AEI:
simulation of the disk ejection mechanism
and
A simple idea about the lag structure

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I. MHD simulations of the AEI

i) 2D disk simulation

ii) Toward 3D: the difficulties

2D MHD Code

- 2D ⇨ OK, because the physics of the AEI does not change much in the dick thickness (as for galactic spirals) v,ρ, … ~ constant in the disk

- logarithm grid ⇨ well adapted to the problem (more dense at low r, allows a disk extending to large r)

- physics similar to galactic spirals ➔ similar method
  - a magnetic potential outside the disk $\vec{B} = \nabla \Phi_M$
  - perturbed currents ➔ jumps of B at the surface

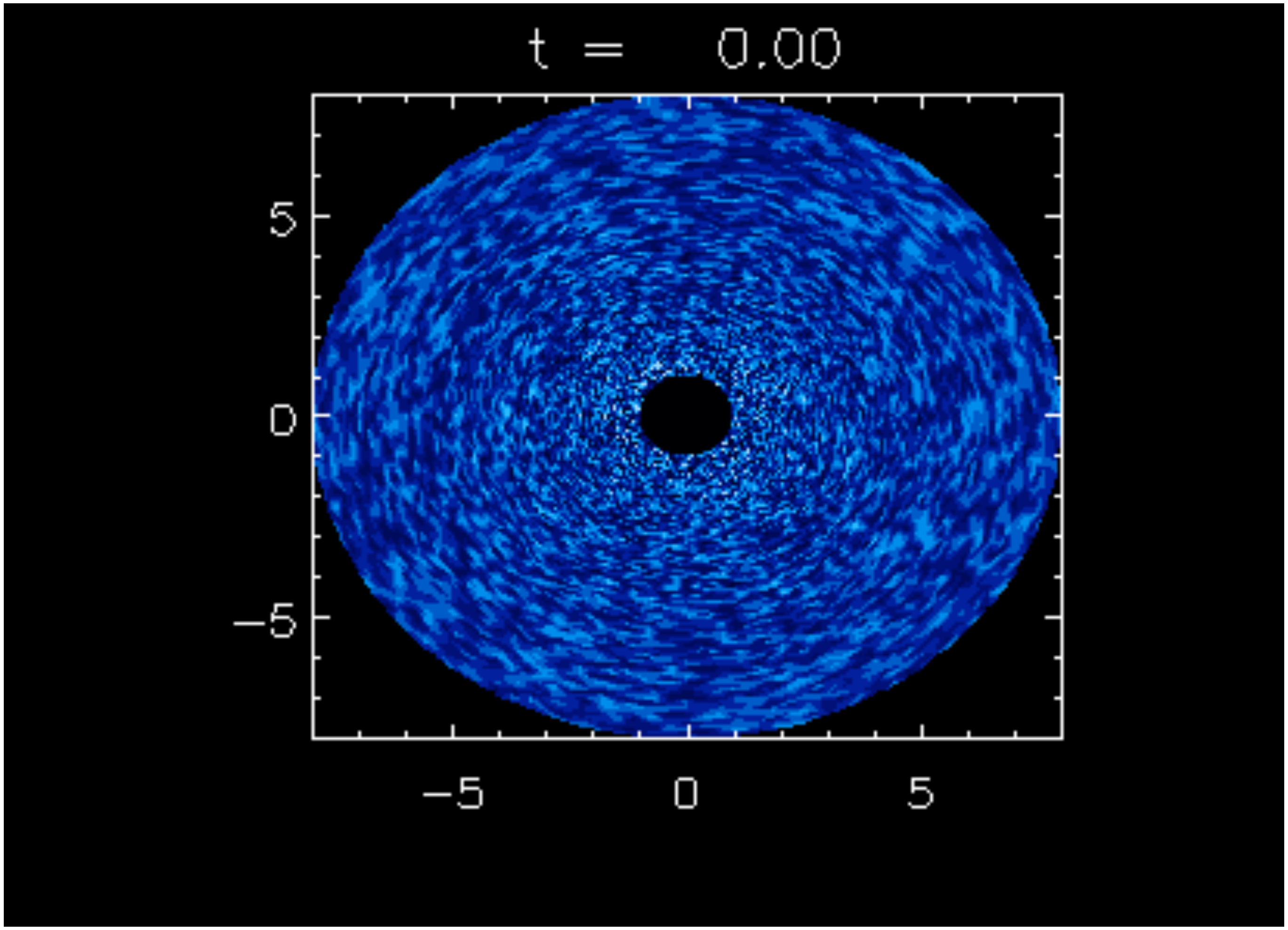
$$\Delta \Phi_M = -B_z \delta(z) \quad \longleftrightarrow \quad \Delta \Phi = 4\pi G \Sigma \delta(z)$$

