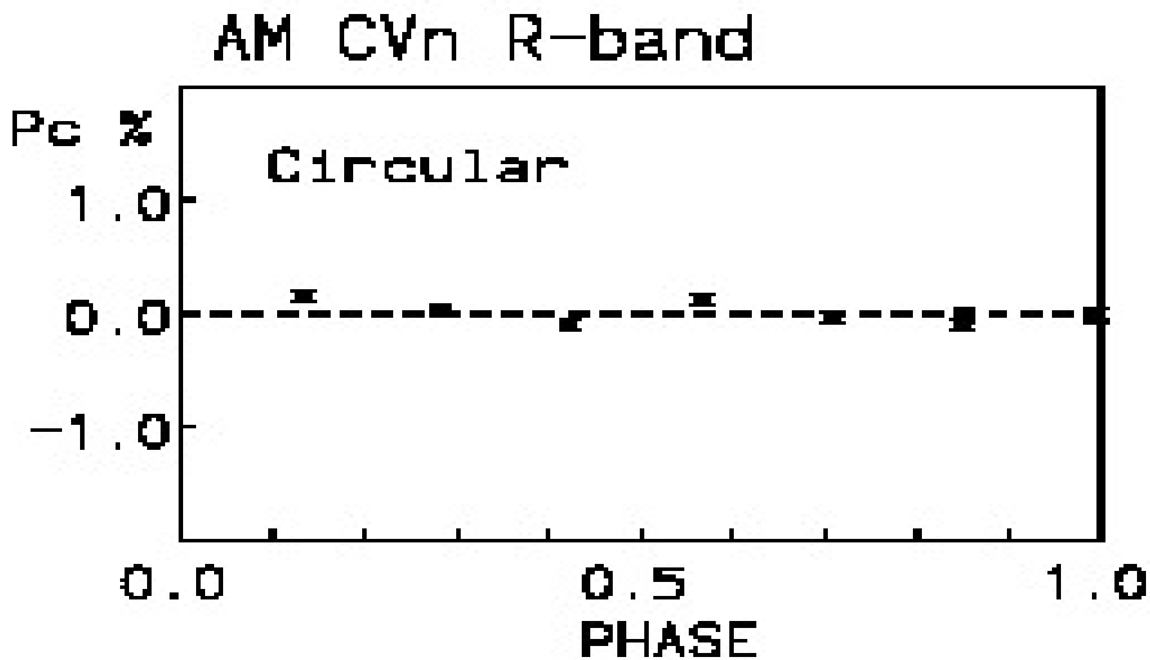
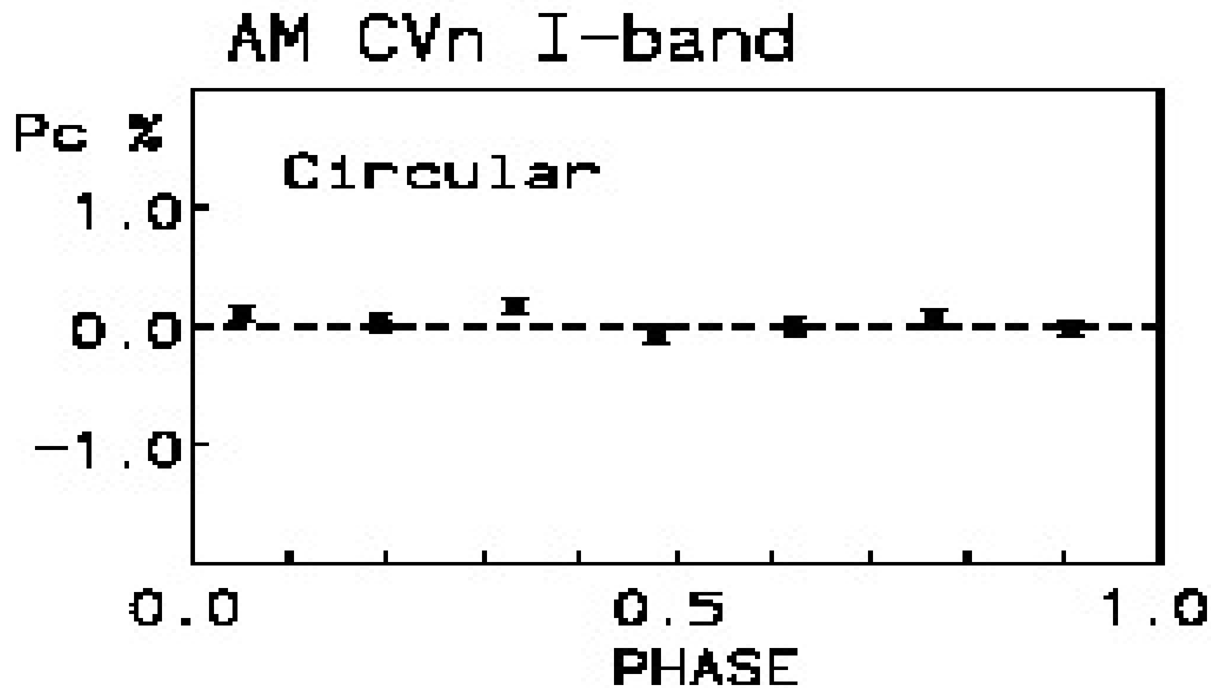


