Numerical Simulations of Accretion-Ejection around Compact Objects: What to include (and what not to)?

P1. Study of Accretion

Ayan Bhattacharjee

UNIST

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Contact: ayan@unist.ac.kr

Why Accretion? How can it affect Gravitational Waves?

GW Emission from Accretion Disk

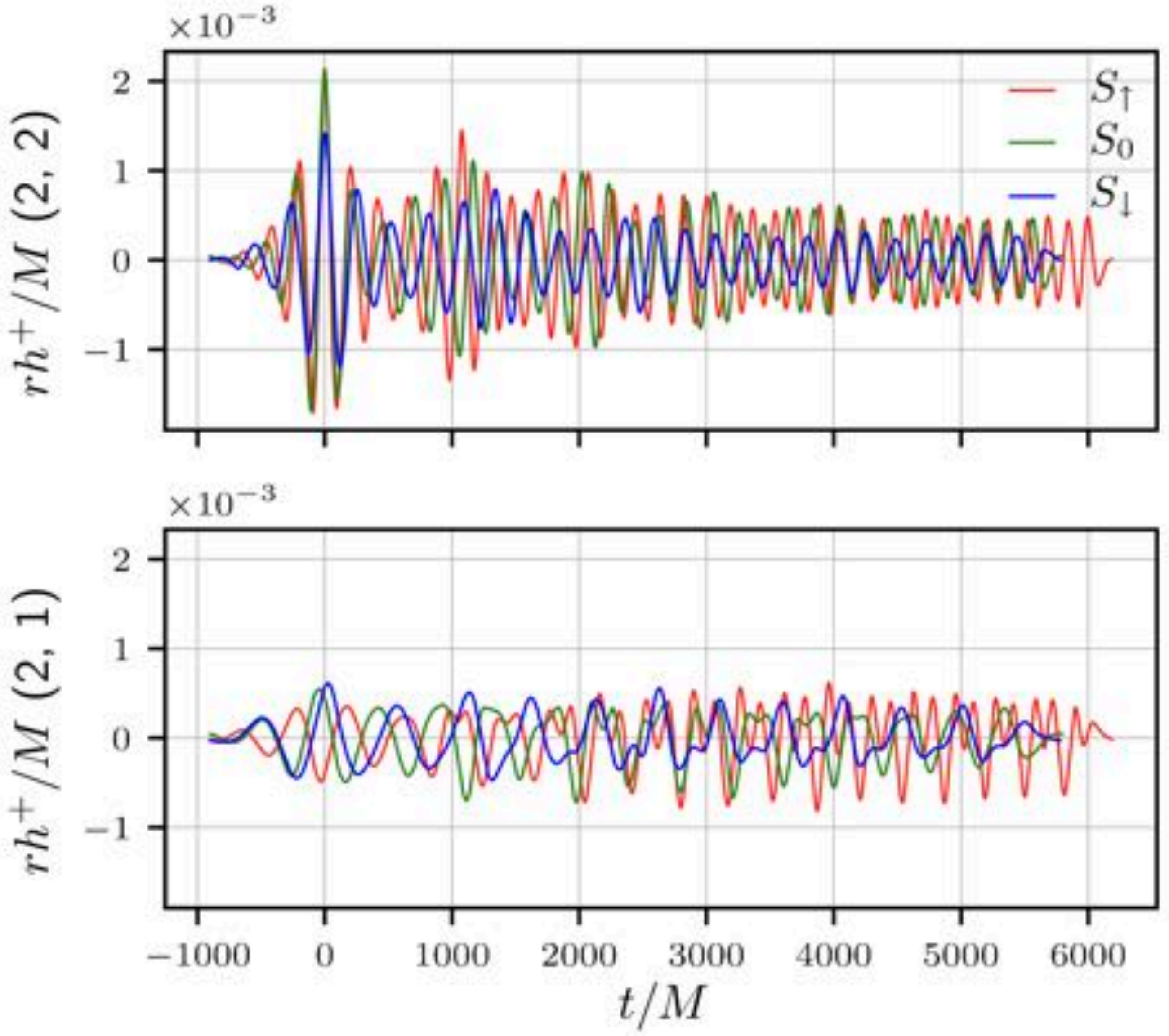


FIG. 8. Strain waveforms for the $l = 2$, $m = 2$ (top), and $m = 1$ (bottom) radiation multipoles. To ease comparison, phases have been rotated to align at maximum amplitude of the $l = 2$, $m = 2$ mode.

Erik Wessel et al. 2021, Phys. Rev, D., 103, 043013

Modification of Merger GW Signals

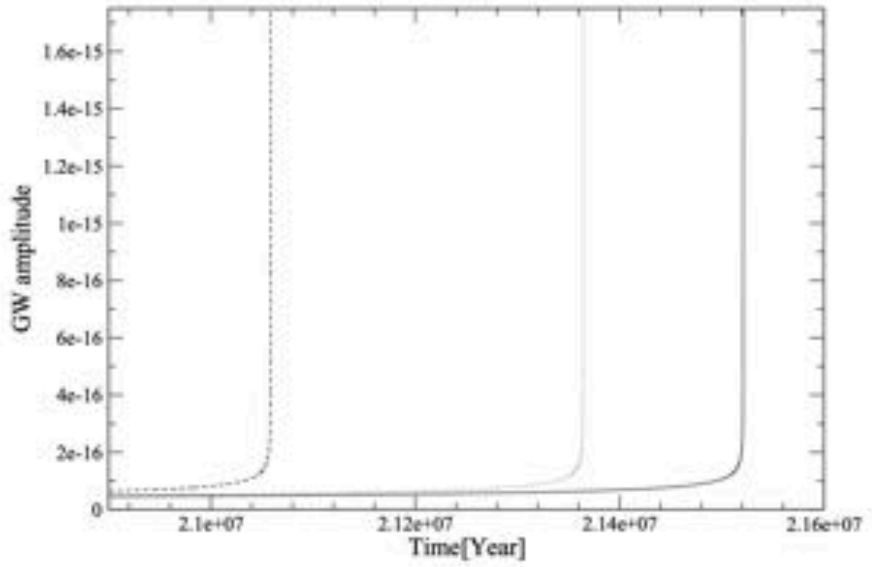


Figure 7. Comparison of the final stages of the chirp amplitude profiles. The solid curve represents the case when the accretion disc is absent. The dotted and the dashed curves are for the cases when the primary accretion rate is one solar mass per year and three solar mass per year, respectively. The coalescence takes place much faster when the disc is present.

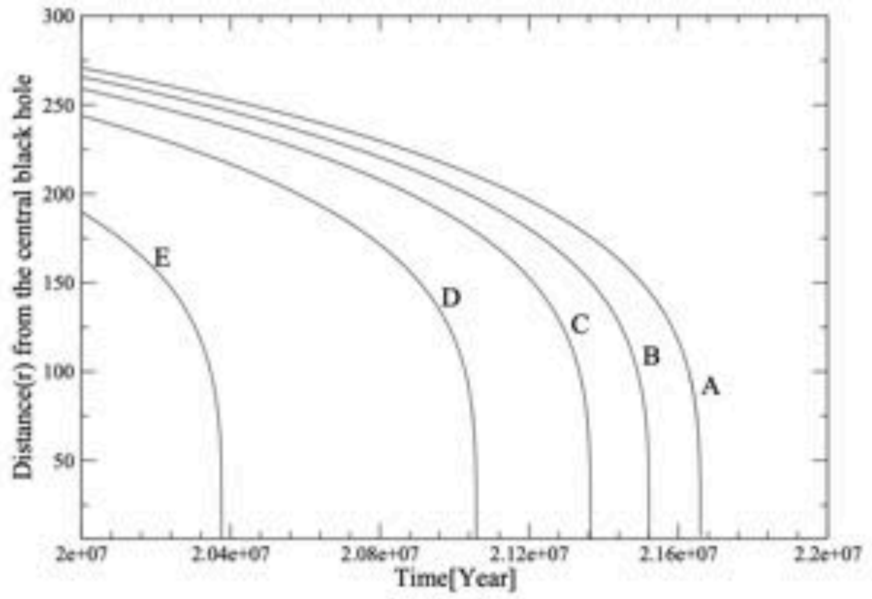


Figure 8. Time taken by the companion for coalescence as a function of the radial distance from the centre. Curves (A) and (B) are drawn without the disc for Kerr parameter $a = 0$ and 0.5, respectively. Curves (C) and (D) are drawn when the accretion disc is present and the companion is accreting at Bondi rates corresponding to, respectively, 1 and 3 $M_\odot\,yr^{-1}$ accretion rates on the primary. The curve (E) is drawn when the companion is accreting at one Eddington rate. Here, the viscosity parameter $\alpha_\Pi = 0.05$ was chosen.