$$\partial_t B_z + \nabla \cdot (B_z \vec{v}) = 0 \quad \longleftrightarrow \quad \partial_t \Sigma + \nabla \cdot (\Sigma \vec{v}) = 0$$

conservation of vertical magnetic flux — continuity

- use of the FARGO scheme (Masset 2000) which remove the keplerian motion from the computation of the time step and limits numerical diffusion

2D simulation

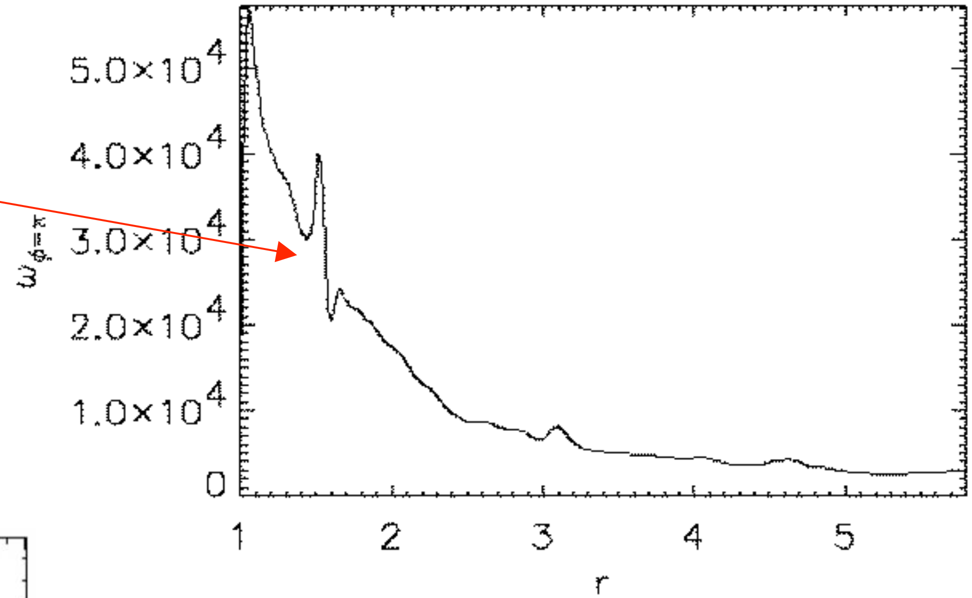


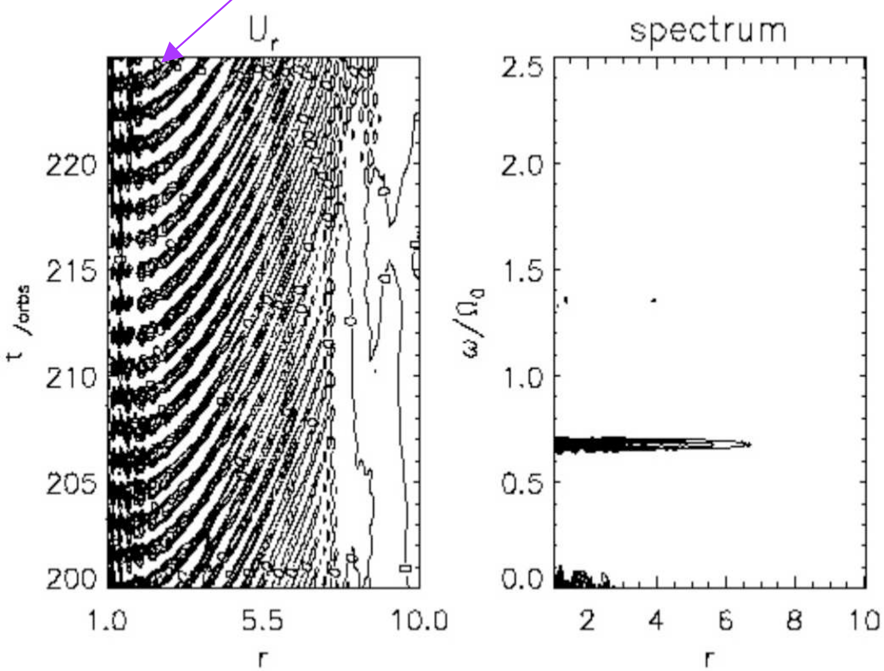
Results from the simulations

vorticity: $W = \frac{\kappa^2}{2\Omega}$

Rossby vortex ⇨ vorticity gradient

sharp feature observed at r ~1.5 ⇨ corotation



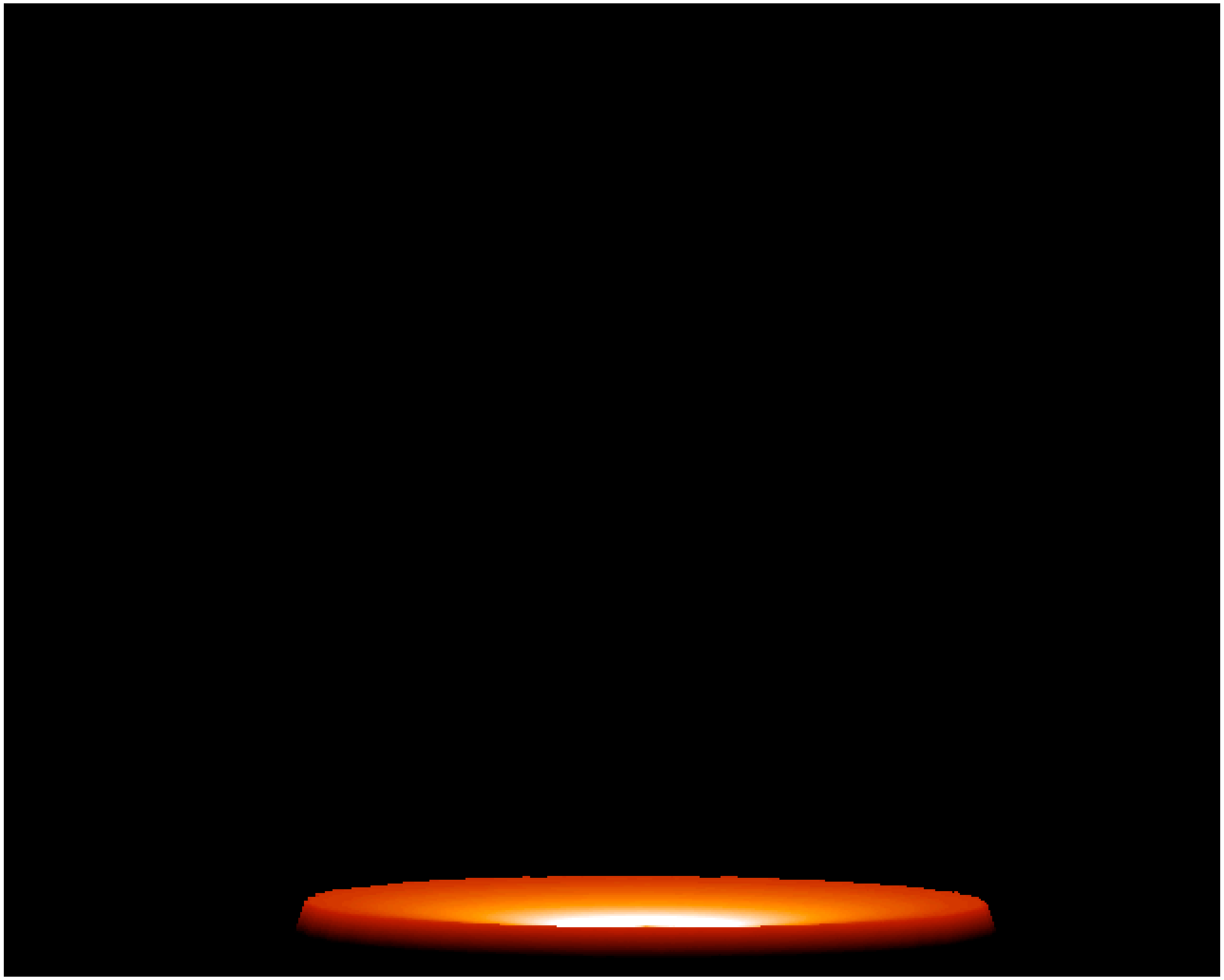


Contour plot of radial velocity against time in the inner disk and spectral analysis (200 to 225 orbits)

