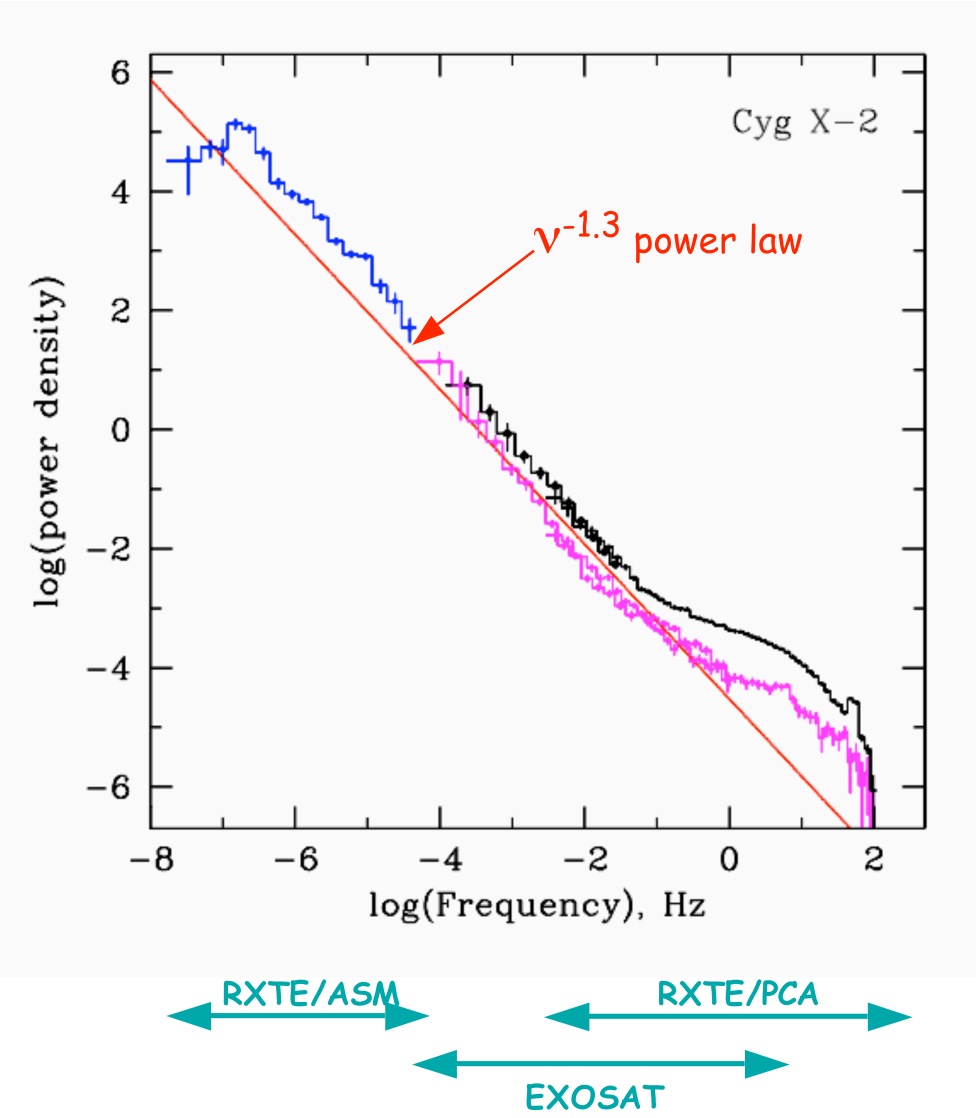
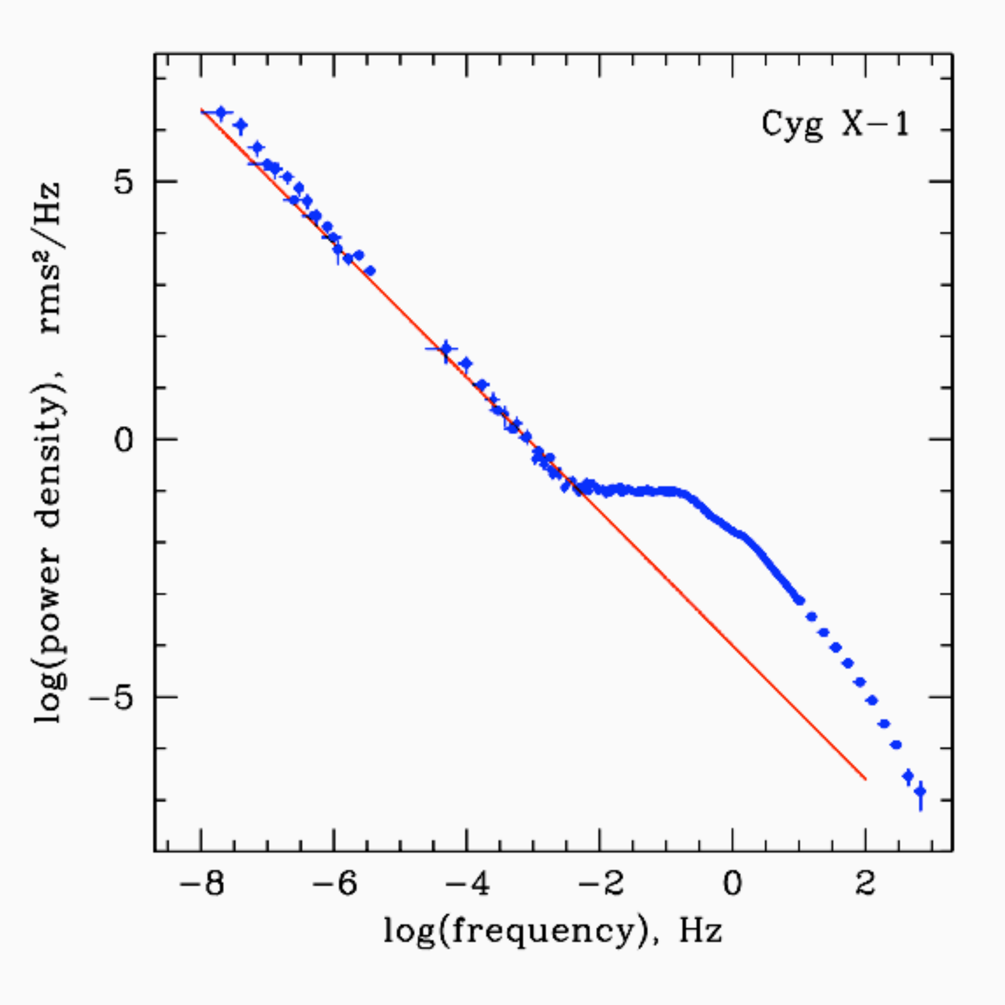
X-ray variability, viscous time scale & Lindblad resonances in LMXBs

Marat Gilfanov & Vadim Arefiev

X-ray variability in LMXBs



X-ray variability in LMXBs



Timescales

- observed:

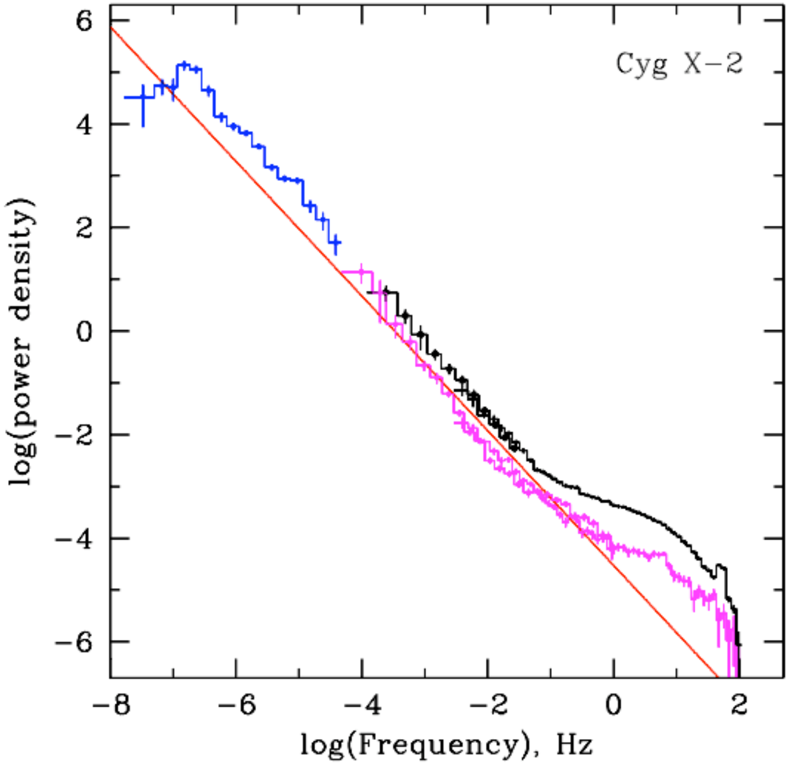
  from $\lesssim 10^{-2}$ sec to $\gtrsim 10^{8}$ sec

