Probing Radiation Pressure Instabilities in NS X-ray Binaries using GLADIS

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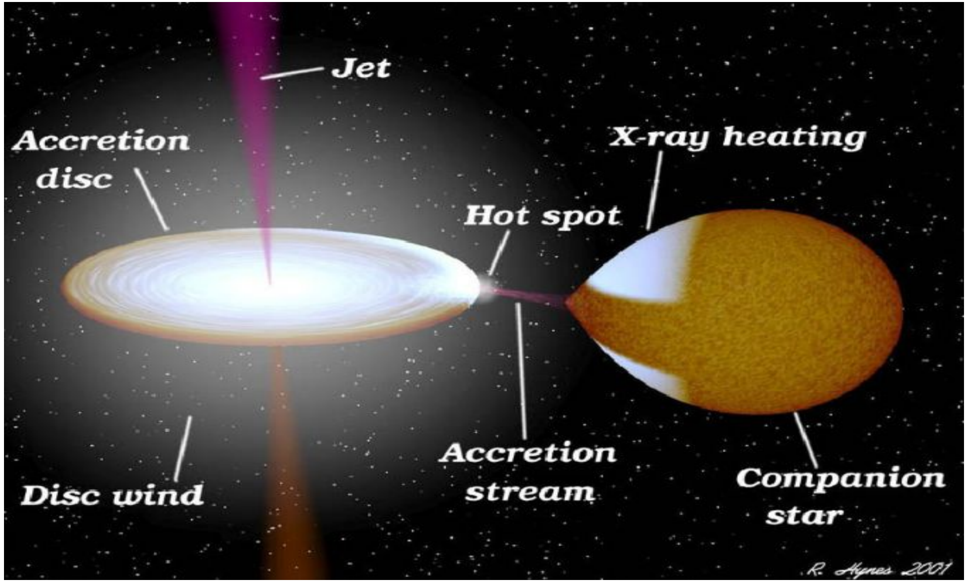

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PAiP-2025,
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Target Systems - X-ray sources showing instabilities in accretion disks

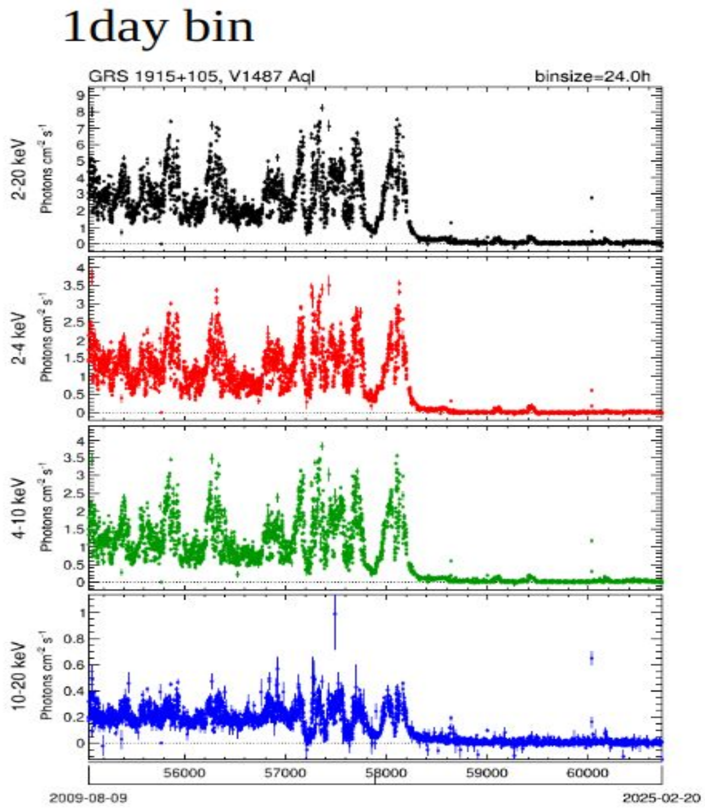
- Variabilities in light curve/spectra of accretion disks - Short term and Long term

- Present in accretion disks around AGNs (BH accretors) and **Xray binaries (NS and BH accretors)**

- Thermoviscous instabilities in the disk
  a) **Partial Hydrogen Ionization** ⇒ Long term variations in spectra (duty cycle of years/months)

  b) **Radiation Pressure instabilities (RPIs)** ⇒ Short term variations in spectra (duty cycle of days)

- RPI present mainly in the inner regions of the disk. where radiation pressure is dominant.



