Standing shocks in accretion flows around black holes and associated observational signatures

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Fundamental concepts of accretion (Chakrabarti, 1996)

- Black hole accretion: **transonic** flow.

- 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 presence of **multiple sonic points**, the flow may have one or two dynamically important **standing shocks.**

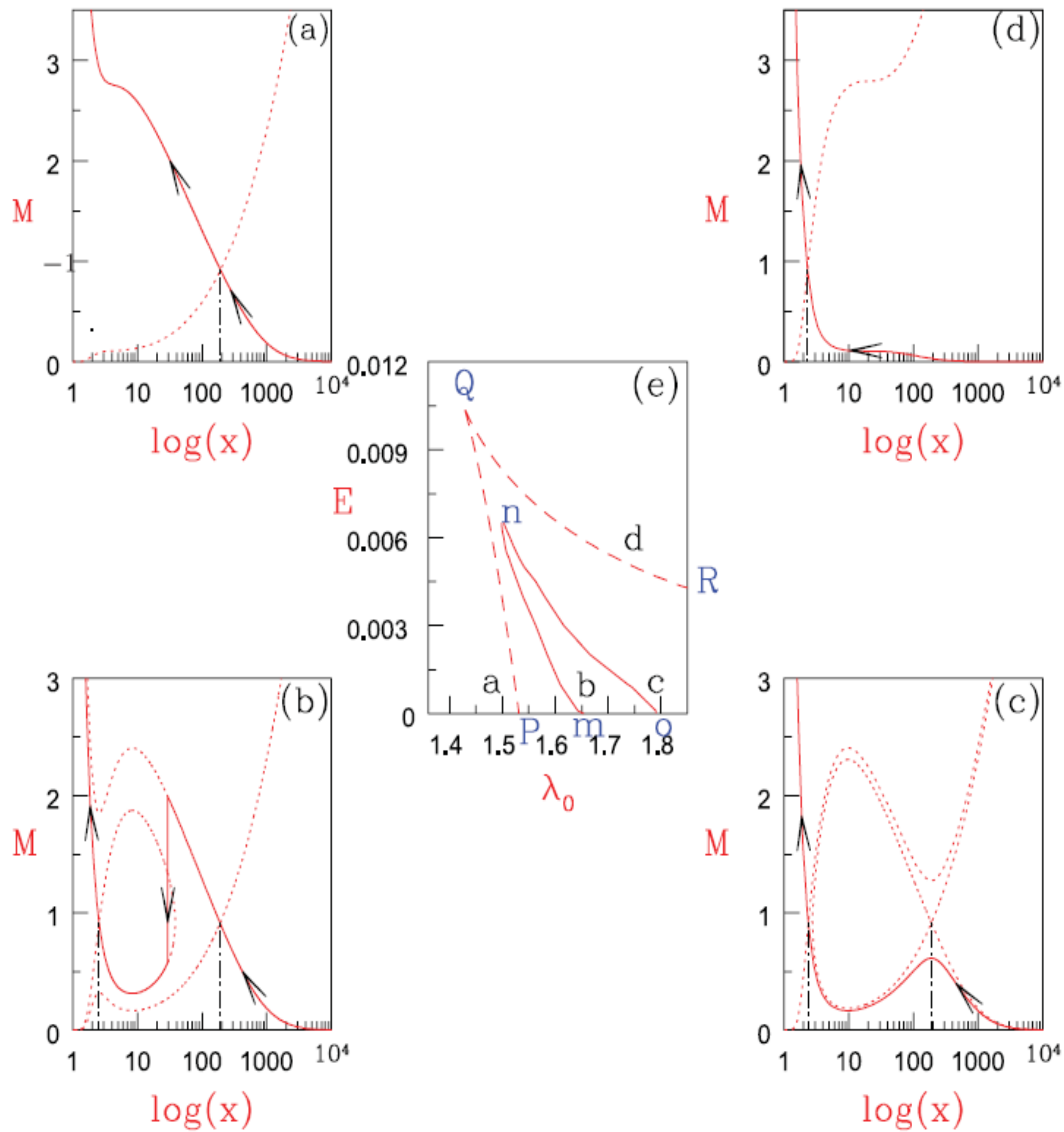
Theoretical Solutions for Advective flow

M: Mach number

x: Distance from black hole

E: Specific energy

λ_0: Specific angular momentum



Kumar & Chattopadhyay (2013)

