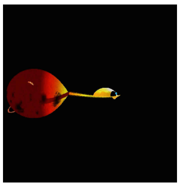

Constraints on QPOs in accreting magnetic white dwarfs from XMM observations and simulations

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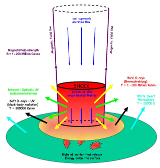
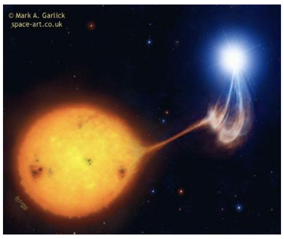


Abstract: Optical fast (0.3-1 Hz) quasi-periodic oscillations (QPOs) are detected in some of the accreting magnetic white dwarfs (Polars). They have been related to plasma instabilities arising from the post-shock region above the white dwarf surface where the matter cools down through visible cyclotron radiation before being accreted on the compact object. As the shock region also mainly cools by Bremsstrahlung X-ray emission, significant counterparts of these oscillations are expected in the keV emission. Using the XMM-Newton satellite database, we search for QPOs in a homogeneous sample of 24 brightest Polars observed in the (0.5-10 keV) range. No QPOs were detected with limits in relative amplitude ranging from 7 to 71%. We provide for the first time a direct comparison of these observations with theoretical predictions of 2D hydrodynamical models developed in the context of the on-going laser experiment POLAR project (Falize et al. 2012, Michaut et al. 2012). The comparison provides important constraints of the influence of the mass accretion rate and the magnetic field strength on the development of the plasma instabilities and the damping processes.



What Polars are :

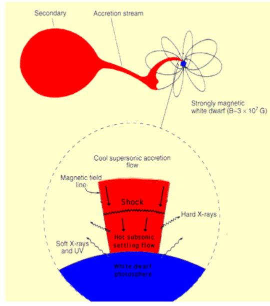
- - Semi-compact binary systems including an accreting magnetic white dwarf (WD).
- - Strong WD magnetic field (B = 10 to 200 MG) synchronizing the WD rotation with the orbit and guiding the accretion flow
- - Shock formed close to the WD surface (at a typical distance of 1000 km), with release of the gravitational energy in the hot post-shock region , mainly as X-ray bremsstrahlung and optical cyclotron emission
- - Remarkably, accretion plasma thermal instabilities in Polars have been predicted since 1981 from time-dependent hydrodynamic equations. It has been shown by Langer et al. (1981) that a non-stationary shock could develop with typical oscillations period ~ (1-2) s, of the order of the radiative cooling time of the post-shock gas.

What oscillations are :

- - Optical QPOs with (1-5%) amplitude in the range (1.25-2.5s) were first discovered in 1982 and are now detected in five polars (Larsson 1995).
- - Oscillations interpreted as cyclotron emission modulated by the shock thermal instabilities
- - However strong damping process expected when cyclotron substantially contributes to the cooling (Wu, 2000).

Oscillations are expected in X-rays from the Bremsstrahlung emission but no X-ray QPOs were yet detected from the Polars. Only very sparse studies were yet available, limited to only a few individual sources.

We present here a first systematic search for X-ray QPOs in a significant sample of 24 Polars.



X-ray observational results

Data :

- - Among about 120 known Polars, 65 observed by the XMM-Newton satellite
- - Homogeneoue sample of 24 sources selected because bright enough (flux > 0.3 cts/s) for searching X-ray QPOs in the (0.5-10 keV) range (PN imaging and timing mode).

Analysis:

- - Fast Fourier transforms performed onto background subtracted light curves binned with a temporal resolution of 0.1s into consecutive 102.4 s segments and summed up to larger time intervals.
- - Statistical analysis done in the context of the formalism described in van der Klis (1889).

Results :

- - **No significant peaks** in the mean FFTs were found in any of the sources, with the maximum FFT value being always lower than the detection limit at 2.6 sigma (99% confidence level).
- - The derived **rms upper limits** in the interval (0.1-5) Hz range from 6.8 to 71% depending on the statistical quality of the observation (i.e. count rate).
- - To check for possible transitory QPOs, we also search for significant peaks in FFTs summed in typical consecutive 27.3 min intervals for each source. **No positive results** were obtained.

Conditions for QPOs from simulations :

- - Numerical simulations are performed with a 2D hydrodynamical code, HADES-COOL in a plane-parallel geometry (Michaut et al. 2011).
- - Hydrodynamics equations in Euler coordinates
- - Radiative losses via a 'bremsstrahlung + cyclotron' cooling function appearing as a source term (Busschaert et al. 2014, in preparation).

They confirm that, when a significant fraction of the energy is released in cyclotron, the shock oscillations are strongly damped, suppressing the QPO.