- **EXAMPLES OF THE DATA:**


AM CVn B-band
Pc %
Circular
1.0
0.0
-1.0
0.0
0.5
1.0
PHASE


AM CVn R-band
Pc %
Circular
1.0
0.0
-1.0
0.0
0.5
1.0
PHASE


AM CVn I-band
Pc %
Circular
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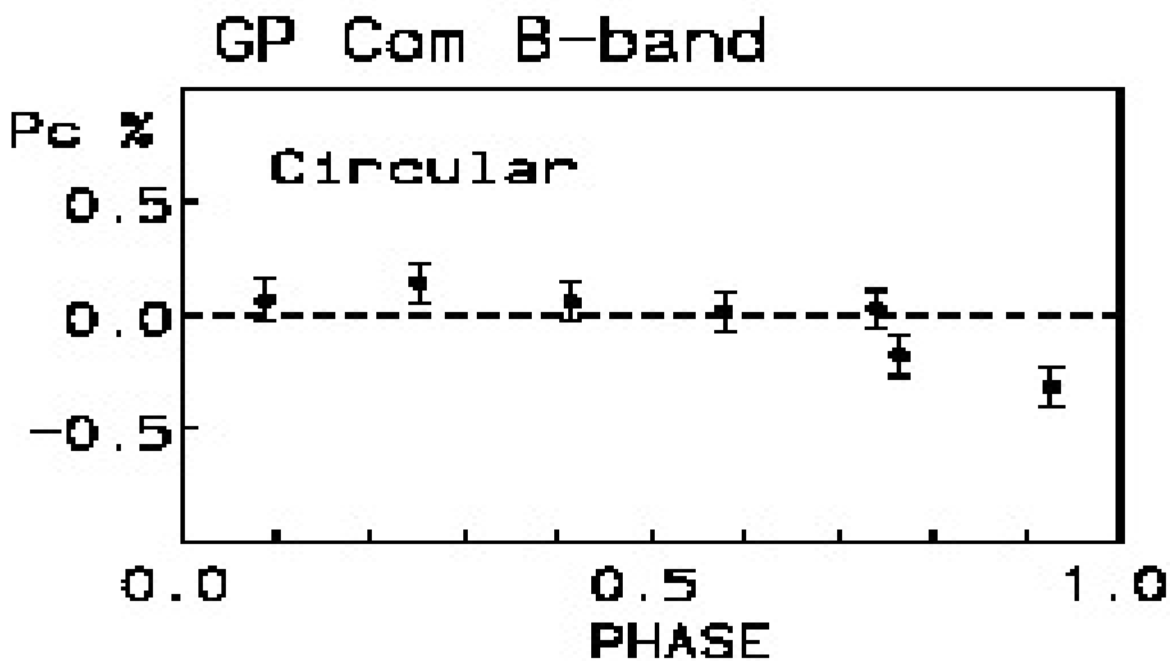
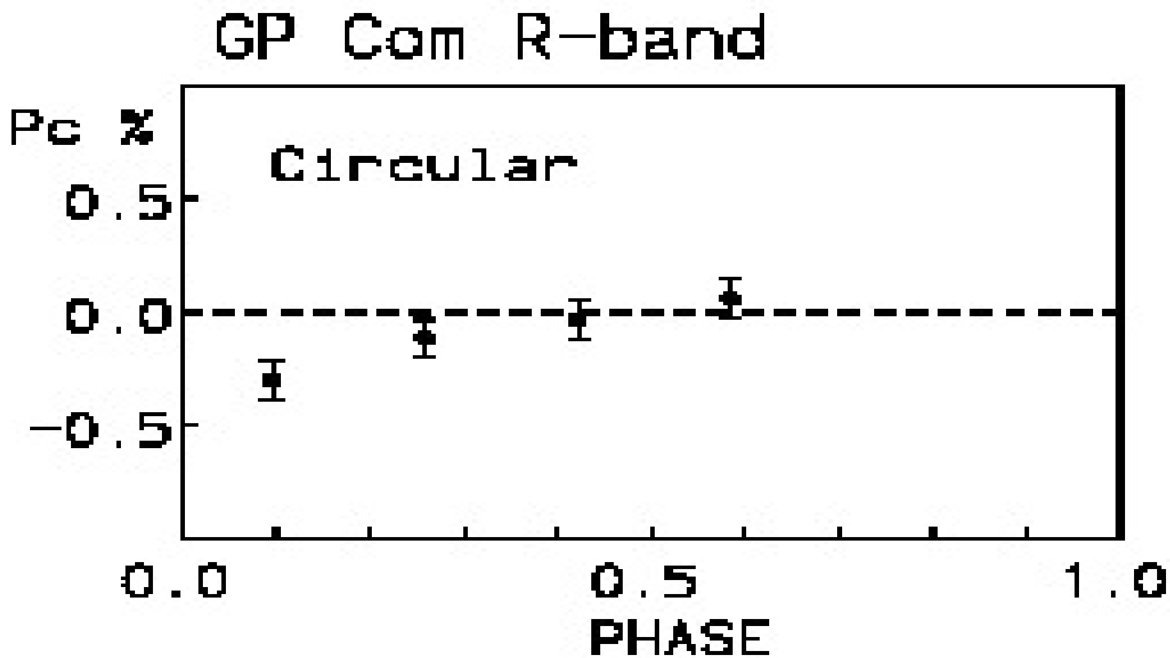
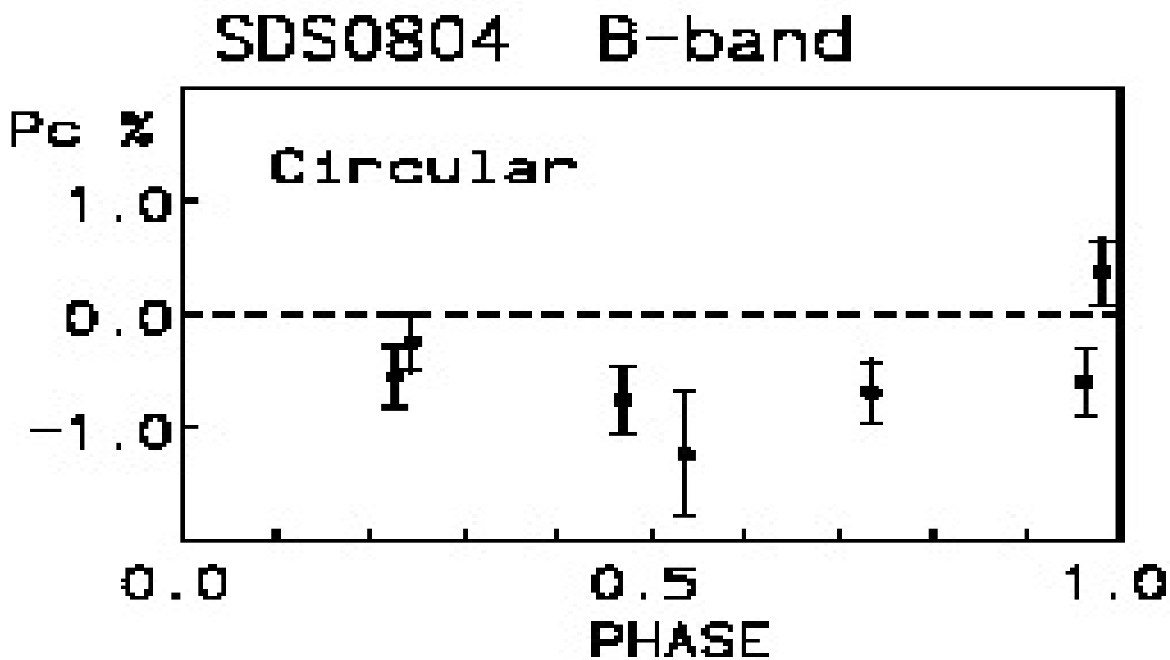
−1.0
0.0
0.5
1.0
PHASE