⇨ propagation beyond the corotation and standing pattern inside

⇨ m=1 mode

Results from simulations (2)



disk with inclinaison of 70 degree

Toward 3D: the difficulties

div B = 0 (CT but difficulties with AMR structure, 2nd order)

initial condition of the disk + corona

magnetic boundary condition

cylindrical geometry

⇨ a lot to be done, work in progress in many groups

II. About the jet/wind powering

i) Alfven waves emission

ii) Variational form

iii) Alfven wave flux

Alfven Wave Emission

The Rossby vortex twists the foot point of the field line going through the disk. If the disk has a low density corona:

twist ➔ propagation by the mean of Alfven wave

➔ energy and angular momentum extracted from the inner part of the disk will be transferred toward the corona where they can power a wind or a jet

From observation it seems that most of the accretion energy is emitted in the jet.

➔ we have to compute the efficiency of the Alfven wave emission and compare it with the observation.

First step: dispersion relation: $k_z^2 V_{A\infty}^2 = \frac{\Omega}{m\Omega'^2}\,\partial_s \ln\left(\frac{W}{V_A^2}\right)\tilde{\omega}^3$

➔ we obtain Rossby-Alfven wave, i.e. wave that propagate as Alfven waves but affected by the vorticity gradient.
$(\omega - m\Omega)^3$ ➔ propagation on ONE side of the corotation.

- we can now compute the flux of Alfven wave

Variational form

We describe the system with a variational form ⇨

$$\int_{s_{min}}^{s_{max}} \alpha\tilde{\omega}^2 \left(|\nabla_\perp \overline{\mathcal{Y}}|^2 - |\nabla_\perp \overline{\Phi}|^2\right) ds + 2\int_{s_{min}}^{s_{max}} \alpha\Omega\Omega' \, |\partial_s \overline{\Phi}|^2 \, ds$$

$$+2m \int_{s_{min}}^{s_{max}} \partial_s(\alpha\tilde{\omega}\Omega) \, |\overline{\Phi}|^2 \, ds - 2m \int_{s_{min}}^{s_{max}} \tilde{\omega}\partial_s(\alpha\Omega) \, |\mathcal{Y}|^2 \, ds$$

$$+[\alpha\overline{\Phi}^\star(\tilde{\omega}^2\nabla_\perp\overline{\Phi} - 2\Omega\Omega'\partial_s\overline{\Phi})]_{s_{min}}^{s_{max}} - [\alpha\tilde{\omega}^2\overline{\mathcal{Y}}\nabla_\perp\overline{\mathcal{Y}}^\star]_{s_{min}}^{s_{max}}$$

$$+2i[m\alpha\Omega\Omega'\overline{\Phi}^\star\overline{\mathcal{Y}} - \alpha\tilde{\omega}\Omega(\overline{\mathcal{Y}}\nabla_\perp\overline{\Phi}^\star + \overline{\Phi}^\star\nabla_\perp\overline{\mathcal{Y}})]_{s_{min}}^{s_{max}}$$

$$-\int_{s_{min}}^{s_{max}} \int_d \Phi^\star \nabla_\perp^2 \nabla^2 \Phi \, dz \, ds - \int_{s_{min}}^{s_{max}} [\mathcal{Y}\partial_z\nabla_\perp^2\mathcal{Y}]_{z_{min}}^{z_{max}} \, ds$$

F = energy of the wave

+ **i** (outgoing wave + coupling with the Rossby vortex

+ k_z Alfven wave)

imaginary term ➔ amplification or damping of the wave

→ Alfven wave flux

The Alfven terms are singular at the vortex (corotation)