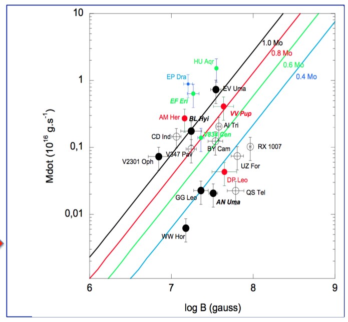
To evaluate this effect, we examine the ratio of the bremsstrahlung to cyclotron cooling time : $\varepsilon_s = t_{br}/t_{cy}$ at the shock, expressed by:

$$\epsilon_s = 1.086\,(A_{16})^{57/40}\,(B_7)^{57/20}\,(\dot{M}_{16})^{-37/20}\,(M_o)^{117/40}\,(R_9)^{-117/40}$$

where : $A_{16} = A/10^{16}$ cm^2 (A: cylindrical column cross-section), $B_7 = B/10^7$ G (B: magnetic field), $Mdot_{16} = Mdot/10^{16}$ g.s^{-1} (Mdot: accretion rate), M_o = M/Msun and $R_9 = R/10^9$ cm (M and R: WD mass and radius).

Figure 1 shows a (B-Mdot) diagram for the sample of analyzed polars with available X-ray luminosities and distances used to derive Mdot. The sources are shown with filled symbols of different colors according to their mass [0.3-0.5 Mo range (blue), 0.5- 0.7 (green), 0.7-0.9 (red) and 0.9-1.2 (black)] . When no mass determination is available, an 1Mo mass is assumed (open symbols). The 5 polars with known optical QPOs are shown in italics.

- The diagonal full lines show the B-M_dot relation corresponding to ε_s=1 for different WD masses. Sources above their corresponding mass line are expected to be Bremsstrahlug dominated and potential candidates for QPOs.
- The sources most strongly dominated by Bremsstrahlung cooling are the lowest mass systems and/or the highest luminosity and lowest magnetic systems.
- Remarkably, out of the five systems showing optical QPOs, four are over or close to the QPO criterion.



Comparison with hydrodynamical models :

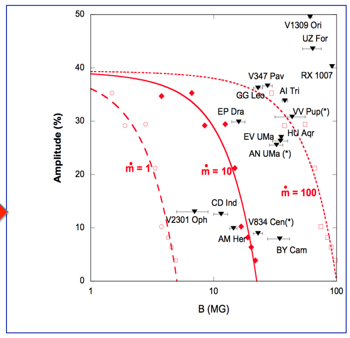
We produced a grid of models according to the four parameters governing the post-shock region: the magnetic field B, the accretion rate Mdot, the accretion column cross-section A and the WD mass M [the radius R is related by an approximate M-R relation (Nauenberg 1972)].

The emission is integrated through the accretion column in the (0.5-10 keV) energy range to compare with observations. The total bremsstrahlung and cyclotron emissions are also computed. Temporal variations are studied excluding the onset of the shock, over a range of time sufficient to insure that the oscillations were in a non-transitory stabilized regime.

Figure 2 shows the QPO amplitudes versus the magnetic field strength B predicted by the numerical simulations of the shock instability for a typical WD mass of 0.8 Mo, a column cross-section of 10^{14} cm^2 and for different values of the specific accretion rate *mdot* = Mdot/A (dashed curve *mdot* = 1.0, full curve =10 and dotted curve = 100 g.cm^{-2}.s^{-1}). Also reported are the derived upper limits on Polars (0.1-5 Hz) oscillation amplitudes in the X-ray (0.5-10 keV) flux.

- Typical oscillation amplitudes up to 35% are predicted with the amplitude decreasing very steeply with B due to the cyclotron damping, with a cut-off varying significantly with *mdot*.
- Among the low-field polars, three sources, AM Her, CD Ind and V2301 Oph have also the lowest upper limits (< 10%) for X-ray QPOs from our sample and yield interesting constraints derived from interpolations following the dependency in the different parameters of the formula for ε_s .

- For AM Her: QPOs are expected at a level less than 10% (as implied by observations), only if A > 4.5 10^{14} cm^2 and *mdot* < 6 g.cm^{-2}.s^{-1}.
- For CD Ind: the derived upper limit of 13% imposes A > 1.4 10^{14} and *mdot* < 10 g.cm^{-2}.s^{-1}.
- For V2301 Oph (prime candidate for QPOs with its weakest field B = 7 MG): expected simulated QPO amplitude is 21% for an observed $Mdot_{16}$ = 0.07 assuming A= 10^{14} cm2, above our derived limit of 13%. A slightly higher cross section A≥ 1.3 10^{14} cm^2 is therefore requested. Despite its low field, V2301 Oph is still below the detection level mainly because of its low accretion rate.



Conclusions: : No X-ray QPOs were detected in Polars from a significant sample of 24 sources, spanning a wide range of B field and accretion rate. Numerical simulations performed for a grid of parameters demonstrate that QPOS should be indeed produced and their amplitudes are a monotonic function of the key parameter ε_s which depends only on four physical parameters and therefore can be used to derive the relevant source parameters. In most sources, the three parameters (B, M and Mdot) can be evaluated from independent observations so that the upper limits derived for the amplitude of X-ray QPOs can effectively constrain the column size and thus the geometry of the accretion flow as a whole.

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