Basu et el., 2008, MNRAS, 388, 219

Modification of BH Mass due to accretion

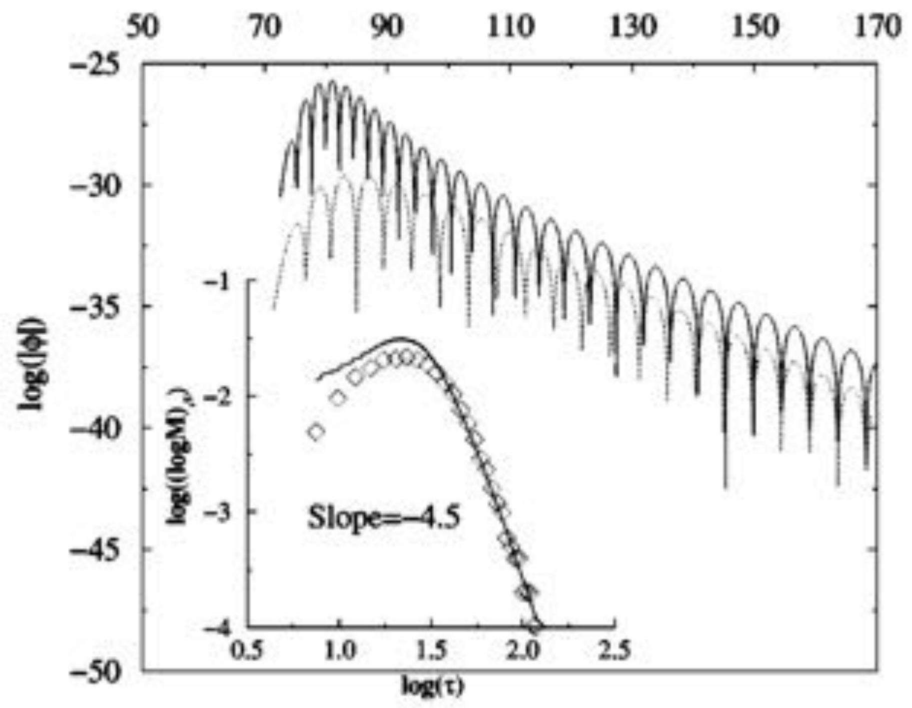
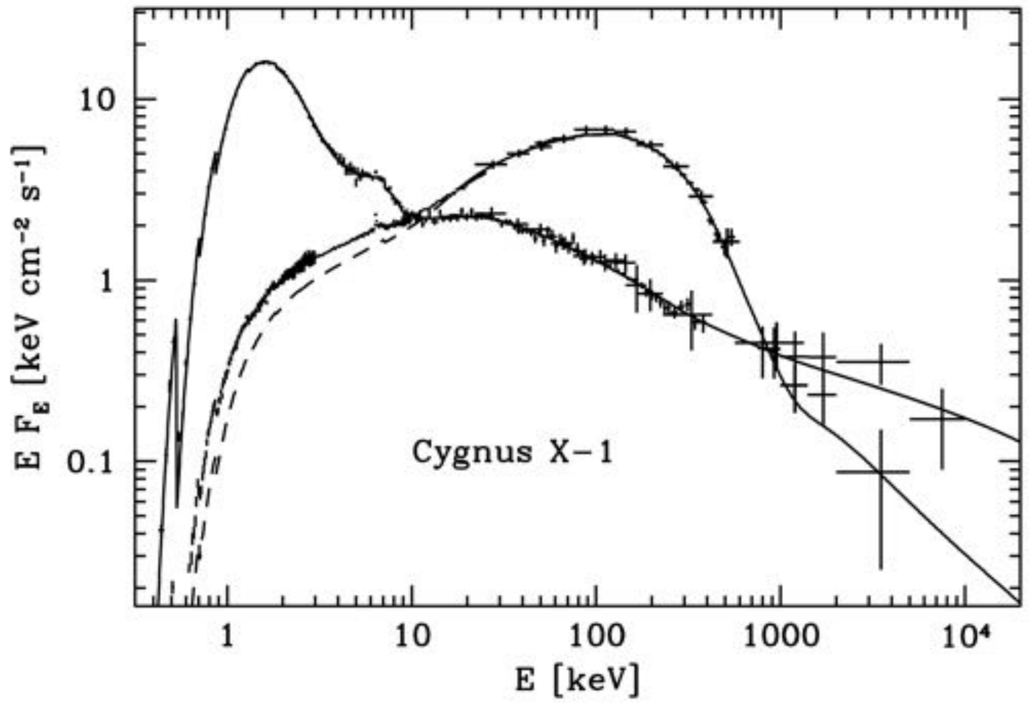


FIG. 3. Typical modulated wave forms and correlations between frequency and accretion rates. The logarithm of the signal is shown as a function of time for an $l = 3$ and $r_c = 15$ simulation (solid line). The dotted line indicates the ringdown of a *vacuum* black hole with $M = 1$. The decay rate modulation is particularly evident here. We have not analyzed this effect quantitatively. The inset shows the late time behavior of the signal frequency in correlation with the accretion rate, as a function of time (same simulation) The solid line depicts the evolution of the accretion rate $d\log(M)/d\tau$ versus observer time τ. That quantity is derived from the location of the horizon and is governed directly by the amount of inflowing fluid. Overlayed on the mass accretion rate is the logarithmic time derivative of the signal frequency. At late times the accretion flow leads to a power law slope (in this case the slope equals −4.5) and we find that the ISF curve itself follows a power law of the same slope.

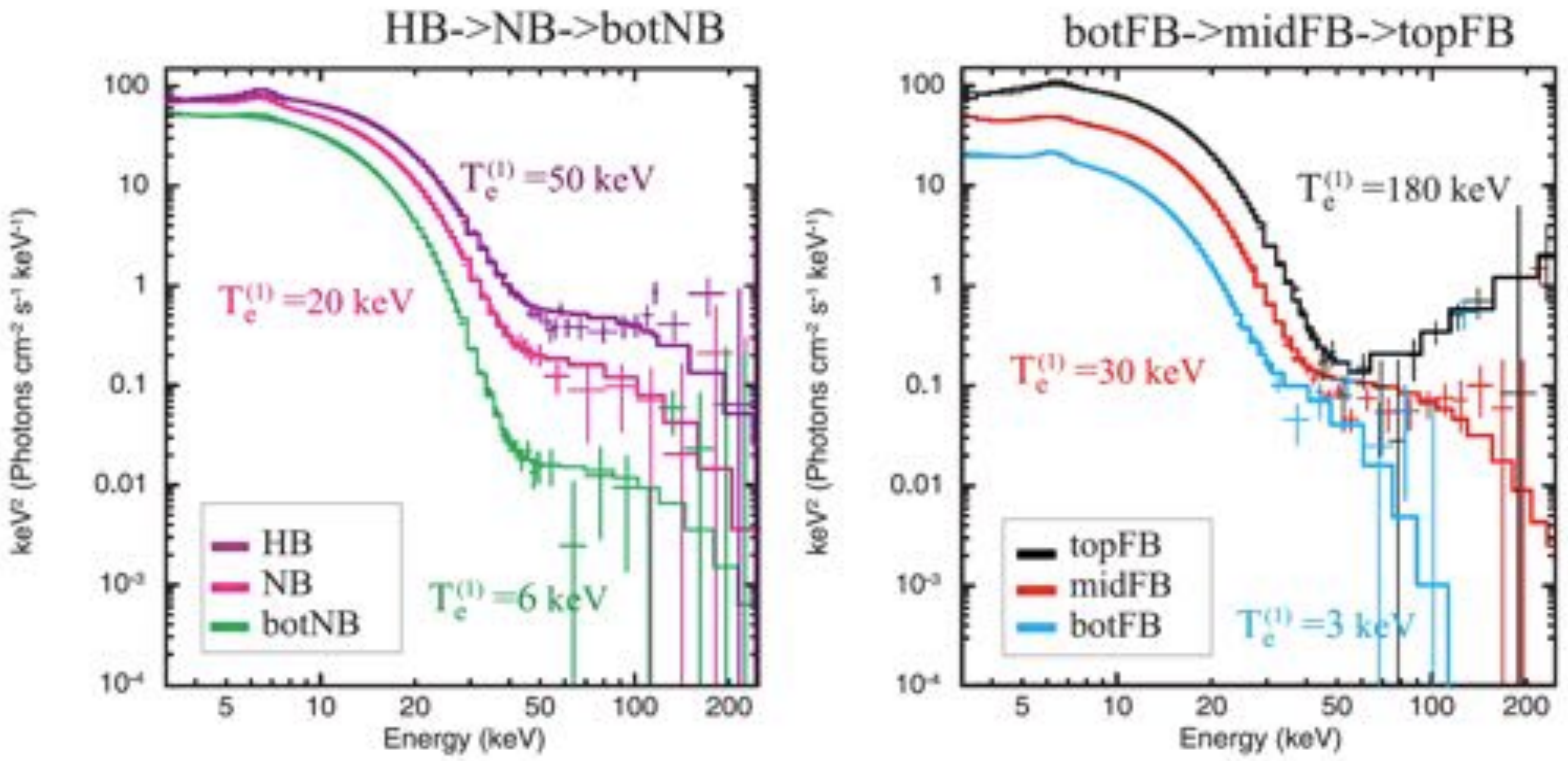
Papadopoulos & Font, 2001, Phys. Rev. D., 63, 044016

