Shocked advective flows around black holes and associated observational signatures

Chandra Bahadur Singh (SWIFAR-YNU, China)
Toru Okuda (Hokkaido University of Education, Japan)

Collaborators: Ramiz Aktar (NTHU, Taiwan), Junxiang Huang (SWIFAR-YNU, China),
Santanu Mondal (IIA, India), David Garofalo (KSU, USA)

The MG17 meeting, Pescara, July 11, 2024

国家自然科学基金委员会
NSFC

Fundamental concepts of accretion

- Black hole accretion: transonic flow (flow having supersonic to subsonic transition).

- At event horizon, radial velocity is always greater than sound speed hence supersonic.

- While far away from black hole, negligible radial velocity while still having some temperature hence subsonic.

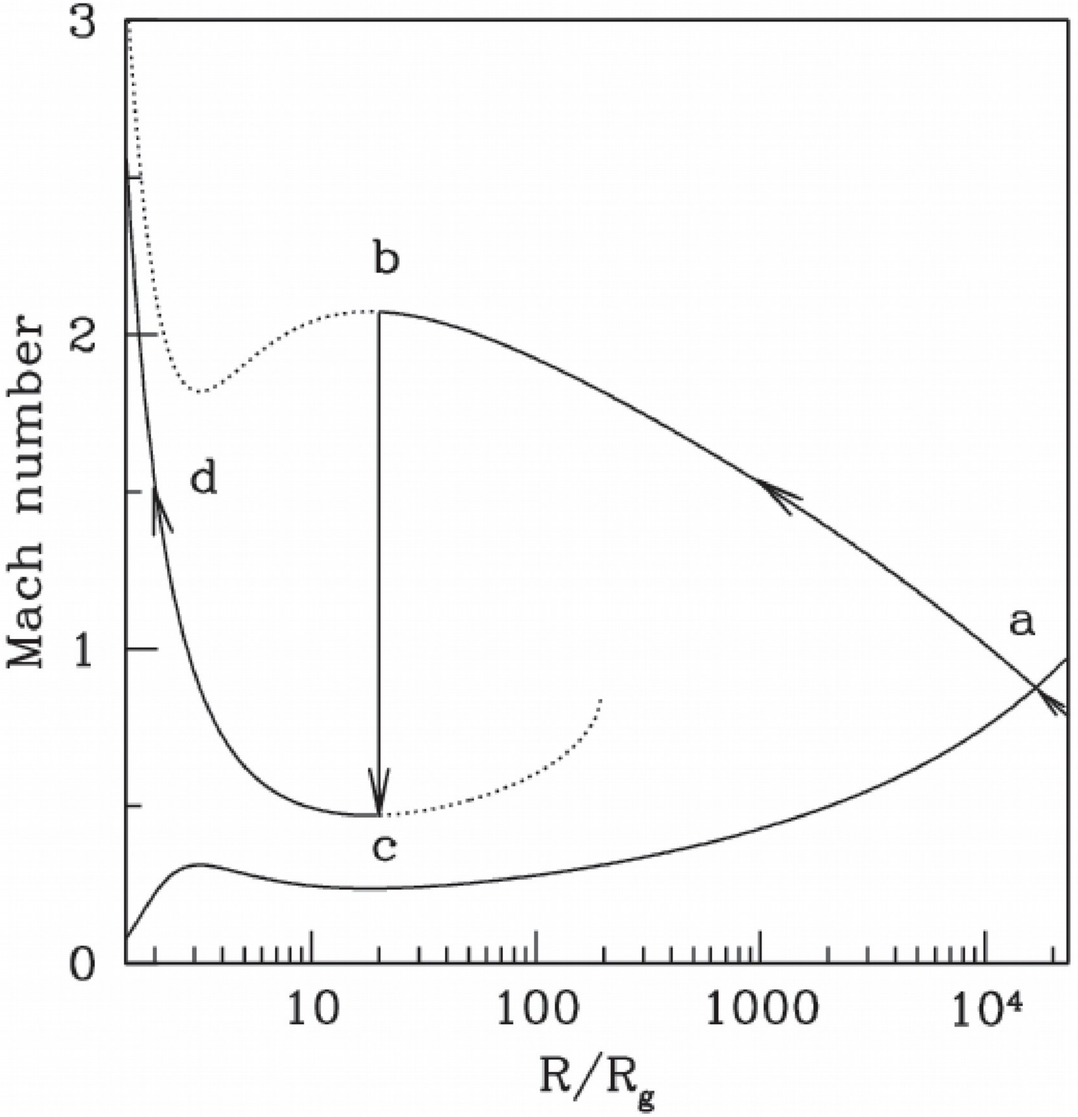
- Flow must pass through at least one sonic point or even more such points.

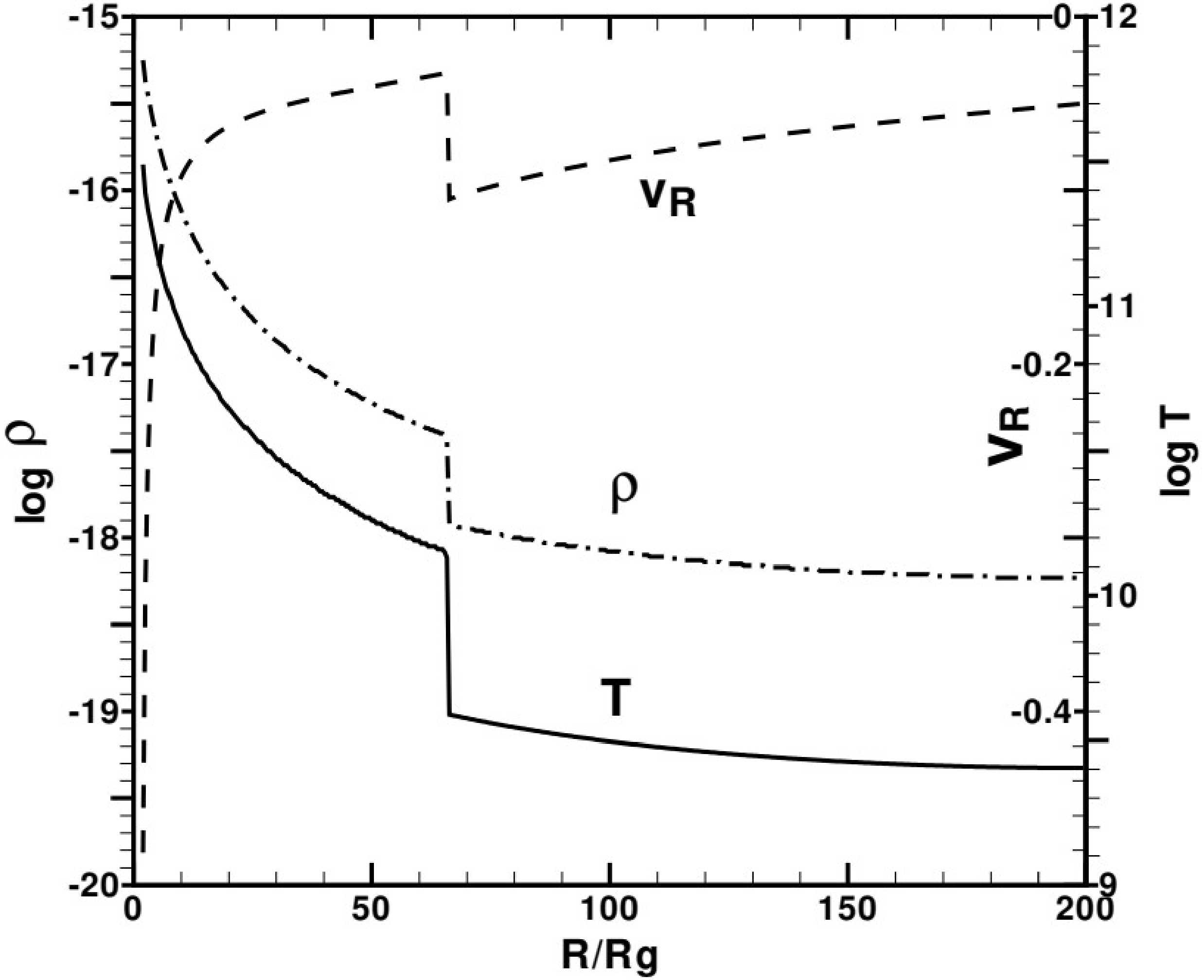
- In case of stars, gas with even a small specific angular momentum cannot fall to a central object as it faces an infinite potential barrier.

- In case of black hole, gravity always wins with terms $\sim -\frac{1}{r^n}$ for all positive integer n while in case of centrifugal force it is just $\sim \frac{1}{r^3}$.

- In presence of multiple sonic points, flow is richer in topological properties and may have one or more dynamically important shocks.

Theoretical and Simulated 2D HD flows

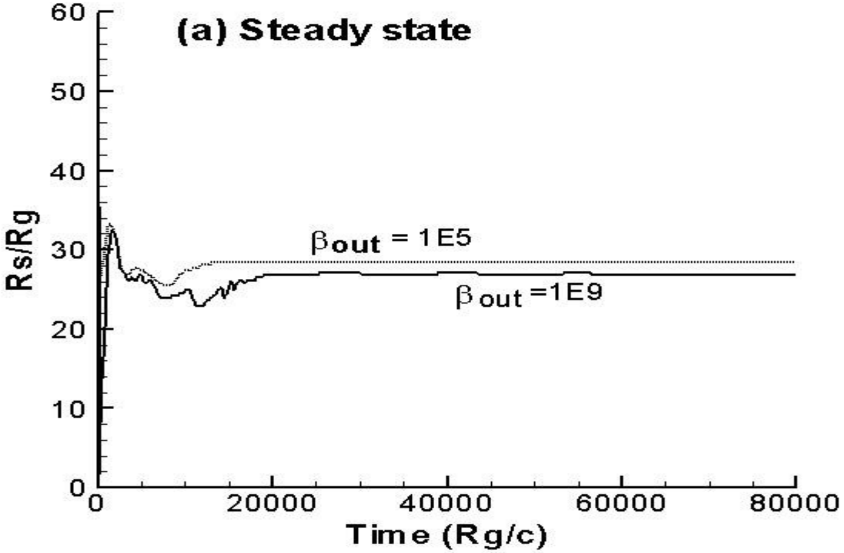


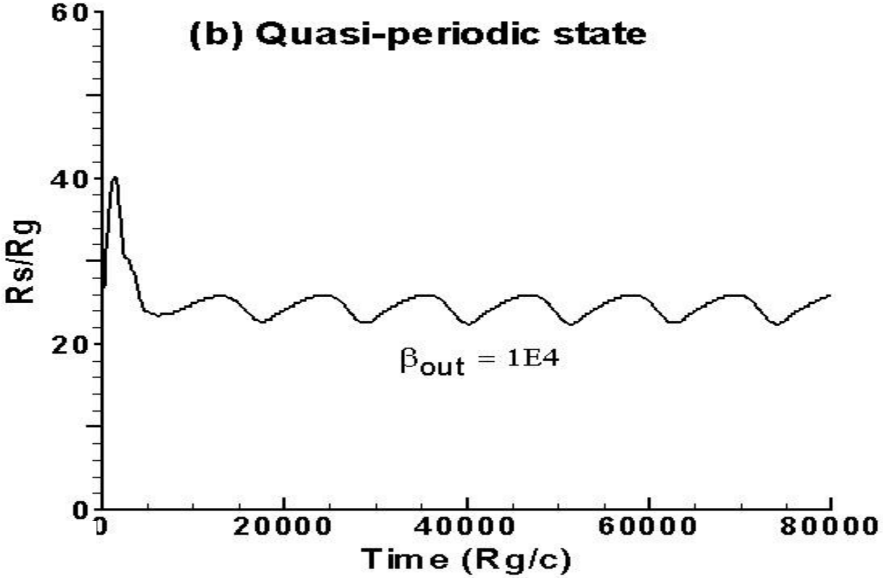


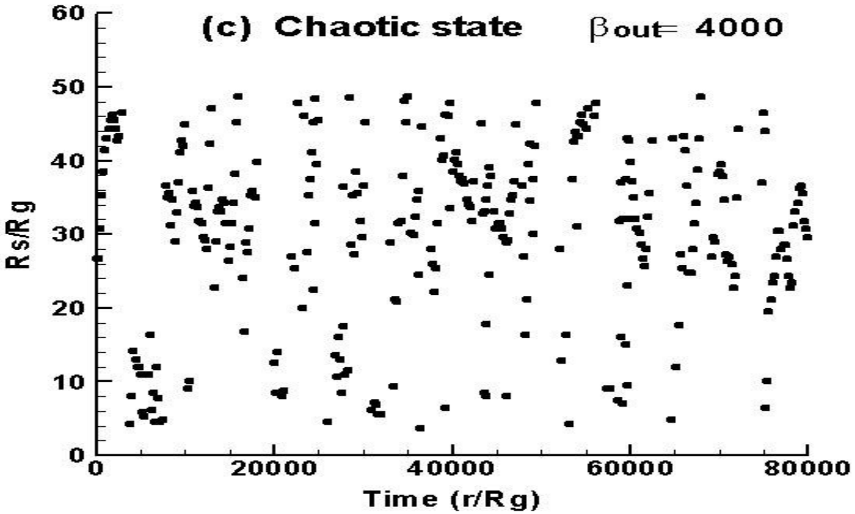
(**CBS**, Okuda & Aktar, RAA, 2021)

Magnetic field and standing shock

Prof. Okuda







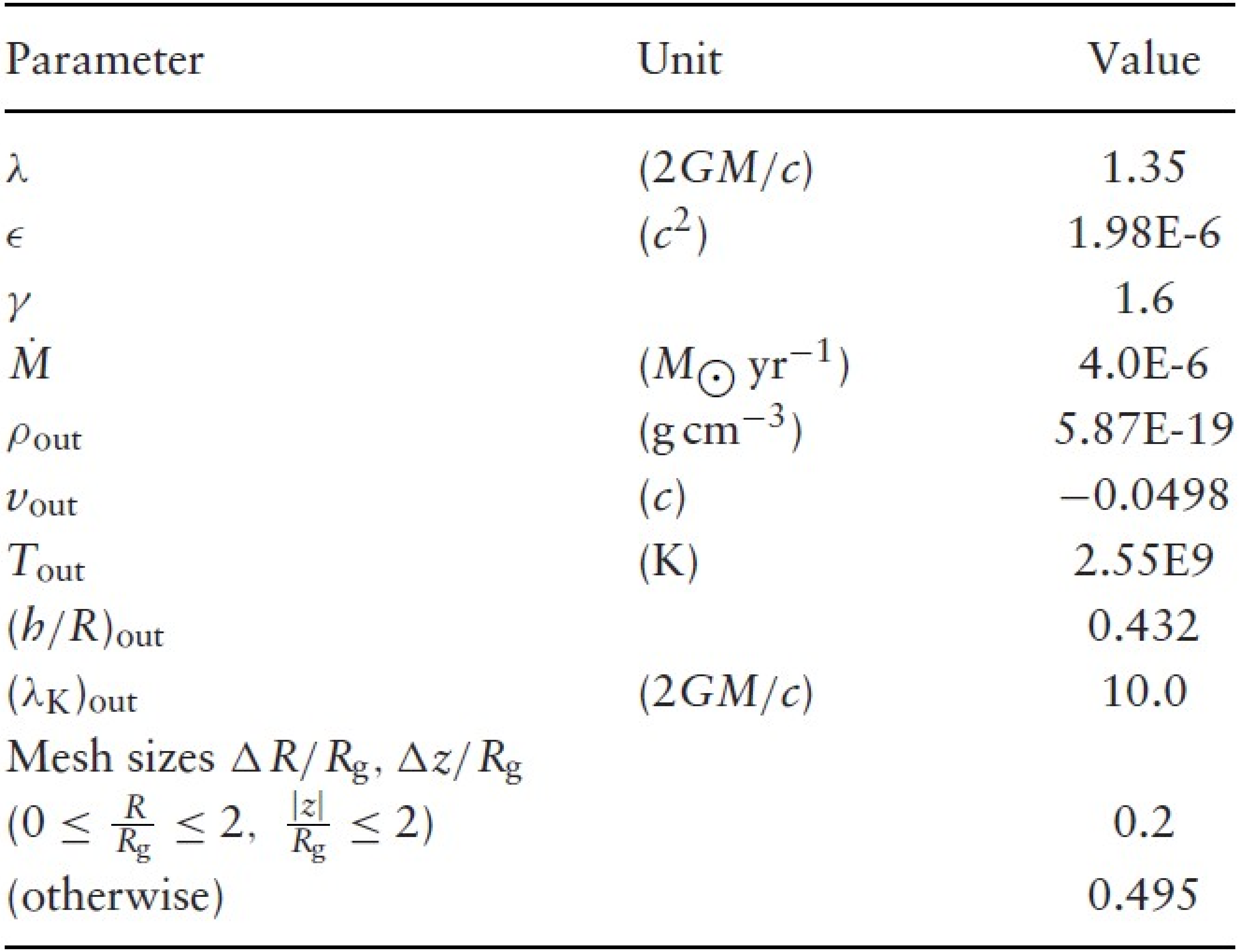
(Okuda, **CBS** et al., PASJ, 2019)

Simulating advective flows around black holes (Fiducial case)

PLUTO code : Magnetohydrodynamic module.

Sgr A*: Supermassive black hole with 4 million solar mass.

2.5D pseudo-Newtonian simulation with ideal equation of state.



Parameter	Unit	Value
λ	$(2GM/c)$	1.35
ϵ	(c^2)	1.98E-6
γ		1.6
$\dot{M}$	$(M_\odot\,\mathrm{yr}^{-1})$	4.0E-6
ρ_{out}	$(\mathrm{g\,cm^{-3}})$	5.87E-19
v_{out}	(c)	−0.0498
T_{out}	(K)	2.55E9
$(h/R)_{\mathrm{out}}$		0.432
$(\lambda_{\mathrm{K}})_{\mathrm{out}}$	$(2GM/c)$	10.0
Mesh sizes $\Delta R/R_{\mathrm{g}}$, $\Delta z/R_{\mathrm{g}}$		
$(0 \leq \frac{R}{R_{\mathrm{g}}} \leq 2,\ \frac{\lvert z\rvert}{R_{\mathrm{g}}} \leq 2)$		0.2
(otherwise)		0.495

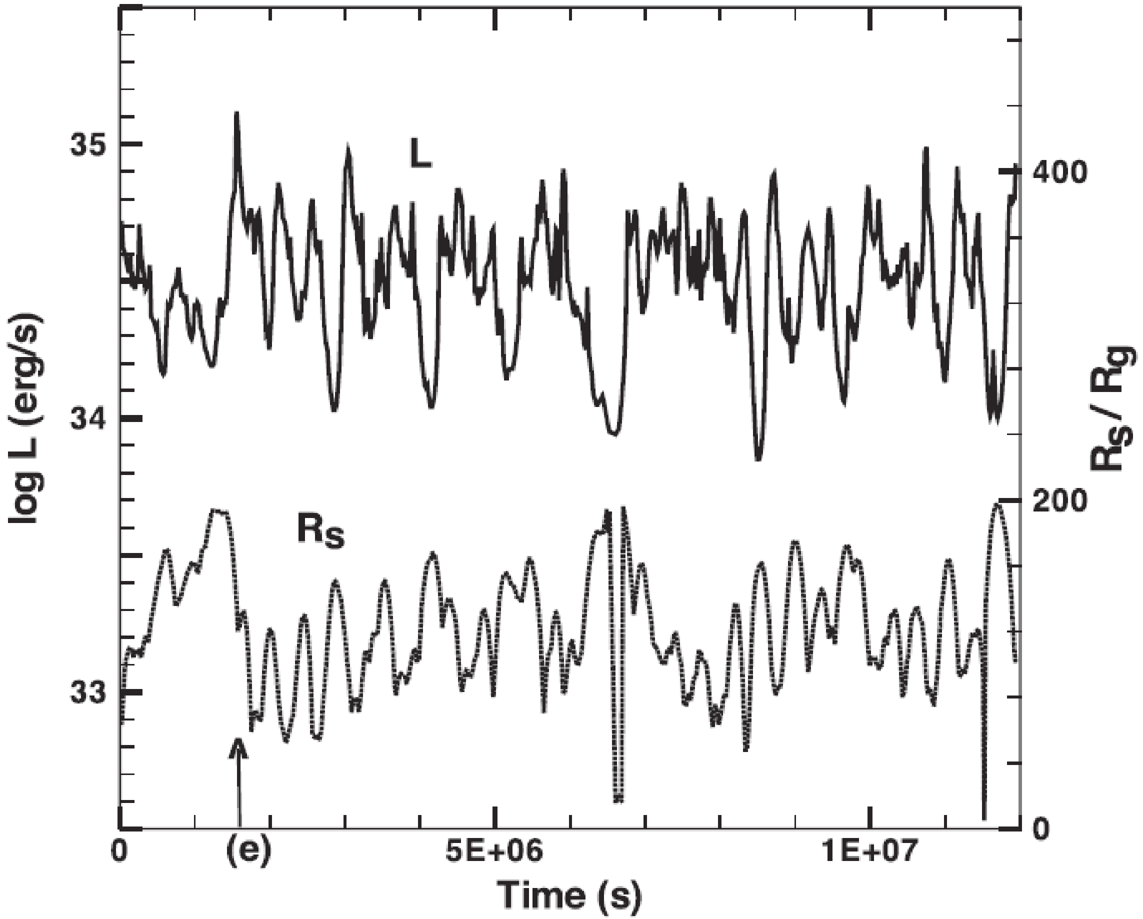
(Okuda, **CBS** et al., PASJ, 2019)

Variable nature of SgrA*

Magnetic field brings change in behavior and shock starts regularly or chaotically oscillating.

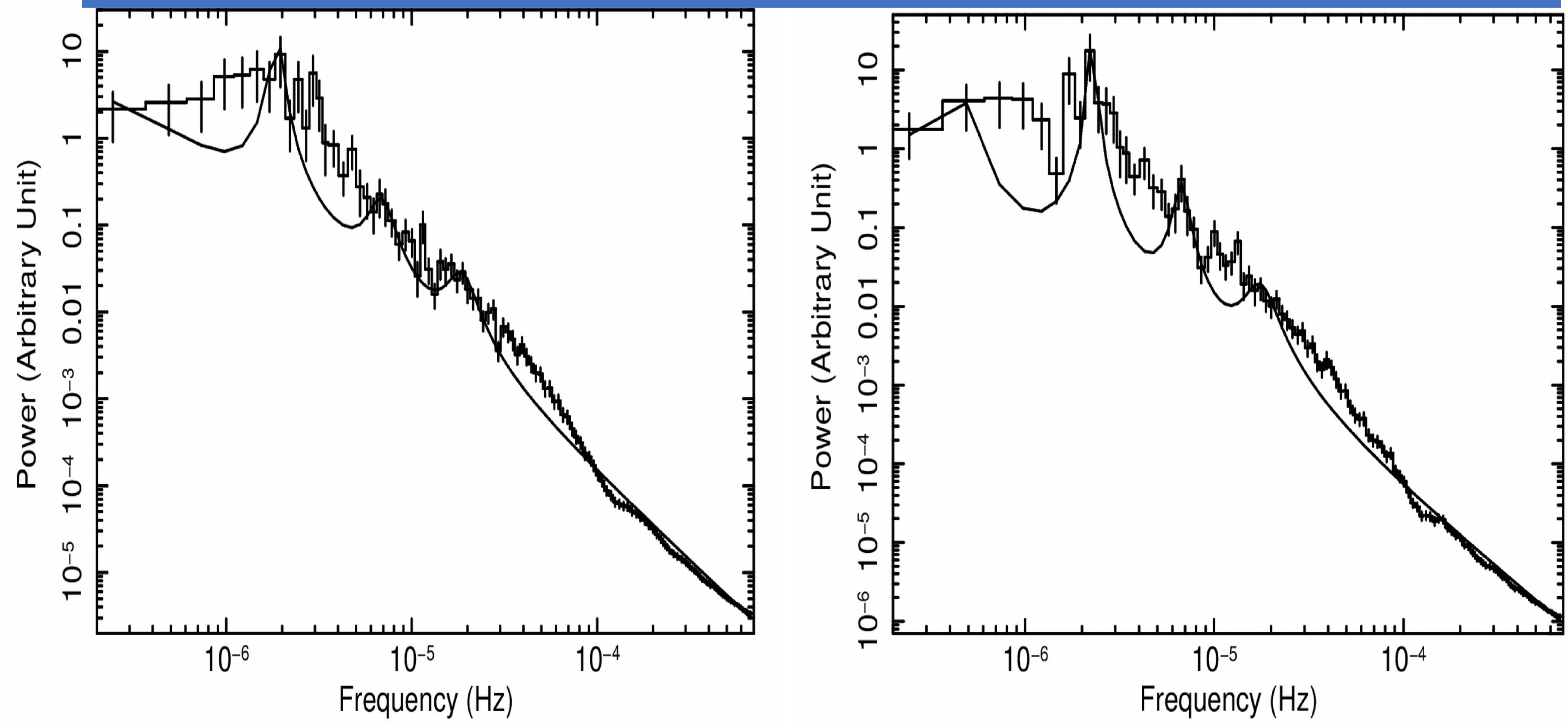
Shock oscillates in the range 60–170 Rg.

Time-dependent behavior of luminosity compatible with observations where flares with a frequency of ∼ 1 per day and bright flares occurring every ∼ 5–10 days.



(Okuda, **CBS** et al., PASJ, 2019)

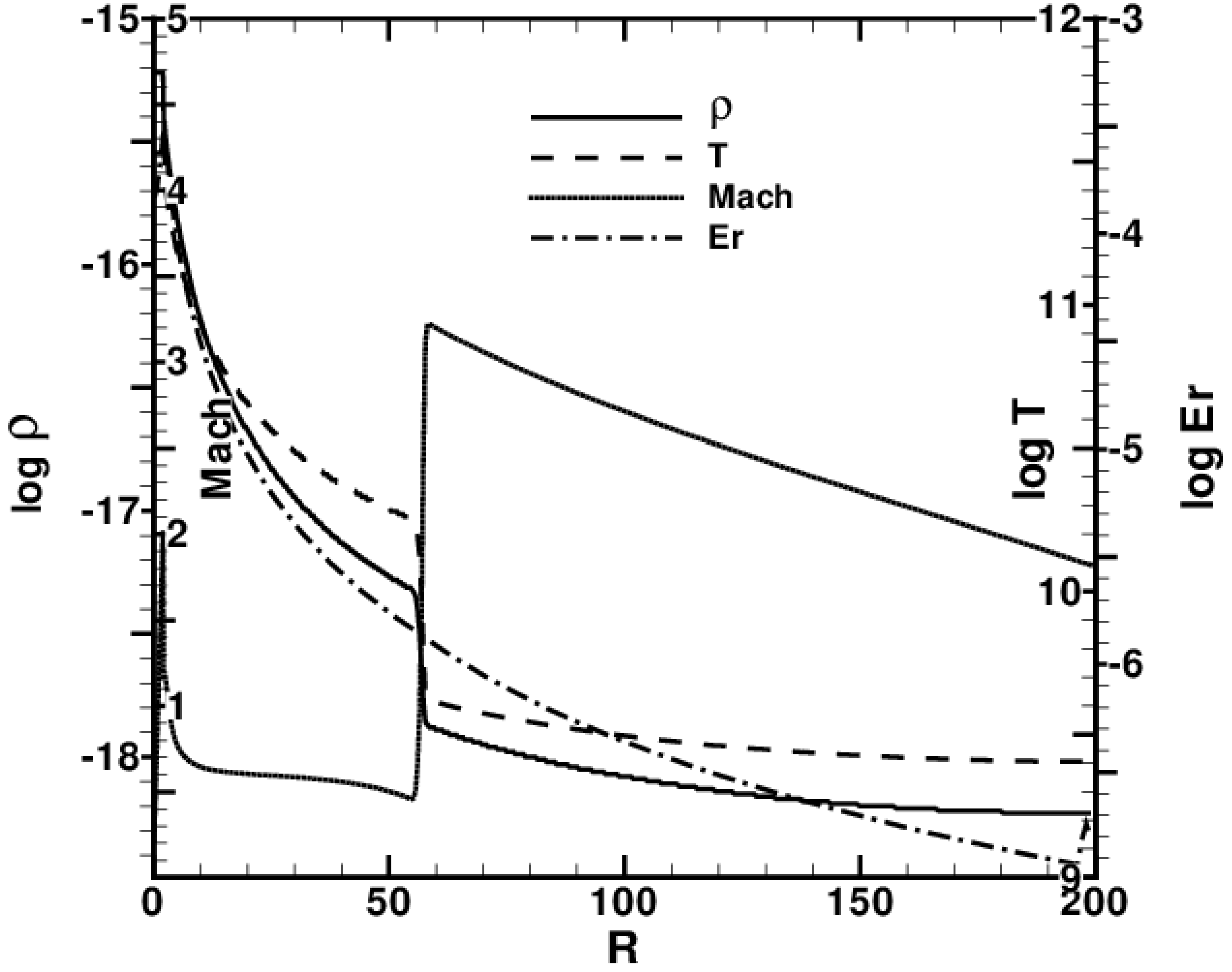
Power density spectra for a resistive MHD flow with different resistivity values



(**CBS**, Okuda & Aktar, RAA, 2021)