Simulating flow around SgrA*

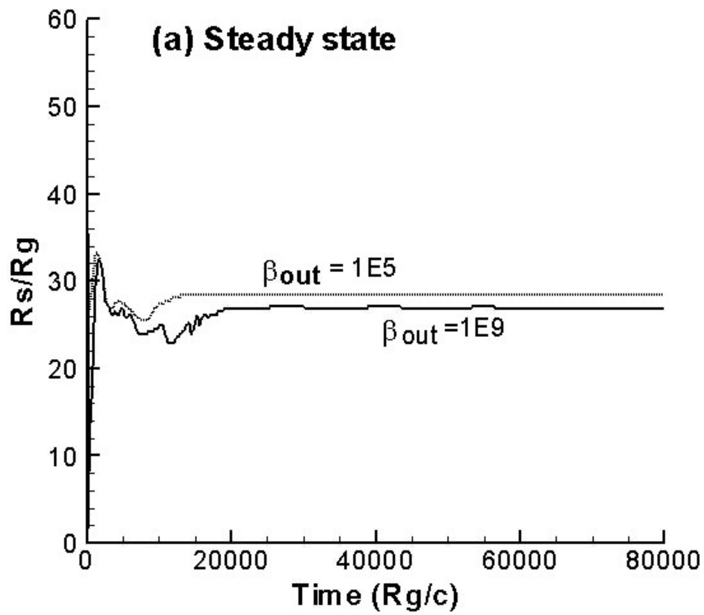
PLUTO code.

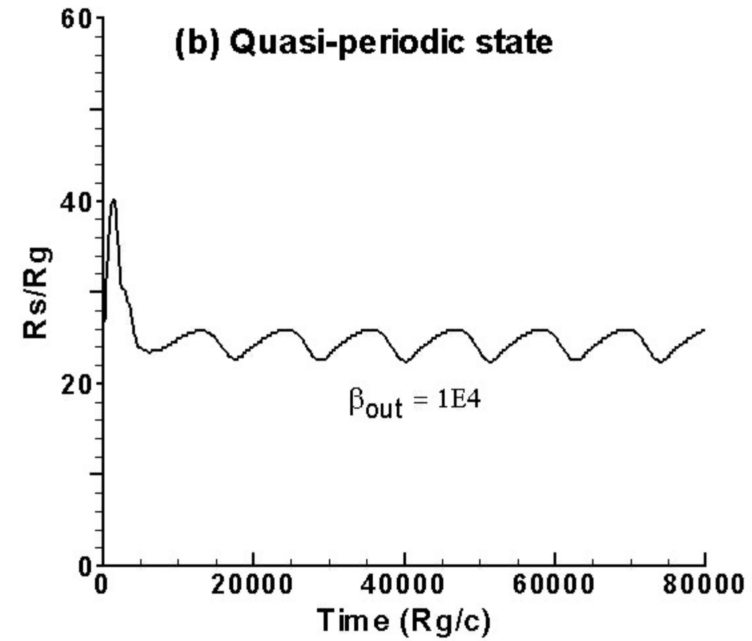
Sgr A*: Supermassive black hole with 4 million solar mass.

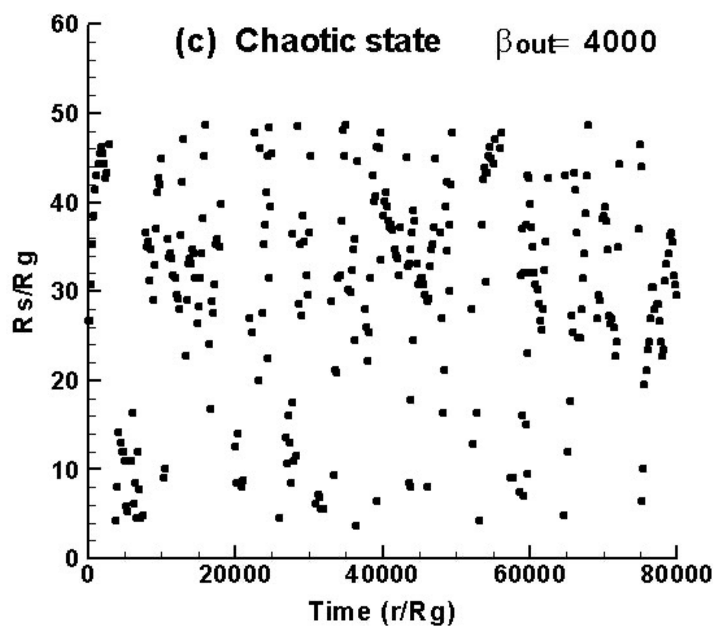
2.5D **pseudo-Newtonian** simulation with ideal equation of state.