- X-ray emitting region

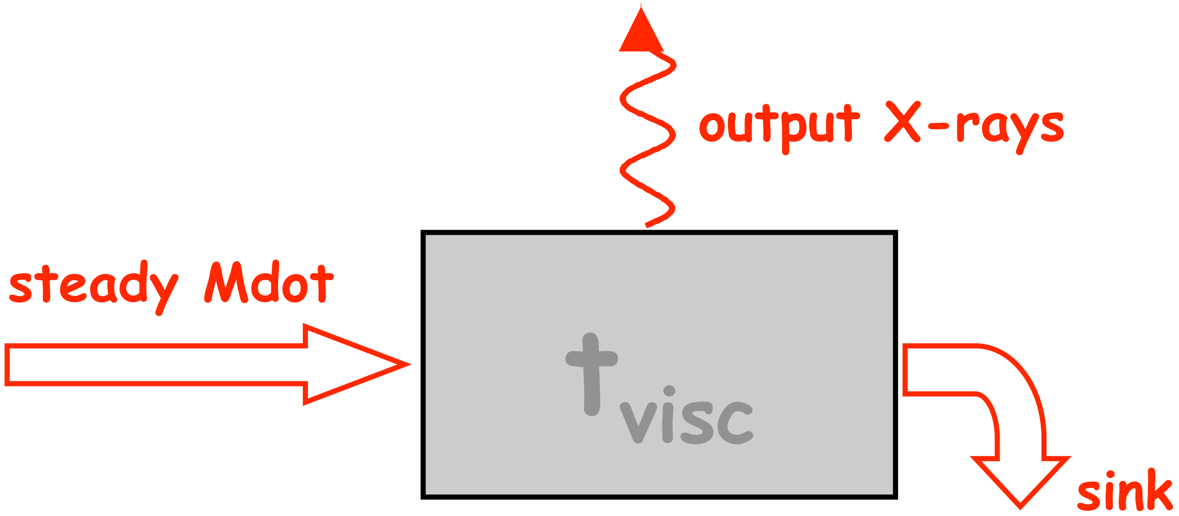
  size: ~3-50 R_g

  timescales: ~ sec – msec

the longest timescale ~ sec

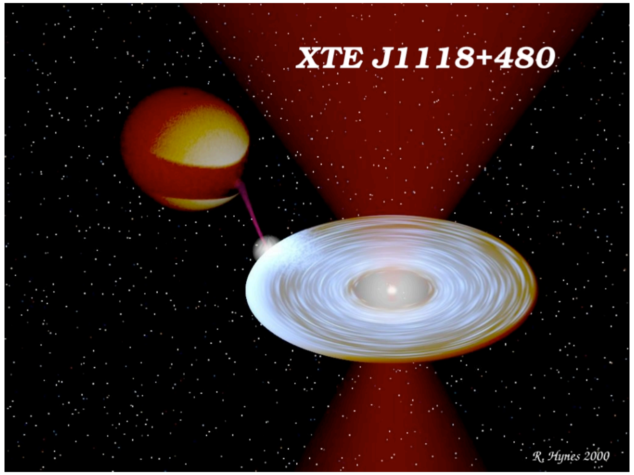


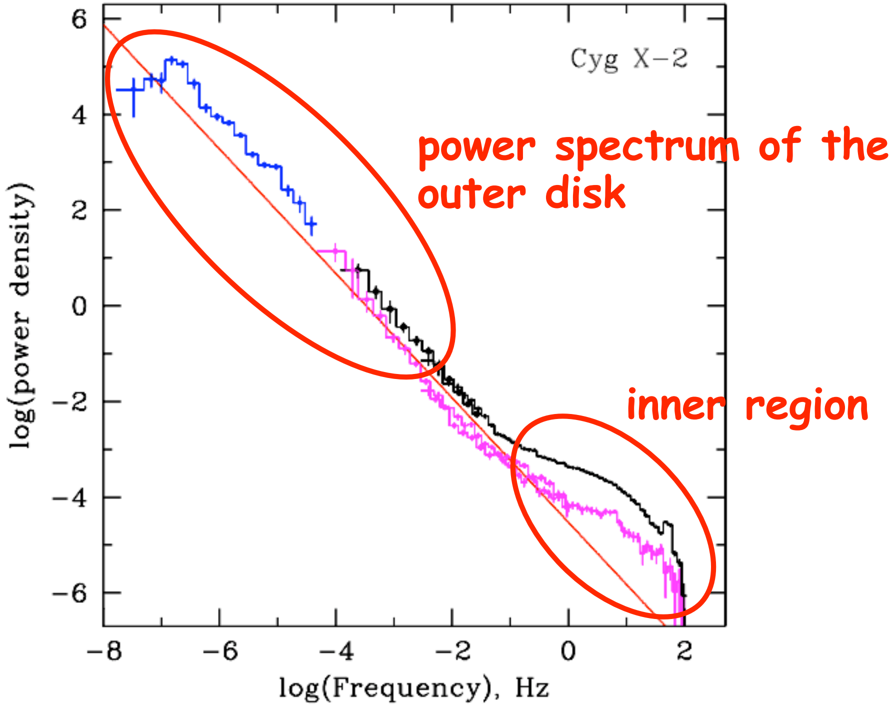
Timescales



t_{visc} ⇨ longest X-ray variability timescale

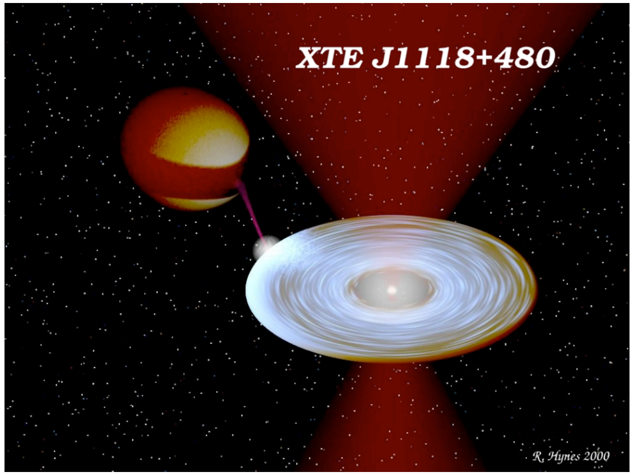
Timescales

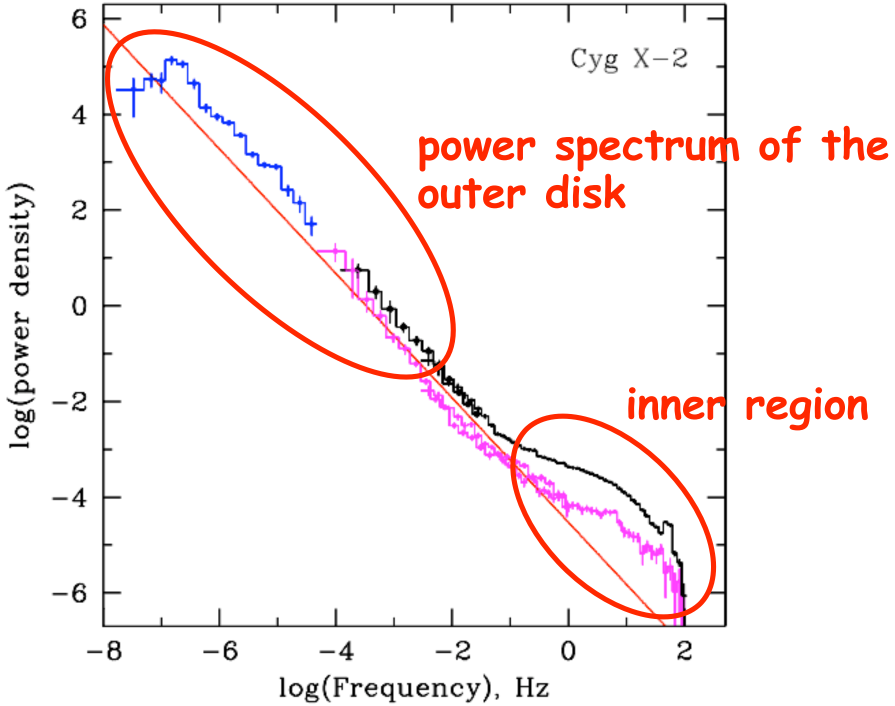




low frequency perturbations are generated in the outer disk and propagate to the X-ray emitting region

Timescales





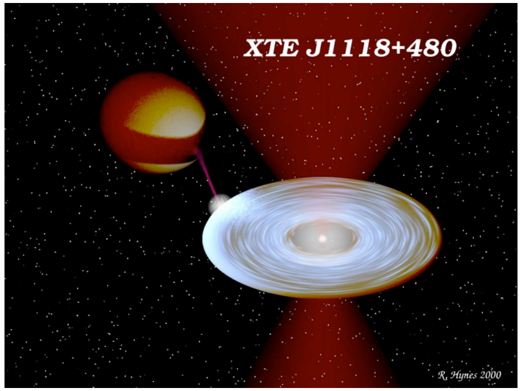
power spectrum of the outer disk

inner region

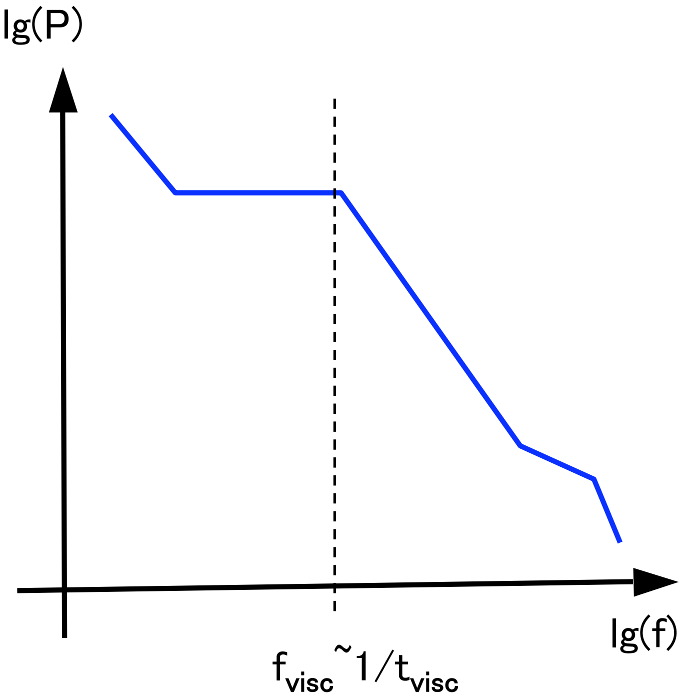
each radius **r** produces variations on timescale **~tvisc(r)**

Longest time scale in the disk

- disk – finite size R_{out}
  $t_{visc}(R_{out})$ - longest time scale



- uncorrelated events - flat PDS



break in the power density spectrum at $f \sim 1/t_{visc}$

Viscous time scale

$$t_{visc} \approx \frac{R_d}{v_R} \approx \frac{R_d^2}{\nu}$$

α-parameterization of viscosity (Shakura & Sunayev, 1973):

$$\nu \approx (\text{free path}) \times (\text{velocity}) \approx \alpha H c_s$$

$$t_{visc} \approx \alpha^{-1} \left(\frac{H}{R} \right)^{-2} \Omega_K^{-1}$$

Viscous time scale

+3rd Kepler law →

$$\boxed{\frac{f_{visc}}{f_{orb}} \approx 3\pi\alpha\left(\frac{H_d}{R_d}\right)^2\left(\frac{R_d}{a}\right)^{-3/2}(1+q)^{-1/2}}$$

$$q = \frac{M_2}{M_1}; \quad a \text{ - binary separation}$$

expected numbers:

$$\frac{H}{R} \sim 0.02; \quad \frac{R}{a} \sim 0.4; \quad \alpha \sim 0.1 \quad \rightarrow \quad \frac{f_{visc}}{f_{orb}} \sim 10^{-3}$$

Sample of LMXBs

- ~persistent
- P_{orb} is known and within accessible range
- sufficiently bright

