Abstract:

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

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What Polars are:
- Semi-compact binary systems including an accreting magnetic white dwarf (WD).
- Homogeneous sample of 24 sources selected because bright enough (flux > 0.3 ct/s) for searching X-ray QPOs in the (0.5-10 keV) range (PN imaging and timing mode).

What oscillations are:
- Optical QPOs with (1-5%) amplitude in the range (1.25-2.5 s) were first discovered in 1982 and are now detected in five polars (Superem 1995).
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Conclusions:

- 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 (0.5-15) Hz range from 0.8 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 27.5 min intervals for each source. No positive results were obtained.

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 propose 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 (Falise 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.

X-ray observational results:

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

Analysis:
- Fast Fourier transforms performed on background subtracted light curves binned with a temporal resolution of 0.2 into consecutive 128 A segments and summed up to larger time intervals.
- Statistical analysis done in the context of the formalism described in van der Klis (1989).

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 (0.5-15) Hz range from 0.8 to 71% depending on the statistical quality of the observation (i.e. count rate).
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Conditions for QPOs from simulations:

- Numerical simulations are performed with a 2D hydrodynamical code, HADES-ICOL in a plane-parallel geometry (Michaut et al. 2013).
- Hydrodynamics equations in Eulerian coordinates.
- Radiative losses via a Bremsstrahlung + cyclotron cooling function appearing as a source term (Buschaert 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: \( \gamma = \tau_{\text{cool}}/\tau_{\text{brems}} \), at the shock, expressed by:

\[ \gamma = \frac{N_{\text{e}}v_{\text{e}}N_{\text{H}}}{A_{0} \omega_{\text{c}}^{2}} \]

where \( A_{0} = 3 \times 10^{20} \text{cm}^{-2} \text{MeV}^{-1} \text{s}^{-1} \) and \( B_{0} = 10^{10} \text{G} \).

The QPOs are hence strongly damped by the bremsstrahlung cooling.

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 Msol range (blue), 0.5-0.7 (green), 0.7-0.9 (red) and 0.9-1.2 (black)).

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 Msol.

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 monotonous function of the key parameter \( \varepsilon \), 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.

References: