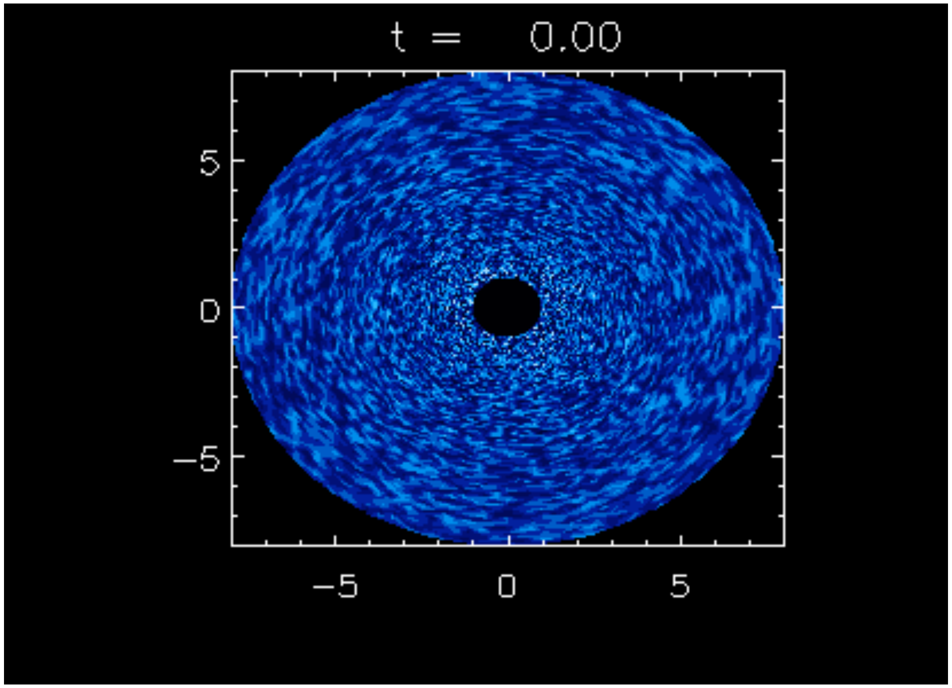
Accretion-Ejection Instability: a model for the LF-QPO in microquasars

Peggy Varnière

University of Rocester, USA



I. Presentation of the Instability

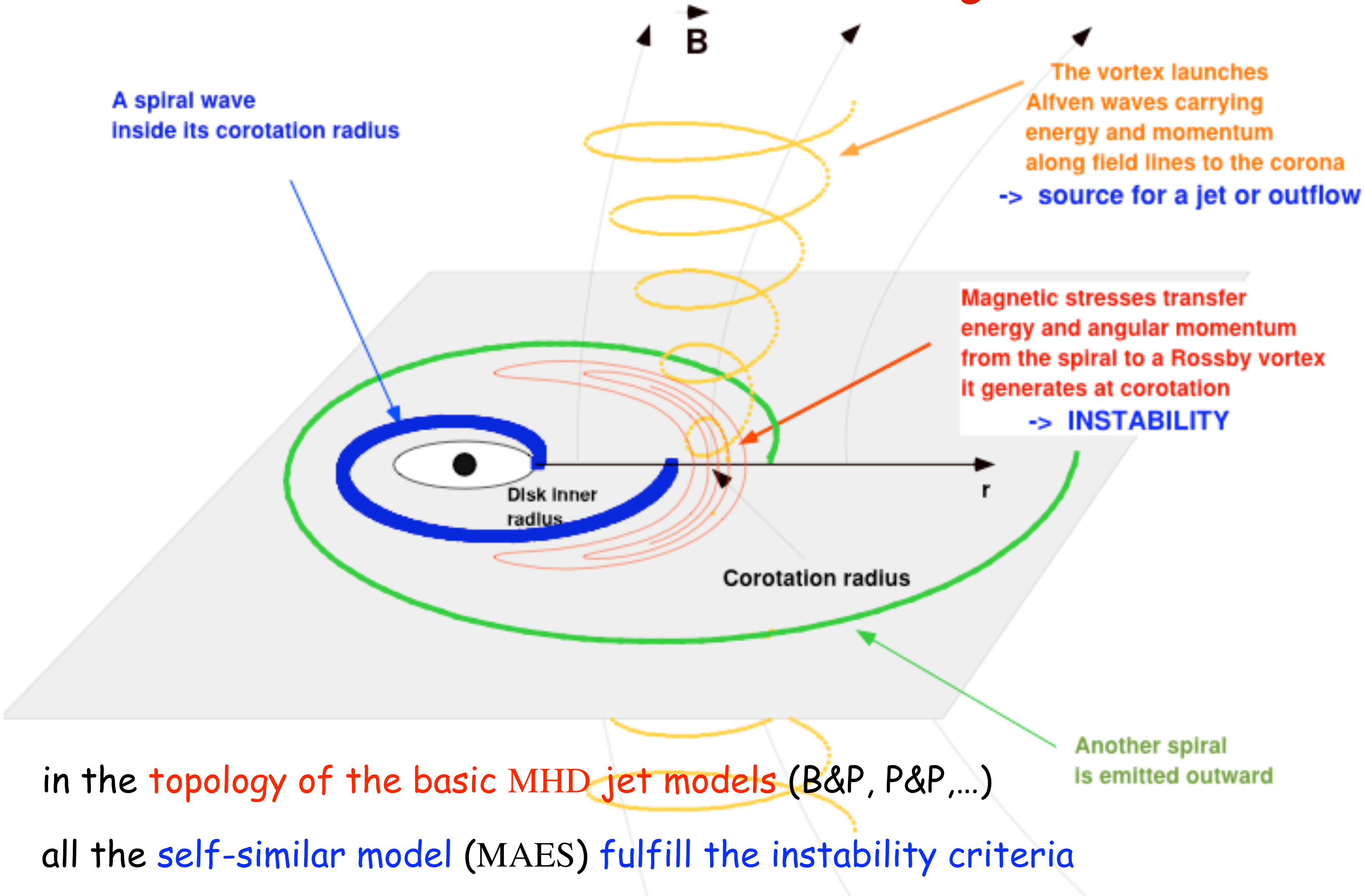
II. Ejection ability

III. The AEI as a model for the low frequency QPO

IV. The Magnetic Flood Scenario / 30 min cycle of GRS 1915+105

V. Conclusion and Perspectives

AEI: Basic Theory



in the topology of the basic MHD jet models (B&P, P&P,...)

all the self-similar model (MAES) fulfill the instability criteria

to simulate those mode, 2D simulation are enough (as for galactic spiral)

Accretion-Ejection Instability

- properties of the spiral

➔ most often the $m = 1$ (one armed spiral) with $\omega \sim 0.1 - 0.3\ \Omega_{int}$ (rotation frequency at the inner edge of the disk)

- differential rotation + differential vorticity

➔ unstable by coupling to a Rossby vortex (~ great red spot of Jupiter)

- extracts energy and angular momentum from the disk (➔ accretion) and stores them in the Rossby vortex

- if the disk has a low density corona

energy and angular momentum from the vortex are transferred upward as Alfven waves to the corona

➔ power for a jet or a wind

Variational form

We describe the system with a varionational form ➡

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

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

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

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

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

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

Efficiency of the mecanism: ratio of the flux emitted toward the corona to the energy removed from the inner region

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

For a typical X-ray binaries $h/r \sim 10^{-2}$

$F_{Alfven}/F_{disk} \sim 1$ *very efficient mechanism if* $\rho_{corona}/\rho_{disk} \sim 10^{-6}$