Why ‘unified model’? A. Spectral Properties

Cygnus X-1

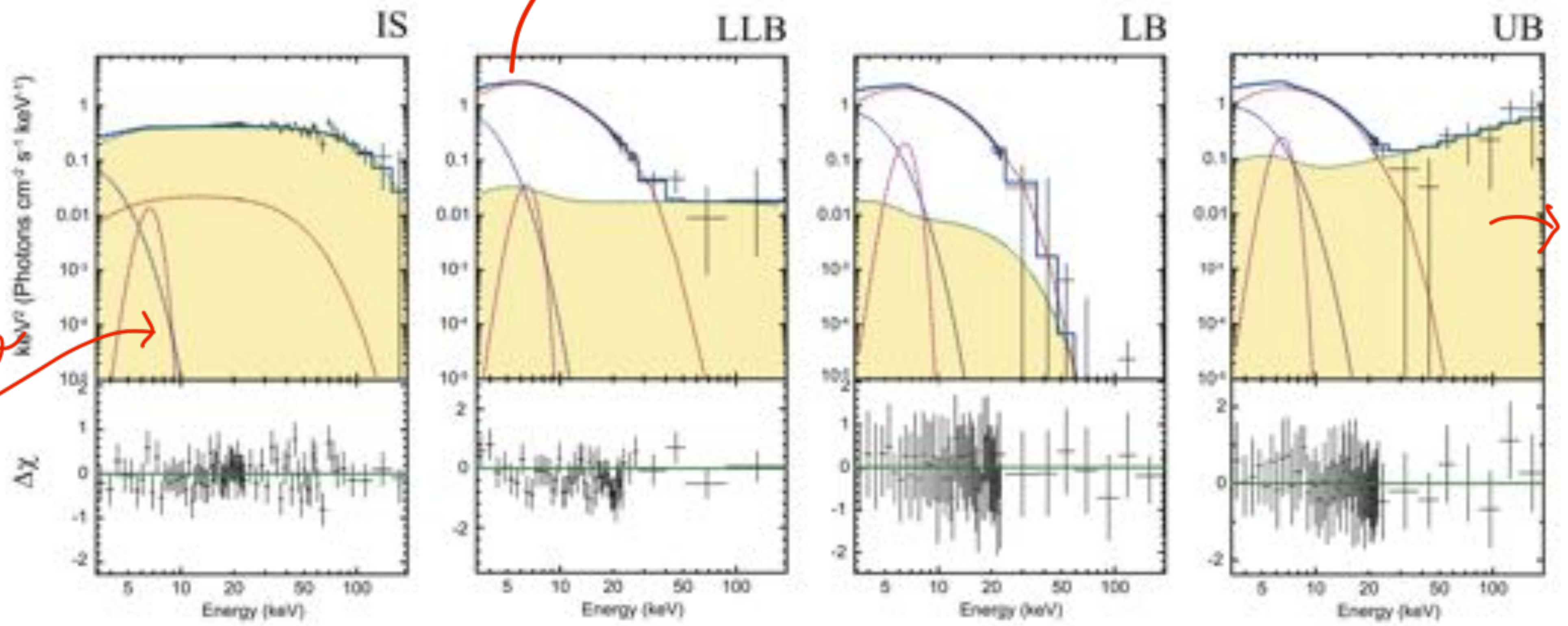


McConnell *et al.,* 2002, ApJ*,* 572 984



Scorpius X-1

→ From NS



Fe line →

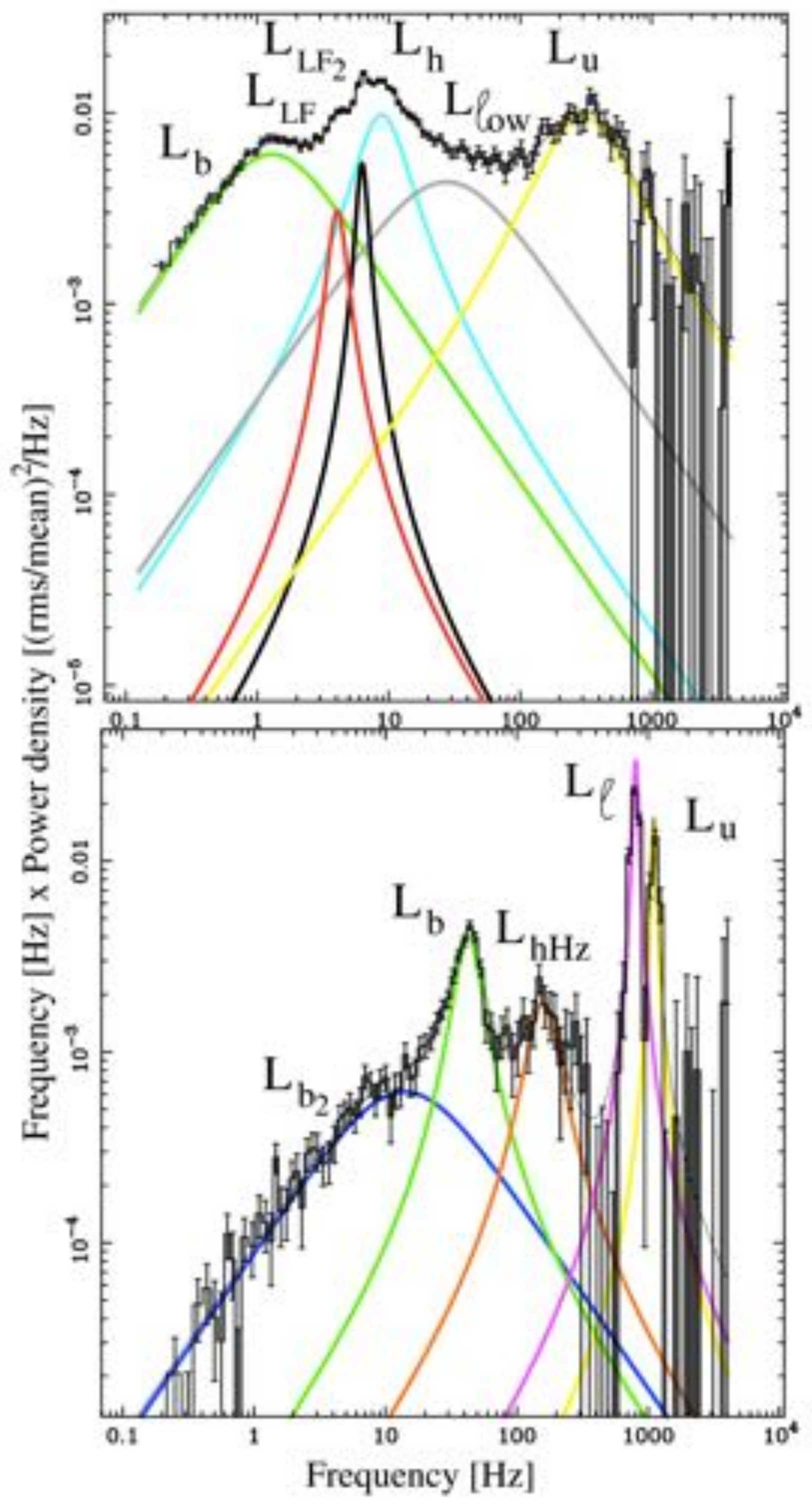
→ from disk

4U 1705-44

Seifina, Titarchuk, Shrader, et al. 2015, ApJ, 808, 142

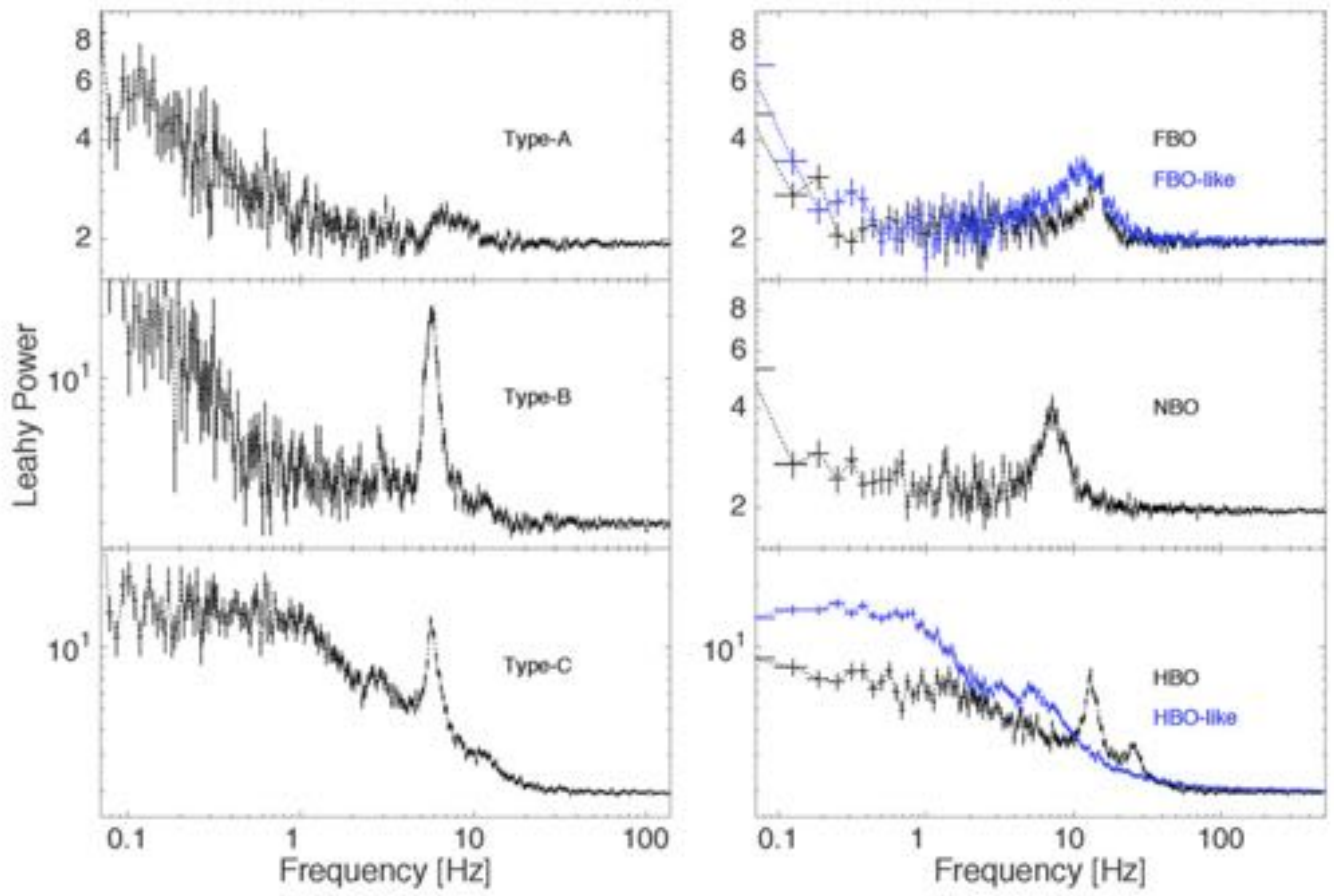
Why ‘unified model’? B. Timing Properties