⇨ propagation of the singularity in the corona

Alfven wave flux

Efficiency of the mechanism: we compute the ratio between the flux emitted toward the corona by the mean of Alfven wave and the energy transported by accretion (flux stored at the corotation)

$$\frac{F_{Alfven}}{F_{disk}} \sim \left(\frac{\rho_{corona}}{\rho_{disk}}\right)^{1/2} \left(\frac{r}{h}\right)^{3/2}$$

typical aspect ration for an X-ray binary: $h/r \sim 10^{-2}$

➔ $F_{Alfven}/F_{disk} \sim 1$ very efficient mechanism when the density become greater than $\rho_{corona}/\rho_{disk} \sim 10^{-6}$

III. About the changing lag

i) the lag problem
ii) a simple idea
iii) example of GRS 1915+105
iv) application / toy model

The Observed Lag Structure

The phase lag structure between the hard and soft X-ray photons observed in GRS 1915+105 and XTE J1550-564 has been said to be « complex » because :

- the phase of the low-frequency Quasi-Periodic Oscillation (QPO) fundamental Fourier mode changes sign with time (negative to positive to negative)

- the sign of the odd and even harmonics lag behaves differently

➔ Difficult to explain in the framework of the comptonization model

Aim and Idea

❋ **Aim:** how to have a lag that changes sign without changing the physical process at the origin of both the soft and hard X-ray

how to have the coherence between them dropping without changing the physical process that relate them

❋ **Idea:** adding a new effect (absorption) on the top of the low energy band of the QPO modulation (suppose to come from an orbiting structure coherent with the AEI)

➔ behavior of Fourier Transform in case of an absorb signal

Lag: a simple derivation

$$\delta t(\nu_j) = \frac{arg(X_2) - arg(X_1)}{2\pi\nu_j}$$

➔ a change in any **one bands**, caused by internal or external phenomena, can create a sign reversal of the lag

Ex:

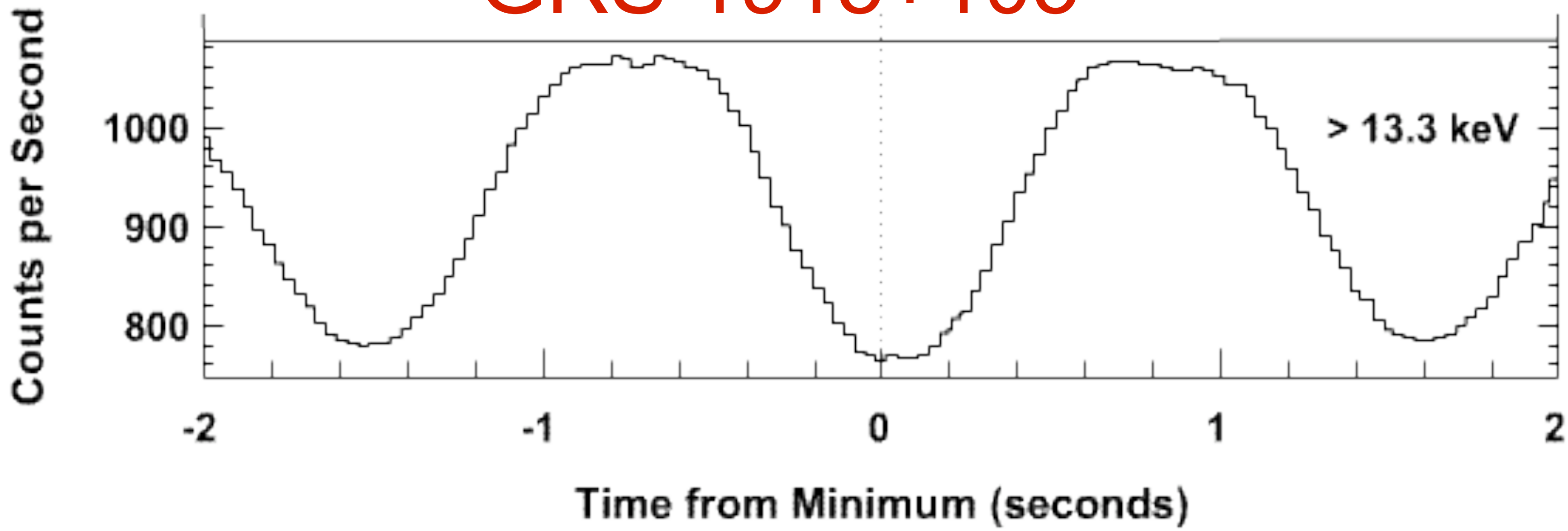
$$\cos\theta + \epsilon\ \sin\theta = \frac{1}{\cos\phi}\ \cos(\theta - \phi)$$