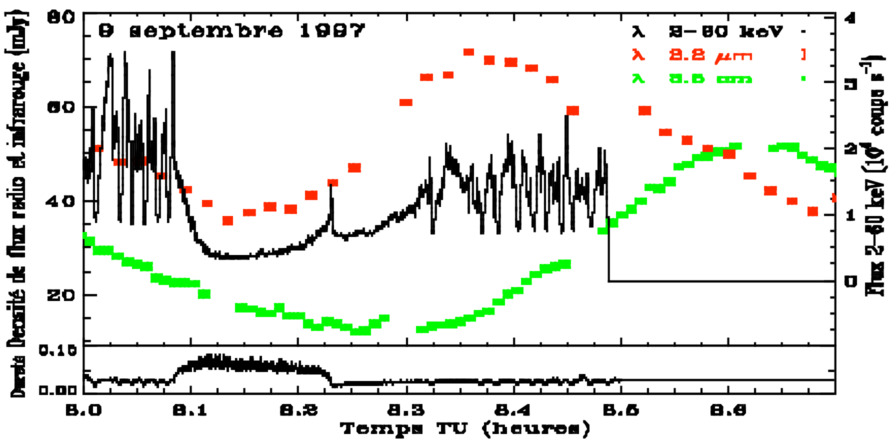
AEI: a model for QPO

- frequency between 1-10 Hertz
  - ➥ the spiral wave frequency $\omega \sim 0.1\text{-}0.3\ \Omega_{int}$ (rotation frequency at the inner radii of the disk)
- long stability in time
  - ➥ coherent large scale structure as in galaxies
- rms amplitude up to 20%
  - ➥ up to 10% in the simplified simulation
- correlation with the soft flux (disk)
  - ➥ successful comparison with observations
- QPO associated with a state where the power-law flux (corona) dominates
  - ➥ accretion energy is not deposited locally (no heating of the disk)
- linked with the presence of a jet
  - ➥ AEI linked naturally QPO and transfer of energy upward
- temporal lag sometimes changing sign, sub harmonics structures
  - ➥ geometrical effect linked to the jet

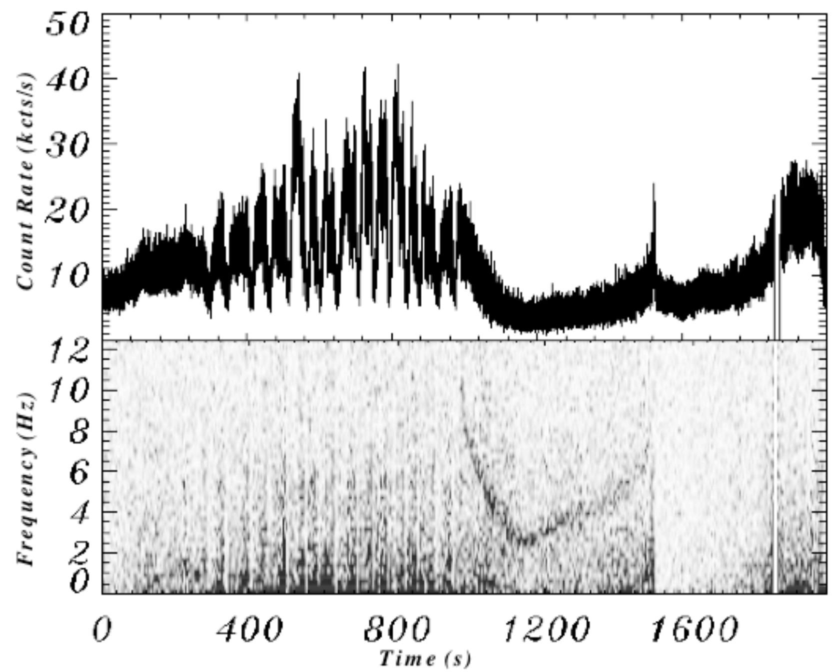
Some Observations: 30min cycle of GRS 1915 + 105

The 30min cycle (β) is the second most common state of GRS 1915 +105 after χ.

It is a transition from the high state to the low state and return to high state.



❇ radio and IR emission after the X-ray spike



❇ Low-Frequency Quasi Periodic modulation of the X-ray flux during the transition up to the spike

❇ one observation: the QPO appears just before the transition

Magnetic Flood Scenario

The Magnetic Flood Scenario is an attempt to explain the 30 min cycle of GRS 1915 + 105 using the AEI as a model for the LF-QPO and see what it can say about the source

✧ high state: turbulence such as created by the MagnetoRotational Instability

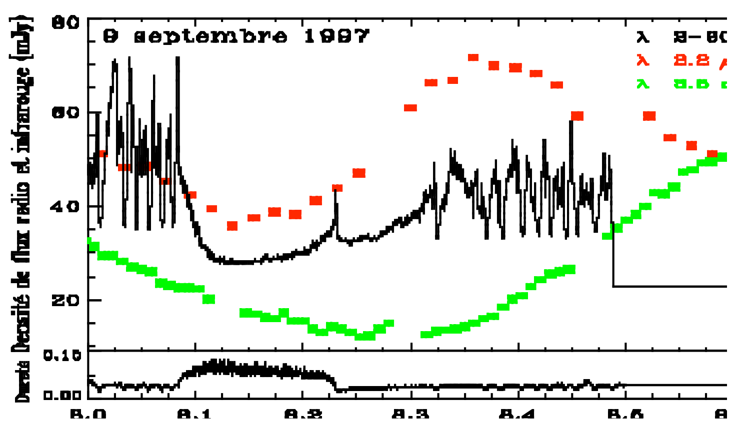
→ accretion of magnetic flux toward the inner region makes β decrease

✧ $\beta \sim 1$ in the inner region: the AEI turns on and a QPO appears

→ at the same time the energy and angular momentum are transported by the spiral wave: no heating of the disk, β decreases faster… → sharp transition

✧ change in the magnetic configuration

→ the disk is not unstable to the AEI anymore.



