MHD simulations of oscillating cusp-filling tori around neutron stars

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Motivation

The oscillations of neutron star accretion disks may modulate the X-ray flux by a general relativistic effect, the overflow of "Roche lobe" (or a cusp-filling torus) near the innermost stable circular orbit. The overflow is achieved by terminating the inner edge of the torus by a "cusp", which is the point of self-crossing of the equipotential surface for any stationary rotating fluid with given angular momentum. We performed axisymmetric magnetohydrodynamic simulations of oscillating cusp-filling tori around a non-rotating neutron star. Our simulations show that the mass accretion rate carries a modulation imprint of the oscillating torus, and hence so does the boundary layer luminosity.

Simulations

Numerical code PLUTO was used to perform the simulations. The Kluźniak-Lee pseudo potential was used to construct the constant angular momentum tori in equilibrium. The inner edge of the torus is terminated by a "cusp" in the effective potential. The initial motion of the model tori was perturbed with uniform sub-sonic vertical and diagonal velocity fields. As the configuration evolved in time, we measured the mass accretion rate on the neutron star surface and obtained the power spectrum (see Figure 2).

Models

Model	Resolution	B_{NS}	B_{NS} profile	Perturbation
IHDV	420 × 300	–	–	vertical
IHDD	420 × 300	–	–	diagonal
IMHDD1	420 × 300	900 G	dipole	diagonal
IMHDD2	140 × 100	9000 G	dipole	diagonal

Table 1: A list of models with model name, resolution, strength of the magnetic field and the initial profile of the magnetic field. The type of velocity perturbation is also listed.

Conclusions

For the first time we numerically study the modulation of the mass accretion rate on the neutron star surface. We draw the inference that, both the vertical and diagonal excitations of cusp-filling tori excite the radial epicyclic mode in such tori. We expected that the vertical epicyclic mode may be excited, however the uniform velocity perturbations fail to excite the vertical eigenmode of the cusp-filling torus. The vertical eigenmode is suppressed as there is no restoring force at the cusp. Our simulations confirm the modulation mechanism of the neutron star boundary layer luminosity by disk oscillations. The strong presence of the radial epicyclic frequency in the boundary layer luminosity (presumed to be the lower kHz QPO) and the absence of the vertical epicyclic frequency (presumed to be the upper kHz QPO) may be interpreted as corresponding to the high Q-factor of the lower kHz QPO and the low Q-factor of the upper kHz QPO. The results of our numerical analysis are relevant to the ASTROSAT mission equipped with LAXPC which will investigate the quasi-periodic oscillations in low mass X-ray binaries with low magnetic field neutron stars.

References

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Results

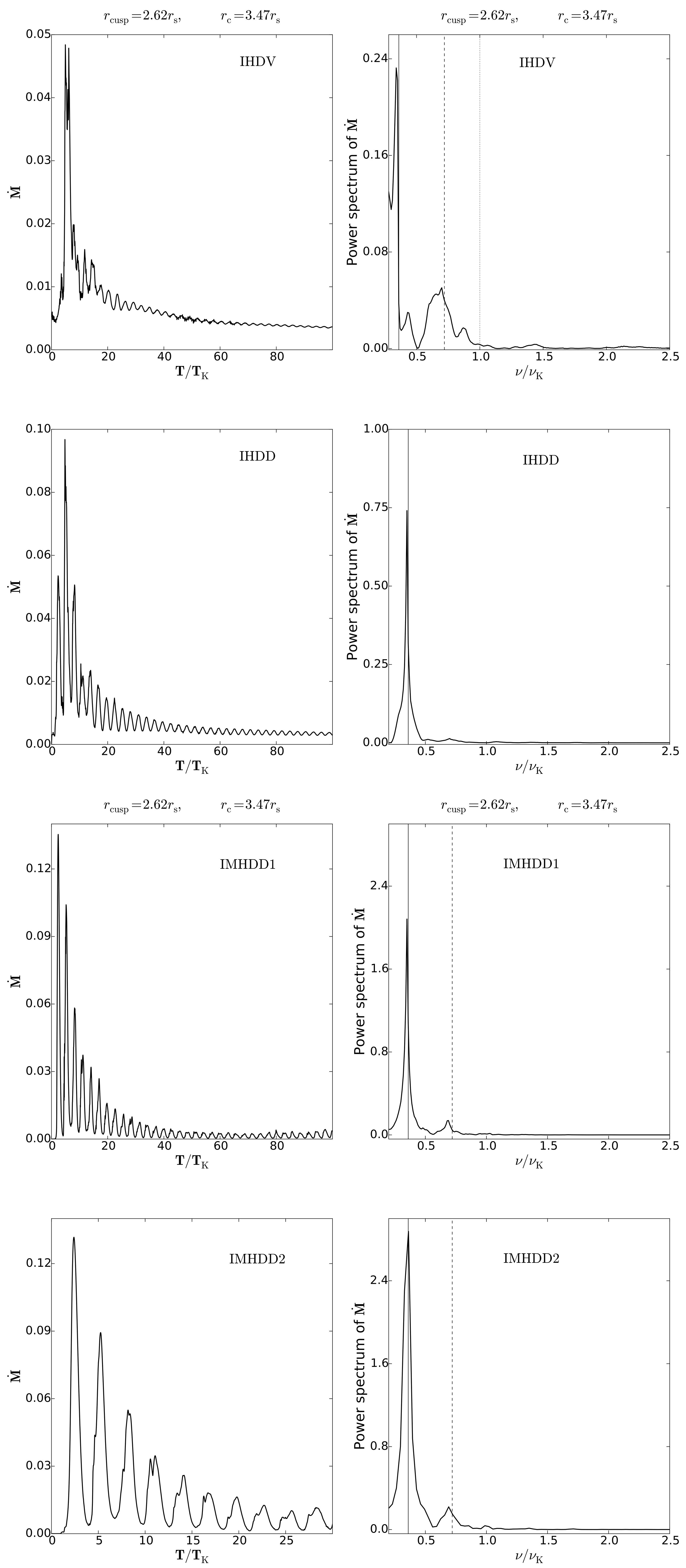

Fig. 2: Left panels: Mass accretion rate on the neutron star surface as a function of Keplerian time T_K at center of torus r_c for models in Table 1, in the units of $\dot{M} = 1.6 \times 10^{-10} M_\odot \mathrm{yr}^{-1}$. Right panels: Power spectrum of $\dot{M}$ measured on the neutron star surface for models in Table 1. Frequencies are in units of Keplerian frequency ν_K at center of torus r_c. The solid line (all right panels) and dotted line (top right panel) corresponds to the theoretical frequency values of the radial and vertical eigenmodes of slender tori at r_c, respectively. The eigenfrequencies of the radial and vertical epicyclic modes of the oscillating tori are 0.36 ν_K and 1.0 ν_K at r_c, respectively. The dashed line correspond to the first harmonic of the radial mode of the torus. Additional frequencies may also be present in the simulations.