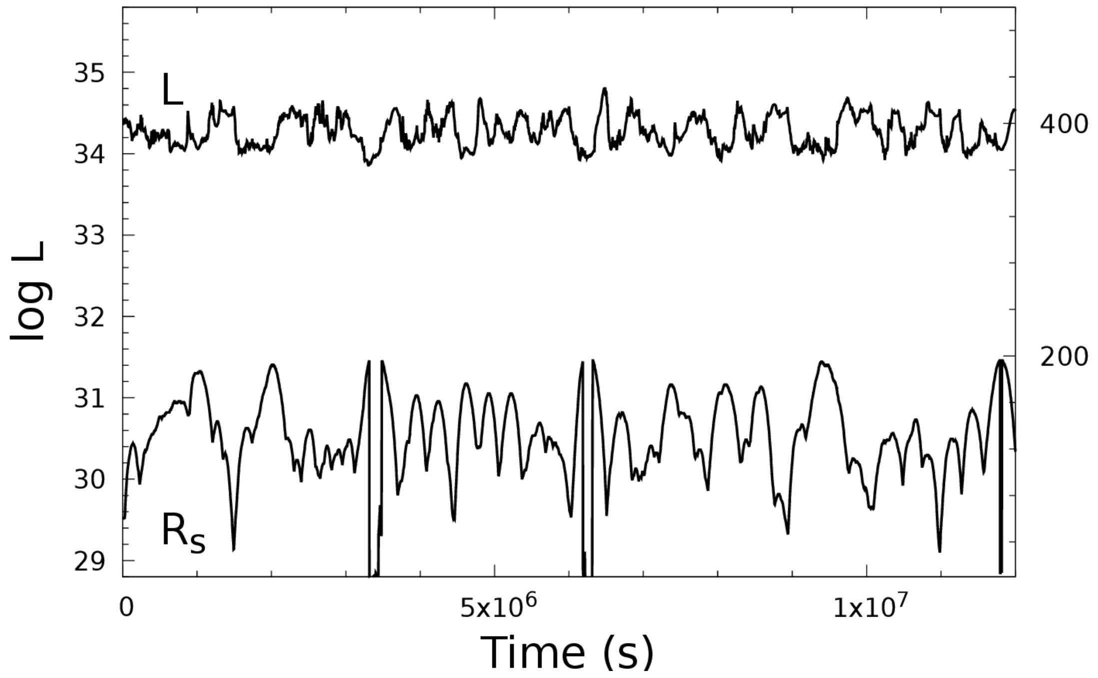
Special relativistic radiative simulations

Parameter profiles for 2D SRRHD simulations.

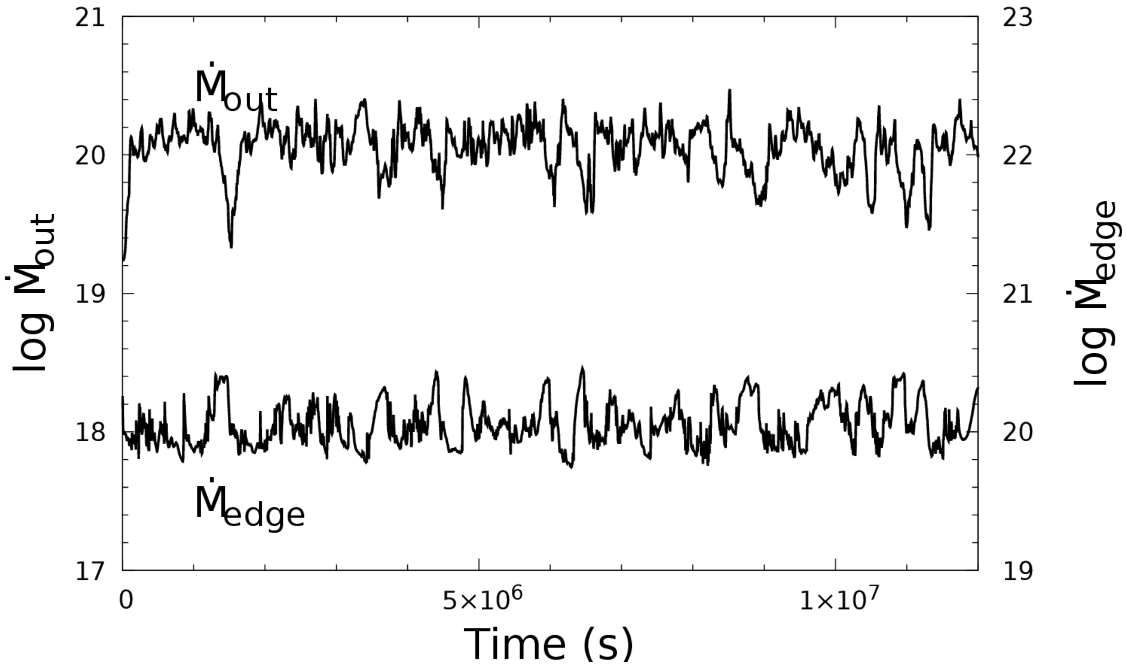


(Okuda, **CBS** & Aktar, MNRAS, 2022)

Variation of Luminosity and shock-location with time

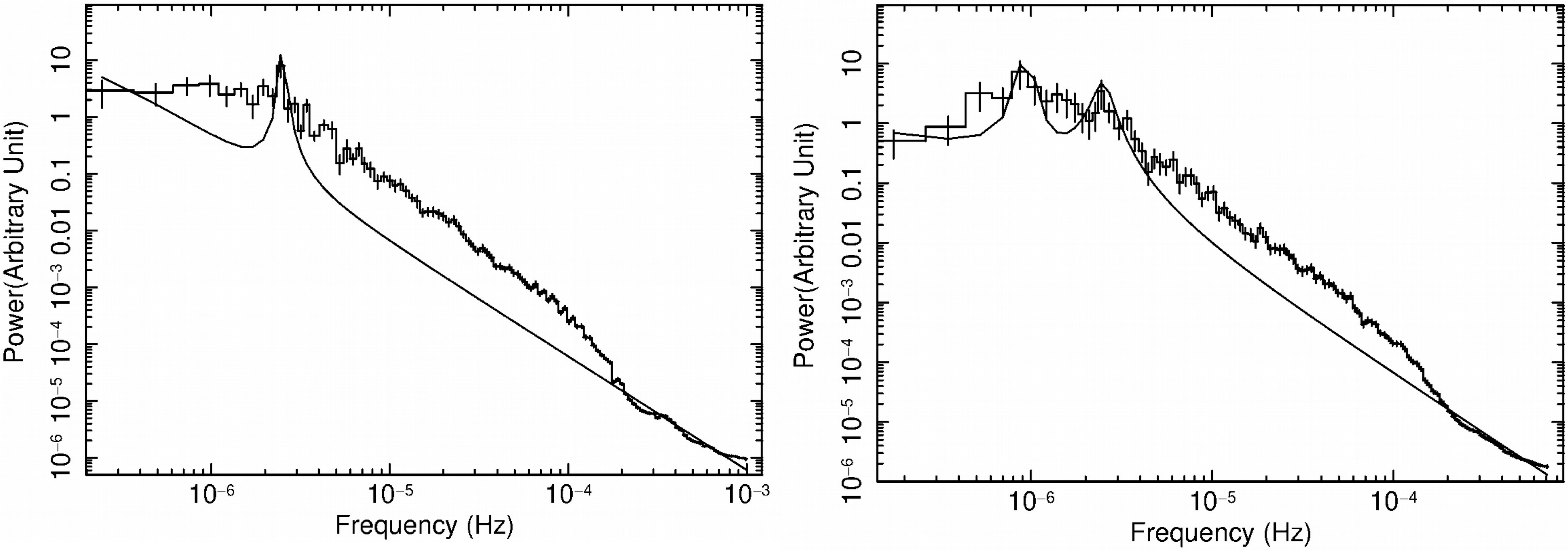


Evolution of Mass inflow ˙ and outflow rates



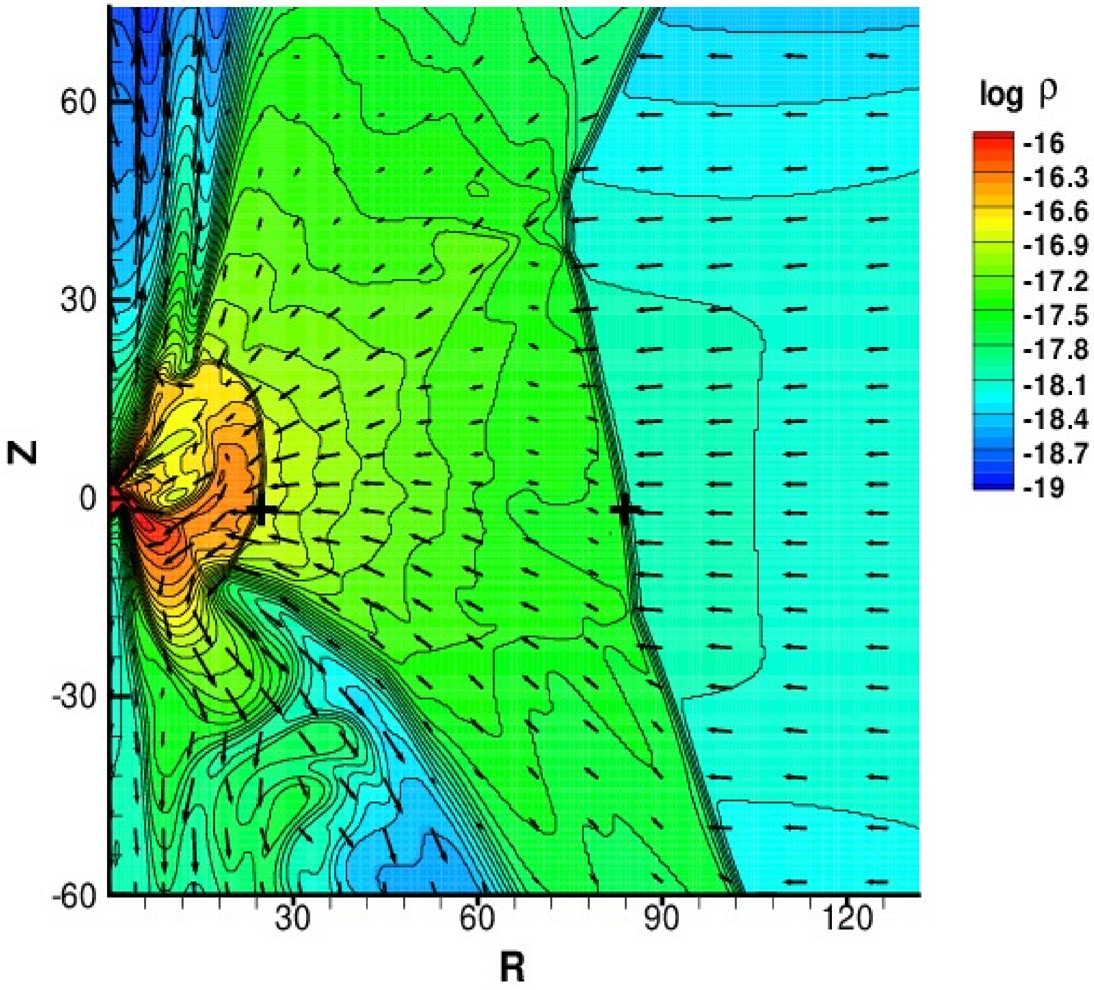
(Okuda, **CBS** & Aktar, MNRAS, 2022)

Power density spectra (PDS) for different models

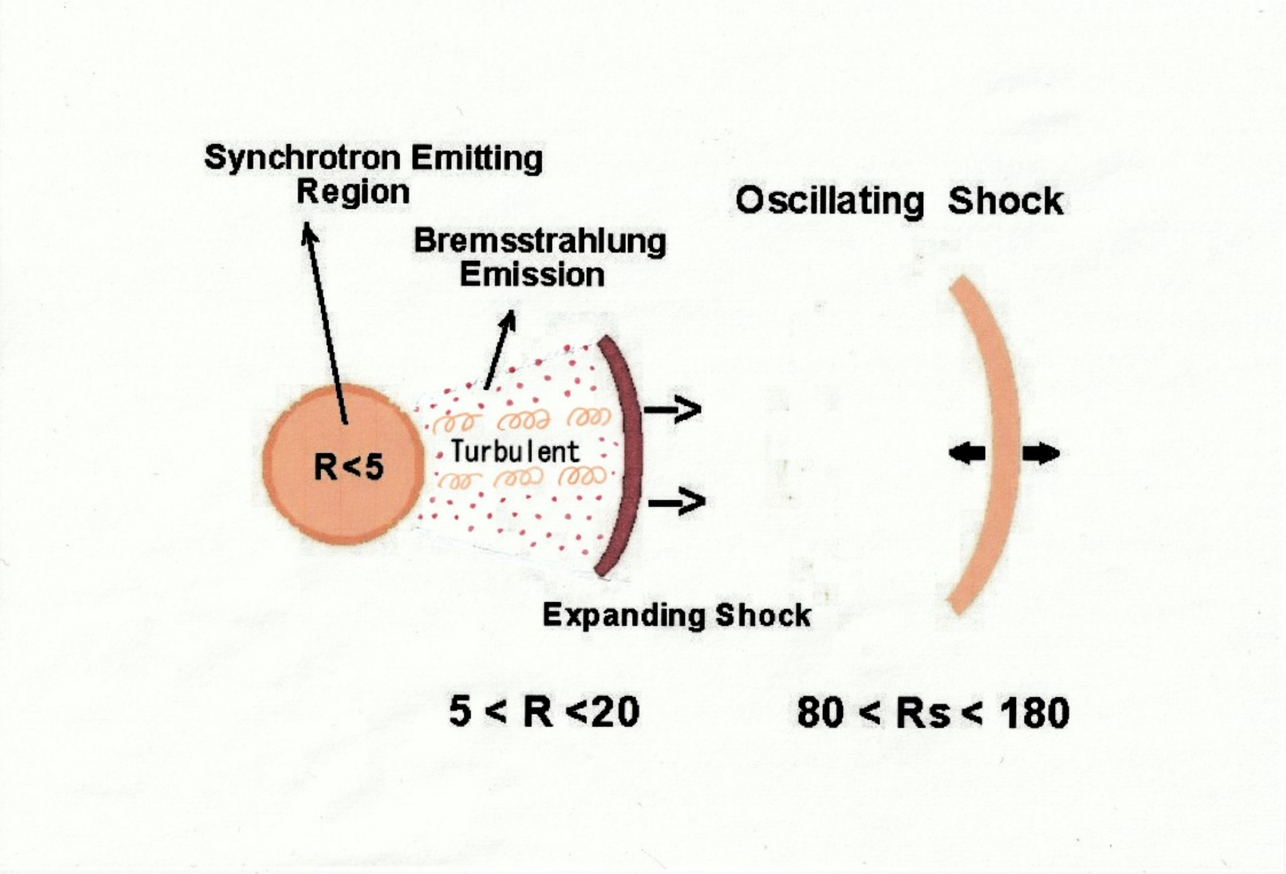


(Okuda, **CBS** & Aktar, MNRAS, 2022)

Thick contour lines: outer oscillating shock & expanding inner shock.
Crosses show the shock location points on the equator.

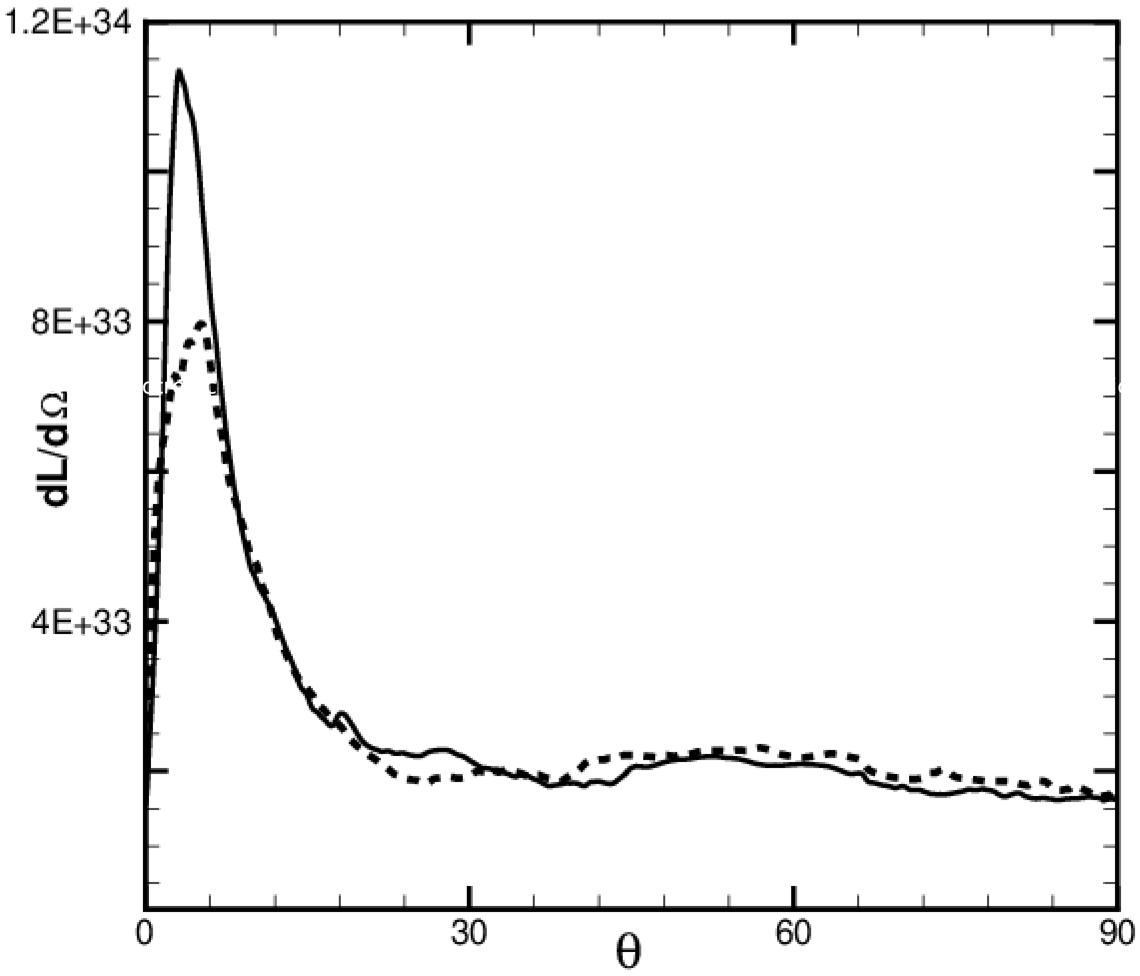


Schematic diagram of the oscillating shock model.



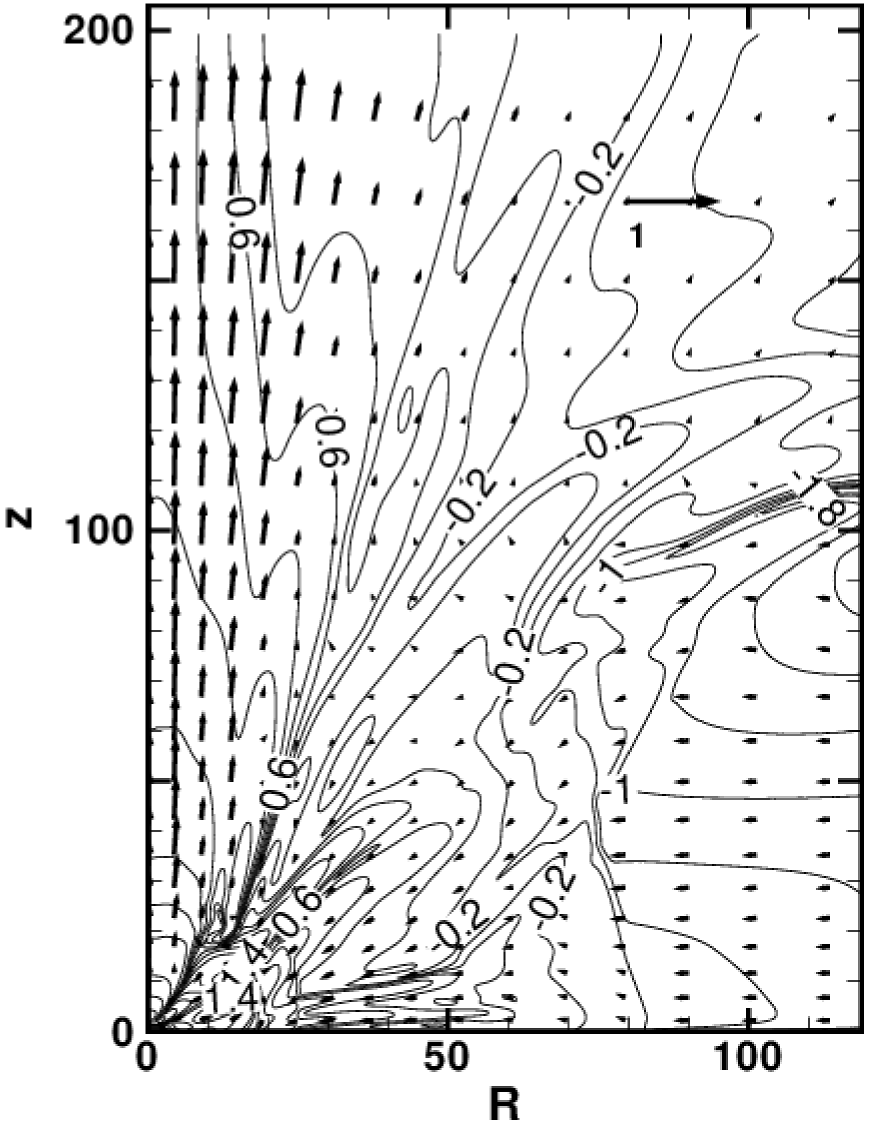
(Okuda, **CBS** & Aktar, MNRAS, 2022)

Averaged radiation distributuion : anisotropic property along the rotational axis on the outer z-boundary but isotropic nature on the outer R-boundary.



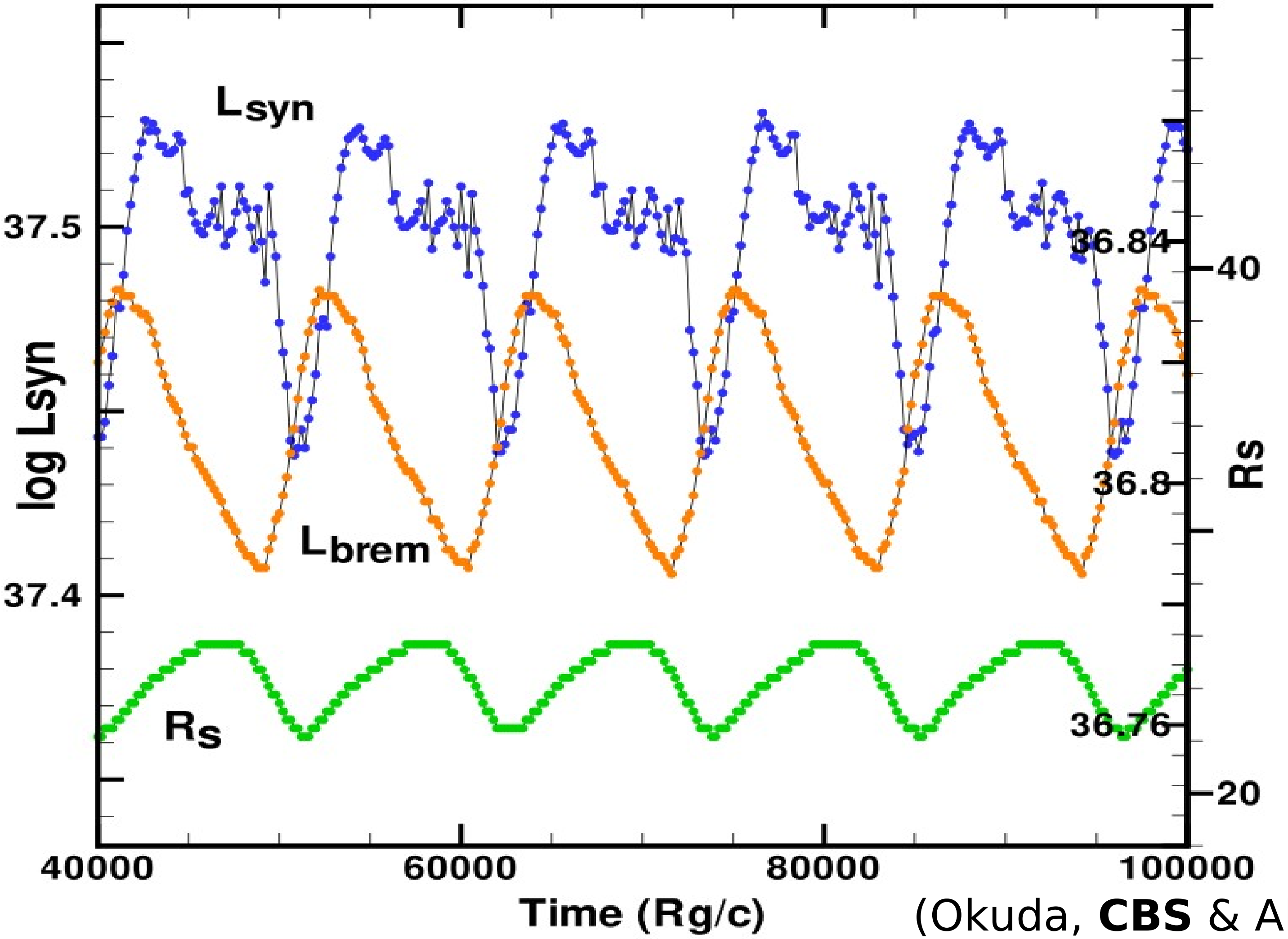
(Okuda, **CBS** & Aktar, MNRAS, 2022)

Velocity vectors with contours of the magnetic field. Jet at the outer surface attains ∼0.6c velocity and collimated in a narrow angle ∼15 degrees.



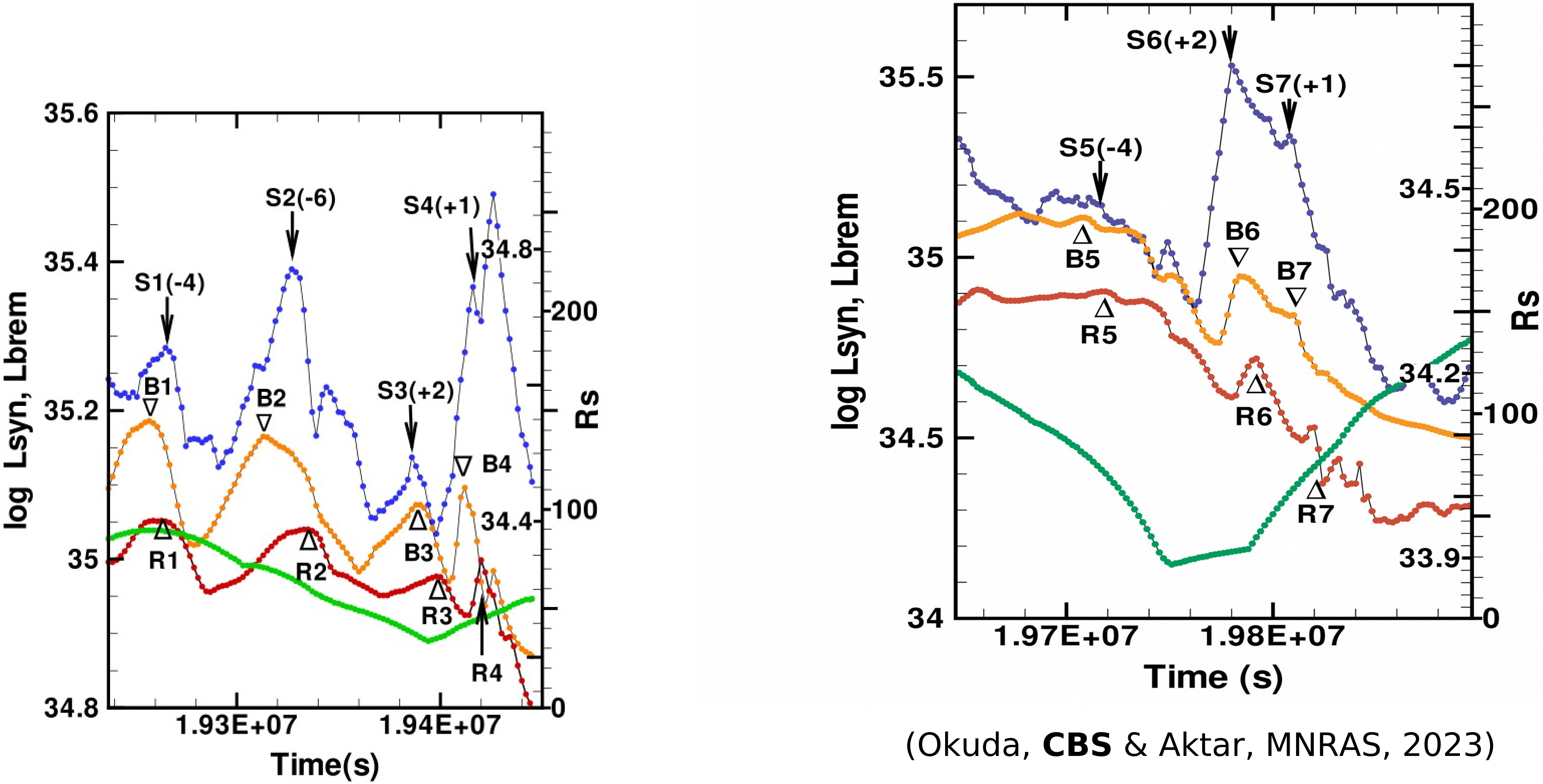
(Okuda, **CBS** & Aktar, MNRAS, 2022)

Evolution of different parameters



(Okuda, **CBS** & Aktar, MNRAS, 2023)

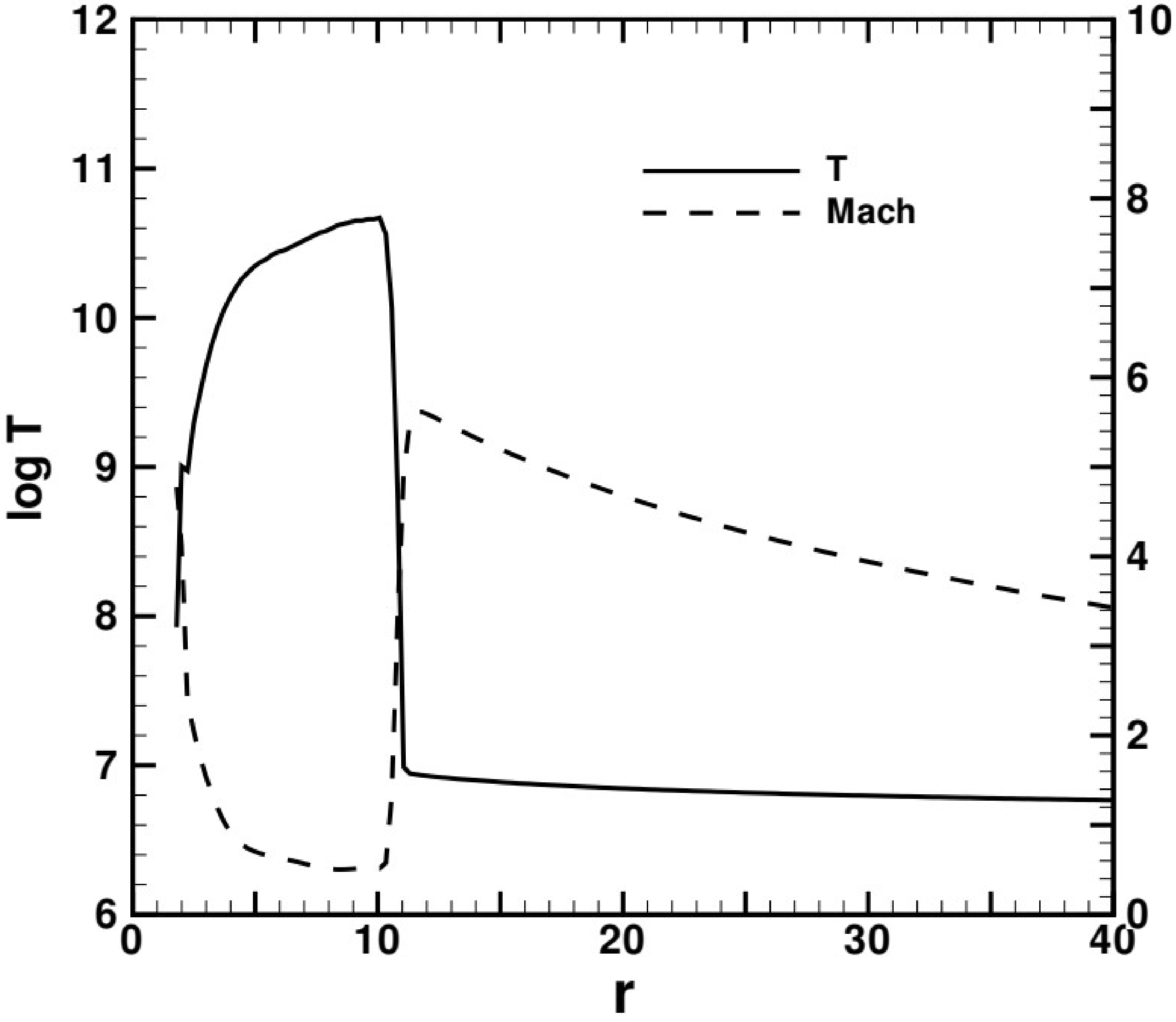
Luminosity curves at 22 GHz (blue), 43 GHz (orange), 350 GHz (black), and oscillating shock location (green) on the equator

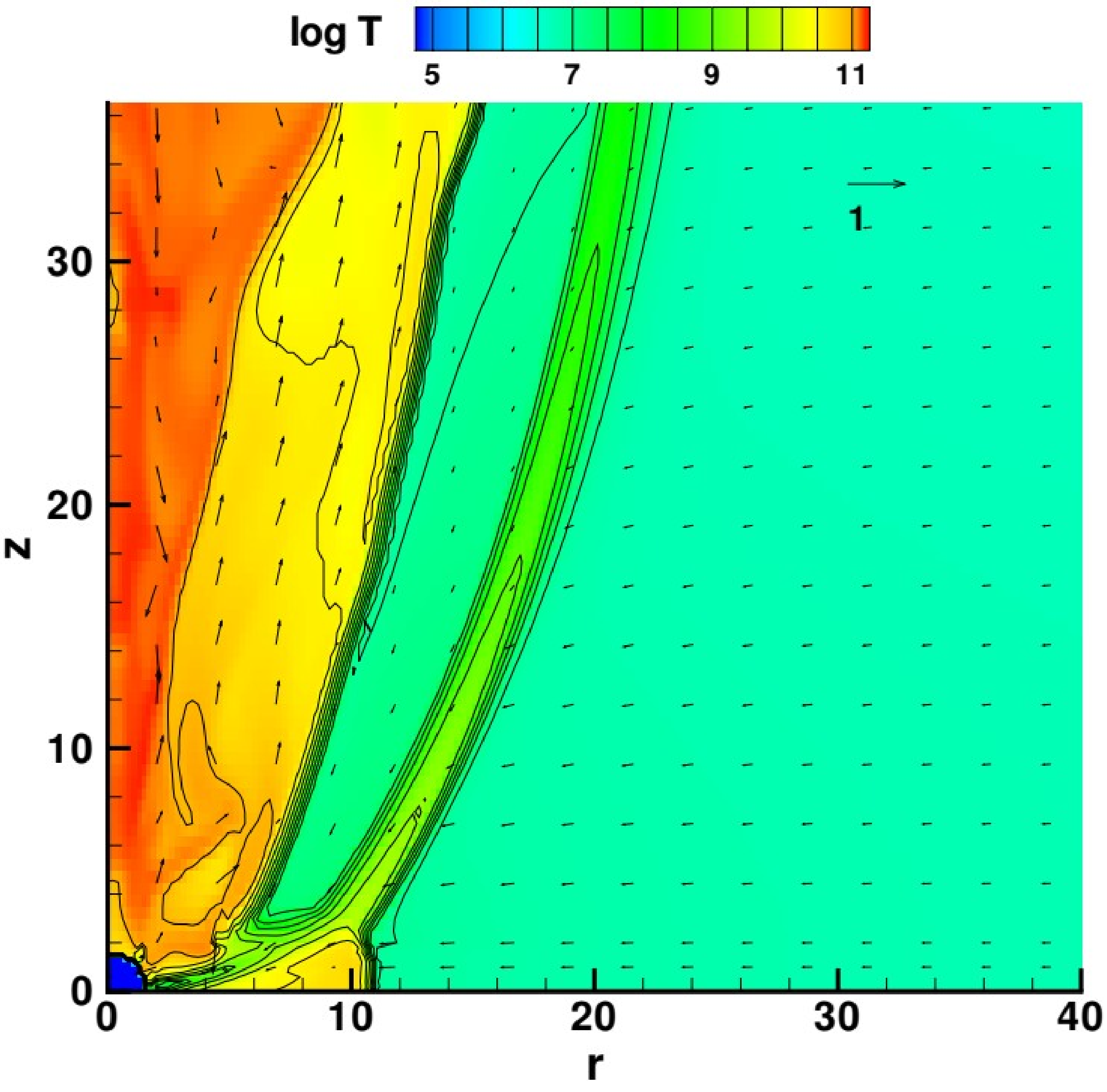


(Okuda, **CBS** & Aktar, MNRAS, 2023)

Simulation works for super-Eddington sources

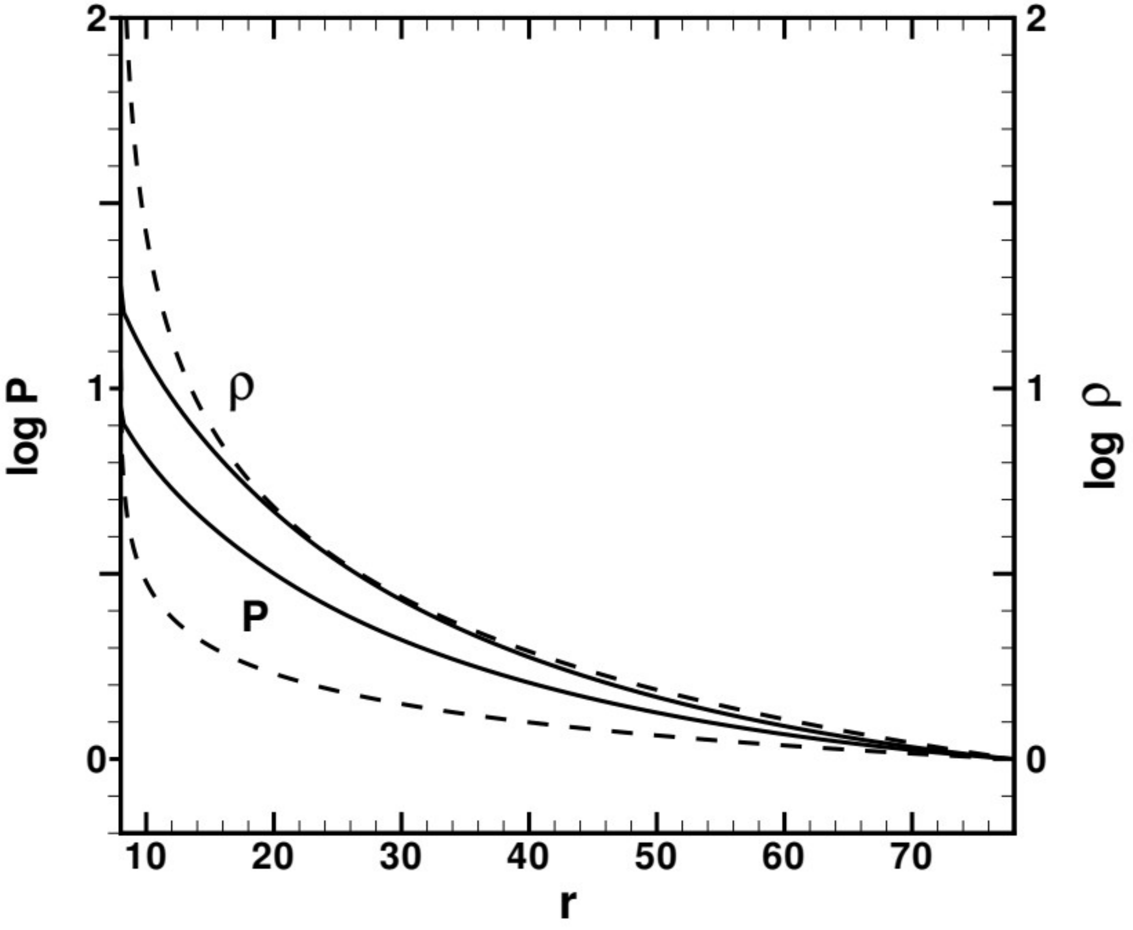
1D profile and 2D contours (fiducial case of a super-Eddington flow)