$$\tan\phi = \epsilon$$

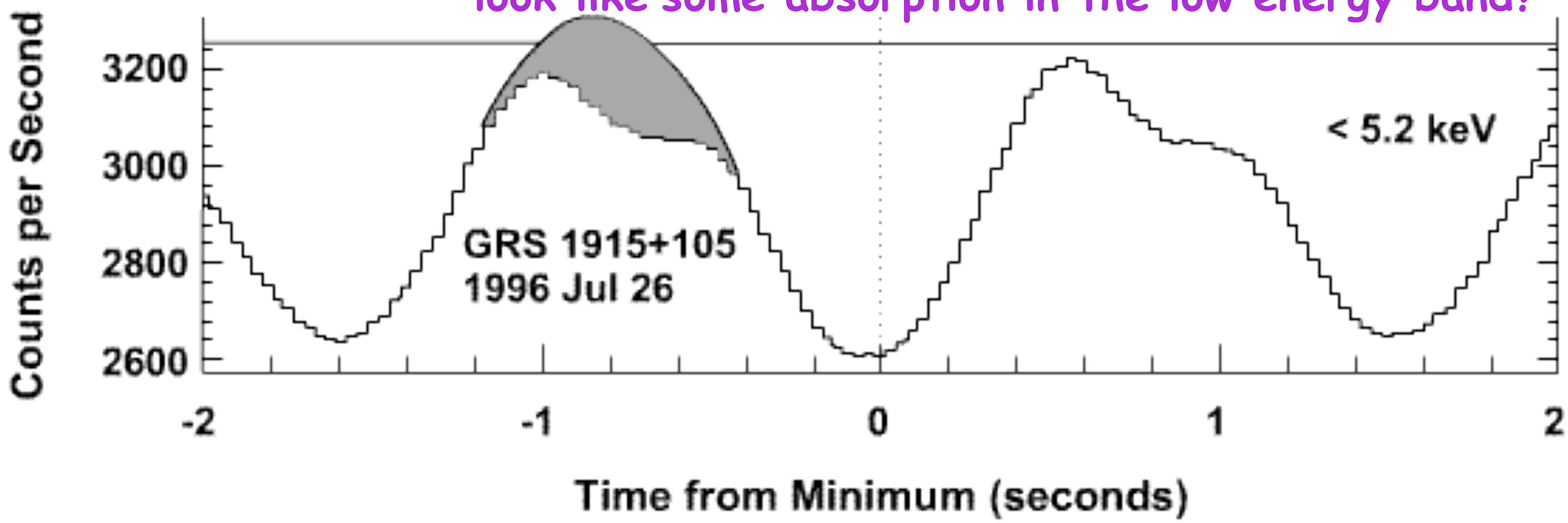
➔ using this in the low energy band, one can reproduce the observed behavior of the lags and harmonics

If there is an absorption of a small part of the QPO modulation in the low energy band and not in the hard one this simple fact can explain the changing sign of the lag