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
$\rho_{\rm out}$	$(\mathrm{g\ cm}^{-3})$	5.87E-19
$v_{\rm out}$	(c)	−0.0498
$T_{\rm out}$	(K)	2.55E9
$(h/R)_{\rm out}$		0.432
$(\lambda_{\rm K})_{\rm out}$	$(2GM/c)$	10.0
Mesh sizes $\Delta R/R_{\rm g}$, $\Delta z/R_{\rm g}$		
$(0 \le \frac{R}{R_{\rm g}} \le 2,\ \frac{\lvert z\rvert}{R_{\rm g}} \le 2)$		0.2
(otherwise)		0.495

Magnetic field and standing shock

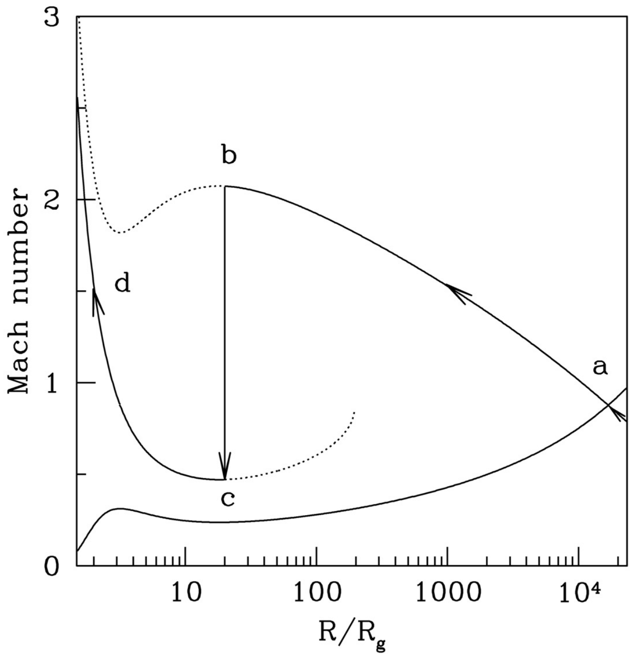


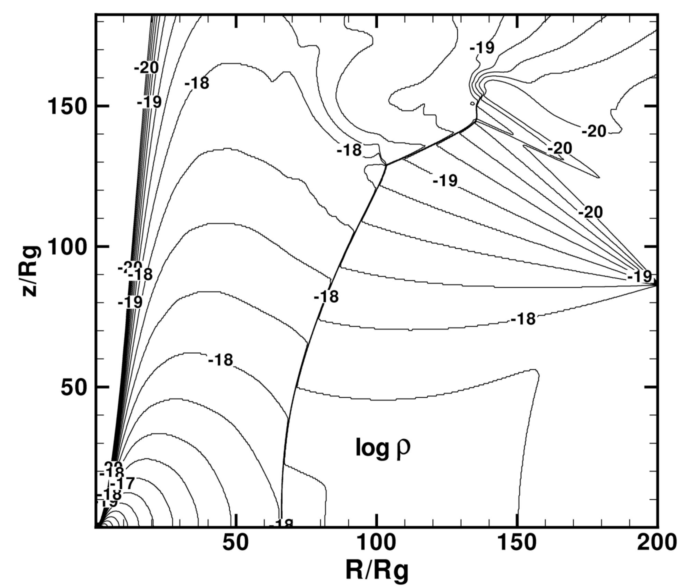




(Okuda, **CBS** et al., PASJ, 2019)