- ASM (RXTE)
- EXOSAT

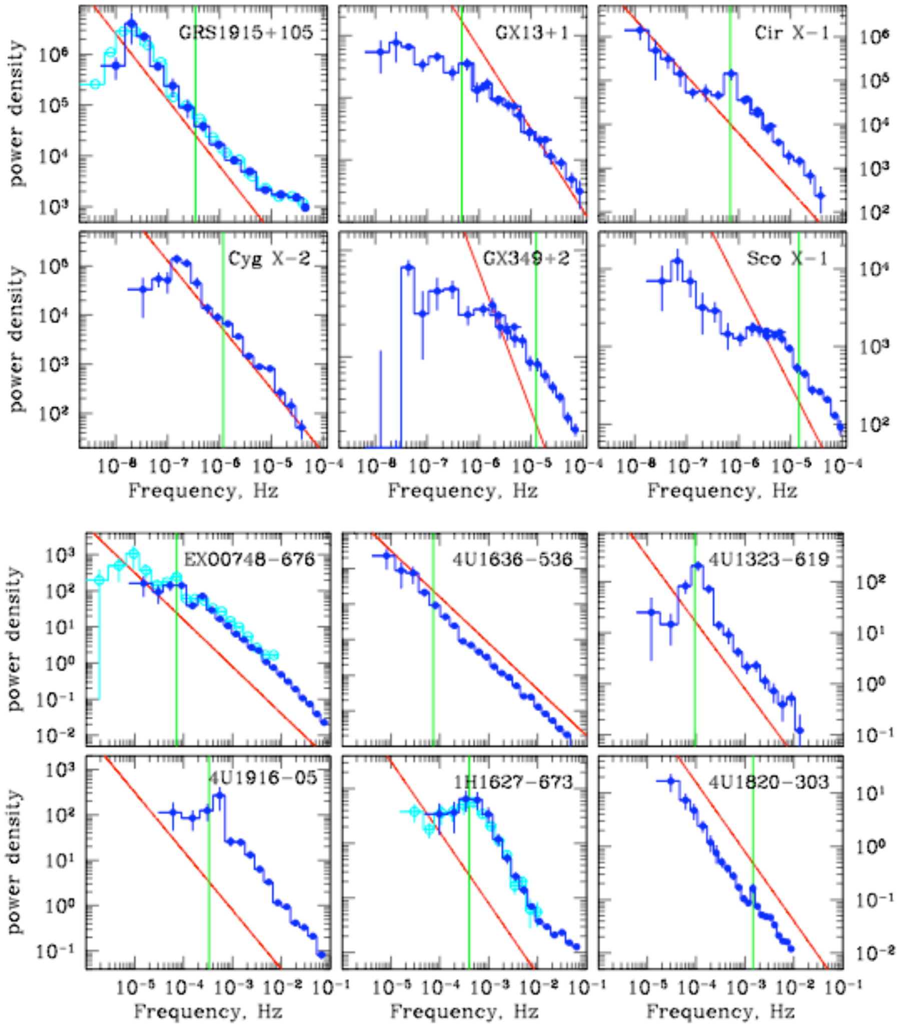
➔ 12 sources

Power density spectra

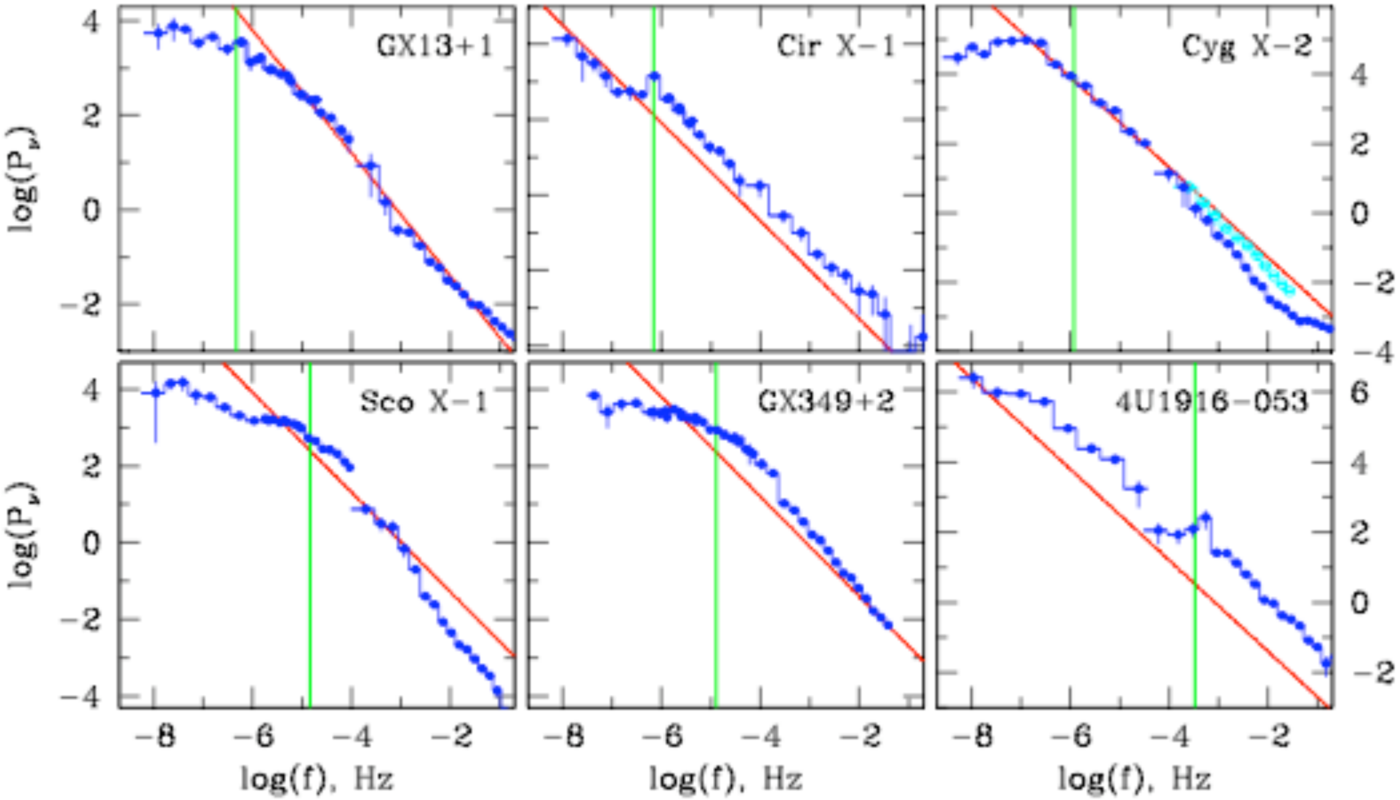
- **low frequency break** ~flat @ lower freqs.