GP Com B-band
Pc %
Circular
0.5
0.0
−0.5
0.0
0.5
1.0
PHASE



GP Com R-band
Pc %
Circular
0.5
0.0
−0.5
0.0
0.5
1.0
PHASE



SDS0804 B-band
Pc %
Circular
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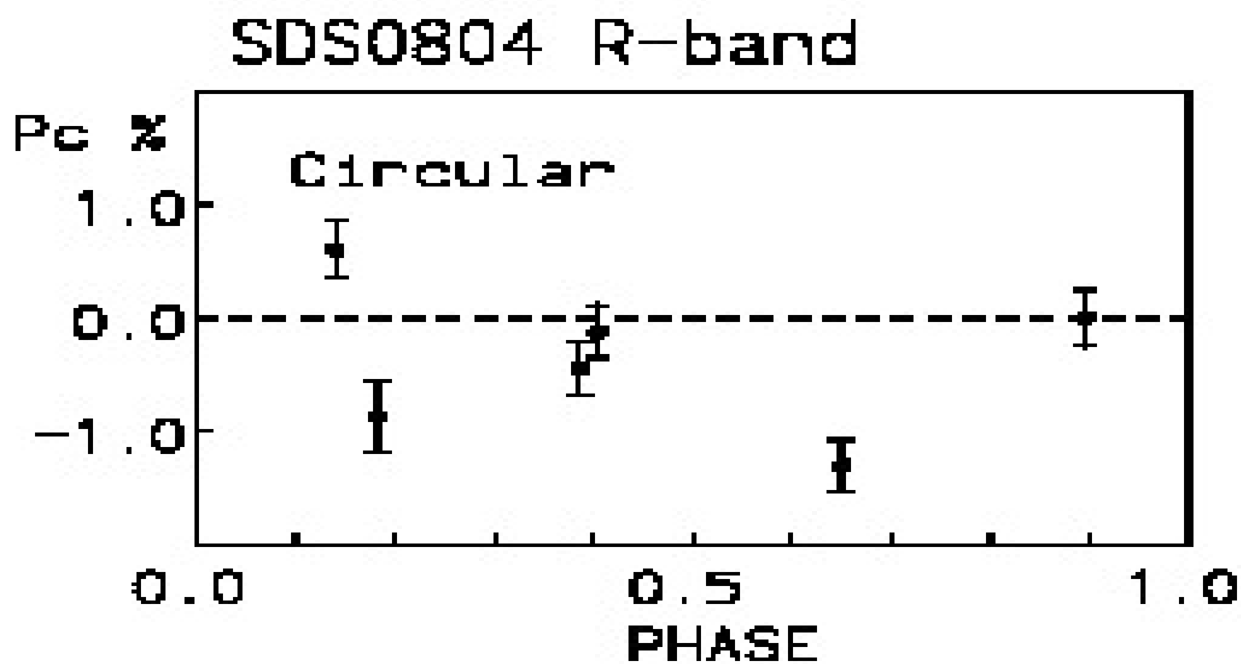
0.5
1.0
PHASE


SDS0804 R-band
Pc %
Circular
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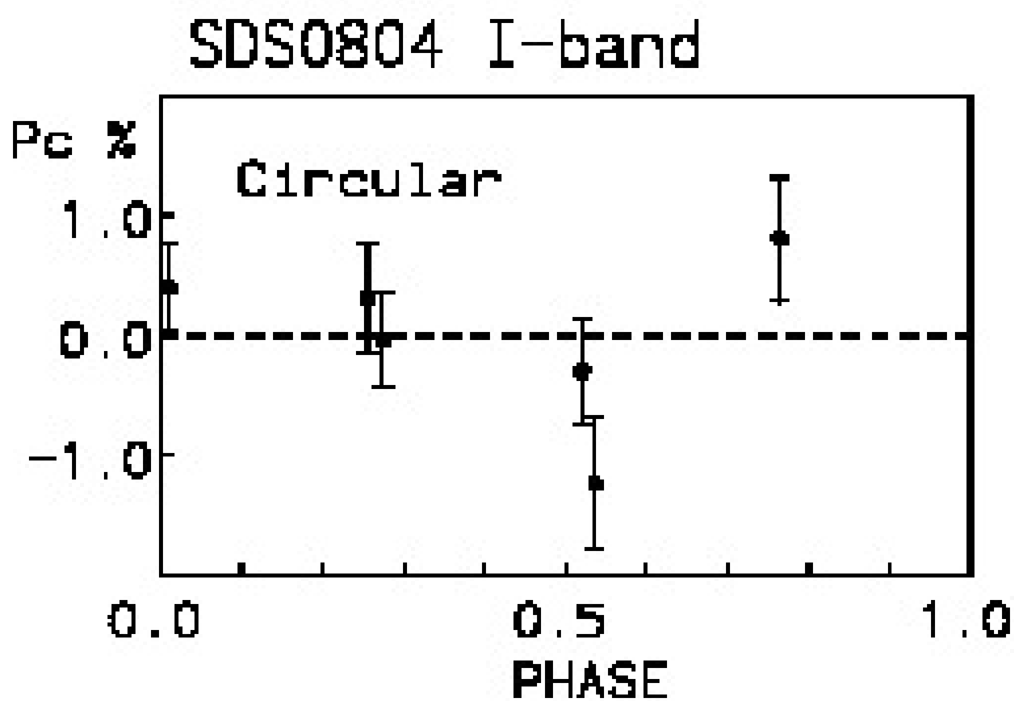
-1.0
0.0
0.5
1.0
PHASE


SDS0804 I-band
Pc %
Circular
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0.5
1.0
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