Variabilities in the light curve of BH Xray Source - GRS 1915+105,

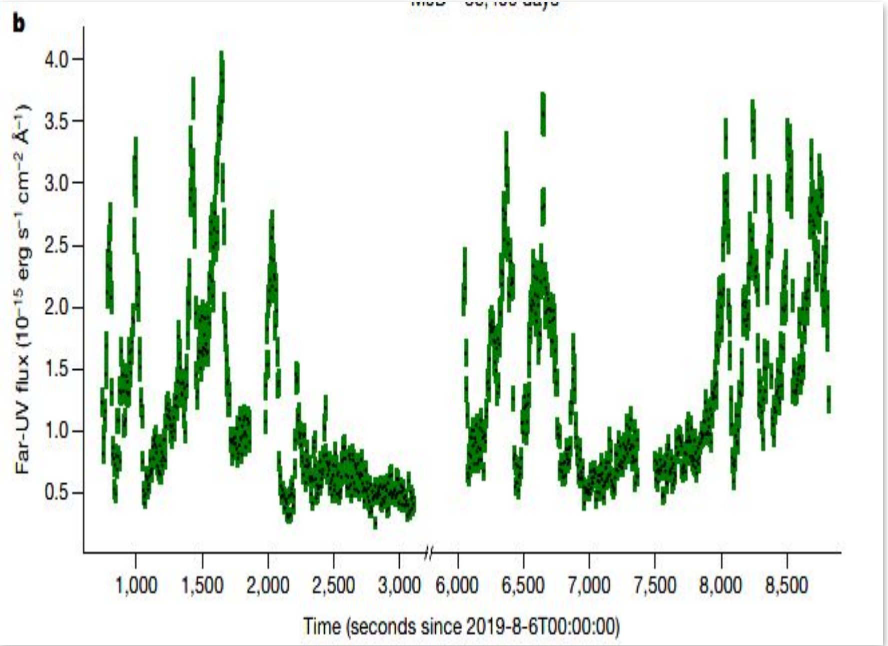
Aim - To model RPIs for NS X-ray sources

- GLADIS - Global Accretion Disk Instability Simulation

- Januik et al 2002 model explained the **RPIs in BH Xray Binaries**, such as GRS 1915-105, was later modified to include AGNs.

- Our aim is to modify the code to explain the Xray sources with **NS accretors (NS LMXBs)** such as Sco X-1 , SWIFT-J1508.

- For NS systems, we need to :
  a) Inclusion of **NS Boundary effect** as the inner boundary of the accretion disk
  b) Inclusion of **effects of Irradiation** from the central object.



Short-term variabilities in SWIFT-J1858.6-0814 , Source : Segura et al Nature 2022

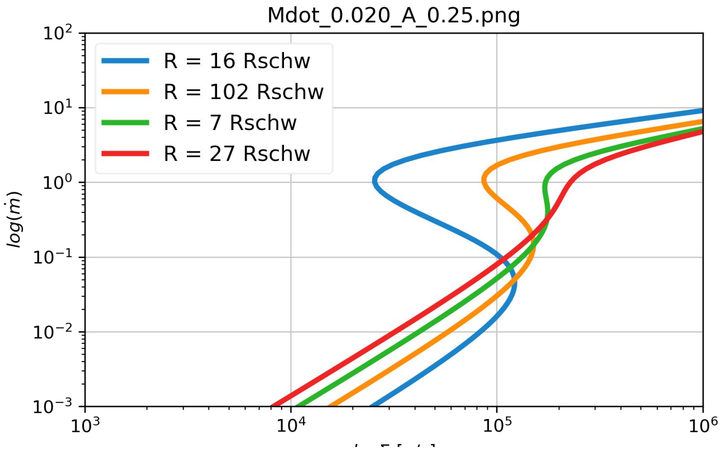
Working with the code GLADIS

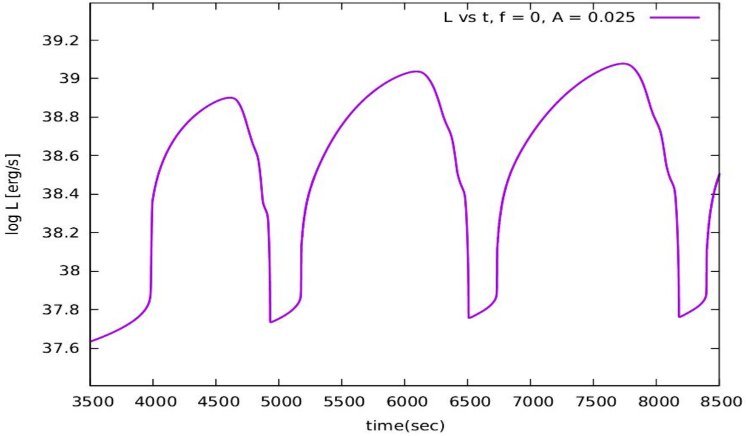
- Calculates the radial grid with vertically average structure for **an alpha-viscosity Shakura-Sunayev** model of accretion disk (**1D , time-dependent simulation.**)

- Calculates a grid in values of local accretion rate for stationary solutions , plotted as **Stability curves**.

- Calculates **the time evolution** of all the physical quantities at every point of the **radial grid.**

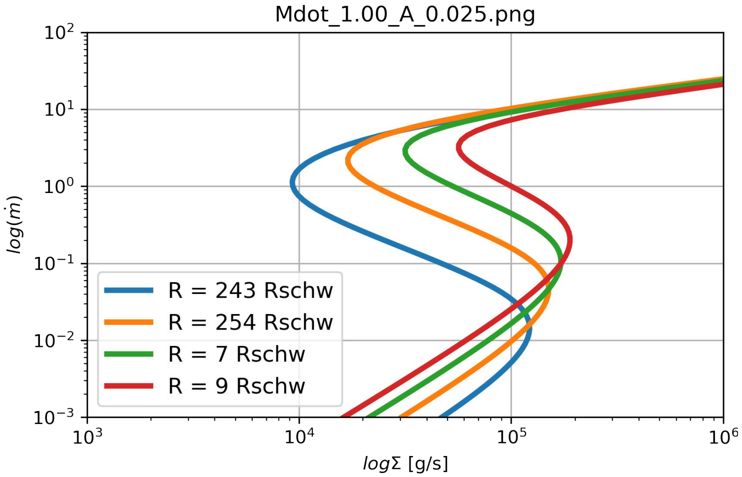
- Can take into account the effect of **outflow** from disk & **corona (1D + 1D case).**

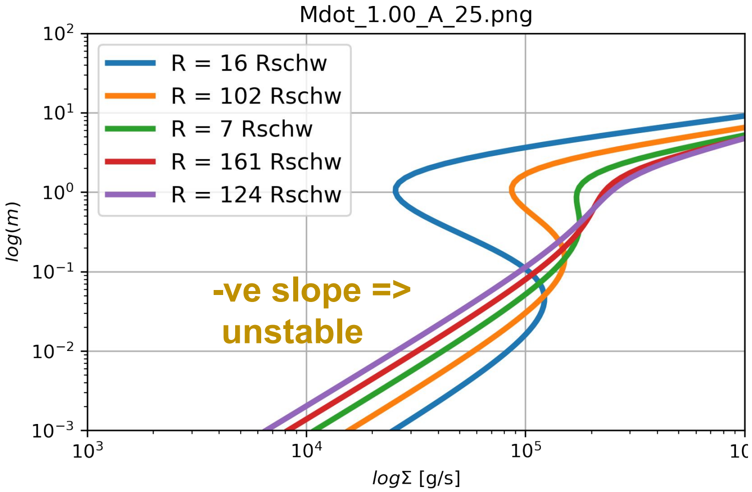


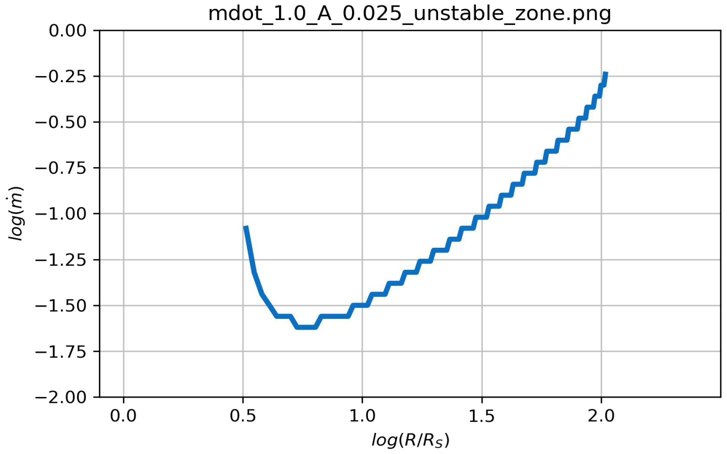


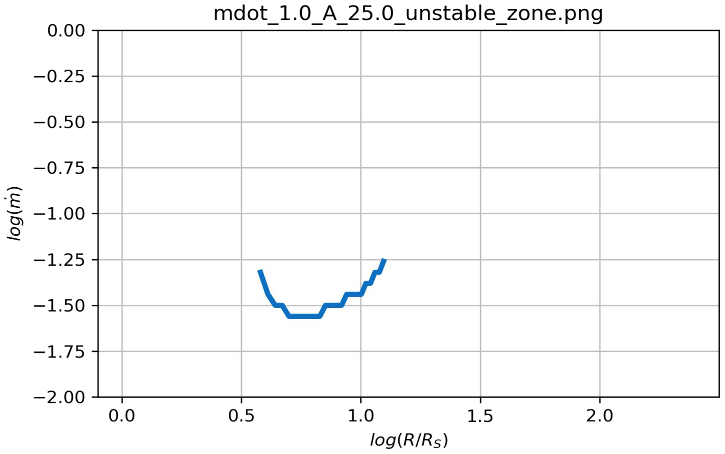
Stationary solution and time evolution of luminosity.

Stationary solutions - Stability curves of the disk







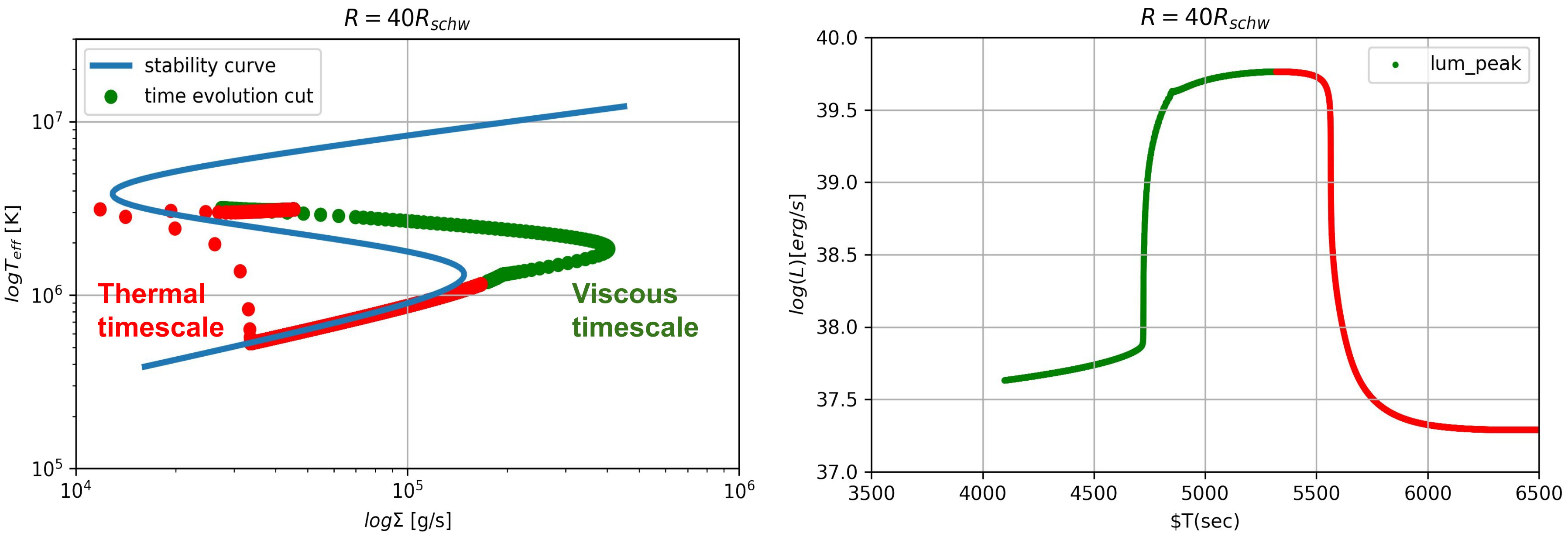


Variation of instability zones of Accretion disk for different values of outflow parameter A.

Higher outflow parameter A ⇒ lower instability zone

Depends also upon the type of central object - BH, NS or AGN.

Time evolution - Showing the instability oscillation cycles of the disk



Time evolution of the disk throughout one outburst cycle, the cycle in T_{eff} vs surface density(Σ) plot (Left), Luminosity vs time (Light curve) (Right). ,
colour : rising part to the peak(green) , decaying part (red).

Summary and Work in Progress

- Familiarised with the code through **stationary solutions** showing instability zone of the disk and **the instability oscillation cycles** of the disk.

- Working on including **the calculation of viscous flux** for the case of a **NS with a boundary layer effect** A/Q Popham&Sunayev ApJ 2001.

- Immediate goal : To verify the variation of physical quantities (angular & radial velocity, height etc) A/Q NS total flux prescription from Popham&Sunayev 2001.

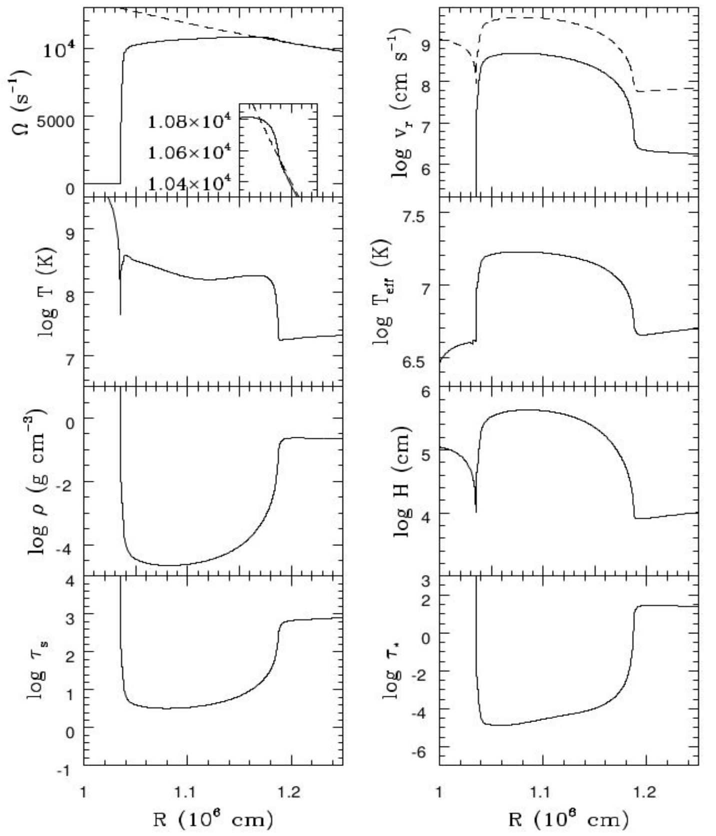


Figure : Variation of Ω, H, T, ρ according to the modified flux prescription.
Source : Popham&Sunayev ApJ 2001


Getting infinities and segmentation faults
My extra subroutine

THANK YOU !!

Vertically average structure of the disk

Standard viscosity prescription

$$\tau_{r\varphi} = -\alpha P \,.$$

Total flux dissipation

$$F_{\rm tot} = \frac{3GM\dot{M}}{8\pi r^3} f(r)\,, \quad F_{\rm tot} = C_1 \tfrac{3}{2} \alpha P \Omega_{\rm K} H$$

Viscous flux dissipation

$$\frac{dF}{dz} = \alpha P \left(-\frac{d\Omega_{\rm K}}{dr} \right),$$

$P = P_{gas} + P_{rad}$

Vertical hydrostatic equilibrium

$$\frac{1}{\rho}\frac{dP}{dz} = -\Omega_{\rm K}^2 z\,,$$

$$\frac{P}{\rho} = C_3 \Omega_{\rm K}^2 H^2 \,.$$

Energy transfer

$$\frac{dT}{dz} = -\frac{3\kappa\rho}{4acT^3} F_l \,.$$

$$F_l H = C_2 \frac{acT^4}{3\kappa\rho}$$

Where F_l is the local energy flux in the vertical direction.

Vertical coefficients C1, C2 and C3 calculated A/Q [Muchotrzeb & Paczynski 1982] & [Homa et al 1991]

Stationary solutions of the disk

To obtain the stability curves, the time-independent energy balance equation :

$$C_1 H \frac{3}{2} \alpha P \Omega_K = C_2 \frac{1}{H} \frac{acT^4}{3\kappa\rho} - \frac{1}{2\pi r} \dot{M} T \frac{dS}{dr} ,$$

is solved, along with the hydrostatic equilibrium equation. where entropy derivative can be written as :

$$T \frac{dS}{dr} r = \frac{P}{\rho} q_{\mathrm{adv}} ,$$

For the local energy flux F_l , $F_l = F_{\mathrm{tot}}(1 - f_{\mathrm{adv}})$,

Where f_{adv} is given by

$$f_{\mathrm{adv}} = \frac{F_{\mathrm{adv}}}{F_{\mathrm{tot}}} = -\frac{2rP_e q_{\mathrm{adv}}}{3\rho_e GMf(r)} ,$$

For the NS boundary layer case, Viscous dissipation flx is given by

$$Q^+ = -\frac{\dot{M}}{4\pi R} [\Omega R^2 - j\Omega_K(R_*)R_*^2] \frac{d\Omega}{dR} .$$

Where we have a different angular velocity than keplerian, obtained by integration of

$$\dot{M} \frac{v}{v_R} \frac{d\Omega}{dR} R^2 = \dot{M} \Omega R^2 - \dot{J} .$$