GRS 1915+105

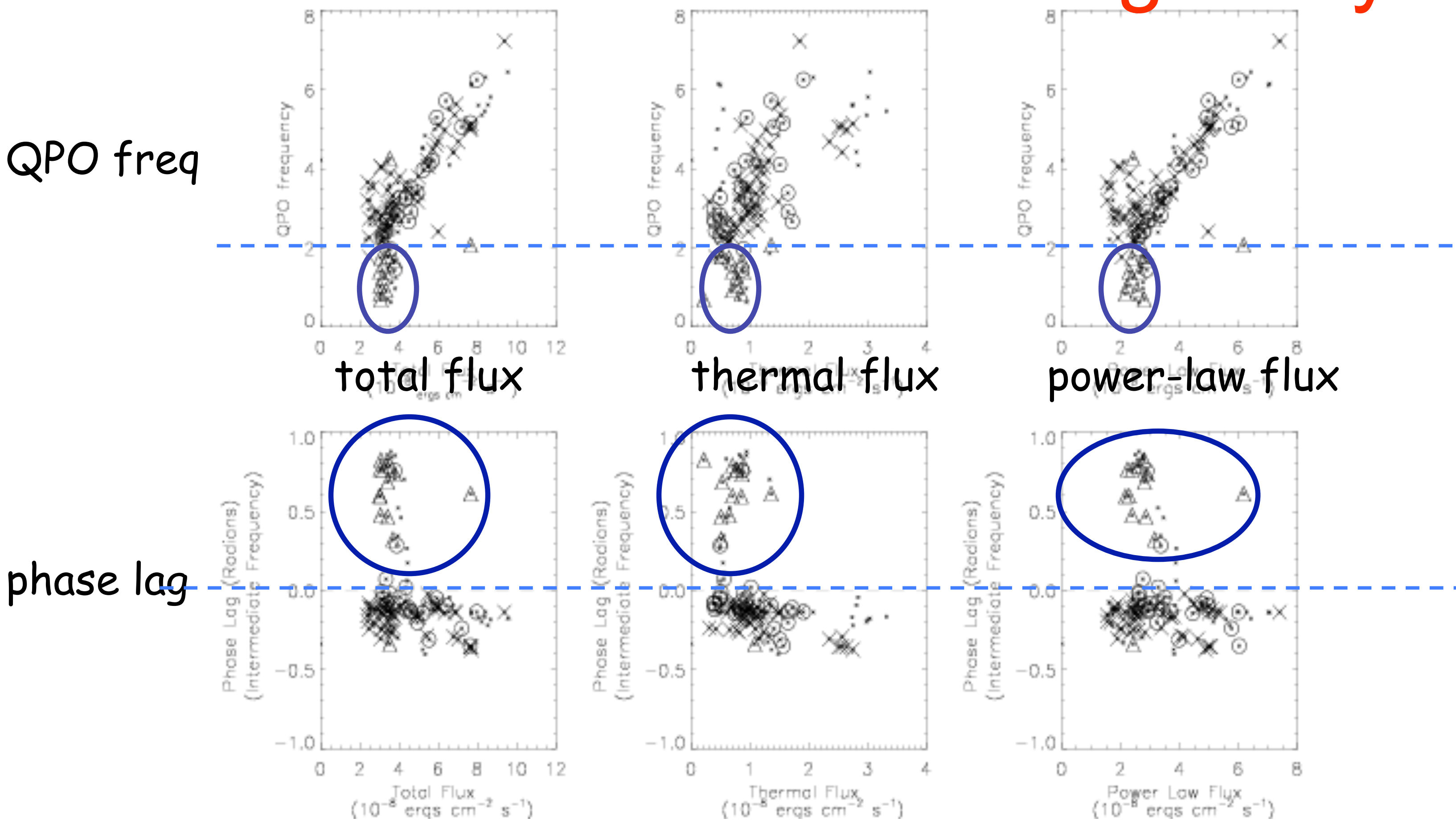


look like some absorption in the low energy band?



more constraints from observations...

GRS 1915+105: Timing/X-ray



the temporal properties correlate with the different component of the X-ray flux BUT two populations can be distinguished

➔ QPO freq > 2 Hz , usual correlation with the total and power-law fluxes

➔ QPO freq < 2 Hz , no correlation (similar flux level)... those points are the only ones exhibit positive phase lag and also have high radio flux