- **power law** @higher frequencies

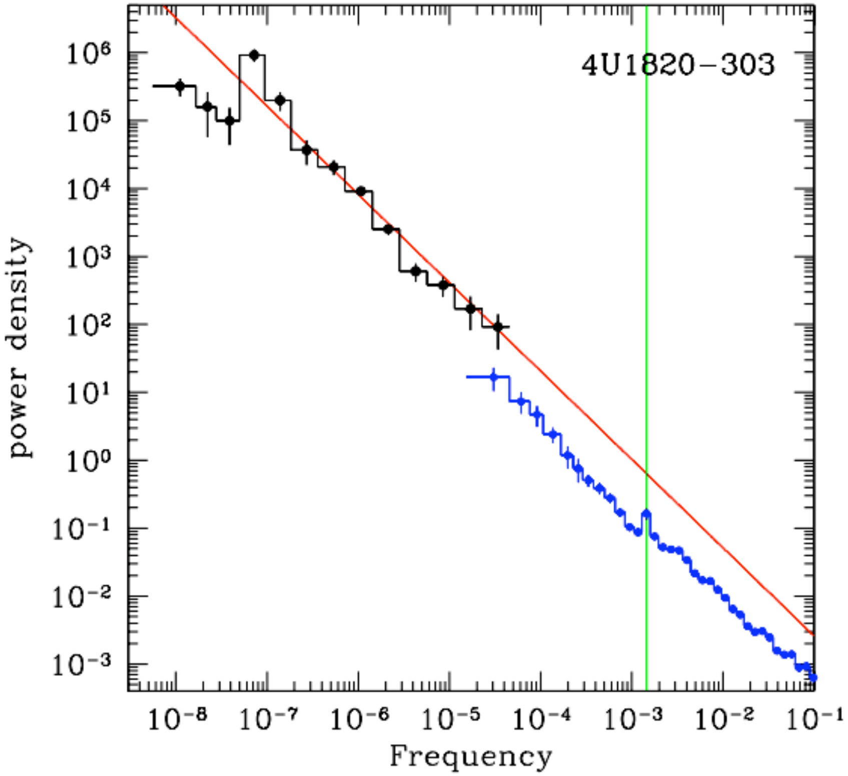
$$P_\nu \propto \nu^{-1.3}$$

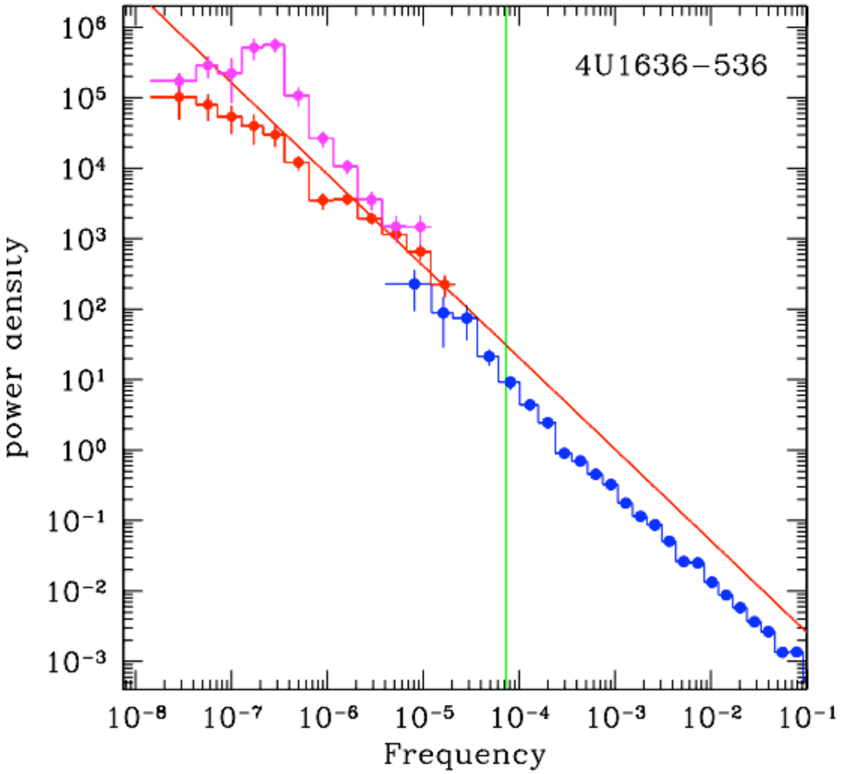


Broad band power spectra



4U1820-303 and 4U1636-536



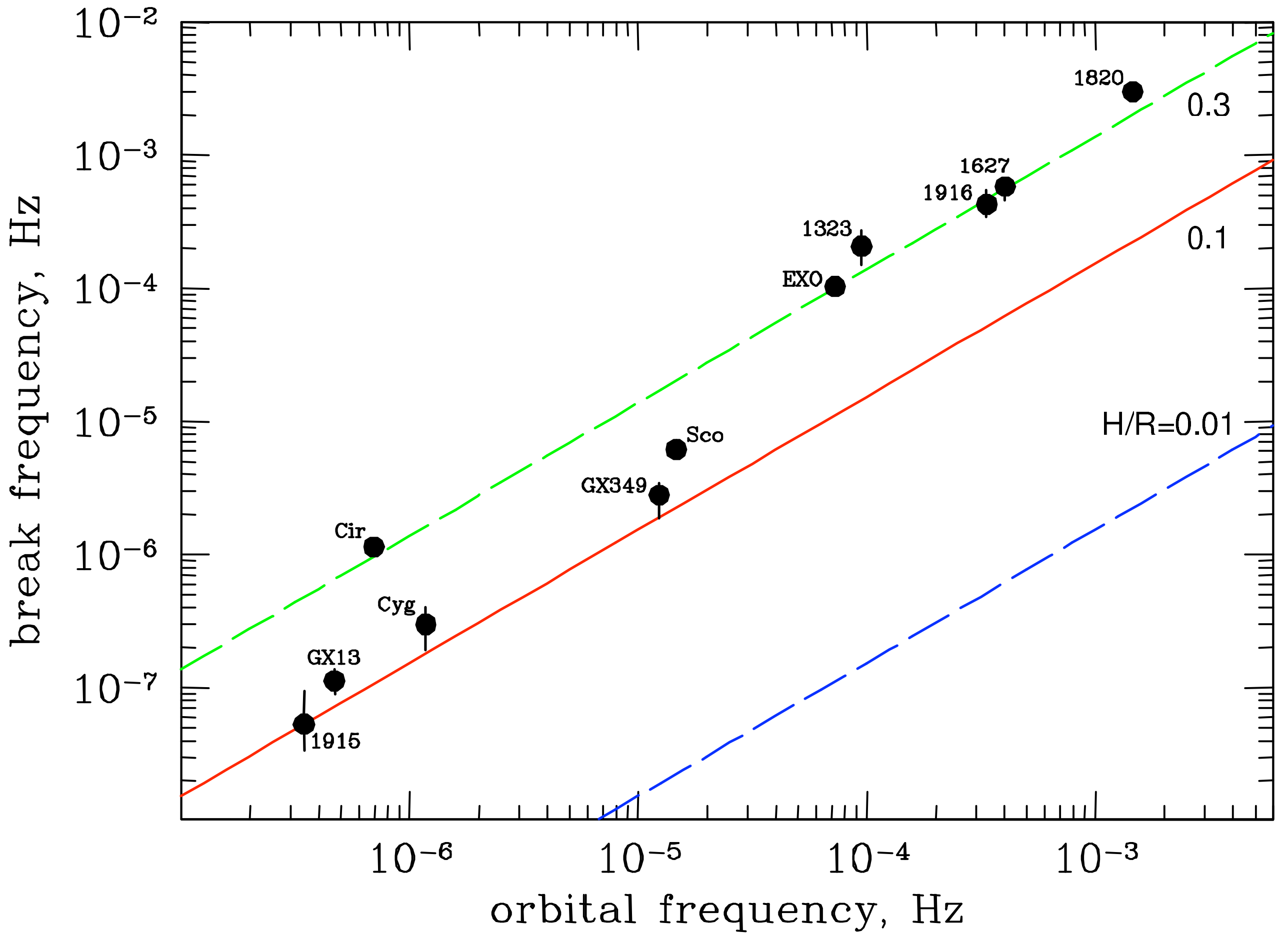


triple system, P_3~180^d

break frequency ⟺ viscous time scale

$$f_{break} \sim 1/t_{visc}$$

Break frequency

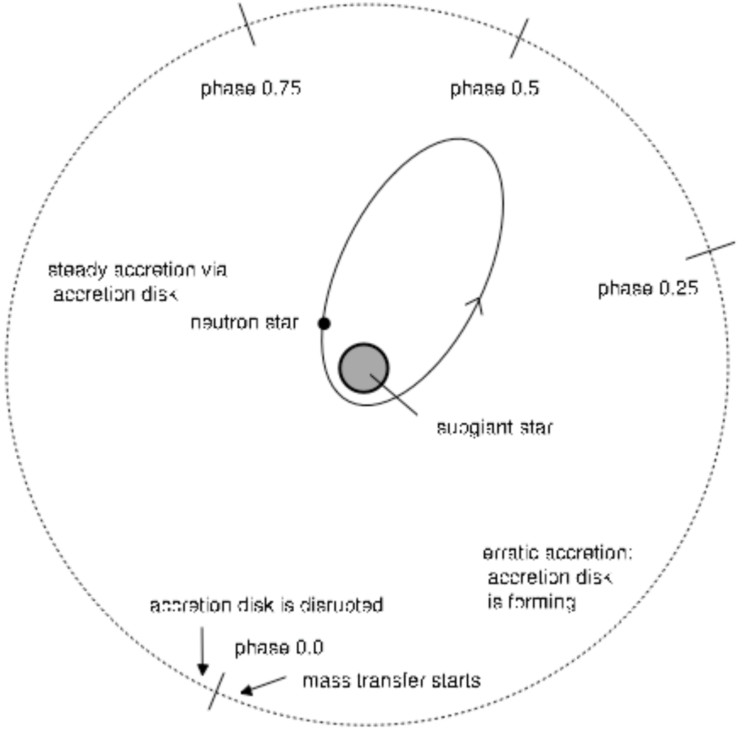


Cir X-1

- eccentric orbit
  e~0.7-0.9
- Roche lobe overflow at periastron
- substitution:

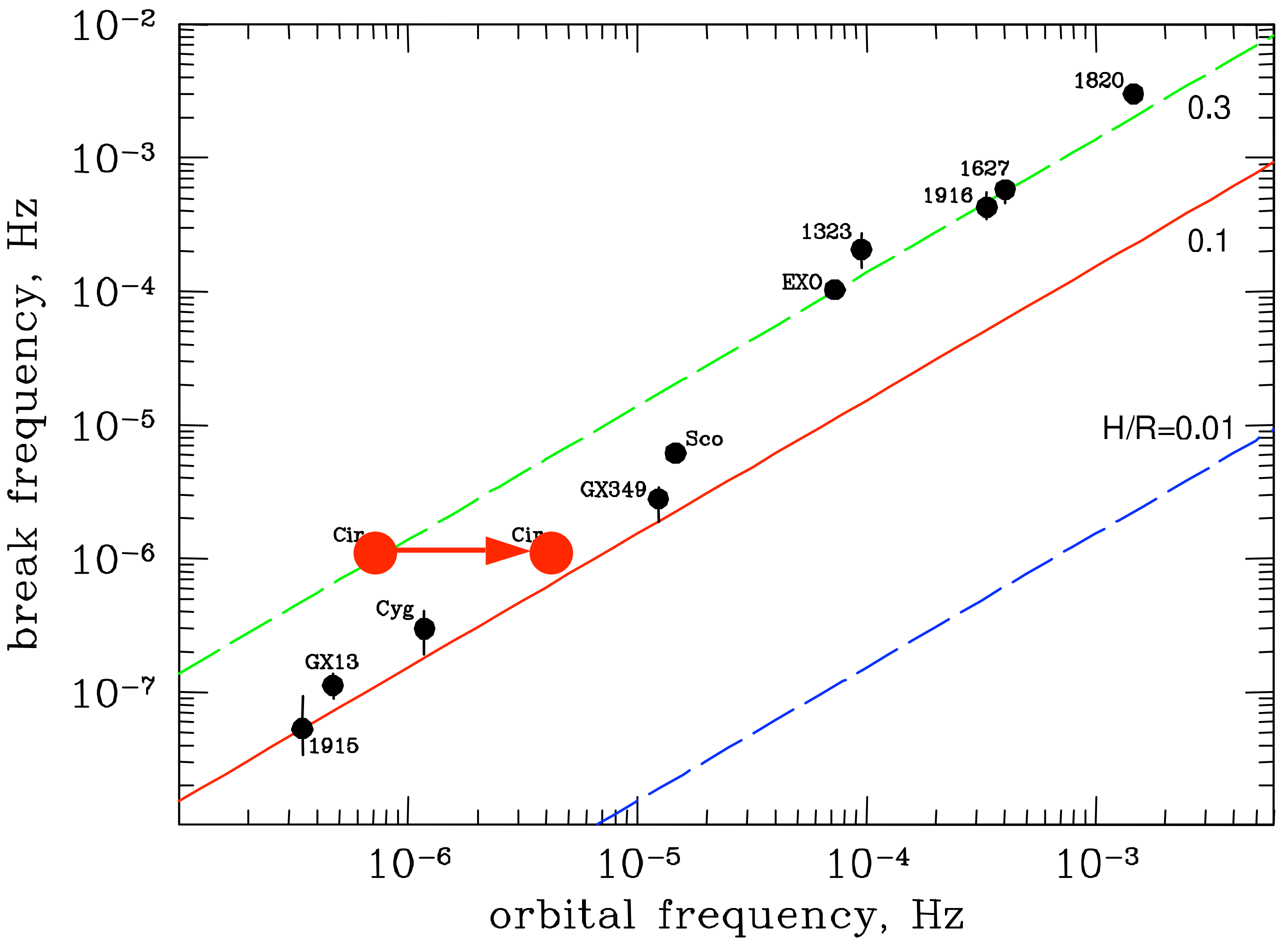
$$a \rightarrow a(1-e)$$

$$P_{orb} \rightarrow P_{orb}(1-e)^{3/2}$$



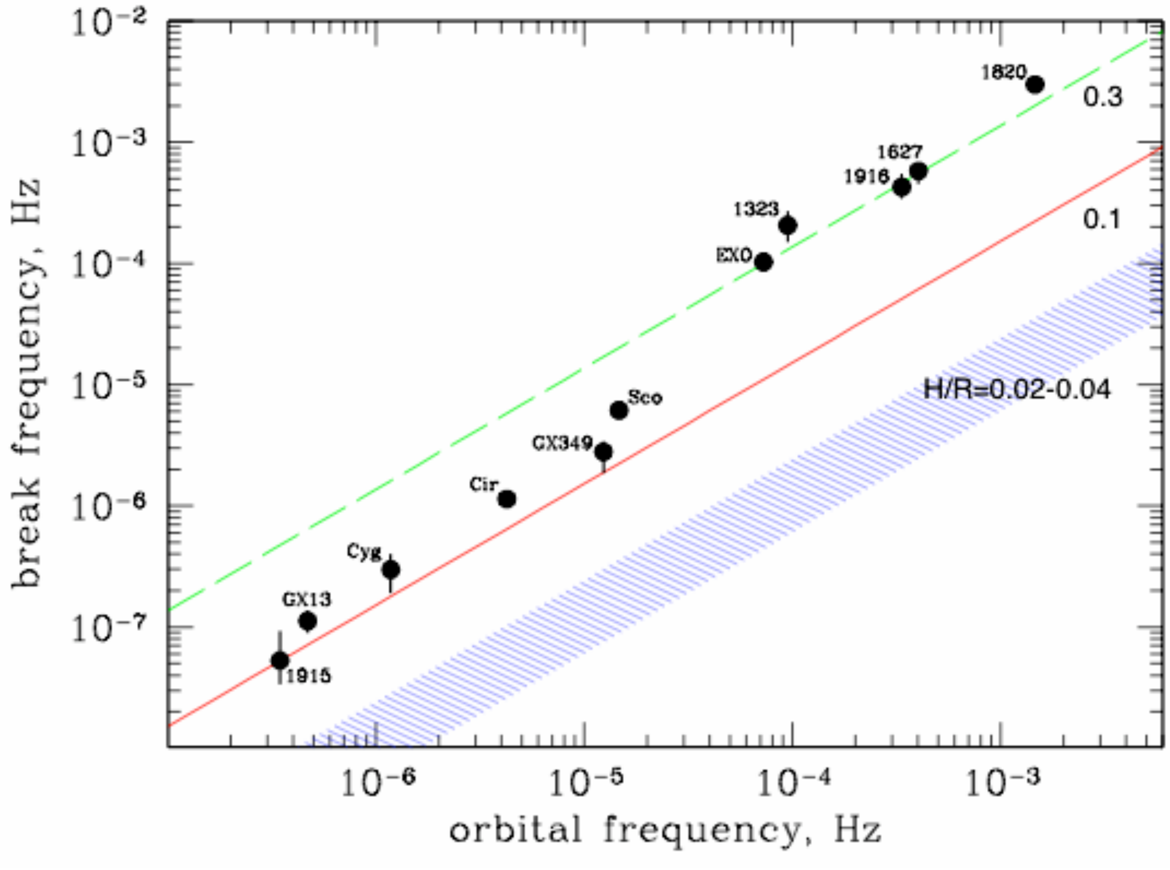
from Johnston et al., 1999

Break frequency



Break frequency

$$\frac{f_{\mathrm{visc}}}{f_{\mathrm{orb}}} \approx 3\pi\alpha\left(\frac{H_d}{R_d}\right)^{2}\left(\frac{R_d}{a}\right)^{-3/2}(1+q)^{-1/2}$$

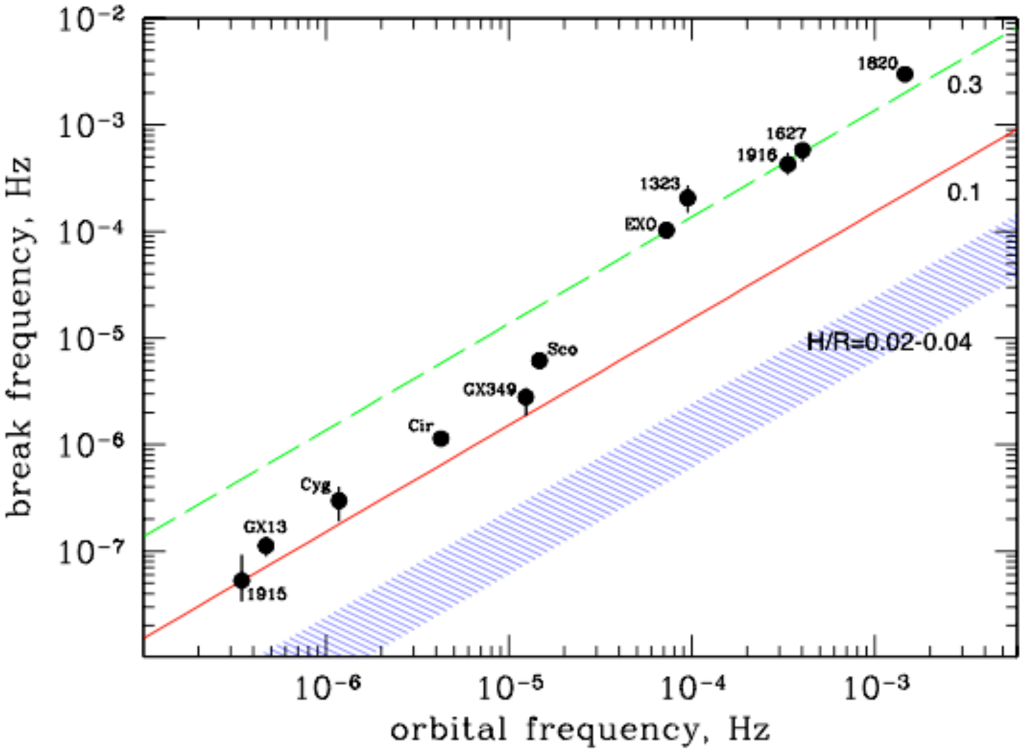


Viscous time scale

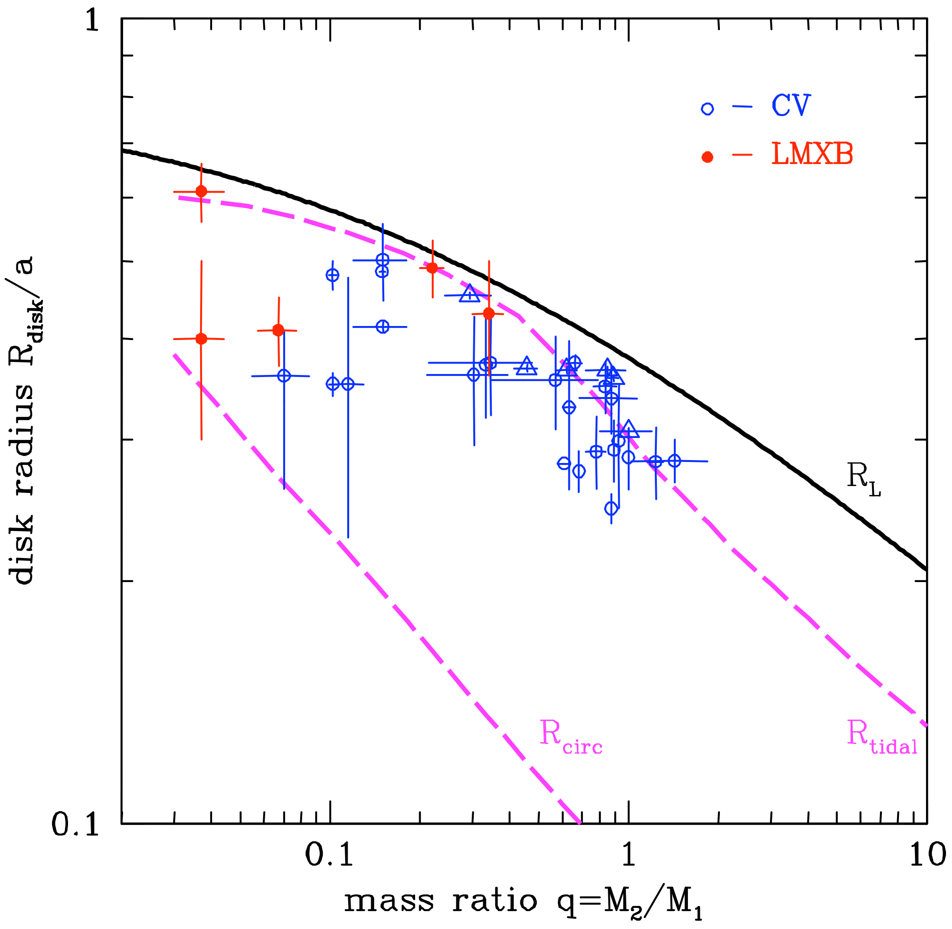
- t_{visc} is shorter

$$t_{visc} \approx \frac{R_d}{V_R}$$

- 2 possibilities:
  - R_d is smaller
  - V_R is larger



Disk radius



$R_d \sim R_{tidal}$

CV data:

Hessman, 1988, Hessman & Hopp, 1990; Rutten et al., 1992; Harrop-Allin & Warner, 1996

LMXB data:

Orosz & Kuulkers, 1999; Shahbaz et al., 2004; Torres et al., 2004; Zurita et al., 2000

V_R and disk thickness

- in standard disk theory

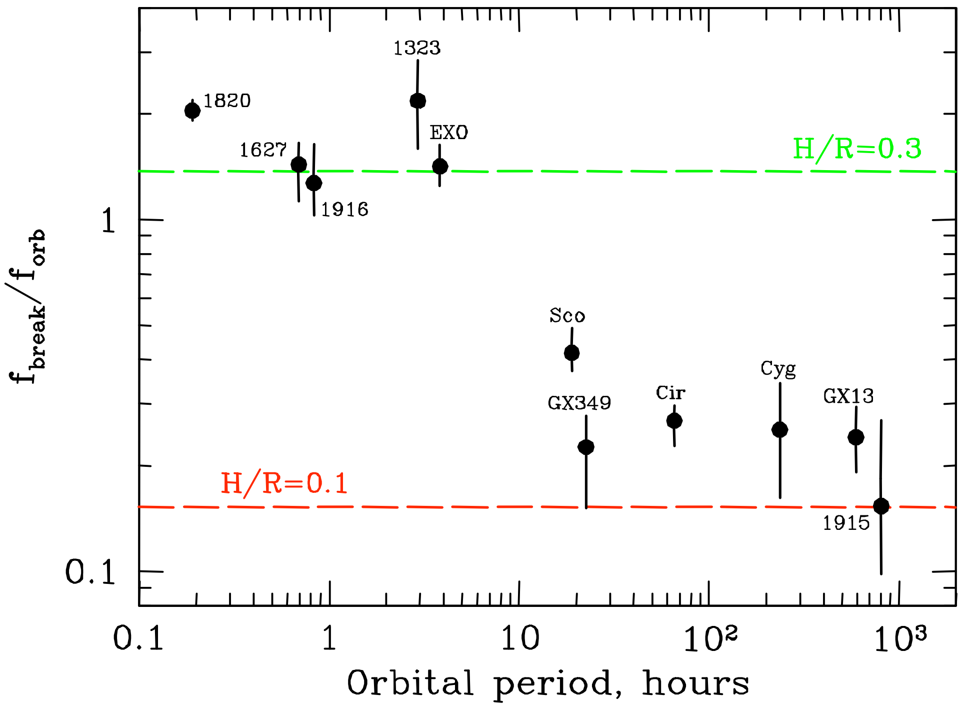
  $V_R \Leftrightarrow H/R$

  $H/R \sim \text{few} \times 10^{-2}$

  $t_{visc}/t_{orb} \sim 10^{-3}$

- t_{visc} data $\Rightarrow$ $H/R \sim 0.1$

$$\frac{f_{visc}}{f_{orb}} \approx 3\pi\alpha \left(\frac{H_d}{R_d}\right)^2 \left(\frac{R_d}{a}\right)^{-3/2} (1+q)^{-1/2}$$



Further comments

- robust conclusion - $H/R \sim 10^{-2}$ would require
  $\alpha \sim 5\text{-}800$ or $R_d/a \sim 0.005\text{-}0.05$

- thickness of the outer disk

- appears to be supported by the eclipsers statistics

Semi-thick disk ?

- disk with given H/R

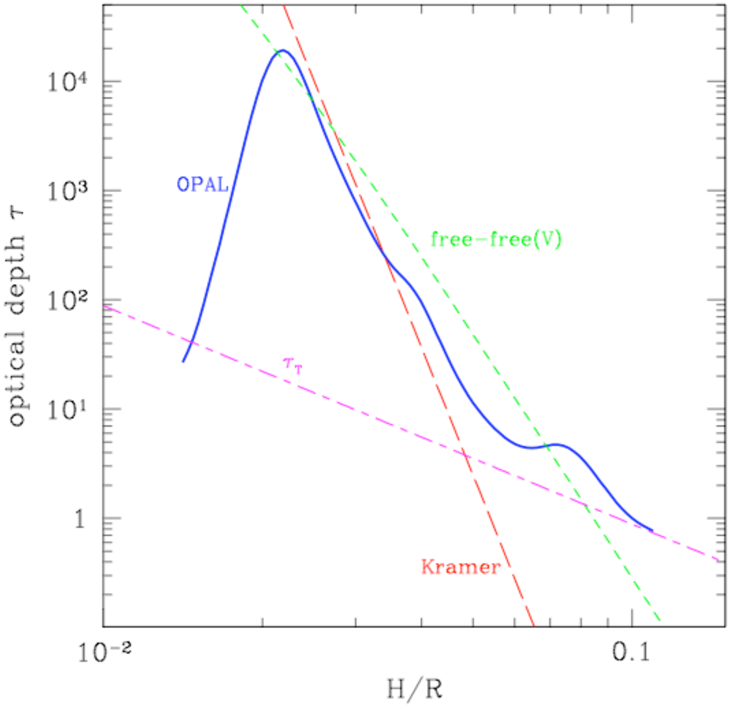
  $\tau \propto (H/R)^{-(12 \div 3)}$

- $H/R \sim 0.1 \Rightarrow \tau \leq 1$

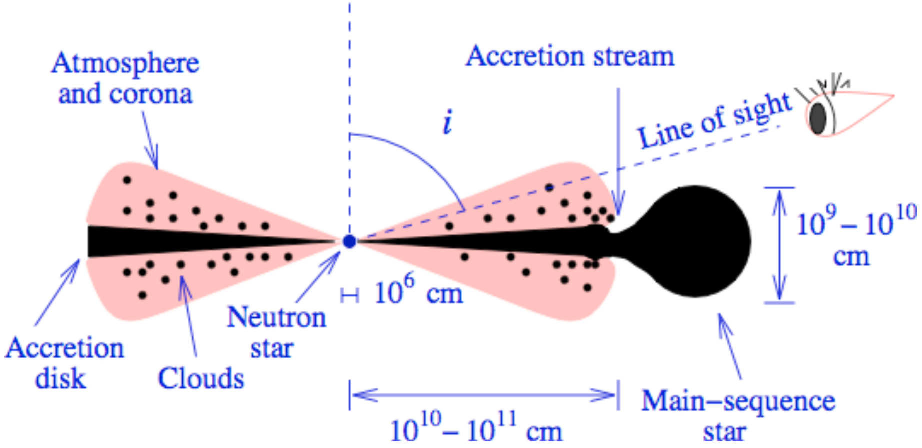
- contradicts to optical data

standard disk + coronal flow

vertical optical depth of disk



Disk + coronal flow



(Jimenez-Garate et al., 2002)

Mdot(disk) ~ Mdot(corona)

$\Sigma_{corona}/\Sigma_{disk} \sim (H_c/H_d)^{-2} \leq 0.1$

$T_{corona} \sim 10^{-2}\ T_{vir} \sim 10^5\text{-}10^6$ K

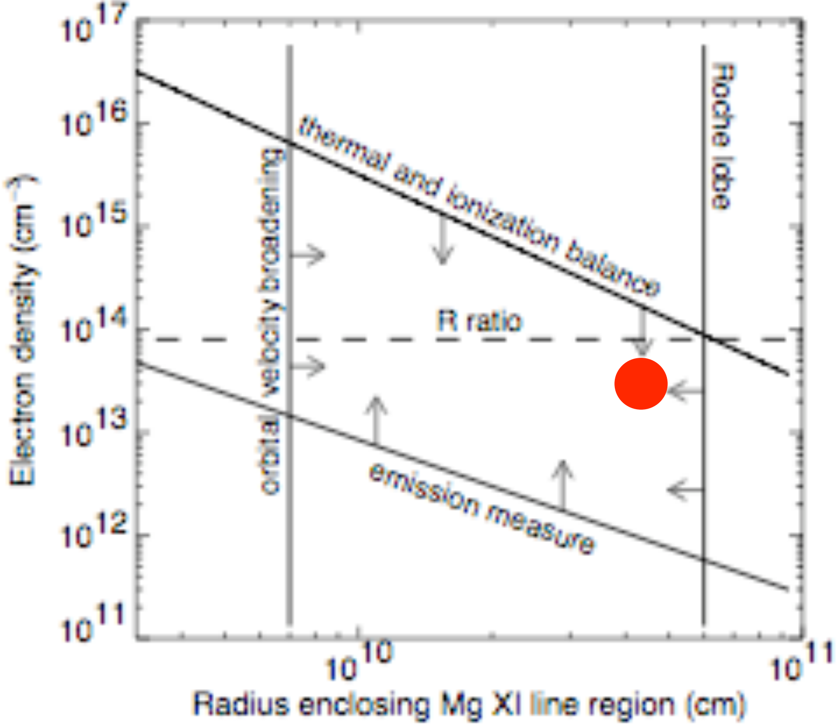
$nH \sim 10^{23}$ cm^{-2}

$nR \sim 10^{24}$ cm^{-2}

Chandra and XMM-Newton observations

- X-ray spectroscopy of high inclination LMXBs
- complex absorption and emission features
- photoionized corona

EXO 0748-676



from Jimenez-Garate et al., 2003

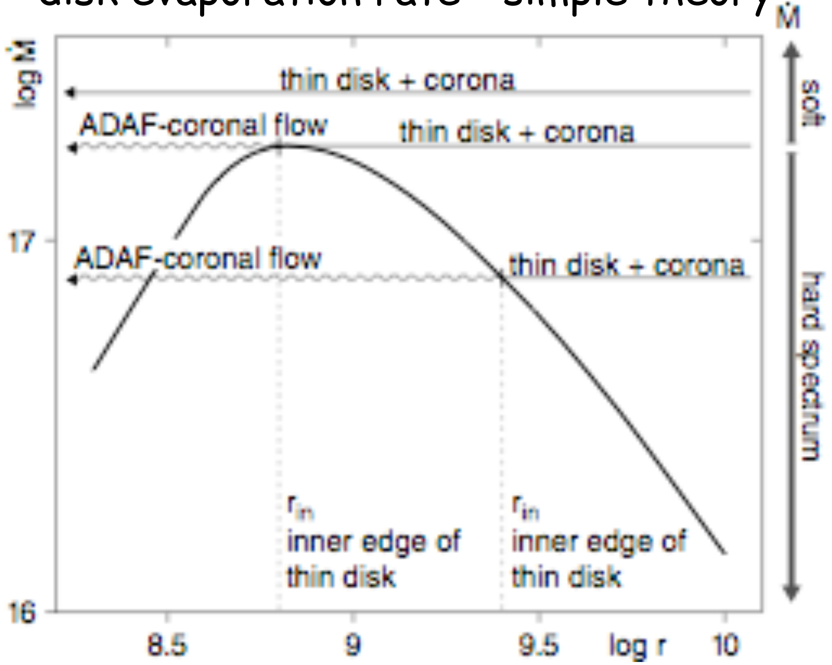
Other evidence

- ADC (accretion disk corona) sources
- partial eclipses (~10-50 %) in LMXBs
- modeling of eclipse light curves ⇒ corona parameters

Origin of the coronal flow

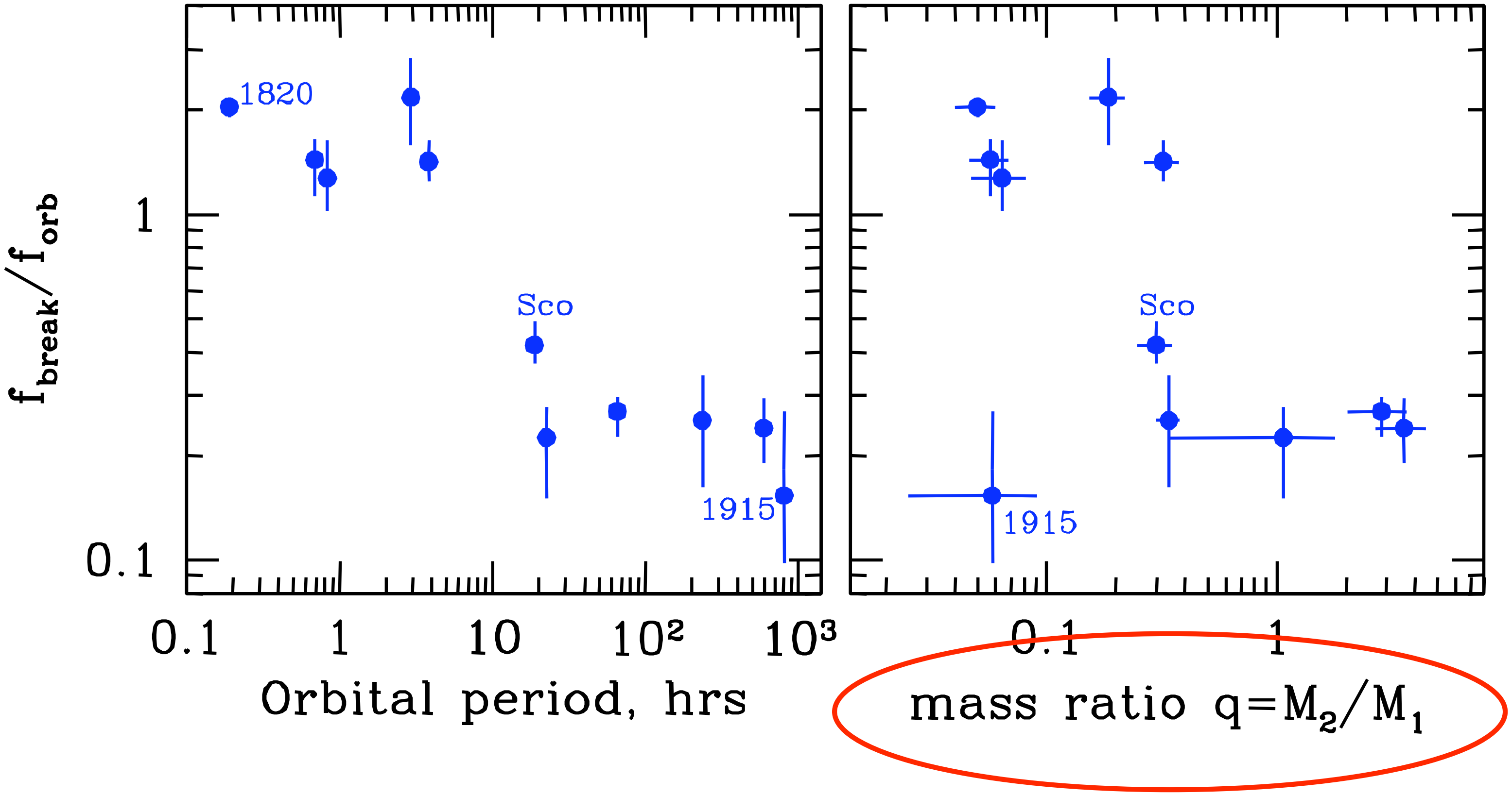
- disk evaporation (Meyer & Meyer-Hofmeister, 1994, 2000)
- role of irradiation
  - Compton cooling/heating of the corona
  - heating of the outer disk ?

disk evaporation rate - simple theory



Meyer & Meyer-Hofmeister, 1994, 2000

Viscous time in wide and compact systems



Tidal resonances in binaries

- resonance:

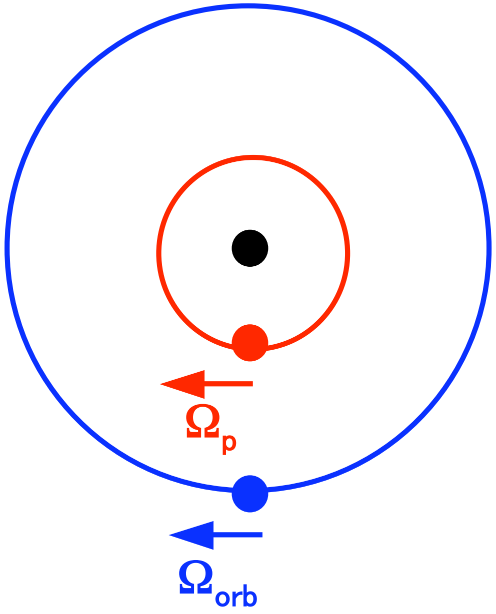
  Ω_p commensurate with Ω_{orb}

- radial location of resonances:

$$k\ \Omega_p = m\ \Omega_{orb}$$

$$R/a=(k/m)^{2/3}(1+q)^{-1/3}$$

- strongest - low order resonances

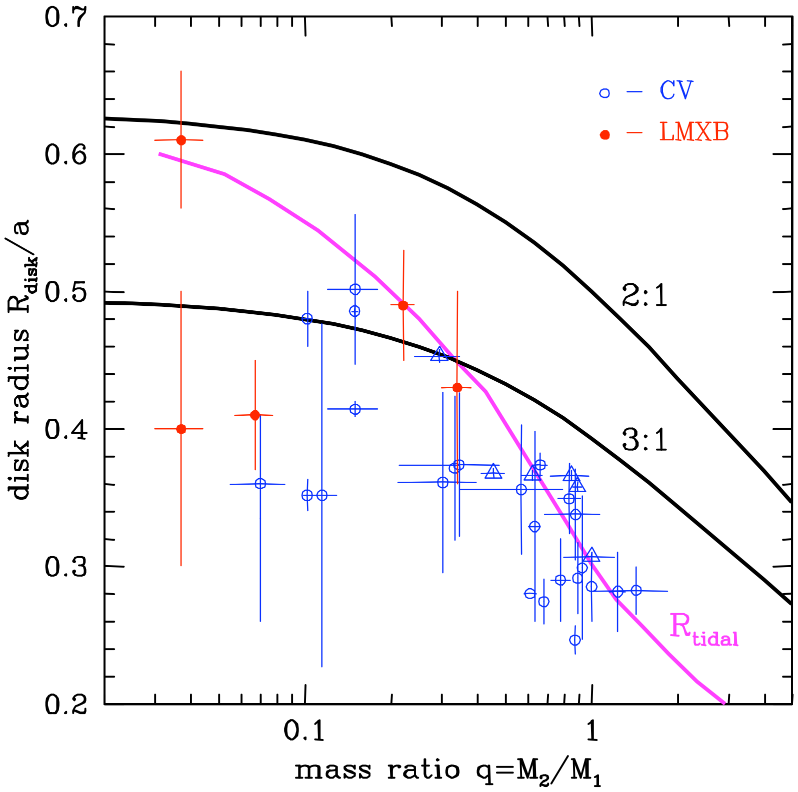


Tidal resonances

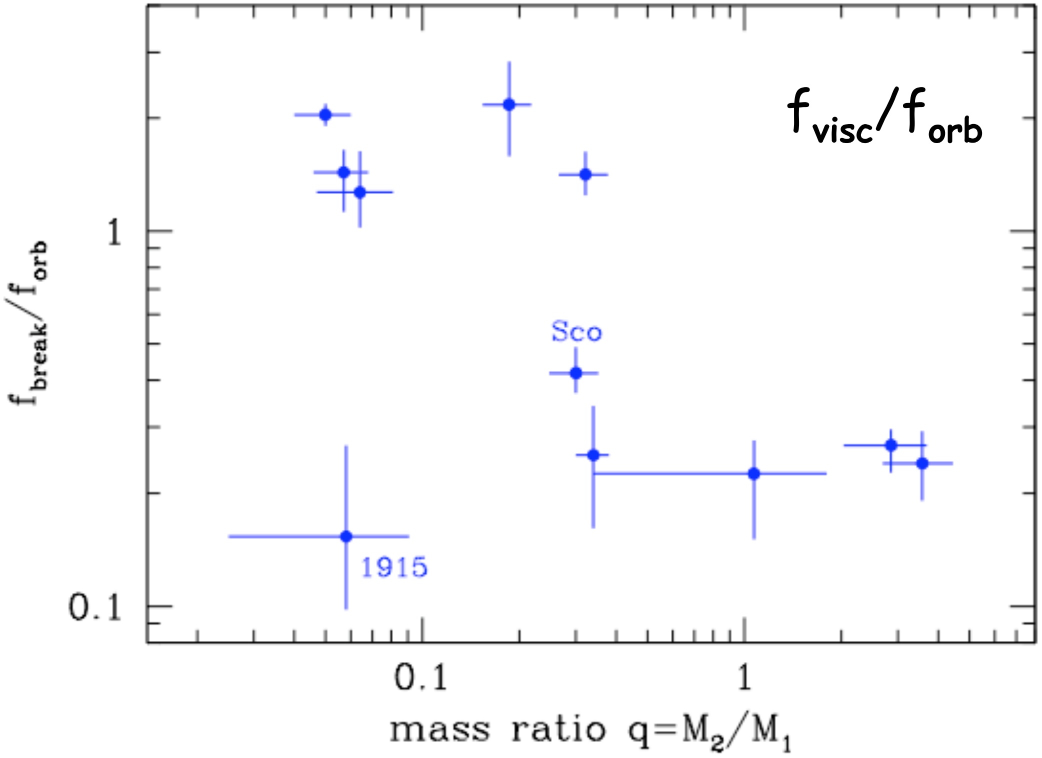
- disk extends to the resonance radius
- 2:1 resonance: $q<0.02$
- 3:1 resonance: $q<0.35$

- superhumps in CVs and LMXBs incl. 4U1916-053

  Whitehurst & King; Lubow; Truss et al.
  Callanan et al., 1995; Haswell et al., 2001