Conclusion and Perspectives

- Instability in the disk as an explanation for LF-QPO
  - ✧ agreement on frequency, general properties, ...
  - ✧ really creates a modulation of the flux

- linear theory of the AEI shows the emission of energy and angular momentum toward the corona as Alfven waves with high efficiency

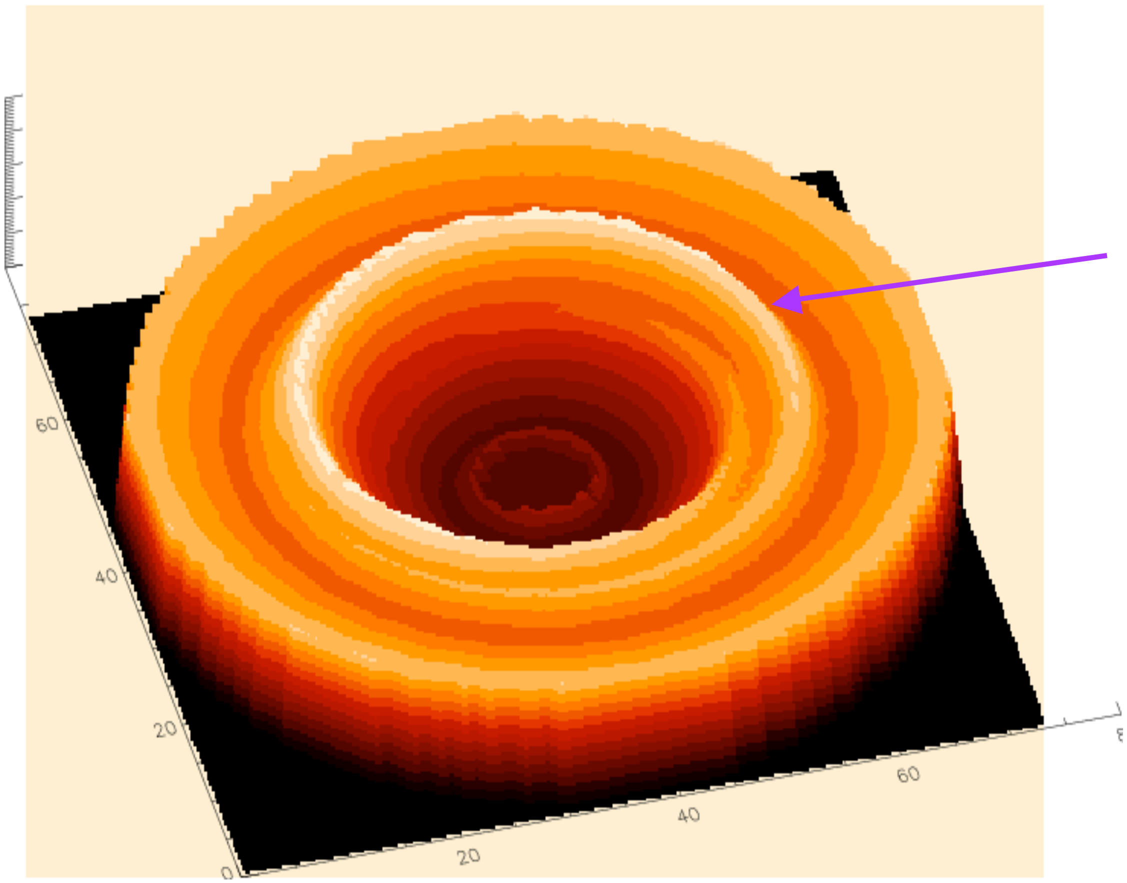
  → energy to power a wind or a jet

➡ the Magnetic Flood: a working scenario for the 30 min cycle of GRS 1915 + 105

Flux Modulation from the AEI

work in progress with M. Muno MIT/UCLA

the effects of the spiral shock is the creation of a hot-point in the disk
→ and also a thickening of the disk



from 2D non-linear MHD simulation we get the following (with a simplistic model for disk height and temperature)

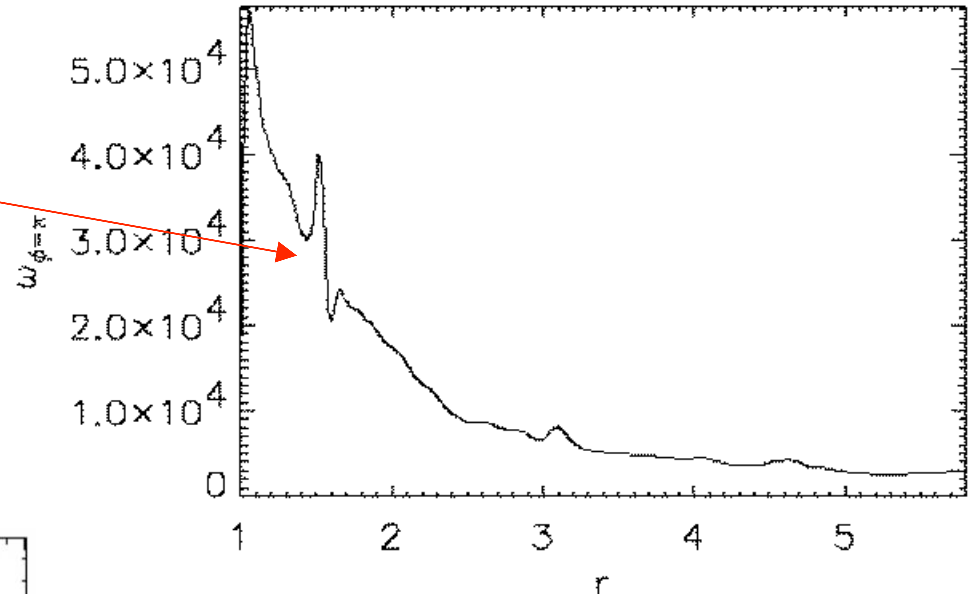
computing the X-ray emission from such an accretion disk **shows a modulation in the flux** comparable with the low-frequency Quasi-Periodic Oscillation observed in X-ray Binaries

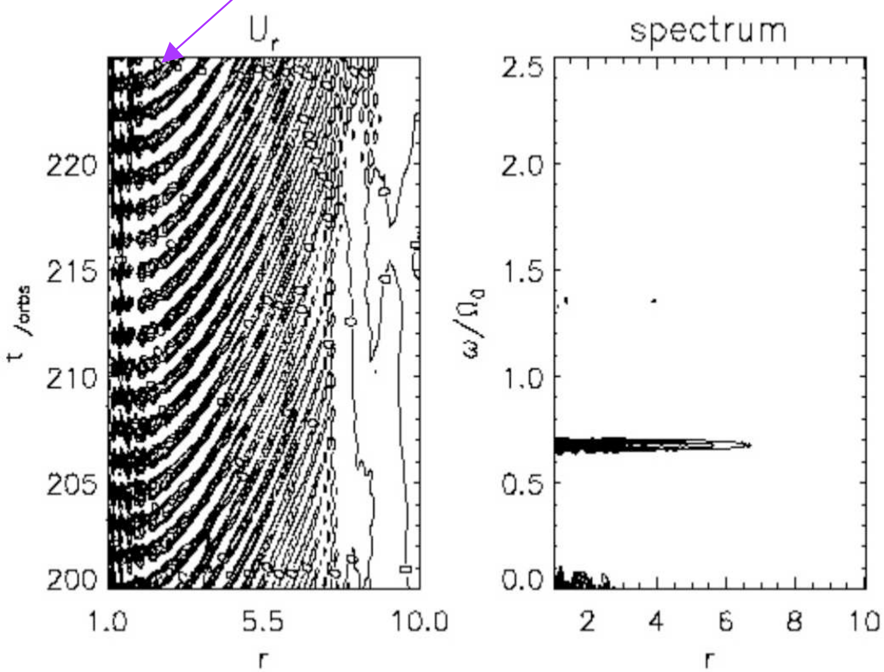
Results from the simulation (2)

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 after the corotation and standing pattern inside

⇨ m=1 mode

Emission of Alfven Waves

The Rossby vortex twists the footpoint of the field lines threading the disk.
If the disk has a low density corona:

twisting ⇐ emission of Alfven Waves

⇐ energy and angular momentum extracted from the disk will be transfered to the corona where they can power a wind or a jet

We describe this via a variational form: ⇐

F = energy of the waves **+ i (** outgoing spiral + coupling with the vortex

+ kz Alfven Waves**)**

imaginary term √ amplification or damping of the wave

the Alfven terms are singular at the vortex radius