High-frequency QPO



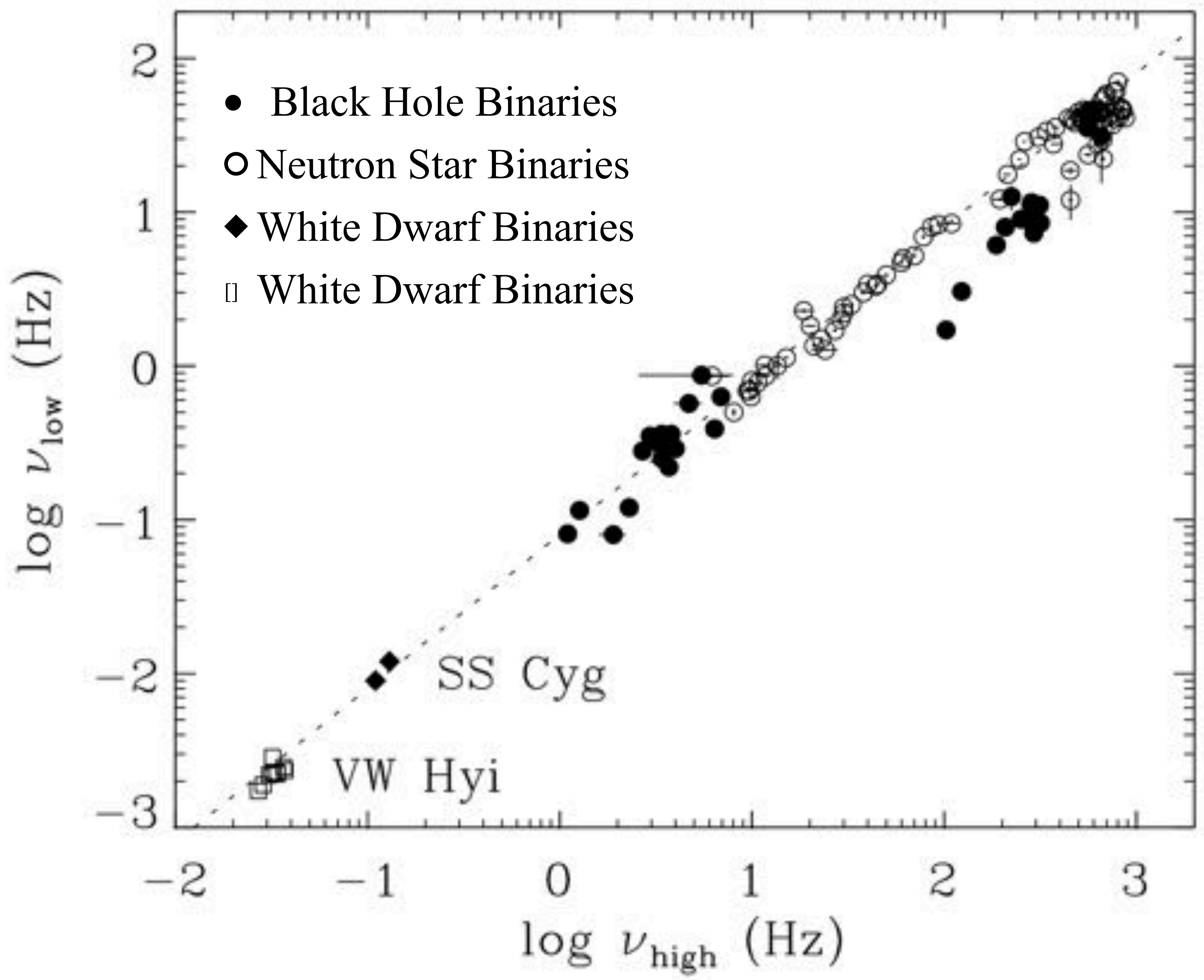
Van Doesburgh, van der Klis, 2017, MNRAS, 465, 3581

Low-frequency QPO



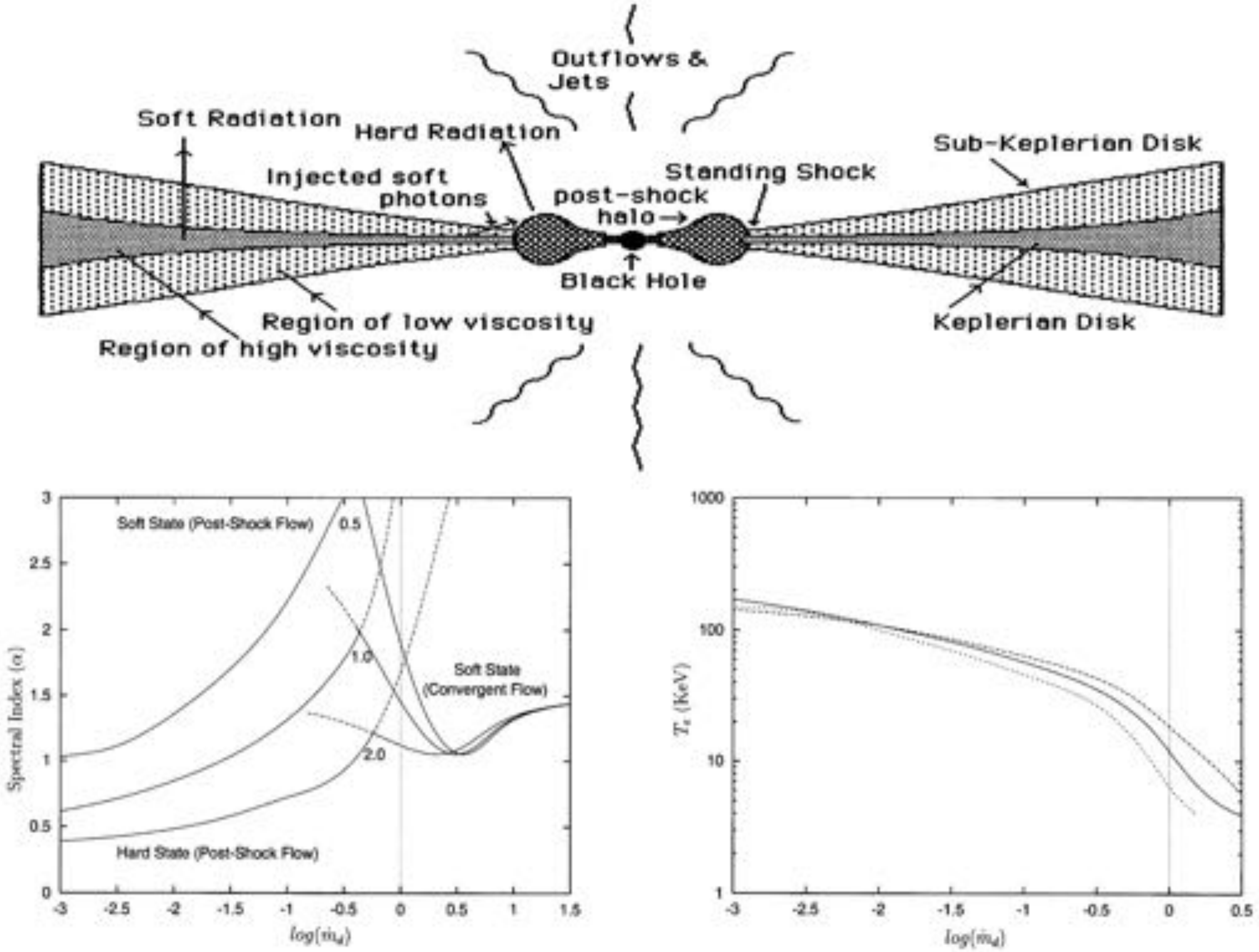
Motta et al. 2017, MNRAS, 468, 2311

ν_{low}-ν_{high} Correlation

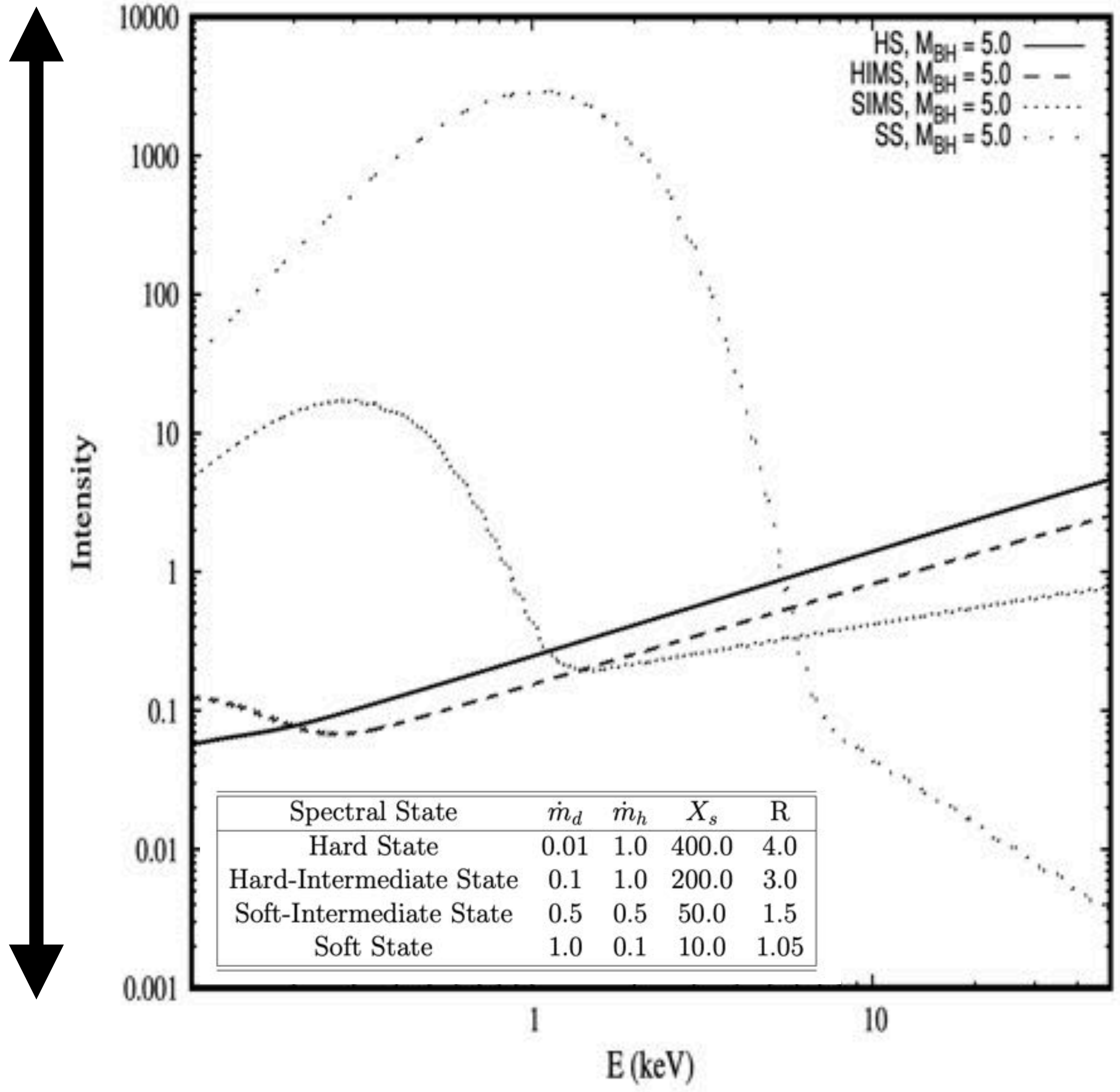


Mauche, 2002, ApJ, 580, 423

What is ‘Two-Component Advective Flow’?



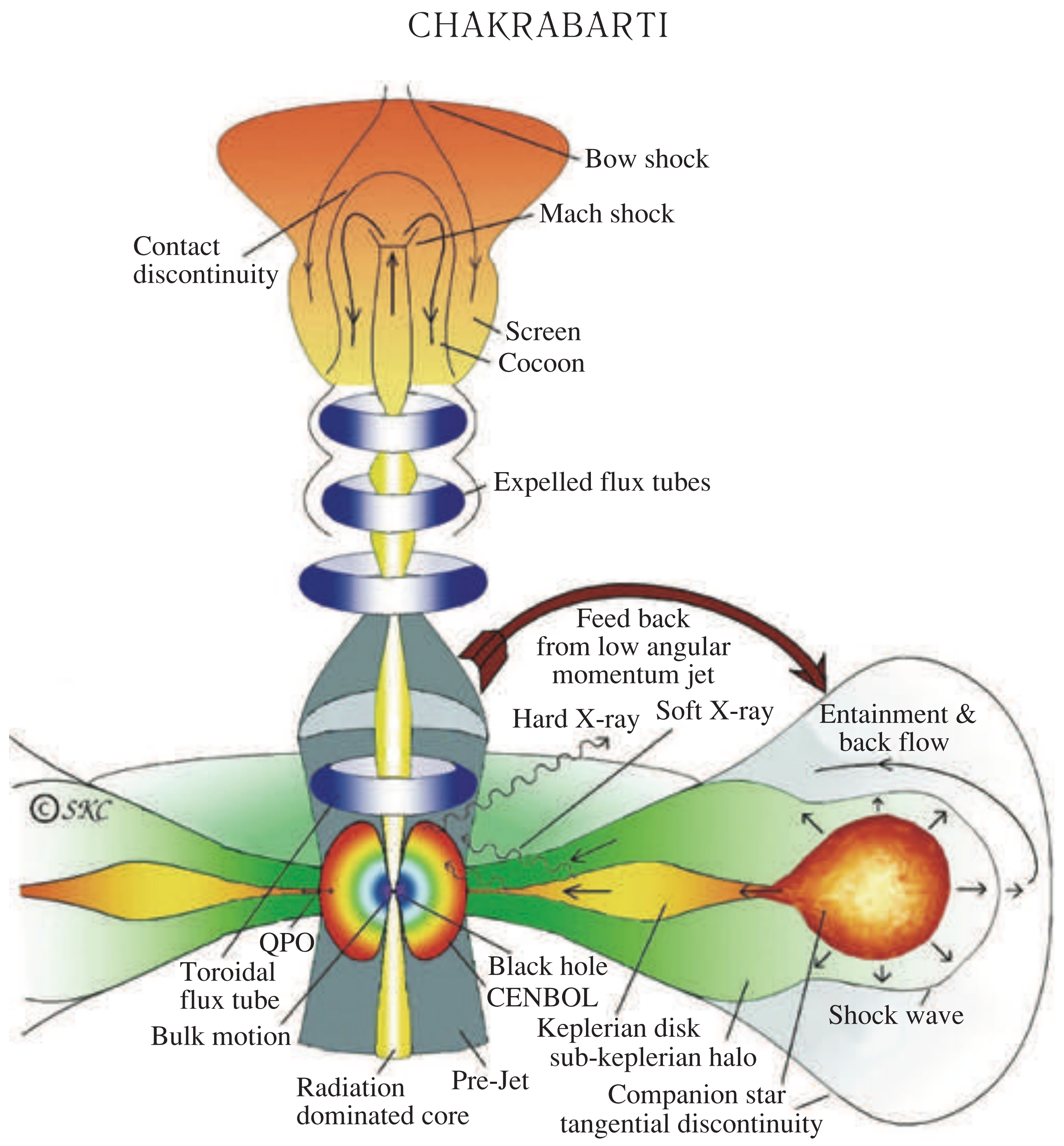
Chakrabarti and Titarchuk, 1995, ApJ, 455, 623



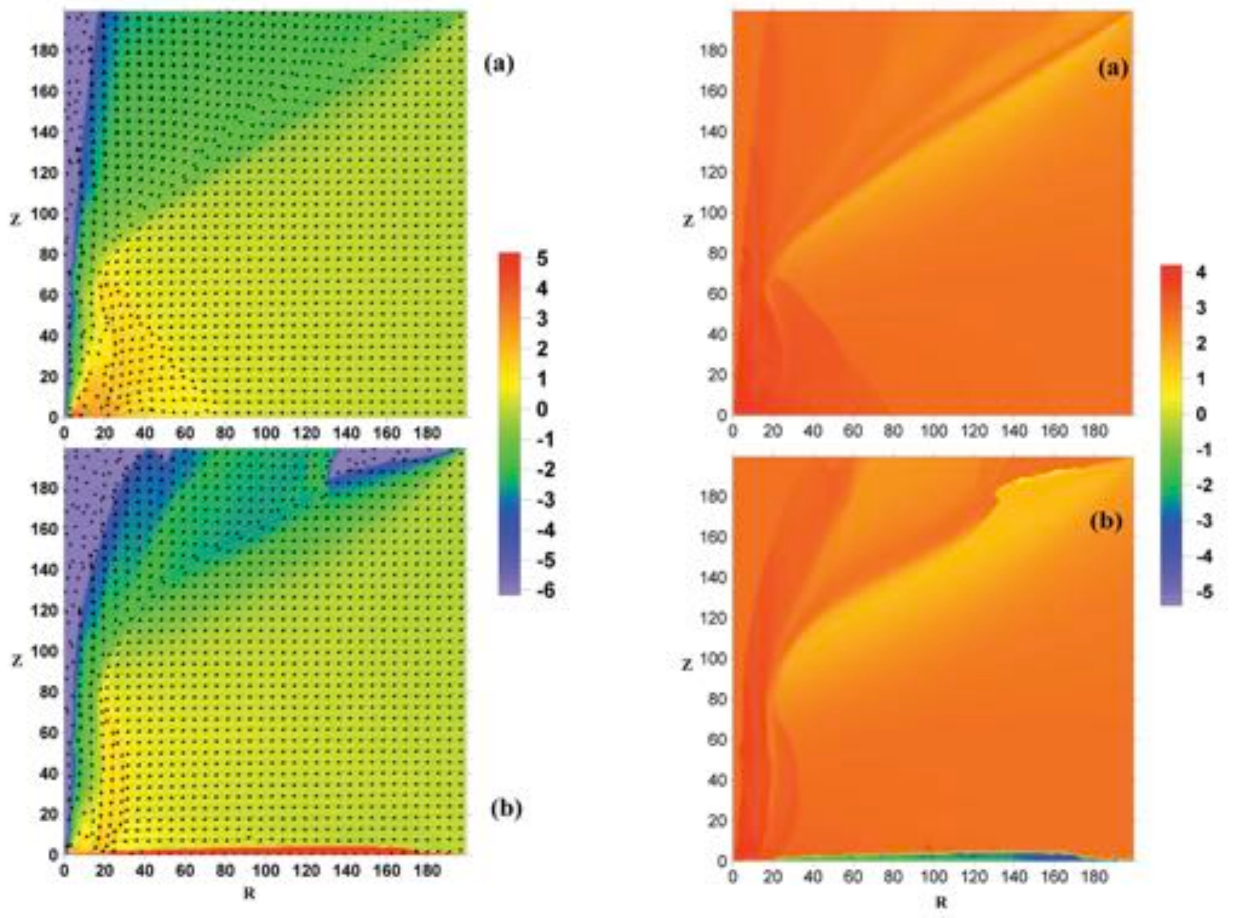
Spectral State	$\dot{m}_d$	$\dot{m}_h$	X_s	R
Hard State	0.01	1.0	400.0	4.0
Hard-Intermediate State	0.1	1.0	200.0	3.0
Soft-Intermediate State	0.5	0.5	50.0	1.5
Soft State	1.0	0.1	10.0	1.05

0.1-50.0keV

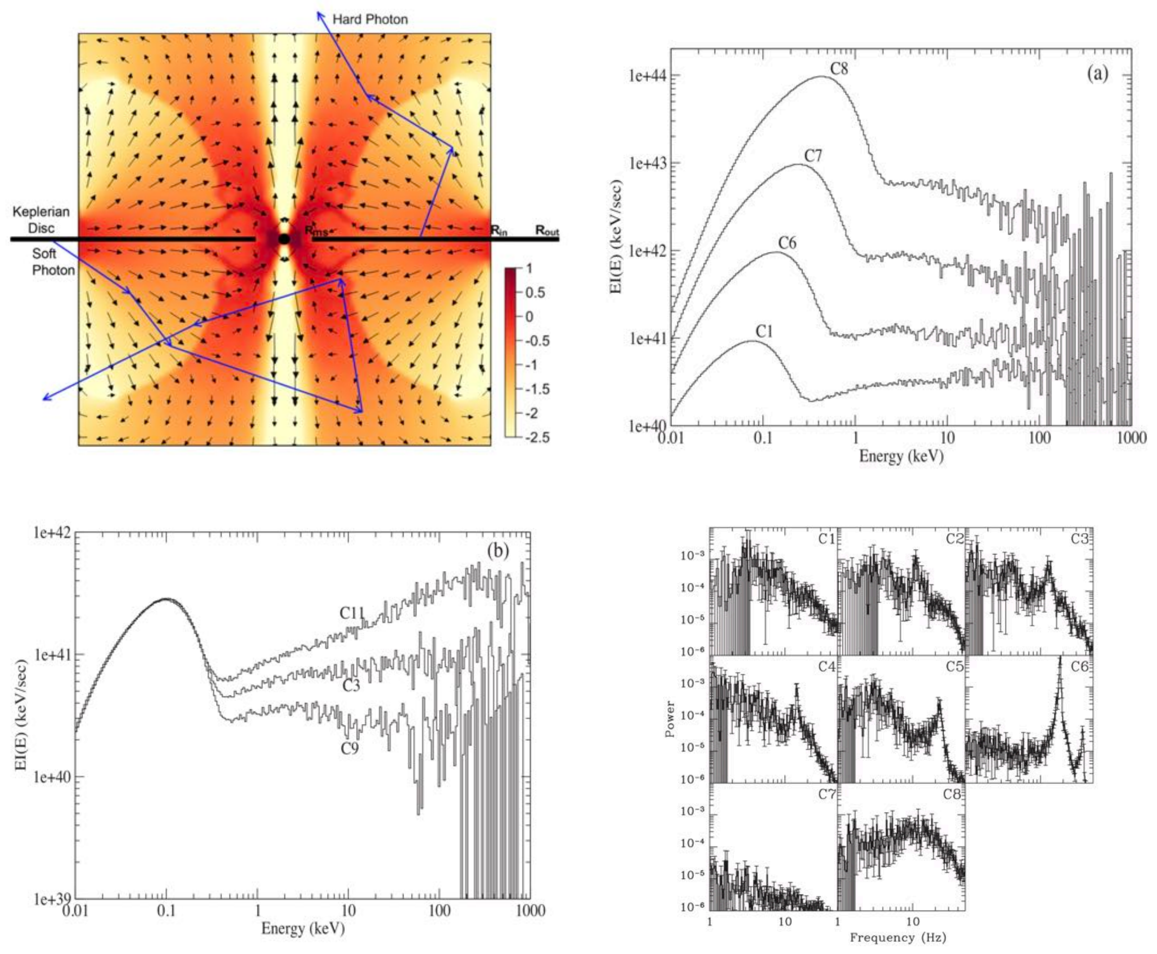
What is 'Two-Component Advective Flow'/TCAF?



Chakrabarti, 2015, Whither TCAF?, arXiv: 1509.00565



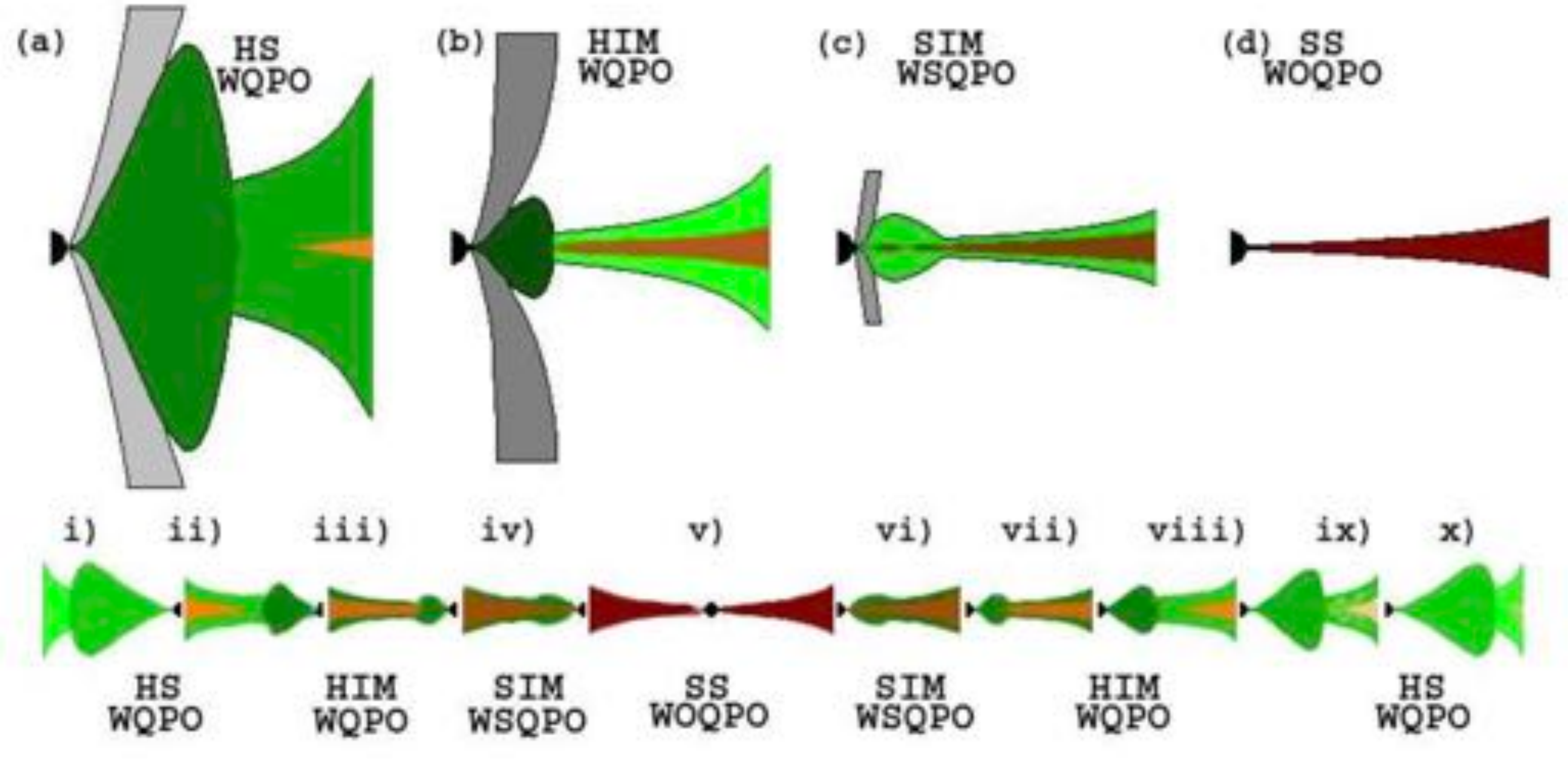
Giri, K., and Chakrabarti, S.K., 2013, MNRAS, 430, 2836



Garain, S., Ghosh, H., and Chakrabarti, S.K., 2014, MNRAS, 437, 1329

1. Accretion around black holes occur through two components: a thin Keplerian disk which emits blackbody radiation; a thick radiatively inefficient sub-Keplerian disk.
2. Numerical simulations confirm the formation of such structures.
3. Temporal features such as QPOs can also be explained through this.

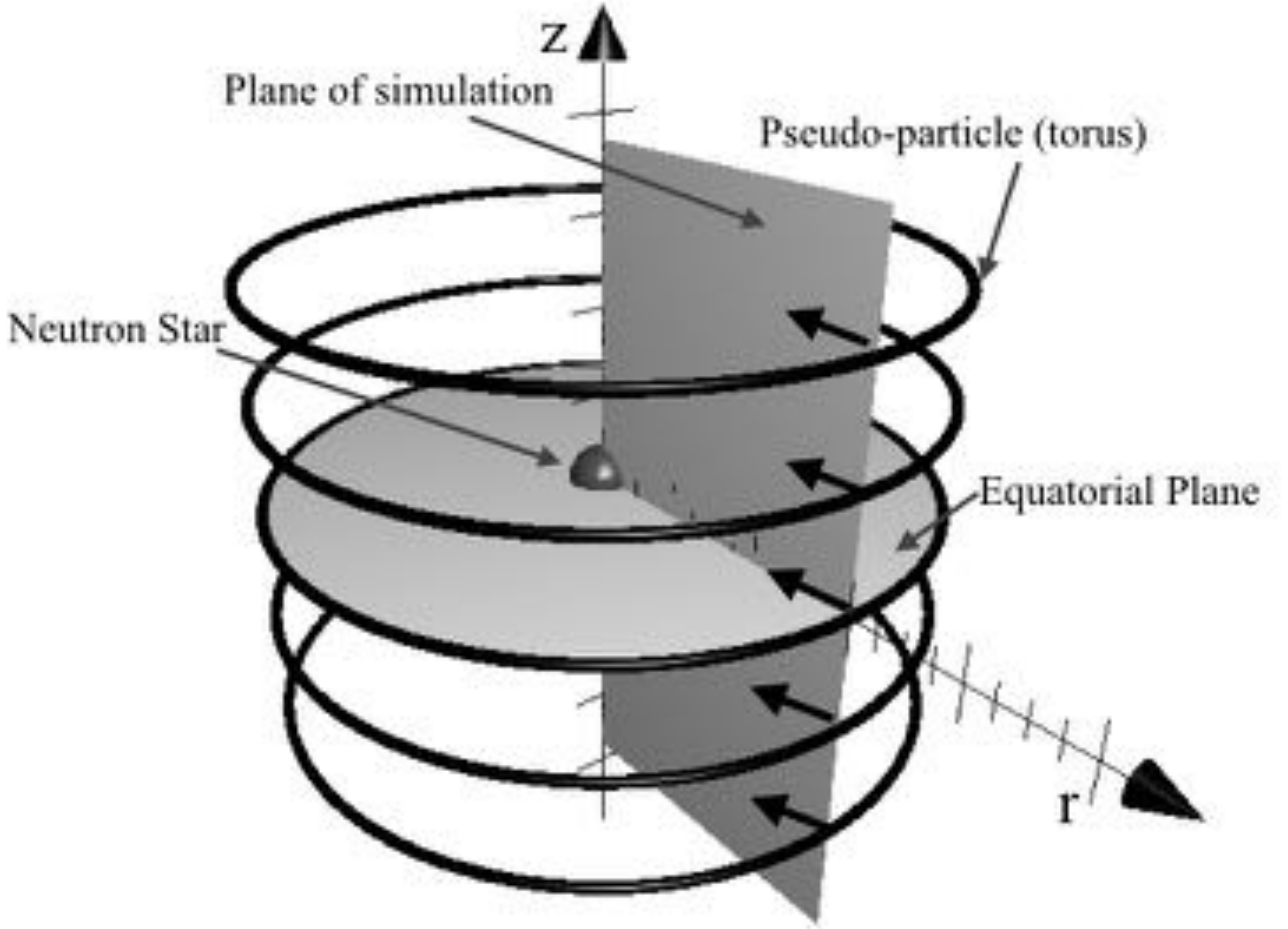
How does TCAF explain the spectra and timing?



1. Spectral states and timing features are connected. Both can be explained by the TCAF parameters: $\dot{m}_d, \dot{m}_h, X_s, R$
2. Interplay of $\dot{m}_d, \dot{m}_h$ leads to formation, oscillation and motion of the shock, which in turn controls the Comptonization.
3. During a rising phase of outburst, $\dot{m}_d$ rises ($\dot{m}_h$ decreases). Opposite happens during the declining phase.

Chakrabarti, S. K., 2016, Study of Accretion processes Around Black Holes becomes Science: Tell Tale Observational Signatures of Two Component Advective Flows, arXiv:1604.05955

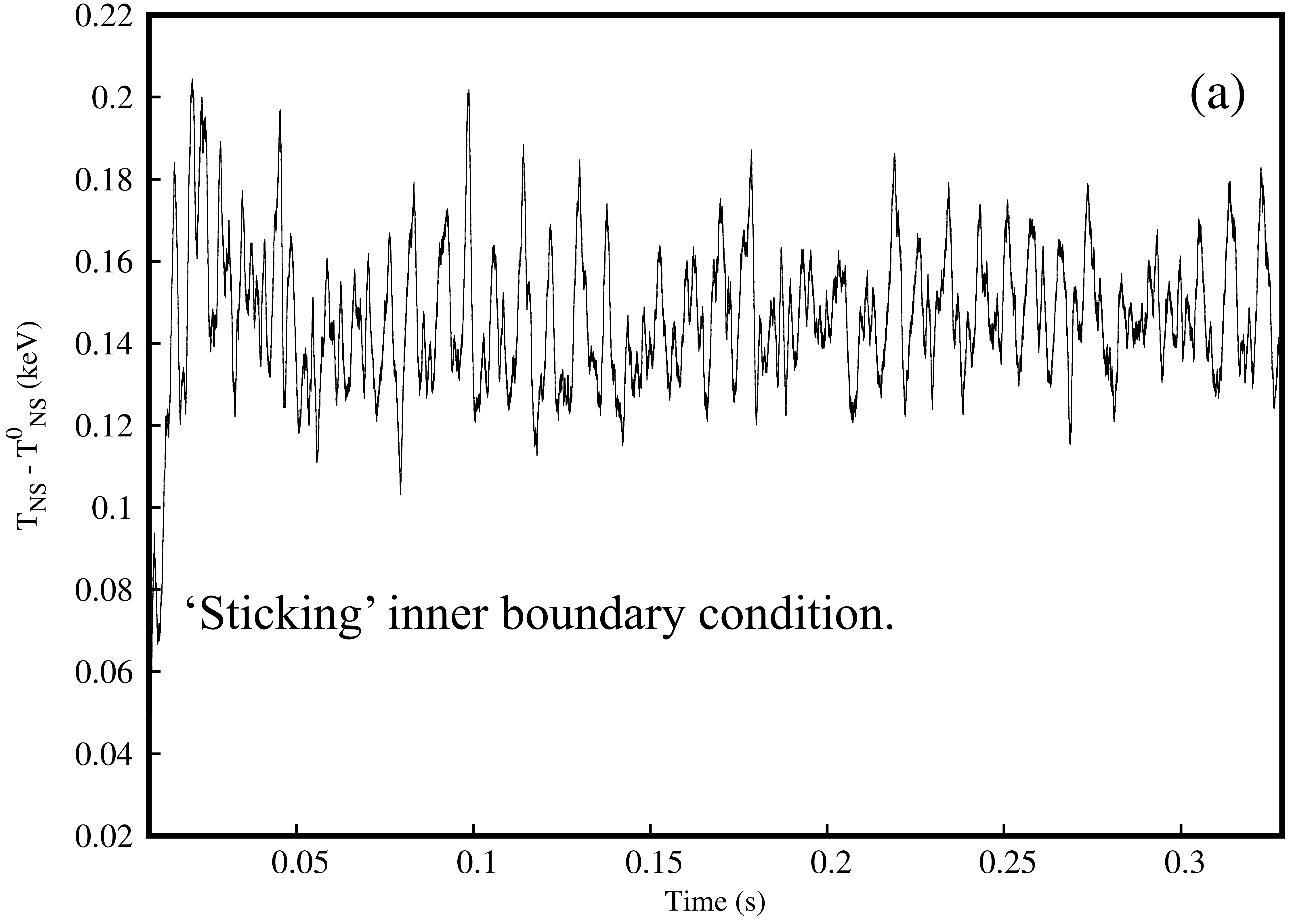
Simulation Setup: Accretion around Neutron Stars



1. Axisymmetric system.
2. Smoothed Particle Hydrodynamics formalism for solving conservation equations.
3. Inner boundary specified by the neutron star surface.

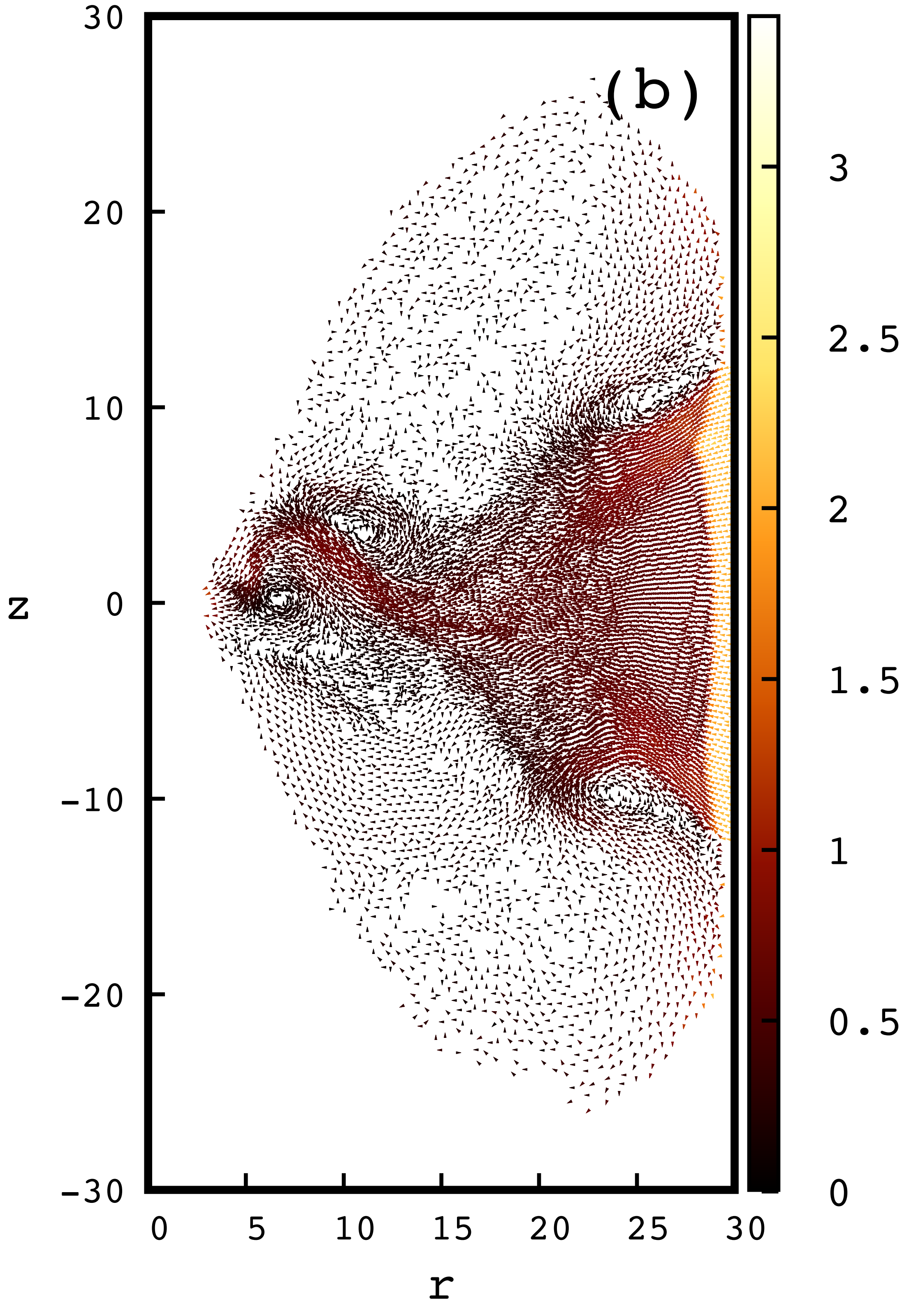
Results: Timing Properties

Surface Temperature



‘Sticking’ inner boundary condition.

Mach Number



1. Variation of T_{NBOL}.
2. Multiple shocks in the flow.
3. Inner part dominated by instability.
4. Ejection from post-shock region.

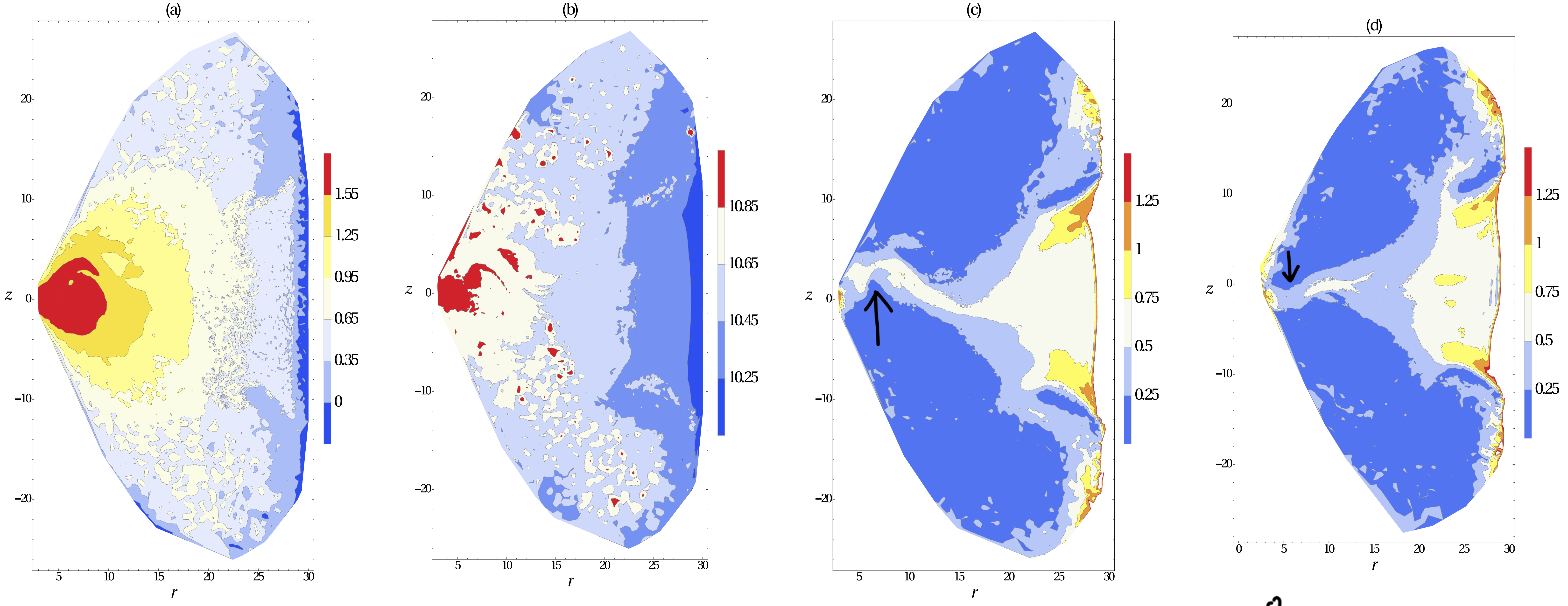
Bhattacharjee and Chakrabarti, 2019, ApJ, 873, 119

Results: Timing Properties

Density

Temperature

Mach Number



$\lambda = 1.8$

1. Rise in density and Temperature in the post-shock region.
2. Vertical oscillation of inner hot region.

Bhattacharjee and Chakrabarti, 2019, ApJ, 873, 119