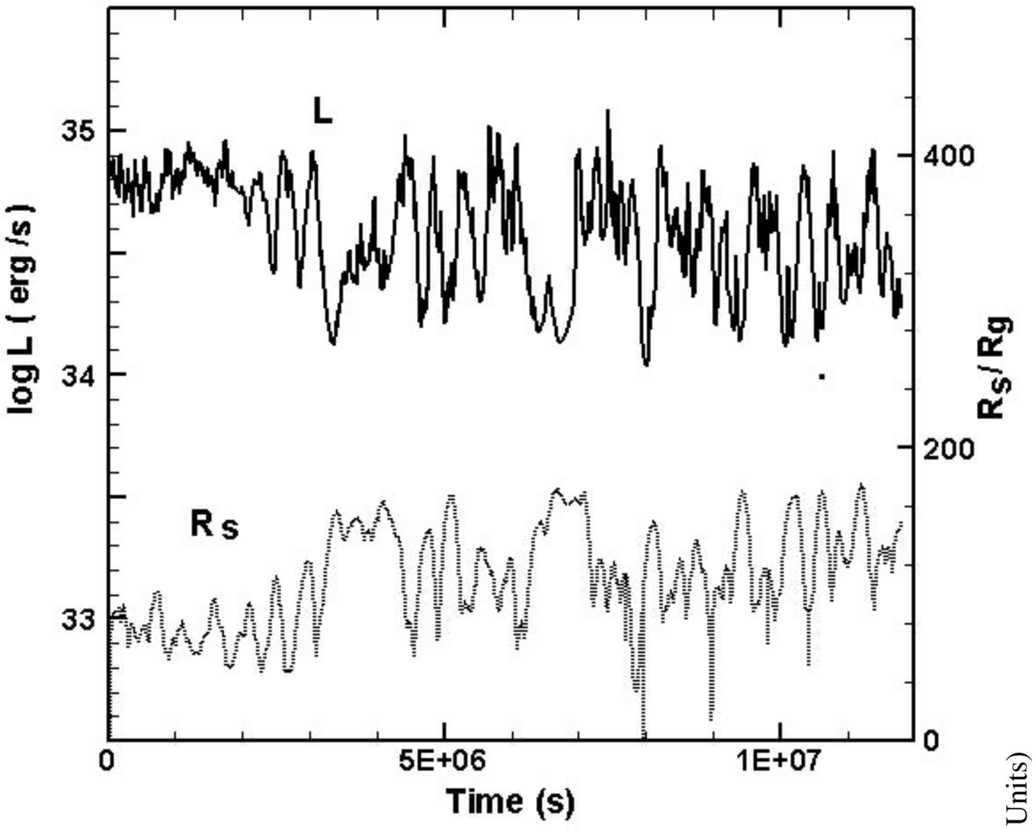
Theoretical and Simulated HD flows

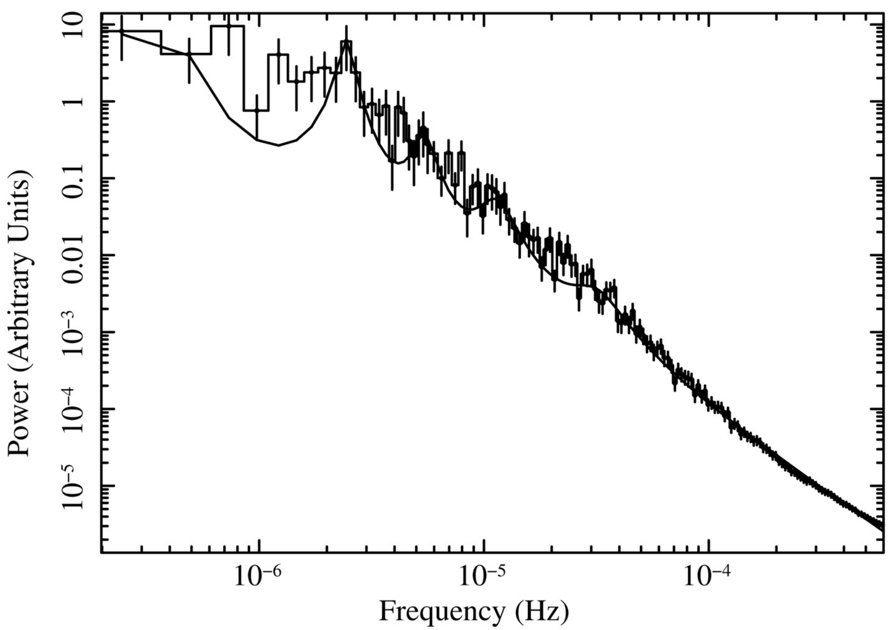




(Okuda, **CBS** et al., PASJ, 2019)

Variability and associated PSD for MHD flows around Sgr A*





(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 Schwarzschild radii.

- Flares with a frequency of $\sim$ one per day and bright flares occurring every $\sim$ 5–10 days.

Conclusions

- The standing shock in advective flow plays an important role in behaviour of outflows.
- As the magnetic field becomes dynamically important, luminosity, mass outflow rate is enhanced and oscillates leading to stronger flare phenomena.
- The magnetic pressure increases in the outflow region and leads to enhancement of mass outflow rate, compared with the flow without magnetic field.
- The flare phenomena of Sgr A* may be explained by the unstable mass-outflow.

(Okuda, **CBS** et al., PASJ, 2019 ; **CBS**, Okuda & Aktar, RAA, 2021)

Related works

SRRMHD simulations

- Flare due to synchrotron emission lags that of bremsstrahlung emission by 1-2 hours (Okuda, **CBS** & Aktar, MNRAS, 2022).

- Synchrotron emission confined in a core region of 3 Schwarschild radii, while the bremsstrahlung emission in a distant region of 10-20 Schwarschild radii (Okuda, **CBS** & Aktar, MNRAS, 2022).

- Observed delay times of 0.5-5 hours between radio and X-ray, 20-30 minutes between 22 and 43 GHz, and ~18 minutes between 8 and 10 GHz in Sgr A* (Okuda, **CBS** & Aktar, MNRAS, 2023).

- Radiative shock models with the super-Eddington luminosities show a possible model for the superaccretor SS 433 and ultraluminous X-ray sources with stellar-mass black holes (Okuda & **CBS** 2021).

The trouble with people is not that they know so little, but that what they know is largely not true.

~ Mark Twain

Thank you.