Tidal resonances

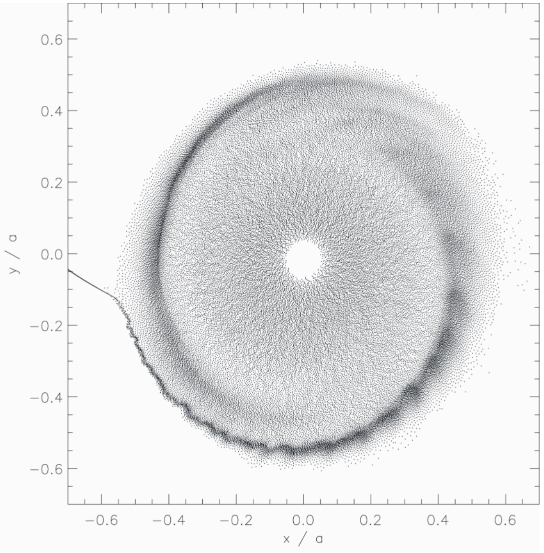


3:1 resonance: $q<0.35$

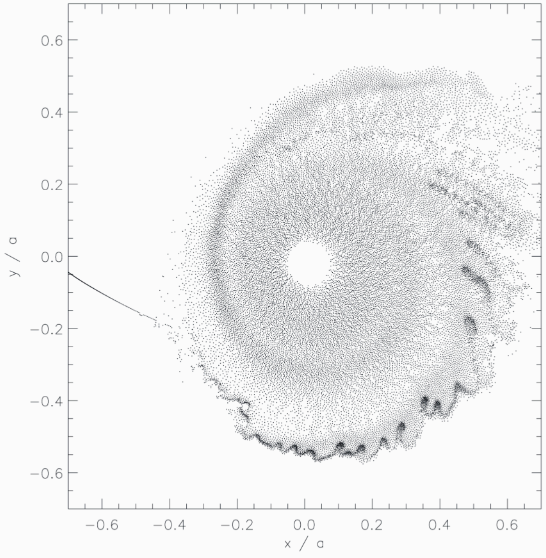
SPH simulations

q=0.07

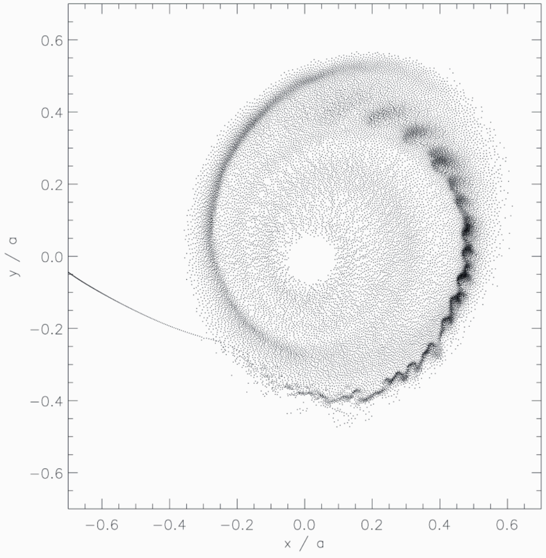
t=6 Porb



t=90 Porb



t=190 Porb



From Truss et al., 2002

Tidal resonances and viscous time scale

- mass transfer in tidal waves
- extra heating in the outer disk by tidal forces
- non-trivial definition of the t_{visc} for an eccentric precessing disk

GRS1915+105

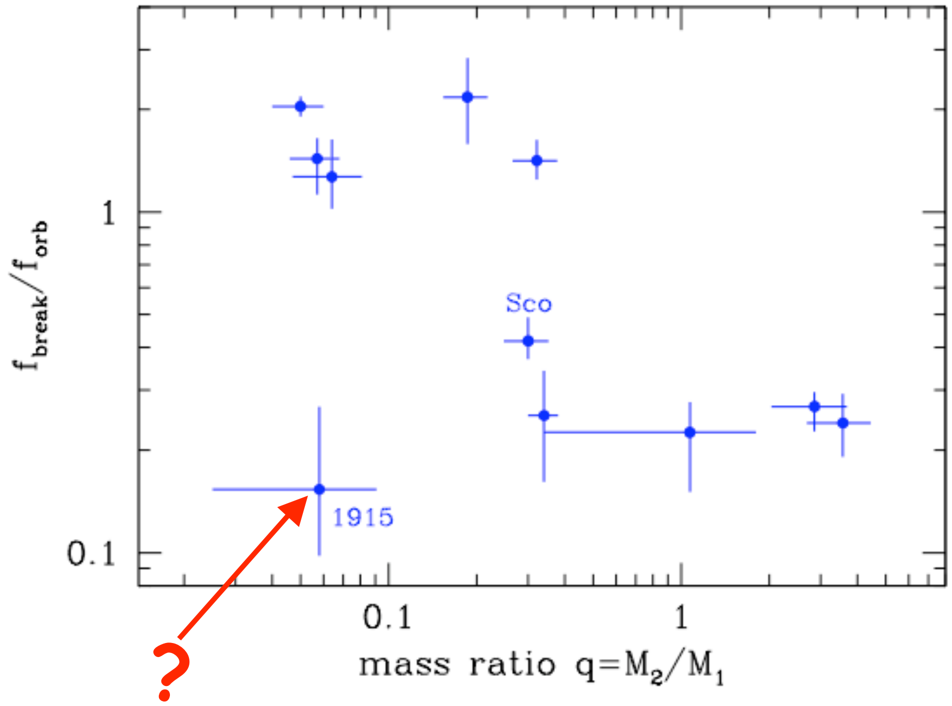
transient source:

- $R_{disk} \sim R_{circ} < R_{res}$
  cf. CVs - no superhumps in normal outbursts

- tidal instab. growth time
  (Whitehurst & King, 1991; Lubow, 1991)

  $\tau \geq 10^2 P_{orb} \sim 10$ yrs

$f_{visc}/f_{orb}=P_{orb}/t_{visc}$



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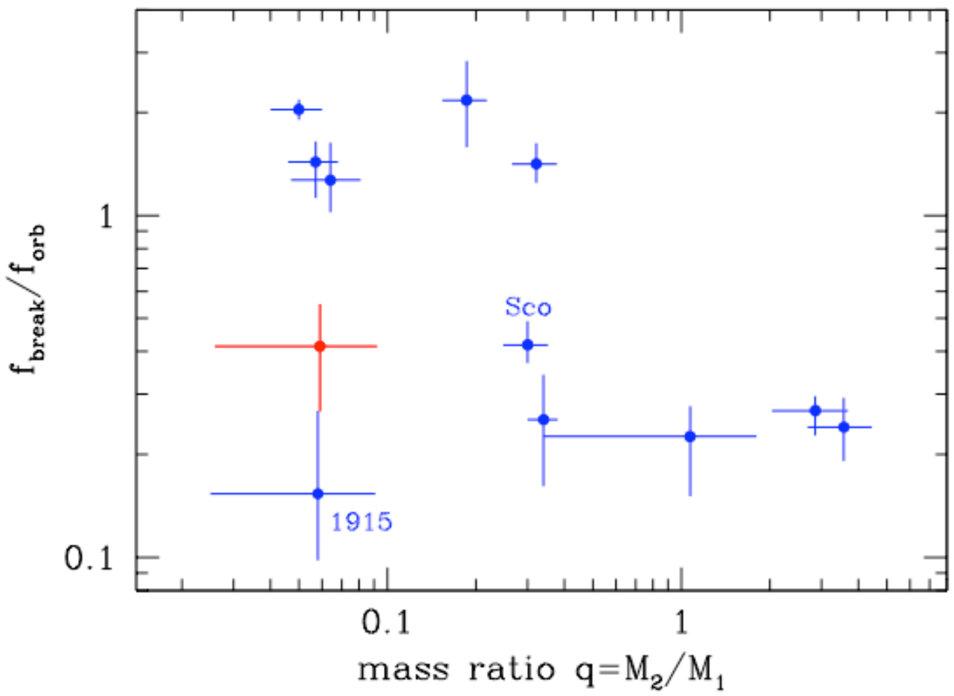


Marat Gilfanov

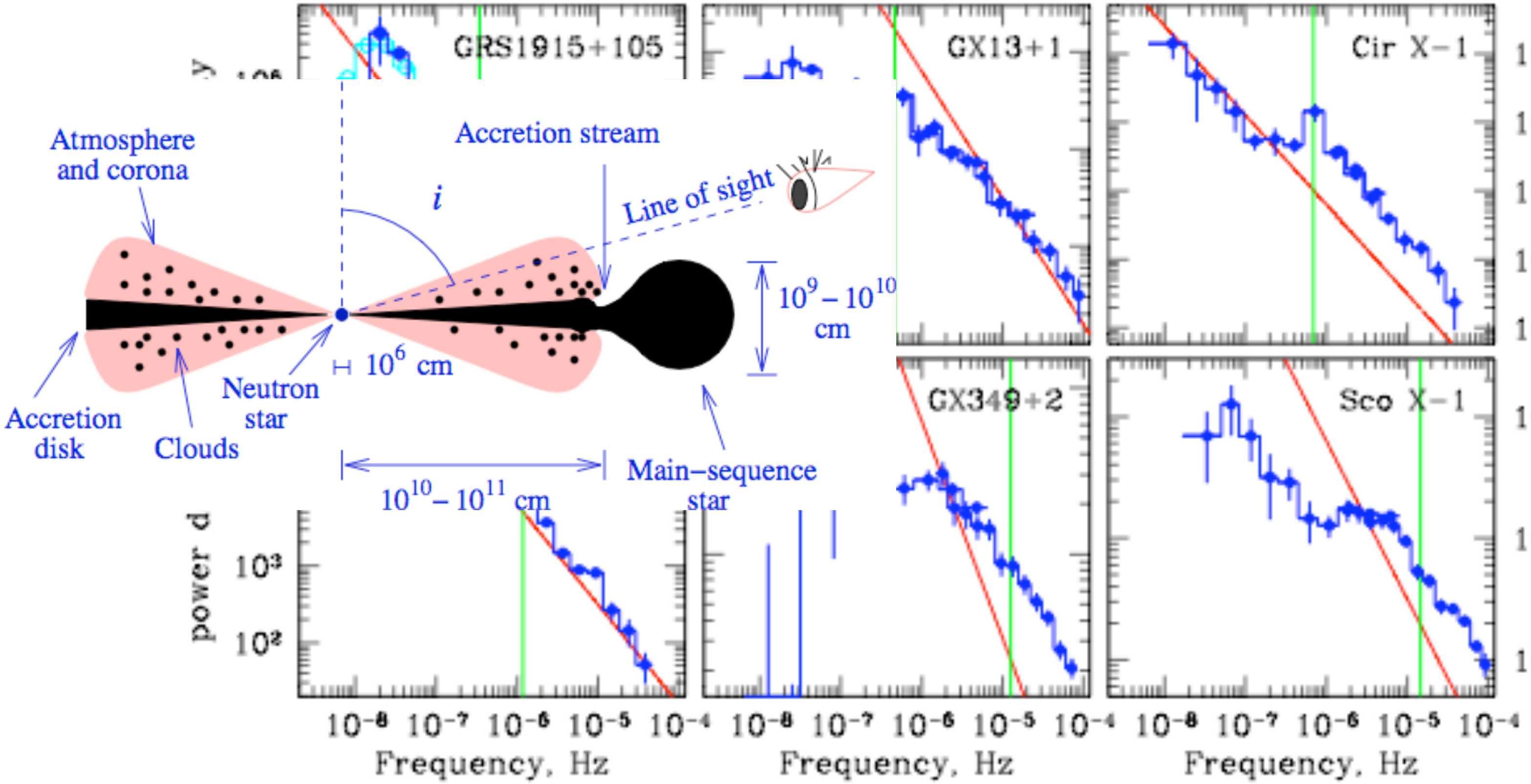
Funäsdalen, 27/03/2008

Conclusions

- features in PDS due to viscous time of the disk
- coronal flow with H/R~0.1
  M_{dot}(corona) ~ M_{dot}(disk)
- 3:1 Lindblad resonances in small-q systems

The End

Geometrically thin disk



Geometrically thin disk