GRS 1915+105: timing/radio

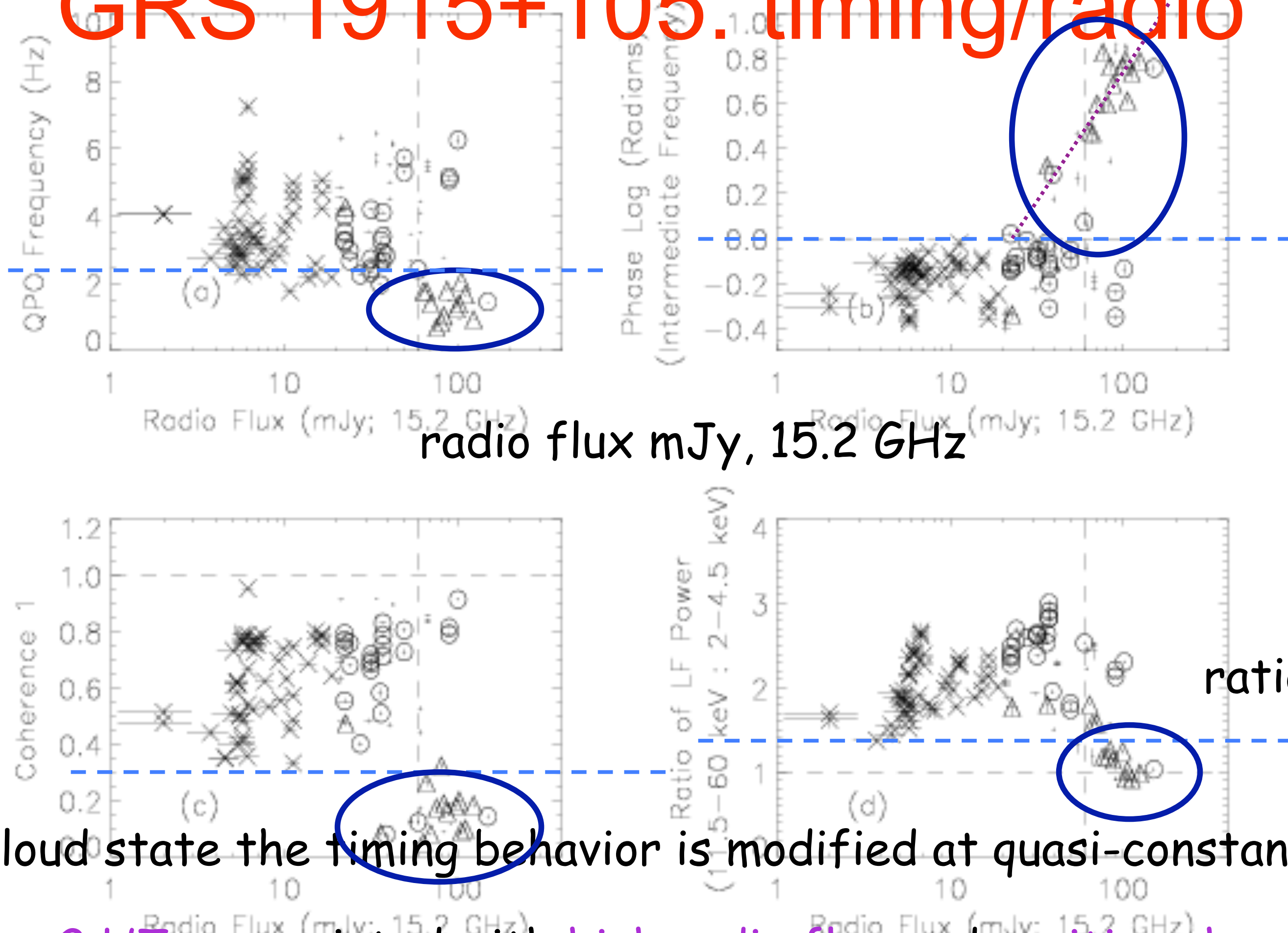
QPO freq

phase lag

radio flux mJy, 15.2 GHz

coherence

ratio of LF power



in the radio-loud state the timing behavior is modified at quasi-constant X-ray flux

- QPO freq < 2 HZ : associated with high radio flux and positive phase lag

- those points also have a low coherence between the soft and hard X-ray

(meaning the hard component cannot be deduced from the soft one by a linear transformation)

➔ either these QPOs arise from a different mechanism (one related to the jet and the other not) or there is a threshold in radio flux above which new phenomena appear in addition to the QPO mechanism.

Application to microquasars obervation

Using the constraint from observations together with the Fourier Transform behavior in case of an energy dependent absorption.

What can produced that absorption:

- need to find what may produce the absorbed part of the QPO modulation at low energy, and need to be related to the jet emission.

↳ Suppose the base of the jet/corona gets « between » the observer and the structure that create the modulation. This will induce a small modulation on top.

In fact any structure that can absorb a part of the low energy modulation and related to the jet may work. We will continue to study this by using numerical simulation and produce synthetic spectra that will be compare with observations.

↳ This simple model is able to explain the changing sign of the lag and the drop of coherence...

absorption? toy model...