(Okuda & **CBS**, MNRAS, 2022)

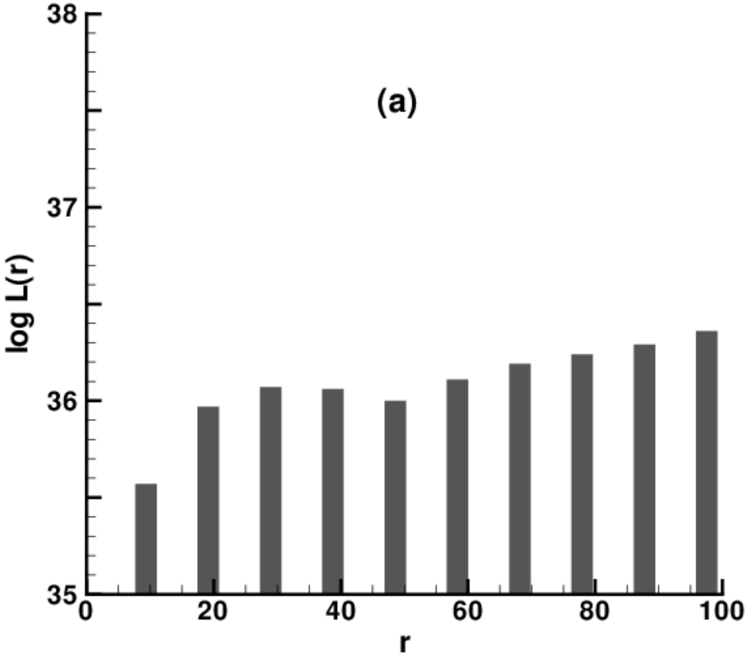
Parameters for simulations (solid lines) and analytical results (dashed lines).

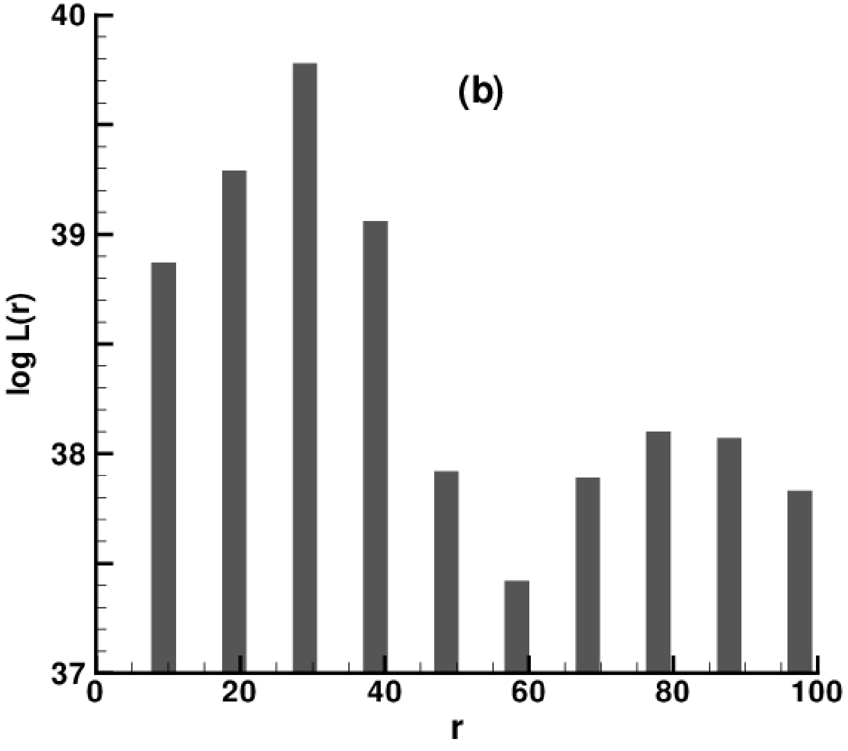


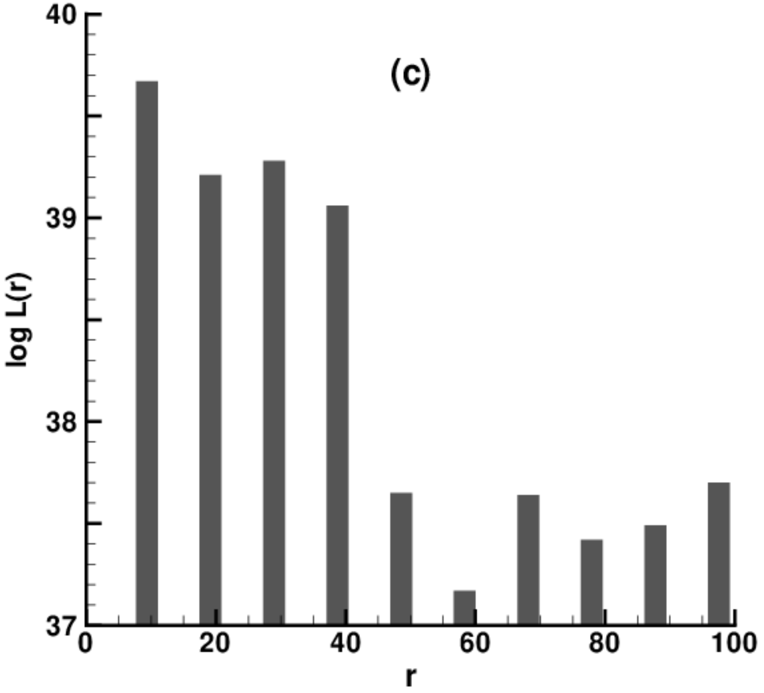
(Okuda & **CBS**, MNRAS, 2022)

(a) Optically thin model never show strongly anisotropic distribution of the radiation.

(b) & (c) Most of the radiation in optically thick models from the funnel region

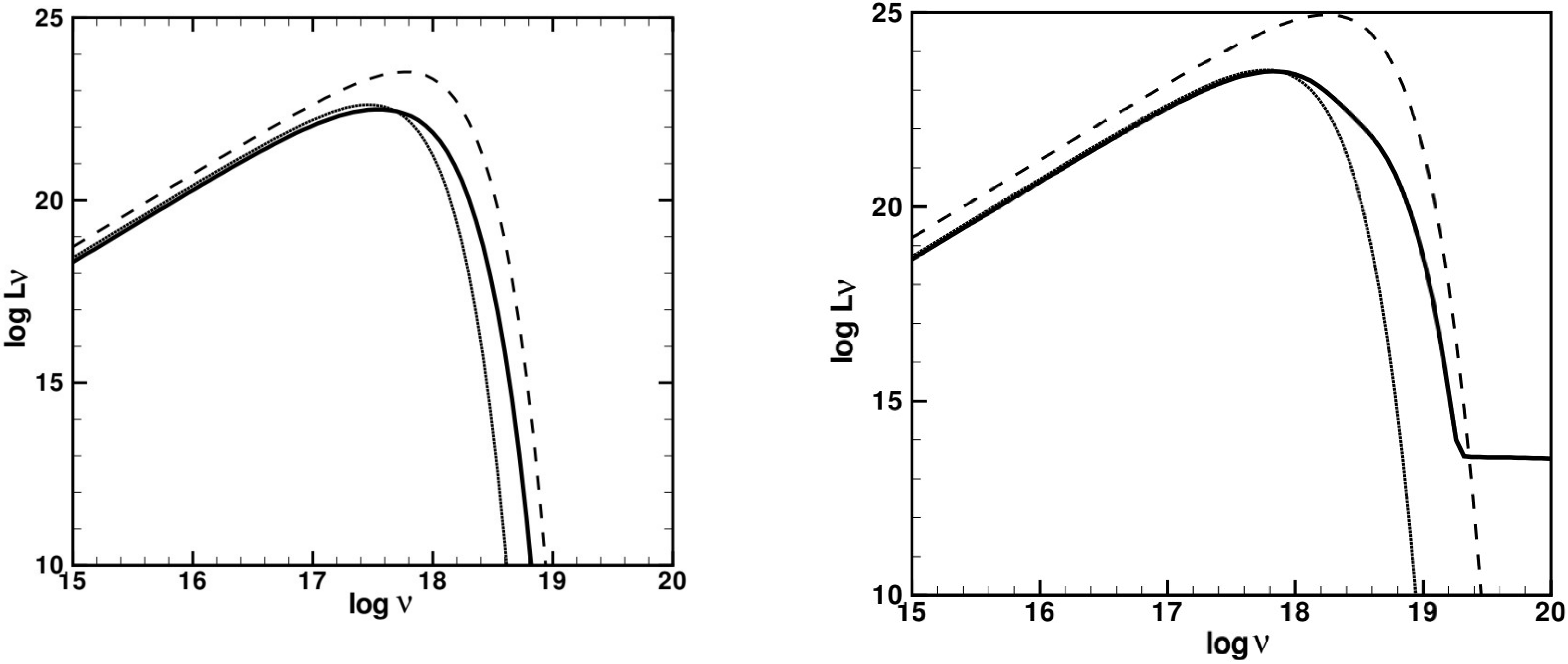






(Okuda & **CBS**, MNRAS, 2022)

Spectral fitting for different cases: total luminosity = 8 & 18 L_{Edd}



(Okuda & **CBS**, MNRAS, 2022)

Summary

Our work comprises of semi-analytical, numerical and modeling studies of various accreting sources which are sub-Eddington to super-Eddington.

In black hole accretion physics community, we usually consider corona+disk components. Quite often, corona with ad-hoc properties is placed somewhere around black hole .

The properties of corona around black hole can be naturally obtained solving set of conservation equations.

Advective flows around black holes with shocks in sub-Keplerian flows do nice work in explaining observed spectral as well as temporal properties for black hole X-ray binaries to supermassive black holes.

Thank you.